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ELECTROPHYSIOLOGICAL CORRELATES OF INFORMATION PROCESSING IN VISUAL HEMINEGLECT

by

Christopher A. Dywan

Submitted in partial fulfilment of the requirements
for the degree of Doctorate of Philosophy

at

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DEDICATION

To Jane Dywan and Sidney Segalowitz for unwavering parental support.

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ABSTRACT

Visual hemineglect provided within-patient comparison of information processing in the intact and neglected fields. Experiment One, addressed whether N400 amplitudes for centralized picture-targets that were preceded by lateralized picture-primes would reflect the implicit semantic priming reported for stimuli in the neglected visual field (e.g. McGlinchey-Berroth et al., 1993, 1996). In Experiment Two, an oddball paradigm was used to determine whether P300 amplitudes are sensitive to manipulations of stimulus target-value and relative stimulus probability for target and non-target letters in the neglected field when concurrent behavioral responses indicate subjective unavailability of the eliciting stimuli. Both paradigms had behavioral components to evaluate the extent to which the contralesional stimuli remained subjectively unavailable. The implicit behavioral priming results of Experiment One are compatible with accumulating evidence that considerable processing occurs for information in the neglected field even when it remains subjectively unavailable. Moreover, the N400 provides a robust correlate of the semantic associations formed automatically between the targets and primes. In Experiment Two, P300 amplitudes were sensitive to the targetness of lateralized stimuli bilaterally for the controls but only in the intact field of the patients. For patients, P200 amplitudes were sensitive to the targetness of the lateralized stimuli whether in the intact or neglected field, even when concurrently obtained behavioral responses indicated no subjective awareness of the contralesional stimuli. Thus, for these patients with hemineglect, as for other brain-damaged groups, disruption of cortical top-down processing can be associated with the release of earlier and more automatic neural responses with which P200 amplitudes correlate. Finally, for half of the patients ($n = 5$), reliable P300 amplitude differentiation was elicited for stimuli in the neglected field, including two patients who showed no awareness of the stimuli. This stimulus differentiation, for stimuli of which the patients were unaware, highlights ambiguities related to for P300 interpretation.

ABBREVIATIONS AND SYMBOLS

A	attended condition
AA	attended-attended condition
A-D	analogue to digital
ANOVA	analysis of variance
ASA	automatic spreading activation
AU	attended-unattended condition
cm	centimetres
CNV	contingent negative variation
CVA	cerebral vascular accident
df	degrees of freedom
EEG	electroencephalogram
EOG	electro-oculogram
EP	evoked potential
ERF	event-related magnetic field
ERI	event-resolution imaging
ERP	event-related brain potential
η^2	Eta squared; measure of strength of relationship
F	computed value of F statistic
fMRI	functional magnetic resonance imaging
GCS	Glascow Coma Scale
HSD	Tukey's honestly significant difference or Tukey a procedure
Hz	hertz
IAMP	innovative assessment methods program
ISI	inter-stimulus interval
KΩ	kilo-ohm
LED	light-emitting diode
LHD	left hemisphere damage
LPC	late positive component
M	mean or arithmetic average
MEG	magnetoencephalography, magnetoencephalogram
MMN	mismatch negativity
ms	milliseconds
MS	mean square
MSE	mean square error
μV	micro-volts
n	number in a sub-sample
N	total number in a sample
ns	not statistically significant
%	per cent
p	probability; also the success probability of a binomial variable
PET	positron emission tomography
PMN	phonological mismatch negativity
PPVT-R	Peabody Picture Vocabulary Test-Revised
r	Pearson product-moment correlation

r^2	Pearson product-moment correlation squared; coefficient of determination
RHD	right hemisphere damage
s	Second
SD	standard deviation
SE	standard error
SOA	stimulus onset asynchrony
SPECT	single photon emission tomography
SPS	syntactic positive shift
SW	slow wave
t	computed value of t-test
T	computed value of Wilcoxon's or McCall's Test
U	computed value of Mann-Whitney test
U	Unattended condition
UA	Unattended-attended condition
UU	Unattended-unattended condition
X^2	Computed value of chi-square test

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INTRODUCTION

Most theories of hemispatial neglect, particularly those that presume an attentional deficit, remain vague about the fate of visual information falling in the neglected hemifield (McGlinchy-Berroth, Milberg, Verfaellie, Alexander, & Kilduff, 1993). According to Behrman and Meegan (1998), considerable controversy surrounds this issue which remains far from settled. The purpose of this dissertation was to develop a pair of visual event-related potential (ERP) paradigms for dynamic "on-line" measures of the processing of information presented to the neglected and non-neglected visual fields of patients with visual hemineglect (or extinction). Patients with hemineglect are typically aware of ipsilesional but not contralesional information. This lateralized deficit of awareness presents an opportunity to use ERPs to examine the processing fate of information of which the individual shows no subjective awareness. Comparison of the ERP components elicited by neglected and non-neglected information offers an opportunity to further our understanding of the selective information processing deficits associated with the neglect syndrome. It may also help to clarify some unresolved issues pertaining to the endogenous versus exogenous processing nature of several of the ERP components that have been central to many investigations of cognitive information processing.

Prior to the presentation of the two ERP experiments, the literature pertaining to the neglect syndrome will be reviewed with attention to the clinical manifestation, some of the major theoretical accounts of the syndrome, and evidence for the processing of information outside of subjective awareness. Relevant ERP methodology has been reviewed with attention given to the meanings ascribed to the P300 and N400 as electrophysiological correlates of information processing in the human brain. The literature review will conclude with a summary of ERP investigations of the neglect syndrome.

Following the literature review, the two ERP experiments using individuals with and without unilateral visual neglect will be presented with specific attention to each experiment's rationale, methods, results, and conclusions. For the first experiment, a Lateralized Semantic Priming Paradigm was developed with the amplitude of the N400 as an electrophysiological correlate of semantic processing. For the second experiment, two versions of a Lateralized Oddball Paradigm were developed with the amplitude of the P300 as an electrophysiological correlate of stimulus differentiation effects (within the versions of the paradigm) and relative stimulus probability effects (between the versions of the paradigms). The dissertation will conclude with a general discussion in which the conclusions derived from the two experiments will be compared and directions for further research will be offered.

CHAPTER ONE

THE HEMINEGLECT SYNDROME

Unilateral brain damage, most typically involving the right parietal lobe, is associated with a lateralized syndrome of deficits characterised by an inability to report, orient, or respond to contralesional stimuli or events (Heilman, Watson, & Valenstein, 1985). To this definition, an impairment in the ability to explore the contralesional side of space has been added (Vallar, 1998). Regardless of the specific behaviour being assessed, the syndrome has been differentiated from more global deficits on the basis of the selective impairment observed contralesionally in the light of the comparative preservation of the ability ipsilesionally (Vallar, 1998). The syndrome of hemispatial neglect has intrigued many investigators because it frequently occurs in the absence of damage to the relevant primary sensory regions of the brain (or to their immediate projections). Moreover, direct assessment typically reveals sparing of the relevant primary sensory functions.

Examples of the behavioural deficits characteristic of the syndrome of hemineglect have been presented in the literature for over a century (Halligan & Marshall, 1993). During this time, many different terms, definitions, and underlying mechanisms have been proposed for the syndrome and for specific components of the syndrome. Most contemporary accounts of this often devastating and sometimes dramatic syndrome have tended to emphasise the disruption of various attentional processes (Mesulam, 1999). Nevertheless, the attempt to find a single definition that adequately captures the many different behavioural manifestations of the syndrome has been elusive (Mesulam, 1999). For example, when words such as attention are used to operationally define the behavioural deficits and to describe the hypothetical constructs put forward to account for the deficits, terms such as attention can lead to conceptual confusion (Bisiach, 1999). To paraphrase Bisiach (1999), patients with neglect do not pay attention to one side of space; therefore the syndrome represents a disorder of attention. The functional definition, cited at the beginning of this review, was selected to avoid this type of circular assertion.

This review starts with a description of the clinical features of the hemineglect syndrome. Several ways in which the investigation of hemineglect has contributed to a better understanding of visual awareness and the extent to which information may be processed in the neglected visual field in the absence of subjective awareness will then be discussed. The review will conclude with a brief summary of some of the main theoretical accounts of hemineglect.

General Clinical Features

Hemineglect may be diagnosed following unilateral brain damage when the ability to report, respond, orient or explore contralesional stimuli or events has been selectively impaired despite evidence that primary sensory processing within the relevant modality has been spared (Heilman, et. al., 1985; Vallar, 1998). To convey the full range of behavioural manifestations of the syndrome and the devastating impact they may have for patients, this definition will be supplemented with some of the illustrative clinical cases described in the literature (e.g., Bisiach, 1999; Halligan & Marshall, 1993; Heilman, et al., 1985).

Patients with hemineglect may fail to notice or respond to people approaching from the contralesional side. Some may bump into contralesional obstacles when walking or manoeuvring a wheel chair. Others may fail to use contralesional limbs even in the absence of severe motor impairment. The lack of movement of the contralesional limbs on request may contrast with normal participation of these limbs in semiautomatic activities, such as unfolding a handkerchief. In the absence of a genuine dressing apraxia, patients with hemineglect may fail to dress or groom parts of the contralesional side of their bodies. They may fail to eat food from the contralesional side of the plate. Reading or writing may be initiated or terminated in the middle of the page or in the middle of an individual word. When asked to copy or draw an object from memory, they may distort or omit all or part of the contralesional half and then express the opinion that it is complete.

Patients with hemineglect may be unable to describe from memory the contralesional side of a familiar scene. Some may deny the presence of severe paralysis affecting limbs on the contralesional side of the body. Others may demonstrate no apparent deficit for an isolated contralesional stimulus. Their contralesional neglect may be evident only when contralesional and ipsilesional stimuli are presented simultaneously (Driver & Mattingley, 1998). This component of the syndrome is generally referred to as contralesional extinction on double simultaneous stimulation or extinction for short (Critchley, 1949). Extinction may be present along with or in the absence of other forms of hemineglect and thus, extinction and other forms of hemineglect may be dissociated. Visual extinction of the more contralesional object may occur even if both items are presented in the ipsilesional visual field (Rafal, 1998) and may represent a relatively mild form of neglect (Kohler & Moscovitch, 1997).

These clinical examples help to illustrate what investigators intend to convey when they state that patients with severe hemineglect sometimes behave as if the contralesional half of their world had suddenly ceased to exist (Bisiach, 1999; Mesulam, 1999; Rafal, 1998). They also illustrate how vastly different manifestations of hemineglect appear to entail a different frame of spatial reference or co-ordinates upon which to define the relative terms ‘ipsilesional’ and ‘contralesional’ (Vallar, 1998). For example, when the patients’ body is used to define personal space, hemineglect may be manifest as a selective impairment involving somatosensory stimuli originating from or delivered to the contralesional side of the body. In reference to extra-personal space, hemineglect may be manifest as a selective impairment for contralesional visual or auditory stimuli. Finally, hemineglect may be manifest internally as a selective impairment for the contralesional portion of a mental representation.

The initial demonstration that patients with neglect can be impaired in their ability to report information from the contralesional portion of their mental representations of space (Bisiach & Luzzatti, 1978) provided some of the most convincing evidence that hemineglect could not be accounted for by purely sensory based impairments. In this demonstration, patients with left hemineglect were to imagine themselves in a familiar town square, the Piazza del Duomo, in Milan. They were found to report fewer landmarks on the contralesional side of the imagined scene regardless of whether they were to describe the scene from one end of the square facing the cathedral or from the other end facing away from the cathedral. As described by Bisiach (1999), similar results have been reported when patients have been asked to describe other mental representations, such as maps of their country or the layout of their homes. Whereas this form of neglect may be manifest along with more perceptual forms of the syndrome, the two have also been dissociated (see Rafal, 1998).

The multimodal nature of the functional deficits also argues against purely sensory accounts of the syndrome. As indicated in the examples, the deficits can involve the somatosensory, visual, and auditory modality either singly or in various combinations (Banich, 1997; Bisiach, 1999; Heilman et al., 1985). There are even reports of hemineglect in the olfactory modality (Bellas, Novelly, Eskenazi, & Wasserstein, 1988). Anatomically, the extent to which the primary sensory inputs cross over from one side of space to the contralateral hemisphere differ for each modality. The cross over is complete in the somatosensory and visual modalities, partial in the auditory modality, and absent in the olfactory modality. Nevertheless, the behavioural manifestation of hemineglect typically affects the contralesional hemispace regardless of the sensory modality involved. The remainder of this review, and the experiments to follow, are focused on the deficits associated with visual hemineglect in extra personal space because it has generally been the most comprehensively investigated and best understood (Driver & Mattingly, 1998).

Visual Hemineglect

As illustrated in some of the clinical examples listed at the beginning of the review, the behavioural impairments associated with contralesional visual hemineglect may initially resemble those of patients with contralesional hemianopia. Patients with hemianopia show blindness for regions of the contralesional visual field following unilateral damage to the striate or primary visual cortex of the occipital lobe. These permanent scotomas or visual field cuts can be defined retinotopically (Driver & Mattingley, 1998). As already mentioned, the lesions associated with contralesional visual hemineglect frequently spare the primary visual pathways (Rafal, 1998). Thus, contralesional visual hemineglect frequently occurs in the absence of blind regions in the contralesional visual field, as indicated by formal assessment by the perimetry of the visual fields (Halligan, Marshall, & Wade, 1990). Even when the lesions responsible for contralesional visual hemineglect extend into the striate cortex and result in contralesional scotomas, the resulting field cuts cannot fully account for the contralesional symptoms of hemineglect (Banich, 1997).

In contrast to the contralesional blindness associated with hemianopia, the contralesional loss of visual awareness associated with hemineglect does not correspond to a purely retinotopic frame of reference (Driver & Mattingley, 1998). For example, in the case of contralesional extinction upon double simultaneous stimulation described at the beginning of the chapter, a contralesional event may be neglected only if an ipsilesional event is presented concurrently and not when the contralesional stimuli has been presented singly (Driver & Mattingley, 1998). In contrast, patients with hemianopia will never perceive an item presented singly in the contralesional field unless they re-orient their head or eyes so that the item will be within the preserved portion of their retinotopically defined visual field (Rafal, 1998).

For patients with hemineglect who show evidence of impaired awareness for contralesional stimuli when presented singly, the rotation of the head and eyes tends not to reduce the lateralized deficits (Vallar, 1998). However, contralesional stimuli are often more likely to be detected when they are particularly salient or when the patient's attention has been explicitly directed toward them. These factors have no effect in the case of scotoma.

As summarised by Vallar (1998), the symptoms of contralesional visual hemineglect have been described in relation to a number of different frames of reference that cannot be defined in accordance with purely retinotopic spatial co-ordinates. The side of space neglected is usually defined with reference to the body midline but it may occur with regard to other spatial reference frames as well (Banich, 1997). For example, in an investigation by Karnath, Christ, and Hartje (1993), a patient's contralesional visual neglect was reduced when his torso (egocentric frame of reference) but not his head (retinotopic frame of reference) was turned toward the neglected side of space. Thus, the frame of reference was defined in relation to the midsaggital plane rather than to the retinotopic image.

In an earlier investigation by Ladavas (1987), it was demonstrated that when patients with visual hemineglect tilted their heads to one side or the other, neglect was manifest in terms of the gravitational co-ordinates instead of on the basis of the laterality of their visual fields. In an investigation by Calvanio, Petrone, and Levine (1987), the degree of hemineglect was influenced by both environment-centred and body-centred co-ordinates. In this investigation, the patient with left hemineglect was turned onto their left or right side. For either condition, visual hemineglect in the detection of objects was found to be most severe for the quadrant that was left with regard to the body and left with regard to gravity and least severe for the quadrant to the right of the body and gravitational midlines. Based on this evidence, the authors suggested that the relative effects of the two frames of reference might be separable (Calvanio, et al., 1987). Hemineglect can even selectively impair patients' performance on visual tasks involving near (within arms reach) or far (beyond arms reach) extrapersonal space (Rafal, 1998).

Visual hemineglect may also be defined in relation to the contralesional and ipsilesional sides of objects, independent of their position relative to the patients' egocentric frame (Vallar, 1998). For an *object-based* deficit, the left and right sides of an object are defined in relation to the patient's viewing position. Thus, a patient with object-based neglect would generally neglect the contralesional half of various objects regardless of whether they appeared in the contralesional or ipsilesional visual field.

In contrast, for an *object-centred* deficit, the left and right sides of an object are defined in accordance with the object itself and are viewer-independent. For example, Behrman and Tipper (1994) demonstrated that neglect can follow the rotation of an object and be represented in its new co-ordinate frame. In this investigation, dumbbell-shaped stimuli were presented with a target that flashed within the confines of one of the two circular ends. Hemineglect was manifest as a response deficit for the contralesional targets. When the dumbbells were rotated around the centre of the visual field, the targets presented on the end that was first on the neglected side were again neglected even though they were now in the ipsilesional field and in an ipsilesional position relative to the other end of the dumbbell.

Object-based and object-centred neglect highlight a paradox in which the reference frame in which neglect is manifest can be defined by the objects or by parts of the objects that are neglected. For some patients with object-based hemineglect, the loss of visual awareness can be manifest for fairly specific categories of stimuli, such as words (neglect dyslexia) or faces (facial neglect). However, hemineglect more typically affects a variety of domains rather than a single modality (Kohler & Moscovitch, 1997). Thus, contralesional visual hemineglect in extrapersonal space has provided opportunities to selectively investigate different frames of spatial reference in which normal visual awareness typically operates simultaneously.

In addition to the impairments within the realm of perception and mental imagery, patients with visual hemineglect can manifest a motor bias involving a reluctance to respond to the contralesional side of the body, even with the ipsilesional right hand. Consequently, performance on many of the tests used to assess visual hemineglect can be influenced by both perceptual and motor factors. Many investigations have been conducted to determine ways to measure their effects independently (e.g., Mattingley, Husain, Rorden, Kennard, & Driver, 1998). In general, the deficits have been found to be more perceptual in some patients with hemineglect and more motor in others (Rafal, 1998). With respect to the diagnosis of hemineglect, these findings have led to a useful distinction between disorders of attention and disorders of intention, which is generally best conceptualised as a continuum (Rafal, 1998). Some researchers have proposed that part of the response bias may reflect impairment in the initial stages of motor planning (Driver & Mattingley, 1998).

Even when confined within the visual modality, the syndrome of contralesional hemineglect following unilateral brain damage can assume a wide variety of forms and a wide variety of spatial referents. Moreover, many of these features can be dissociated from one another. As a result, it is not surprising that a variety of different hypothetical constructs, even within the domain of attention, have been put forward to account for the syndrome or for specific components of the syndrome. Some of these accounts will be reviewed at the end of the chapter.

Etiology

Components of the hemineglect syndrome are most commonly due to acute diseases of the brain that do not allow for functional compensation to occur at the same time, such as cerebral vascular lesions, trauma, or rapidly growing tumours (Bisiach, 1999). The cause is most typically vascular damage (Heilman et al., 1985) and the majority of investigations of hemineglect have been based on patients with unilateral stroke (Halligan & Marshall, 1993). Estimates of the frequency of visual hemineglect following stroke vary considerably depending on the tests or criteria used and the time from stroke onset (Halligan & Marshal, 1993). Following right hemisphere stroke, hemineglect has been reported in about 50% of patients with about one in four severely affected. In contrast, it typically affects only about a third of patients following left hemisphere stoke with symptoms that are generally less severe and of shorter duration than those of patients with right hemisphere lesions (Black, Yu, Martin, & Szalia, 1990). More recently, the incidence and severity of neglect were also found to be significantly greater after right than left hemisphere lesions when 138 consecutive patients with CT verified unilateral first strokes were examined within two months of onset (McGlone, Losier, & Black, 1997).

As described by Bisiach (1999), it has been suggested that the prevalence of right neglect for patients with left hemisphere stroke might be underestimated due to concurrent dysphasia that could interfere with the verbal instructions used for the administration of most standardised methods of assessment. However, as described by Bisiach (1999), the association between hemineglect and right rather than left hemisphere lesions has been consistent with the incidence of similar impairments observed during unilateral intracarotid barbiturate injections or unilateral electroconvulsive therapy. These data may also suffer from the consequences of induced dysphasia following left unilateral injections. Nevertheless, as described by Driver and Mattingley (1998), the hemispheric asymmetry for the incidence and severity of neglect may relate to the relative dominance of the right-hemisphere for spatial cognition, attention to the global properties of visual scenes, and arousal. This hemispheric asymmetry in the incidence and severity of hemineglect has been a feature upon which several theoretical accounts of the syndrome have been based.

Neuroanatomical Correlates

The behavioural features of neglect described in this review have most typically been identified after unilateral right hemisphere lesions (Rorden, Karnath, & Driver, 2001). Although the lesions associated with hemineglect may extend into the primary sensory cortices, lesions confined to these regions have not been associated with the syndrome (Vallar, 1998).

Within the right hemisphere of individuals with hemineglect, damage involving the parietal cortex has been identified since the earliest clinco-pathological studies of hemineglect were conducted over half a century ago (Leibovitch, et al. 1998). For example, Vallar and Perani (1986) described how hemineglect is usually observed when damage to the supramarginal gyrus of the parietal lobe extends to include subcortical areas. Although less typical, there have been reports of hemineglect following lesions in other cortical areas, such as the right posterior temporal lobe (Rorden et al., 2001), right superior temporal lobe (Karnath, 2001; Karnath, Ferber, & Himmelbach, 2001) or dorsolateral premotor (Broadmann's areas 8, 6 and 44) and medial (anterior cingulate, supplementary motor area) regions (Vallar, 1998). Similarly, reports of hemineglect following damage to subcortical grey matter, such as the basal ganglia and thalamus (usually the pulvinar) have also been reported (Banich, 1997; Bisiach, 1999; Rorden et al., 2001).

Several of the brain regions most frequently associated with hemineglect were recently investigated using the structural (CT) and functional (SPECT) imaging data obtained from 120 patients who were consecutively admitted to a stroke service with a single right hemisphere lesion (Leibovitch et al., 1998). These brain regions included the parietal lobe, frontal lobe, cingulate cortex, basal ganglia, thalamus, and white matter fibre bundles. The results reaffirmed the primacy of parietal damage, specifically within the inferior parietal lobe, for the incidence and severity of hemineglect. They also reaffirmed involvement of the anterior cingulate cortex.

Although 31% of the patients with neglect had damage restricted to the frontal cortex, basal ganglia, or thalamus, abnormalities in these regions did not emerge as significant contributing components to the severity of hemineglect from the combined multivariate and univariate analyses of the CT and SPECT data. As indicated by Leibovitch et al. (1998), these results should not be taken to mean that these regions of the brain are not involved in the manifestation of neglect. In fact patients with neglect were more likely to have larger lesions compared to patients without neglect. Moreover, the lesions of patients with neglect were more likely to involve two or more key anatomic regions than were the relatively smaller lesions of patients without neglect. Also, damage to Broadmann's area 44 of the frontal lobe cortex was found to play a role in an anatomical correlation study of hemineglect by Husain and Kennard (1996) suggesting a function for the frontal cortex in the manifestation of hemineglect.

Damage to the posterior white matter fibre bundles, specifically involving the inferior and superior longitudinal fasciculi, which pass through the temporal-parietal-occipital junction, was found to be associated with hemineglect (Leibovitch et al., 1998). As described by Leibovitch et al. (1998), these fibre bundles are at a critical junction interconnecting the posterior lobar regions locally and anterior-posteriorly. Damage to these bundles has been shown to affect both proximal areas, such as the parietal lobe, and more distal areas, such as the frontal lobe (Leibovitch et al., 1998). Moreover, the temporo-parietal-occiptal junction is considered to be a poly-modal sensory region in the human brain because it forms connections with the unimodal visual, tactile, and auditory sensory association areas (Leibovitch et al., 1998).

Overall, clinico-anatomical investigations have generally confirmed that hemineglect is usually the consequence of damage in the parietal lobe and more precisely to the inferior parietal lobule. However, cases may be found with extensive parietal damage free from apparent manifestations of hemineglect (Bisiach, 1999). Such exceptions have been attributed to inter-individual variability in cortical organisation or to decreased blood flow in the cortex ipsilateral to the lesion but not directly affected by it (Bisiach, 1999).

Patients with hemineglect often manifest both perceptual and motor components of the syndrome. There has been a tendency for motor neglect to be associated with frontal lesions and perceptual neglect to be associated with posterior lesions in the parietal lobe. (Heilman et al., 1985; Rafal, 1998). However, as described by Driver and Mattingley (1998), the demonstration of specific motor deficits for neglect patients with inferior-parietal damage and not for neglect patients with frontal damage has challenged the generally prevailing view that motor aspects of neglect are caused only by frontal damage. As this review illustrates, the neuroanatomical basis of neglect remains far from settled.

Clinical Course

The onset of hemineglect following unilateral stroke is typically sudden and may be florid (Banich, 1997). Some of the most severe symptoms may remit completely within the first few hours, weeks, or months following their sudden onset (Rafal, 1998). It is rare for all of the symptoms to improve completely (Heilman et al., 1985). After the initial period of recovery, the deficits typically remain stable in about 20% of cases

(Black, et al., 1990).

According to Lavie and Robertson (2001), severe forms of neglect may typically resolve into extinction with stimulation of the contralesional side neglected only in the presence of competing ipsilesional stimuli. Otherwise, when presented alone, the contralesional stimuli may be reported. In some cases, the residual deficits may be difficult to detect using some of the standard bedside screening measures in the relatively distraction-free environment of the clinical assessment room (Rafal, 1998). However, the residual deficits may be evident on more sensitive measures (e.g., the Grey Scales developed by Mattingley, Bradshaw, Nettleton, & Bradshaw, 1994). Moreover, the residual symptoms may also continue to be very disabling in basic daily activities (Rafal, 1998). The presence of hemineglect, particularly a patient's mild disregard for contralesional motor impairments, has been associated with poor functional outcome and can hinder rehabilitation (Bisiach, 1999). Therefore, assessment of the syndrome is of paramount importance and has been a major focus of many investigations.

The mechanisms through which functional recovery or compensation take place are poorly understood (Bisiach, 1999). Recovery and compensation are likely to be provided by structures in the unimpaired hemisphere as well as by surviving circuits in the lesioned hemisphere (Bisiach, 1999). Some have speculated on the potential role of callosal fibres and commissural pathways at the midbrain level between the hemispheres or ipsilateral pathways from the undamaged hemisphere to appropriate motor units (Vallar, 1993).

As reviewed by Robertson (2001), there is growing evidence that non-lateralized attentional deficits are extremely strong predictors of persisting unilateral neglect. For example, Robertson et al. (1997) examined the performance of right hemisphere stroke patients on a non-spatial auditory sustained attention measure, which consisted of maintaining a count of tones. Right hemisphere patients who showed neglect were significantly more likely to have problems with this task than were those who had no obvious neglect even though the two groups of patients did not differ significantly on indices of functional severity such as motor function. According to Robertson et al (1997), the discriminative power of the auditory sustained attention measure was greater than that of the line-bisection task, which is a conventional measure of visual neglect. Similar reports have been based on the results of an investigation in which an auditory continuous performance test requiring the detection of a target letter among non-target distracters (Hjaltson, Tegnér, Tham, Levander, & Ericson, 1996). Non-lateralized reductions in perceptual load or attentional capacity have also recently been reported as a significant modulating factor for the strong ipsilesional bias typically associated with patients with hemineglect (Lavie & Robertson, 2001). Thus, from being considered a deficit specific to one side of space, researchers such as Robertson (2001) have begun to propose that chronic neglect in adults is likely to be seen within a context of more widespread non-spatial attentional difficulties.

Assessment

There is an extensive literature pertaining to the assessment of hemineglect due to the efforts of many investigators to better detect, understand, and treat the deficits. The focus of the present review will be on the assessment of visual neglect primarily for research rather than clinical purposes. For patients with severe hemineglect, the deficits may be evident in spontaneous behaviour (Bisiach, 1999) that may be characterised by gross inattention to contralesional space (Halligan & Marshall, 1993). The presence of hemineglect may be revealed or confirmed by many different means, ranging from extremely simple, although sometimes very sensitive, bedside tasks to sophisticated tests requiring complex instruments (Bisiach, 1999).

The neuropsychological assessment of a patient with hemineglect may be challenging due to co-morbid impairments that can initially resemble hemineglect (Halligan & Marshall, 1993). Two examples provided by Halligan and Marshall (1993) are constructional dyspraxia (a defect in the spatial aspects of a task within the context of an integrity of individual motor movements) and optic ataxia (an inability to perform co-ordinated voluntary conjugate lateral eye movements when these are solely under visual control). As previously mentioned, severe aphasia associated with left hemisphere damage can interfere with the verbal administration of many measures (Bisiach, 1999). Documentation of the extent to which primary sensory processing remains intact is also essential. In the visual modality, this documentation can take the form of perimeter testing for evidence of co-morbid scotoma or field cuts. Given the many dissociations in the behavioural manifestations of the syndrome, an extended and differentiated test battery is required if an exhaustive description of the neglect symptomatology is desired (Bisiach, 1999). However, a briefer battery that may be easily administered at the bedside is generally required for patients recruited soon after stroke onset when the hemineglect is likely to be most pronounced. A battery that is easily readministered is advisable for patients with low stamina who may require several sessions to complete an experimental protocol given the variability in the severity and even presence of hemineglect over time (Bisiach, 1999).

The Sunnybrook Bedside Neglect Battery (Black, Ebert, Leibovitch, Szalai, Blair, & Bondar, 1994; Black, et al., 1990) is well suited for the assessment of patients during early stages of recovery from stroke. This standardised battery of easily administered screening measures consists of two spontaneous drawings, two drawings from copies, two cancellation tasks (figure and line), and four line bisections. Each test is scored in comparison to the performance of a sample of healthy age-matched controls and contributes to a cumulative score which can be classified in accordance with the presence and severity (mild, moderate, and severe) of the neglect deficit. Because the Sunnybrook Bedside Neglect Battery was selected as a measure for the experiments included in this dissertation, samples of each sub-test completed by the patients with hemineglect who participated in Experiments One and Two along with the standardised administration and scoring procedures have been included in Appendix B. The focus here will be to provide a more general description of the ways in which hemineglect may be manifest on versions of each sub-test.

Hemineglect may be demonstrated by asking patients to cancel each item in an array of scattered lines of different orientation (Albert, 1973). The test may reveal omissions or abnormally slow latencies for stimuli on the contralesional side of the display. Bisiach (1999) described several variations of the task. The patient may be asked to cancel or circle a target or targets that have been presented in an array of non-targets. The stimuli can be selected from any category, including figures, shapes, designs, letters, or various combinations of different categories. Varying the degree to which the targets and non-targets are similar, the arrangement of the stimuli, or the ratio of targets and distracters can increase the difficulty of these visual search and cancellation tasks. Bisiach (1999) described a version of the task for which the patients were to pick up a handful of coins spread over a table. This version of the task was intriguing because it permitted the assessment of neglect with the eyes open or closed. Bisiach (1999) cautioned that the results of tests requiring complex perceptual or executive skills could be difficult to interpret due to extraneous factors. On the other hand, specific modifications to the task can sometimes provide a better understanding of a patient's deficits. For example, a visual search and cancellation task for which a patient with hemineglect was to make either highly visible or non-visible marks recently provided evidence of a spatial working memory deficit with spared non-spatial working memory (Wojciulik, Husain, Clarke, & Driver, 2001). The non-visible marks entailed the use of a capped pen and the placement of a sheet of carbon paper under the cancellation sheet. The stimulus array contained 24 identical stimuli (the letter O) and 24 different drawings of common objects. The stimuli to be cancelled could be either the Os (identical targets condition) or the objects (unique targets condition). The authors' conclusions concerning the selective impairment of spatial working memory was based on the greater number of repeat cancellations observed in the non-visual marking condition for targets that were identical (letter Os) relative to the number of repeat cancellations observed for targets that were unique (different objects).

The inability to bisect a line correctly represents one of the classic signs of contralesional hemineglect (Banich, 1997). When asked to bisect a horizontal line, patients with hemineglect may behave as if the contralesional side of the line was absent by bisecting the line to the right or left of the true midpoint (Kohler & Moscovitch, 1997). The rightward placement of patients with left hemineglect stands in marked contrast to normal performance, which is typically more accurate with a slight bias toward the left of the midpoint (Black, et al., 1990). The bias may be present in versions of the bisection task that do not require a motor component (Rafal, 1998). There is a vast clinical and experimental literature pertaining to hemineglect and the bisection of lines or other shapes in a variety of different spatial orientations (see Fink et al., 2000).

Copying and constructional tasks have been described as among the best ways to illustrate the variable and often unusual manifestations of visual hemineglect (Halligan & Marshall, 1993). The objects to be copied or drawn in the Sunnybrook Bedside

Neglect Battery are a daisy and a clock face (Black, et al., 1994; Black, et al., 1990). When a patient with hemineglect attempts to copy the objects, or to draw them from memory, considerable omission, disarrangement, or distortion of the contralesional details may be observed despite reasonable reproduction of the ipsilesional features (Bisiach, 1999). For example, the drawing or copy of a daisy may be confined to the ipsilesional side of the page. The ipsilesional petals or leaf may be omitted entirely or transposed to the ipsilesional side of the drawing. For the copy or drawing of well-known symmetrical objects, such as a clock, Halligan and Marshall (1993) noted that the circumference of the clock face is usually not affected. Numbers, however, may be omitted from the contralesional side or they may all be squeezed in on the ipsilesional side. When asked to copy a more complex scene, evidence of spatially based neglect may take the form of omission of the features on the contralesional side of the display. Object-based neglect may be evident when the contralesional half of each object is omitted at different lateral positions across the stimulus display (Halligan & Marshall, 1993).

The presence or absence of contralesional extinction for double simultaneous stimulation, as described at the beginning of this review, should also be assessed. As described by Rafal (1998) very quick assessment of visual extinction can be accomplished by having the patient fixate on the nose of the examiner whose hands are extended to either side of the patient's visual field. When asked to report whether the examiner moved the left, right, or both fingers simultaneously, the patient with extinction will generally fail to report the movement of the finger in the contralesional visual field but only when paired with movement of the ipsilesional finger.

As mentioned previously, a patient's neglect may be task-specific and may vary across time (Bisiach, 1999). With respect to this variability in performance, it has recently been suggested that what is impaired in hemineglect is not necessarily the capacity to respond to events occurring in the neglected hemispace but rather to produce consistent responses to those events (Bartolomeo, Siéroff, Chokron, & Decaix, 2001).

Also, as previously described (Robertson, 2001), non-lateralized attentional deficits have been reported to be extremely strong predictors of the severity of persisting unilateral neglect (e.g., measures of sustained auditory attention, Robertson et al., 1997).

The assessment of non-spatial attentional abilities may therefore be useful predictors of persisting unilateral hemineglect (see also Hjaltson et al., 1996; Samuelson, Hjelmquist, Jensen, Ekholm, & Blomstrand, 1998).

Fate of Information in the Neglected Visual Field

A long-standing and controversial question about patients with hemineglect concerns the processing fate of neglected information (Behrmann & Meegan, 1998). According to McGlinchey-Berroth, Milberg, Verfaellie, Alexander, and Kilduff (1993), most theories of hemineglect, including those that posit an attentional deficit, remain vague about the fate of visual information that is not available to subjective awareness due to its presentation in the neglected field. There has generally been an assumption that the neglected information is simply unavailable for higher-order operations possibly due to the filtering that is presumed to have occurred at some point. Several researchers have presented evidence, however, that explicitly neglected visual information can be processed implicitly and this implicit processing might involve brain systems leading to and including the association cortex (e.g., Berti & Rizzolatti, 1992; McGlinchey-Berroth et al., 1993). In other words, the behavioural component of these implicit measures was later influenced by the explicitly neglected information that was not earlier captured by the patients' subjective awareness. Some implicit measures have provided evidence of the processing of neglected stimuli to the level of object identity and category membership. For the remainder of this section, some of the implicit methods used to assess the residual processing of explicitly neglected visual information in patients with visual hemineglect will be reviewed to illustrate the degree to which this information may be processed in the absence of subjective awareness.

Implicit Processing of Low-Level Visual Information

Several researchers have shown that patients with visual hemineglect have access to perceptual information on the contralesional side without subjective awareness of the information. For example, a patient's rate of responding during a speeded yes/no detection task provided evidence that he had implicitly processed the onset of the stimuli in the neglected visual field despite his explicit judgement that the stimuli had not been presented (Mijovic-Prelec, Shin, Chabris, & Kosslyn, 1993). For this investigation, the patient was to indicate as quickly as possible whether or not a dot was present in the left or right of a display. As expected, the patient typically denied seeing the dots in the left visual field. However, these incorrect rejections were generally made more quickly than the correct rejections when no dot was actually present. The latency distribution for the denied contralesional dots and detected ipsilesional dots matched more closely than did the slower latency distribution for the true absence trials. Thus, whereas the patient's explicit responses indicated no awareness of most of the contralesional dots, the response times for these incorrect reports indicated that he nevertheless processed the onset of the stimuli implicitly.

Similar evidence of preserved implicit processing of stimulus onset in the neglected visual field of patients with hemineglect was reported by Marzi et al. (1996). These researchers used a simple reaction time task in which the participants were to respond as quickly as possible to the presentation of any flash. Normal performance on the task is characterised by faster reaction times to pairs of flashes presented simultaneously than to single flashes. This summation effect was found to be intact when a pair of flashes was presented at the same time to the contralesional and ipsilesional visual fields of patients with hemineglect even when they explicitly failed to report the presence of the contralesional flash.

Processing Influenced by the Mere Presence of a Stimulus in the Neglected Field

The magnitude of the rightward deviations made by patients with right hemisphere damage and left hemineglect on the classic line bisection task has provided evidence of implicit processing of contralesional visual information that appeared to have escaped subjective awareness. The magnitude of the rightward deviation has been related to the length of the line, although the proportionality constant within the mathematical equation varies from patient to patient (Mozer, Halligan, & Marshall; 1997, Monaghan & Shillcock, 1998). This relationship to total length suggested that sensory information from the entire line was processed beyond a sensory level although only the information pertaining to the ipsilesional segment became available to the patients' subjective awareness.

A similar relationship had been reported between the number of stimuli presented in the display of a cancellation task and the number of targets cancelled by a patient with left hemineglect (Chatterjee, Mennemeier, & Heilman, 1992). For this task, the systematic relationship was described by means of a power function (targets cancelled = K (targets presented) ^{B}, in which the constant (K) and exponent (^{B}) were derived empirically. As summarised by the authors, the data implied that the patient had implicit knowledge of the quantity of stimuli presented in the neglected field, and that this knowledge systematically influenced her explicit behaviour, while remaining outside of her subjective awareness.

Processing of Basic Stimulus Attributes in the Neglected Field

According to Rafal (1998), variation of the clinical test for the extinction of contralesional stimuli provided evidence for some preservation of information processing in the neglected visual field. Some patients with neglect can be much less likely to show contralesional extinction when different objects are shown simultaneously to each of the visual fields than when identical objects are presented. This general observation suggests that information in the unattended field is processed sufficiently for it to be distinguished as different from its art in the ipsilesional field. According to Rafal (1998), this difference presumably triggers an orienting response leading to detection of the contralesional stimuli that would have otherwise been neglected. According to Rafal (1998), this clinical observation stimulated investigations of the attributes for which processing is preserved in the neglected visual field as demonstrated by their contribution to the reduction of contralesional extinction (e.g., Baylis, Driver, & Rafal, 1993).

Attributes of Shape and Colour

The results of an investigation by Baylis et al. (1993) demonstrated that the processing of stimulus attributes, such as colour and shape, may be preserved for neglected stimuli that have failed to reach subjective awareness (see also Cohen, Ivry, Rafal, & Kohn, 1995). This investigation was based on data from five patients with mild left hemineglect for whom the exposure duration of briefly presented coloured letters could be shortened to a point at which they reliably identified single letters in either visual field, and showed extinction on many trials with bilateral stimuli. Once the exposure duration was determined for each patient, coloured letters were randomly presented either unilaterally or bilaterally. The patients were to report what they saw on each side. In one condition, they were to name the letters. In another condition they were to report the colour of the letters. The critical trials were those with bilateral targets for which the patient showed extinction of the contralesional stimuli by reporting only the ipsilesional stimuli.

Extinction was the most frequent for trials during which the bilateral stimuli consisted of letters that were identical in the attribute (i.e., shape or colour) that was to be reported. In contrast, extinction was generally ameliorated for trials during which the bilateral stimuli consisted of letters that differed in the attribute that was to be reported but not when they differed in the other attribute. For example, when the task was to name the letters, the stimulus attribute to be reported was determined by shape rather than colour. In this condition, extinction was most frequent when the stimuli consisted of letters of identical shape even when those letters were presented in different colours. In contrast, extinction was generally ameliorated for trials during which the stimuli consisted of letters with different shapes regardless of whether or not the letters appeared in the same colour. Similarly, when the task was to identify the colour rather than shape of the letters, extinction was most frequent when the stimuli consisted of letters of the same colour even when those letters were of different shapes. Once again, this pattern of results was in contrast to the general amelioration of extinction under this task condition when the stimuli consisted of letters of different colour regardless of whether or not the letters were the same shape or not. In addition to demonstrating that information about the shape and colour of overtly neglected stimuli may continue to be processed outside of subjective awareness, these results demonstrated that the subjective access of these attributes were contingent upon the goals of the task.

Attributes Pertaining to the Basic "Gestalt" Laws of Perceptual Organisation

As the result of many early stages of visual information processing within regions of the occipital lobe, several features of visual object segmentation have been reported to be preserved for stimuli presented in the neglected field of patients with visual hemineglect (see Driver & Mattingley, 1998 for a review). The manipulations in the visual displays used by these researchers involve several of the laws of perceptual organisation associated with the demonstrations of Gestalt psychologists (Benjafield, 1992). Some examples that have been investigated in relation to the syndrome of visual hemineglect include the distinction between figure and ground, perceptual closure, and grouping by proximity.

For example, symmetry about the vertical, which typically exerts powerful effects on figure-ground segregation in normal observers, has been found to be preserved sometimes in the absence of subjective awareness in patients with visual hemineglect (Driver, Baylis, & Rafal, 1992). The visual display used for this demonstration consisted of alternating pseudorandom red and green segments. Either the red or green segments were symmetrical about the vertical. The participants were informed that they were going to be presented with either red shapes on a green background or green shapes on a red background. They were instructed to identify the colour of the shapes. A patient with severe left hemineglect showed the usual effect of symmetry on figure-ground segregation, by tending to report the colour of the symmetrical shapes, with no bias towards reporting the rightmost colour. This normal effect of symmetry about the vertical demonstrated that information about both sides of the perceptual figures were processed. However, the patient's description of the displays upon completion of the task suggested that he was not subjectively aware of the left sides of the perceptual figures. He stated that his chosen shapes looked closer and brighter but did not mention the symmetry feature that typically is most striking to observers without neglect.

To follow up on whether the symmetry around the vertical feature was processed only at a preattentive level in the patient with left hemineglect, Driver et al. (1992) instructed the patient to judge explicitly the symmetry of individual segments taken from the figure-ground displays. The patient's responses were at chance level for displays in which symmetry was manipulated along the vertical axis and at normal level for displays in which symmetry was manipulated along the horizontal axis. These results demonstrated that the information concerning symmetry from the left part of a visual display that was unavailable for explicit verbal report may nevertheless be processed implicitly.

Similar conclusions may be reached from the results of an investigation in which a patient with severe left visual hemineglect was asked to copy a display of alternating bands of colour in which only one colour depicted symmetrical shapes around the vertical (Marshal & Halligan, 1994). The patient attempted to copy only the right but not left side of each symmetrical shape. This result indicated that both sides of each of the symmetrical shapes had been processed preattentively at the early level of figure-ground segmentation and that the left side of each symmetrical figure was unavailable for explicit report due to the patient's neglect.

Perceptual completion is an example of an early object segmentation factor that has been investigated in relation to the extinction deficit. As described previously, extinction of the more contralateral of two concurrently presented visual events is a common deficit of patients with hemineglect. This deficit can be eliminated if the two visual events become segmented as a single object even when the link between the two events required completion behind an occluder (Mattingley, Davis, & Driver, 1997). Each trial in this demonstration began with the presentation of a cube in the centre of the visual display followed by the presentation of black bars which could briefly appear only on the left, only on the right, one the left and right, or not at all. The patient was instructed to indicate whether the bars appeared on the left, on the right, on both sides, or not at all. There were two conditions in which the bars were presented on both sides. One of these conditions was identified as the occluded condition because the bars were positioned so that they appeared to form a single, partly-occluded rod lying behind the cube. The other condition was identified as the segmented condition because positioning of the bars slightly above the cube maintained their segmented appearance. Severe left extinction, which took the form of responding "right-side only" when bars actually appeared on both sides, was evident when the two bars were segmented and was significantly reduced when the two bars were partially occluded by the cube so that they appeared to be a single rod.

A similar elimination of extinction was obtained when the link between the two events required the formation of a subjective figure in accordance with the perceptual law of closure (Mattingley et al., 1997). For this demonstration, each trial began with the presentation of four circles arranged around a central fixation cross. For the following frame, patients with left hemineglect were to indicate whether segments had been removed from only the left circles, only the right circles, the circles on both sides, or from none of the circles. As in the previous demonstration, there were two conditions when the display involved the removal of segments from circles on both sides of the display. The left-sided extinction was again significantly reduced when the removal of the segments led to the percept of a single subjective feature between the circles (e.g., a square) than when this subjective feature was absent.

Grouping or the importance of proximity in determining how stimuli are perceptually organised at a preattentive level, has also been shown to be preserved in visual heminegiect (Driver, Baylis, Goodrich, & Rafal, 1994; Ward, Goodrich, & Driver, 1994; Gilchrist, Humphreys, & Riddoch, 1996). For example, the elimination of left-sided extinction effects in one of these studies demonstrated that attention continues to operate in the reference frame of the group such that visual neglect is determined based on the principal axis of the group (e.g., Driver et al., 1994).

According to Driver and Mattingley (1998), these results are consistent with single-cell recordings in monkeys, lesions effects in human patients, and functional neuroimaging evidence from normal people, which all indicate that these early stages of visual processing are generally performed in extra-striate cortical areas of the occipital lobe. These regions of the occipital lobe along with the afferent connections from the lateral geniculate nucleus into primary visual cortex, are generally spared in patients with parietal neglect. Consequently, Driver and Mattingley (1998) concluded that it should be expected that the attentional deficits typical of the hemineglect syndrome be manifest despite considerable processing of very basic visual information.

Higher Levels of Information Processing in Neglected Visual Field

Letter Flanker Tasks. A patient with left hemineglect reported a target letter faster when it was accompanied by a flanker consisting of the same letter rather than a different letter even when the presentation of the flanker on the contralesional side could not be explicitly reported (Audet, Bub, & Lecours, 1991). In a control experiment, Audet et al. (1991) showed that the facilitation effect for the left-sided flanker was not affected by how well the flanker predicted the target. As described by Audet et al. (1991), it was not larger when the flanker matched the target in 80% of the trials than when it matched in only 50% of the trials as it should have been if the flanker information had been used voluntarily. In combination with the patient's inability to report explicitly the presence of the left-sided flanker, this result suggested that the observed facilitation resulted from implicit processing of information about letter identity in the neglected field. The facilitation was also observed when flankers and targets did not share the same case, suggesting that the neglected flankers were implicitly processed to the level of its abstract identity (Fuentes & Humphreys, 1996).

Reading Tasks. The investigation of the reading errors of patients with hemineglect provided some of the initial evidence that implicit processing of overtly neglected information was preserved in the syndrome. For example, Kinsbourne and Warrington (1962) reported that the reading errors of a patient with left visual hemineglect generally occurred at the beginning of the words in the form of letter substitutions rather than omissions. Because the length of the word was typically maintained, Kinsbourne and Warrington (1962) inferred that this word length was processed implicitly (see also Ellis, Flude, & Young, 1987).

In contrast to the findings of Kinsbourne and Warrington (1962), the reading errors of another patient with left neglect dyslexia most frequently involved the total omission rather than mere substitution of left-sided letters (Vallar, Guarigglia, Nico, & Tabossi, 1996). This pattern of reading error suggested that even the spatial positions of the letters were not encoded. The omission of the initial letters resulted in reading errors that consisted of non-words or real words that differed from the target word. However, despite having neglected the initial letters, the patients verbal associations in another version of the task were generally related to the misread targets. Moreover, associations to the misread words sometimes included the actual target word. As described by Vallar et al. (1996), these results demonstrated how presentation of words in an association task could be used to reveal the implicit processing of overtly neglected letters to a point where the meaning of the entire word was extracted.

A modified version of the Stroop test was used to demonstrate implicit processing of the initial letters of words that were generally omitted during reading tasks by patient with left neglect dyslexia. When asked to name the colours in which colour words were written, the patient's colour-naming time was found to be affected (i.e., delayed) by the meaning of the words even when the beginning letters were omitted in reading.

Matching Paradigms. Patients with hemineglect or extinction are often unable to report the occurrence or identity of a contralesional stimulus particularly when it is presented at the same time as an ipsilesional stimulus. Volpe, Ledoux, and Grande (1979) demonstrated that patients with contralesional extinction may nevertheless perform well above chance (88 to 100% accuracy) when asked to judge whether two simultaneously presented words or pictures were the same or different, even when completely unaware that a contralesional stimulus had been presented. According to the researchers of this investigation, some of the patients who were aware of only one of the stimuli commented that being asked to make a same/different judgement seemed silly. The results of this study provided additional evidence, using implicit measures, that some of the information processed from stimuli that have been overtly neglected may be accessed.

These results have been supported and extended in other patients with visual hemineglect or extinction (Berti, et al., 1992; Karnath, 1988). For example, a follow up investigation by Berti, et al. (1992) indicated that the implicit processing of objects in the contralesional or neglected visual field may extend to a semantic or categorical level in the absence of explicit awareness of the name or identity of the extinguished object. Each trial in this follow up investigation consisted of the simultaneous presentation of a contralesional and an ipsilesional picture that depicted common objects. After judging whether or not the pictures depicted objects of the same name (implicit measure) the patient was to name the objects (explicit measure). The pair of pictures could be given the same name when they depicted identical views of an object, different views of an object, or different exemplars of an object. The patient's explicit naming of the contralesional objects was severely impaired. In contrast, her performance was consistently above chance levels on the matching task even when the pictures depicted objects from different views, or different exemplars of an object. These results indicated that the patient's judgements were not based simply on the preservation of very basic level perceptual matching. The patient's implicit matching of different exemplars of an object despite her inability to explicitly name the contralesional exemplar indicated that processing of the extinguished picture reached a semantic or categorical level while its identity remained outside of the patient's subjective awareness. That matching was successful in the condition in which different exemplars of an object were used provides evidence that the abstract identity of the extinguished contralesional stimuli were implicitly processed during the matching task despite remaining unavailable to the patient's awareness during the explicit naming task.

Whereas some researchers replicated and expanded upon the results and conclusions of Volpe et al. (1979), others expressed more cautionary criticisms. For example, Farah, Monheit, and Wallace (1991) offered an alternative explanation for the results of Volpe et al. (1979). She cited examples of studies in which it has been shown that perceptual degradation of the stimuli presented to normal people also results in a loss of the ability to identify objects prior to the loss of the ability to make same-different judgements (e.g., Farah, Wong, Monheit, & Morrow, 1989). She concluded that the findings of Volpe et al. (1979) do not necessarily, in themselves, indicate that implicit perceptual processing has been fully preserved for extinguished stimuli. This criticism appears to be concerned with the extent of the processing that may take place for neglected information and does not appear to be intended to imply that implicit processing is not taking place. Thus, her point seems to be that an assessment of the extent to which the initial stages of processing remains intact may not be demonstrated by whether or not a later stage of processing has been reached.

Marshall and Halligan (1988) reported evidence of the implicit processing of explicitly neglected information in a case study of a female stroke patient with right hemisphere damage and severe contralesional neglect. The patient was repeatedly presented with two drawings of a house presented one above the other. She explicitly judged the two line drawings as identical despite the presence of flames drawn on the left side of one house. When presented with pictures of houses with or without flames on the left side, the patient consistently selected the houses without flames as the one in which she would prefer to live but never reported the presence or absence of flames as the basis upon when her preference was made. Her consistent preference for the no-burning houses provided evidence of implicit processing of the explicitly neglected contralesional features of the drawings.

In a larger sample of stroke patients with right hemisphere damage and contralesional neglect, Bisiach and Rusconi (1990) only partially replicated the case study of Marshall and Halligan (1988). The patients were also unable to detect left differences in the pairs of drawings on the matching task. In their preference judgements, however, one of the patients chose the drawing of the house without the left-sided flames on some trials only and the other two patients showed a statistically significant preference for the house with flames. When asked to specify the reason for making their choices, they made no reference to any of the relevant differences but rather to insignificant or non-existing differences, regardless of whether they chose the burning or non-burning house.

One reason why the preference portion of the experiment was not replicated with the picture of the burning house may have been because the patients were asked to indicate which drawing they preferred rather than to specify in which house they would prefer to live. Thus failure to replicate the results of Marshall and Halligan (1988) could have been influenced by the more general nature of the question, which was not as personally relevant. The house with flames was more colourful (i.e., red flames) and it may have been preferred as a picture but not for the purposes of living in. It is interesting that both of the patients who showed a preference for the burning house also showed a preference for the drawing of a wineglass that was unbroken compared to one that was broken on the contralesional side (they were also the only patients assessed with this additional item).

Another reason for the failure of researchers, such as Bisiach and Rusconi (1990), to replicate the results of case studies consistently in larger samples may be that covert knowledge of extinguished stimuli represents an uncommon event among patients with left-sided extinction or neglect (D'Erme, Robertson, Bartolomeo, & Daniele, 1993). D'Erme et al. (1993) arrived at this conclusion based on their ability to replicate the results of Volpe et al (1979) in only two out of the six patients that were assessed. One of these patients revealed evidence of covert processing when shapes but not words were used as stimuli. The other patient revealed evidence of covert processing when words but not shapes were used as stimuli.

The ability of D'Erme et al (1993) to replicate a finding in only two out of six patients with neglect illustrates the value of case studies in demonstrating the possibility of an event and a case study may well be the better way to study the phenomenon (e.g., Code, 1996). In other words, the rarity of an event does not preclude the event as a possibility. Thus, to demonstrate implicit processing in the neglected hemifield, it may be more important to ensure that the method of assessment has been tailored to a patient's specific impairments rather than to operate on the assumption that all patients will necessarily show the same patterns of impairment. In the next section, an experiment will be described that serves to demonstrate how the sub-grouping of patients based on their relative degree of impairment on explicit and implicit tests correlated with the general location of the brain lesions (D'Esposito, McGlinchey-Berroth, Alexander, Verfaellie, & Milberg, 1993).

Semantic Priming Paradigms. The results of several semantic priming studies have demonstrated that explicitly neglected information in the contralesional visual field of patients with hemineglect or extinction may be processed implicitly to semantic or categorical levels (for a review see Rafal, 1998, Kohler & Moscovitch, 1997; Vallar, 1998).

For example, Berti and Rizzolatti (1992) presented a picture categorisation task to seven patients with right hemisphere damage and severe contralesional hemineglect. Using a two-button response pad, the patients were to categorise target pictures of animals or fruit that were presented to the ipsilesional (non-neglected) visual field. Each target was preceded by a prime that consisted of a picture (animal or fruit) which appeared in the neglected visual field. The prime and target could be non-congruent (from different categories), physically identical (the same stimulus), or congruent (from the same category). During the administration of practice trials, the patients verbally identified the targets but not the primes. Compared to target responses in the non-congruent condition, response facilitation was demonstrated for both the physically identical and congruent conditions. Thus, the authors concluded that the picture primes presented to the patients' neglected visual field were processed to a categorical level despite having not been explicitly reported during the administration of the practice trials.

McGlinchey-Berroth et al. (1993) also used semantic priming to investigate whether information in the neglected field may be processed for meaning despite being unavailable to the patients' subjective awareness. Separate versions of the protocol assessed the implicit or explicit processing of information presented in the neglected contralesional field of four patients with right hemisphere damage and left neglect.

The implicit component of the protocol consisted of a semantic priming paradigm with a lexical decision task. Each trial began with the presentation of a picture prime on the left or right side of central fixation and a meaningless scrambled pattern on the opposite side. The lateralized picture primes were presented simultaneously with the meaningless patterns in the opposite visual field for 200 ms to simulate the methods typically used to assess the extinction of contralesional stimuli. This presentation format, along with the subsaccadic stimulus display time, were intended to minimise the likelihood that the patients would shift gaze to the critical primes in the left (neglected) field.

After an inter-stimulus interval of 200 ms, a letter-string consisting of a word or non-word was presented at central fixation. The task was to decide whether the target was a word or not. For each target, the preceding prime was either semantically related or unrelated (data from non-word targets were not included in the analysis). Equivalent levels of priming (i.e., faster reaction times for words preceded by related rather than unrelated primes) were obtained for the centralised targets regardless of whether the preceding prime had appeared in the left (neglected) or right (non-neglected) field. The same pattern was obtained for normal control participants. The assessment of a patient with right occipital lobe damage and left hemianopia, in contrast, revealed evidence of semantic priming for primes in the right (intact) but not left (impaired) visual field.

The explicit component of the protocol involved a delayed discrimination task that served as a control measure. In this version, the lateralized primes were followed by a pair of centrally located targets arranged vertically one over the other. Participants were to select the target that had been shown as a prime. Both the patients with neglect and the patient with hemianopia were impaired in their ability to explicitly identify the pictures that had appeared in the left (contralesional) but not right (ipsilesional) field. The dissociation between the results of the implicit and explicit versions of the paradigm, suggested that the pictures presented in the neglected visual field of the patients with left hemineglect had been processed to the level of semantic categorisation while remaining outside of subjective awareness.

Although expressed in terms of conscious and unconscious processing, McGlinchey-Berroth et al (1993) argued that the dissociation between the implicit and explicit processing of information in their results would be difficult to accommodate in theoretical accounts of neglect that imply a complete interruption in the processing of early sensory information. They suggested that current models of neglect should accommodate the possibility that unilateral visual neglect reflects a partial disruption in the ability to form visual representations or a disruption in the ability to intentionally access visual representations.

Comparable results have been obtained when words rather than pictures have been used as the priming stimuli in larger samples of patients (D'Esposito et al., 1993; see also Ladavas, Umilta, & Mapelli, 1997). Of interest in the relatively large sample of 16 patients with neglect following unilateral right hemisphere stroke, three subgroups were identified based on their patterns of performance on implicit priming and explicit discrimination measures (D'Esposito et al., 1993). Some of the patients showed intact priming but poor discrimination in the left visual field (*n* = 7). Some showed normal priming and discrimination in both fields despite clinically apparent left-sided hemineglect (*n* = 2). The remainder showed normal priming but poor discrimination in both fields (*n* = 7). None of the groups differed significantly in terms of the severity of their left-sided hemineglect deficits as determined by the mean ranking of their performance on four clinical measures. As described by the authors, the patients in the first group had posterior lesions and the patients in the second and third groups had extensive deep anterior lesions. Based on these findings, the authors concluded that the clinical presentation of visual hemineglect might be the surface manifestation of at least two different and often interacting processes. They attributed the pattern of deficits of the first group to attentional processes, of the second group to intentional processes, and of the third group to a global attentional disturbance superimposed on the deficits observed in the other two groups.

McGlinchey-Berroth et al. (1996) replicated and extended their previous implicit semantic priming results for explicitly neglected information in a sample of seven patients with contralesional hemineglect. They replicated their previous results by showing response facilitation from the neglected contralesional information when the neglected prime was semantically related to the target (e.g., TEA-CUP). They extended their previous results by showing negative priming (response latency delay) for targets that were preceded by neglected primes that were orthographically similar to a semantically related word (e.g., PEA-CUP). As in the original study, the patients performed at chance when attempting to select the prime which had appeared in the left (neglected) visual field from a pair of vertically aligned alternatives that appeared centrally during a forced-choice discrimination task. Based on these results, the authors concluded that the semantic processing of the neglected lexical words was based on the fully specified perceptual and orthographic features of the stimuli.

Somewhat different conclusions were reached in a similar investigation of hemineglect in which lexical decision and naming paradigms were used to examine the type of lexical information that could be extracted from the neglected visual field (Kanne, 2000). The patients and age-matched control participants in this investigation were required to name a foveally presented word after a parafovial prime was presented either to the left or right visual field. A discrimination task was performed using the same presentation parameters to ensure that the patients were subjectively unaware of the priming words in the neglected visual field. Consistent priming effects on the experimental measure were found for the stimuli in the patients' neglected visual field only when the target was semantically related to the prime. In contrast, consistent priming effects were not found when the prime and target words were related at the level of orthography (e.g., LEMON-DEMON), phonology (e.g., ACHE-LAKE), or both orthography and phonology (e.g. HIDE-RIDE). These results suggest that the implicit behavioural priming effects that have been elicited for stimuli in the neglected visual field may be limited to the semantic features of the lexical stimuli used (Kane, 2000).

In an investigation of repetition rather than semantic priming, the implicit processing of neglected primes from the contralesional visual field was again replicated in a sample of 12 patients with contralesional visual neglect (Schweinberger & Stief, 2001). In this replication, lexical specificity was demonstrated for the priming effect based on the finding that the patients' lexical decisions for centralised target letter strings were facilitated when the priming involved word but not pronounceable pseudo-word stimuli. The absence of repetition priming for pronounceable pseudo-words by patients or controls suggested that the effects in this investigation reflected facilitation in the access to the lexical representation of the target words that was not activated by repetition of the orthographic and phonological features of a meaningless letter string. The authors were careful to point out that these features might still be expected to elicit priming in the context of a target naming task in which they would be relevant. To illustrate this point, they cited a study by Masson and Isaak (1999) in which the non-lexical components of immediate repetition were demonstrated to elicit priming in normal subjects under conditions of masked primes when the task emphasised the phonological processing of the targets.

Of interest, the magnitude of the repetition priming effect in the study by Schweinberger and Stief (2001) was found to be larger when the primes appeared in the patients' contralesional (neglected) rather than ipsilesional (non-neglected) visual field. This finding contrasted with the repetition priming effects of the normal controls, which was reported as larger for primes in the right rather than left visual field. It also contrasted with the non-lateralized semantic priming effects that have previously been reported for patients with hemineglect. To account for the finding of increased repetition priming from neglected contralesional primes, Schweinberger and Stief (2001) noted similar observations of hyper priming in contexts in which a prime is believed to activate its corresponding representations too weakly to reach subjective awareness. The specific examples involved Brocas aphasics who presumably had impaired access to lexical information (Bushell, 1996) and normal participants when the primes have been masked (Carr & Dagenbach, 1990).

In summary, the investigation of visual hemineglect has demonstrated that visual awareness may be selectively impaired in a number of distinct ways that cannot be characterised retinotopically. Moreover, extensive implicit processing including some degree of object identification and semantic categorisation has been revealed for information that has escaped subjective awareness due to visual hemineglect. Overall, the results of the semantic and repetition priming investigations provide some of the most convincing evidence that neglected or extinguished information can be implicitly processed to abstract, semantic, or categorical levels while remaining outside of the patient's explicitly assessed subjective awareness. As describe by Sweinberger and Stief (2001), the precise determination of the point in time when priming influences processing of the target cannot be determined using implicit measures based only on reaction times. In contrast, electrophysiological measures, such as event-related potentials (ERPs) are well suited to elucidate the time course of selection and priming processes as they relate to visual attention (Sweinberger & Stief, 2001). Thus, the integration of ERPs as a direct "on-line" correlate of visual information processing in experimental paradigms in which behavioural response data has traditionally been obtained would be expected to further enhance understanding of visual selection and the implicit priming effects noted in patients with hemineglect.

For this dissertation, ERP compatible versions of semantic priming and visual extinction tasks were developed to determine the extent to which specific theory-based components could be elicited as electrophysiological correlates of different levels of information processing in the neglected and non-neglected fields of patients with visual hemineglect. Before providing a review of the relevant ERP literature, some of the main theoretical accounts of hemineglect will be reviewed.

Theories of Hemineglect

Consistent with a review of the literature, the clinical manifestation of hemineglect has been described as a heterogeneous syndrome of components that can be dissociated from one another for different patients and even for the same patient when tested at different times (Rafal, 1998). Given these differences, it is not surprising that many different accounts of the disorder ranging from the phenomenological to the computational have been proposed for the syndrome or for specific components (Mesulam, 1999). Over time, the conceptual focus has shifted from purely sensorimotor impairments (e.g., Battersby, Bender, Pollack, & Kahn, 1956; Denny-Brown, Meyer, & Horenstein, 1952) to higher level cognitive deficits with relatively preserved sensory information from the neglected parts of space (Viggiano, Spinelli, & Mecacci, 1995). These subsequent accounts have emphasised various domains including the representation of space (Bisiach & Vallar, 1988), the link between representations of space and actions (Rizzolatti & Berti, 1993) and various forms of attention (Heilman et al., 1985; Kinsbourne, 1993; Posner, Cohen, & Rafal, 1982; Posner & Peterson, 1990; Posner, Walker, Friedrich, & Rafal, 1984; Posner, Walker, Friedrich, & Rafal, 1987). Each account has data to support it (Viggiano et al., 1995) but none address all clinical manifestations, leading some authors to question the existence of an identifiable neglect syndrome (Mesulam, 1999).

Sensory Accounts

In a review, the occurrence of features of hemineglect (e.g., contralesional conjugate gaze deviation) with hemianopia and somatosensory deficits was identified as a reason why some authors (e.g., Battersby et al., 1956), initially viewed hemineglect as a sensory motor disturbance, perhaps with mental deterioration (Gainotti, 1993). A model proposed by Denny-Brown et al. (1952) in which hemineglect was ascribed to a defective spatial summation of multiple sensory data due to damage to the parietal lobes was presented as the best known example of a sensory deficit hypothesis (Gainotti, 1993). However, Gainotti (1993) noted how the high-level sensory integration taken into account within the model causes it to appear similar to some of the more contemporary non-sensory theories that are still to be reviewed here. Many of the objections raised to purely sensory accounts of neglect noted by Gainotti (1993) have already been mentioned previously in the present review. Very briefly, compared to patients with hemianopia, those with hemineglect were noted to have sparing of the visual fields and a lack of compensatory behaviour for the unilateral field cuts. The demonstration of neglect for the contralesional side of mental representations (e.g., Bisiach & Luzzantti, 1978) served as one of the strongest reasons why investigators began to focus on higher-order mechanisms in their accounts of hemineglect (Bisiach, 1999). However, although they have not generally been the focus of most contemporary accounts of hemineglect, it should not be assumed that peripheral sensory or perceptual deficits are of no importance for the pathophysiology of hemineglect (Bisiach, 1999). As described by Rorden, et al. (2001), a number of peripheral sensory manipulations, such as proprioceptive stimulation of the neck muscle or caloric vestibular stimulation have been reported to transiently ameliorate severe hemineglect. It has been suggested that modulation of the afferent inputs associated with these procedures may affect hemineglect by compensating for the pathological rotations of spatial coding proposed by some authors (e.g., Karnath, Fetter, & Dichgans, 1996, Rorden et al., 2001). Thus, as noted by Viggiano et al. (1995), the existence of higher level deficits does not imply that lower level impairments are absent for patients with neglect. Deficits at lower and higher levels might interact to produce the full, complex pattern of behaviour associated with hemineglect.

Representational Accounts

The lack of awareness for contralesional space has been attributed to defects in spatial representation (De Renzi, Faglioni, & Scott, 1970). For example, according to one mental representational account, the posterior cortex of the parietal lobe maintains a topographical representation of external space in viewer-centred co-ordinates (Bisiach & Vallar, 1988). Unilateral parietal lobe damage results in hemineglect because the mental representation of contralesional space has been degraded or the ability to spontaneously scan the contralesional side of a preserved representation has been impaired. These spatial perceptual accounts were popularised by the previously described investigation in which patients with hemineglect were asked to describe a well-known vista from different perspectives (Bisiach & Luzzatti, 1978). The descriptions did not involve direct sensory input. The selectively impaired recall of contralesional but not ipsilesional landmarks suggested that the patients' mental representations of the space were disturbed.

As a test of this account, Bisiach, Luzzatti, and Perani (1979) had patients with hemineglect make same-different judgements for pairs of cloud-like shapes that were slowly passed one at a time behind a narrow aperture to permit viewing of only a small strip of each shape at any given time. As each shape was passed behind the aperture, the generation and maintenance of a mental representation of the shape was required for the judgement task. On the trials for which the shapes differed, the difference was on the left or right sides only. Consistent with the investigators' expectations, considerably more errors were made for shapes that differed on the contralesional rather than ipsilesional side.

While this evidence may appear convincing, the account has been criticised as more of a description rather than explanation of the deficits in mental imagery observed in some patients with hemineglect (Marshall, Halligan, and Robertson, 1993). The account has been described as ambiguous with respect to whether the impairment involves an impaired mental representation or an impaired ability to spontaneously scan the representation (McCarthy, 1996). Moreover, when explicitly directed or cued, patients with hemineglect generally demonstrate improvement in their ability to represent and process contralesional space (Riddoch & Humphreys, 1983). This is not easily accommodated by representational accounts without reference to additional attentional factors (Behrman et al., 1997).

Spatial Attention Accounts

Several spatial attention models have been proposed for hemineglect. For example, it has been proposed that hemineglect reflects a unilateral attention-arousal deficit produced by a cortico-limbic-reticular disconnection (Heilman, et al., 1985). According to the model, orienting responses controlled by regions within the left hemisphere are directed towards space on the left of the midline of the head and body. In contrast, those controlled by regions within the right hemisphere can be directed towards space on either side of the body. When unilateral damage involves regions of the brain within a cortico-limbic reticular loop that was responsible for the activation of the arousal system within the hemisphere, the entire hemisphere is rendered akinetic or hypo-aroused and unable to prepare for action.

When the right hemisphere is hypo-aroused, hemineglect is therefore manifest for contralesional space only. In contrast, when the left hemisphere is hypo-aroused, contralesional hemineglect would be relatively less frequent or severe due to the bilateral attentional mechanisms of the right hemisphere, which can compensate for the impaired attentional functions of the left hemisphere.

This account offers an explanation for the asymmetrical incidence and severity of left hemineglect. In contrast, it cannot readily explain object-based, domain specific, or modality specific forms of hemineglect (Marshall et al., 1993). Similarly, it cannot readily explain why cueing to the contralesional side can result in a reduction of the severity of patients' hemineglect (McCarthy, 1996).

Another influential spatial attentional account attributes hemineglect to an imbalance in orienting tendencies induced by unilateral damage (Kinsbourn, 1993). According to this account, the two cerebral hemispheres in an undamaged brain have opposing orientational tendencies for contralateral space that are conceptualised as vectors (Kinsbourne, 1993). A mutually inhibitory balance between the opposing vectors of each hemisphere is generally maintained. Activation of one hemisphere is believed to inhibit the homologous functions in the other hemisphere with the corpus callosum as a possible mediating connection. Whereas the leftward bias of the right hemisphere is intrinsically stronger than the rightward bias of the left hemisphere, voluntary rightward shifts of gaze (attention) can normally compensate for the innate bias to spontaneously orient leftward.

Hemineglect results from unilateral lesions when the spontaneous contralateral orientational bias of the undamaged hemisphere is no longer inhibited by activation within the damaged hemisphere. The asymmetrical incidence and severity of leftward hemineglect following right hemisphere lesions are due to the relatively greater strength of the rightward attentional bias of the left hemisphere.

The vectorial orientational bias within Kinsbourne's (1993) account of hemineglect would be expected to give rise to a gradual decrement in processing across the visual space. This gradual decrement stands in contrast to the marked discontinuity of impairment across the midline suggested by the step function within Heilman's account (Marshall et al., 1993). With no rigidly defined midline, right hemisphere damage might produce a general bias toward right-sided stimuli and away from left-sided stimuli even within the intact right hemispace. This prediction is in accordance with the identification of hemineglect in the left side of a stimulus array presented in the right hemispace as well as in the left hemispace (Bisiach, 1999).

Moreover, the probability of detecting a target would be expected to incrementally increase as the target is shifted toward the ipsilesional side by the relative imbalance between the two separate points on the left-right dimension that is preserved irrespective of the absolute location of these points (Behrmann, Watt, Black, & Barton, 1997). Overall, the results of both reaction time and eye movement investigations have generally been more consistent with a gradual decrement in processing across the visual space, as would be predicted by the vectorial account (Behrmann et al., 1997). However, the account does not easily accommodate domain or modality specific hemineglect (Marshall et al., 1993).

Selective Attention Accounts

Hemineglect has also been attributed to selective rather than spatial attention deficits. For one very influential account, a specific impairment within the context of covert orienting has been implicated (Posner et al., 1982, 1984, 1987). According to this account, covert orienting of attention can be decomposed into three components: disengagement of attention from the original focus; redirection of attention to a new target; and engagement of the new target. These components have been extensively investigated using versions of a visual orienting or cue validity paradigm, as described in the section on ERP investigations of hemineglect. The extinction-like reaction time pattern that characterises the performance of patients with hemineglect on these paradigms suggests that their deficit reflects an impaired ability to disengage attention from ipsilesional stimuli rather than an inability to move attention toward the contralateral space. Using different terminology, similar impairments have been described as an ipsilesional capture of attention or a magnetic attraction (De Renzi, Gentilini, Faglioni, & Barbieri, 1989). These accounts represented some of the first explanations to accommodate the finding that left-sided cueing often reduces the severity of left-sided hemineglect (McCarthy, 1996). A selective deficit within the visual modality, whether referred to as a selective deficit in visual awareness or attention, cannot be used to explain hemineglect in non-visual modalities (McCarthy, 1996).

The author of another selective attention based account of hemineglect introduced the idea that attention is represented by a functional cortical circuit subserved by several brain regions. According to Mesulam (1999), attention designates a number of processes that mediate the selection of the mental or external events that will have preferential access to the capacity limited level of subjective awareness and action. From a network perspective, the impairments reflect unilateral disruption within a cortical circuit that directs attention to the contralateral hemispace.

According to this network account, the distribution of attention to targets in extra-personal space requires a flexible interaction between three cortical regions that have consistently been implicated in the onset of hemineglect and are reciprocally linked to one another within their connections from the reticular structures. The first region, the posterior parietal cortex, is involved with the processing of sensory representations of space. The second region, the frontal eye field cortex, maps the distribution of spatial orientation and motor exploration. The third region, the cingulate cortex, maps the spatial distribution of expectancy and relevance. Each of these cortical representations receives a set of reticular inputs. Motivated by the cingulate cortex, the entire circuit directs attention to target stimuli. Hemineglect may result from damage to any one of these regions, to the interconnections, or to other regions with which they are connected, such as the thalamus and striate cortex. The clinical manifestation of the hemineglect is determined by the anatomical location of the lesion. Mesulam (1999) cautions, however, that no rigid distinctions in the clinical manifestations of the syndrome should be expected because the components of the network are closely interconnected.

According to McCarthy (1996), this account of hemineglect was among the first models that did not attempt to specify the impairment of a single unitary function. It was also among the first models to account for the many different and independent anatomical regions associated with the onset of hemineglect. The principle strength of the model has been its ability to account for many of the variations observed in the manifestation of hemineglect (McCarthy, 1996).

Within a broader context, Mesulam (1999) acknowledged that the behavioural manifestations of hemineglect are heterogeneous. However, to counter claims that the syndrome of hemineglect is a meaningless entity, he suggested that the behavioural manifestations are no less unitary than are those of other clinical syndromes, such as aphasia or amnesia. Thus, he agreed that hemineglect cannot be attributed to a unitary deficit of arousal, orientation, representation, or intention. Instead, he argued that hemineglect represents the collective and interactive outcome of multiple impairments in each of these processes. Thus, as a syndrome, hemineglect is similar to aphasia and amnesia. All three describe a network of syndromes with clinical manifestations that reflect damage to one or more interactive components of a distributed network in which damage to each component is associated with different patterns of physiological and anatomical specialisation. Consequently, he maintained that the symptoms and their severity for a patient with hemineglect will depend on the extent and location of the lesion, its chronicity, and individual differences in pre-morbid cognitive architecture.

Accounts for the Processing Fate of Neglected Information

None of the models reviewed so far specifically address the processing fate of neglected information. Recently, some investigators have developed accounts for the extensive implicit processing that has been revealed for contralesional visual information that has escaped the subjective awareness of patients with hemineglect. For example, as previously described, Schweinberger and Stief (2001) suggested that a centre-surround inhibitory attentional model developed to account for enhanced repetition priming effects under conditions of masked primes might also explain the enhanced repetition priming effects reported for patients with hemineglect when the primes were explicitly neglected. This interpretation implies that relative to the signals of detected or unmasked primes, those of neglected or masked primes are weaker, suggesting that the signal of neglected information is degraded.

Other authors have suggested that extensive residual processing in hemineglect can be understood in the light of what is known about the organisation of the primate and human visual information processing systems. For example, according to an account by Driver and Mattingley (1998), parietal cortex cells that integrate retinal and extra-retinal inputs contribute to the generation of visual awareness. The spatial representations provided by these parietal cells extend beyond retinal co-ordinates. Consequently, the corresponding loss of awareness resulting from damage to these cells is also not strictly retinotopic.

To account for the preservation of early visual processes, such as the figure and ground segregation or perceptual grouping observed for patients with hemineglect, the model posits that areas within the occipital lobe continue to subserve these early stages of visual processing. These occipital regions and the afferent connections from the lateral geniculate nucleus into primary visual cortex typically remain intact for patients with hemineglect due to parietal lobe damage. Consequently, the patients' attentional deficits would be expected to arise in a context of considerable low level processing within the occipital lobe.

To account for the more extensive levels of implicit information processing for patients with hemineglect due to parietal lobe lesions, a distinction is made in the model between two streams of processing in the visual system of the primate and human brain (cf. Mesulam, 1999). Both streams originate in the primary visual or striate cortex and pass through extra-striate regions. The dorsal stream projects to the upper regions of the parietal lobe superior to the site of the lesions that are typically involved in the onset of hemineglect. This stream is involved in the spatial control of action. The more ventral stream projects to the temporal lobe inferior to the site of the lesions that are typically involved in the onset of hemineglect. This stream is involved in object recognition.

Damage to primary visual cortex disrupts the ventral object-recognition stream from its onset and the more dorsal projections from striate cortex. The behavioural manifestation is hemianopia (and possibly blindsight). In contrast, hemineglect due to parietal lobe damage would be expected to leave much of the ventral object recognition stream intact. As a result, significantly more processing of information concerning object recognition would be expected to occur along the intact ventral pathway for patients with hemineglect consistent with the extensively preserved implicit processing that is found in these patients. According to Driver and Mattingley (1998), the challenge for current neuropsychological theory is not in accounting for the preserved processing in neglect. Instead, it is in explaining the dramatic loss of awareness itself, which arises for neglected stimuli that escape subjective awareness despite the considerable processing that these stimuli evidently receive as indicated by the implicit priming effects.

Summary and Conclusions

A complete understanding of the mechanisms underlying hemineglect has remained elusive but progress has been made (Losier & Klein, 2001; McCarthy, 1996). Given the wide range of frequently dissociated manifestations of hemineglect, the formulation of any unitary account of the syndrome would appear unlikely (Marshall et al., 1993; Mesulam, 1999). Whereas the constructs described in this review have been contrasted as rival accounts of hemineglect, it is likely that they may in some cases refer to different aspects of the syndrome and in others be difficult to distinguish from one another (Rorden, et al., 2001; Vallar, 1998). As suggested by Mesulam (1999), the focus has shifted to the relative contribution of spatial, attentional, perceptual, motor, intentional, and even sensory variables for different manifestations of hemineglect.

Clinically, many authors agree that there is merit in maintaining a broad view of hemineglect as a syndrome that reflects right hemisphere specialisation for spatial processing, just as aphasia reflects left hemisphere specialisation for language processing in most people (Marshall et al., 1993; Mesulam, 1999). As is the case with linguistic competence, spatial competence is likely a multi-component system that can be impaired in many qualitatively distinct ways (Mesulam, 1999).

Whereas few contemporary theories of hemineglect attempt to account for the processing fate of neglected information, there has been growing interest in demonstrating implicit processing of this information using both behavioural (as reviewed in this chapter) and autonomic or electrophysiological measures (see Chapter 5). The behavioural data reviewed in this chapter strongly suggest that in some patients, neglected information may be processed implicitly to remarkably high levels despite having escaped subjective awareness (e.g., Baylis et al., 1993; Chatterjee et al., 1992; Driver & Mattingley, 1998; Marshall & Halligan, 1994; Marzi et al., 1996; Mijovic-Prelec et al., 1993; Monhaghan & Shillcock, 1998; Mozer et al, 1997; Rafal, 1998). A fuller understanding of the extent to which information processing is spared for patients with hemineglect in relation to subjective awareness will greatly contribute to an understanding of the neurophysiology of the full syndrome and individual components of hemineglect (Driver & Mattingley, 1998; Marshall et al., 1993).

CHAPTER TWO

EVENT-RELATED POTENTIALS AS ELECTROPHYSIOLOGICAL CORRELATES OF INFORMATION PROCESSING IN THE HUMAN BRAIN: CONCEPTS AND METHODS

ERP Derivation

Event-related potentials (ERPs) are electrophysiological brain responses that arise during sensory, cognitive, and motor processing that can be obtained non-invasively from humans with or without brain damage. The derivation of ERPs begins with the same amplifiers and filters used to obtain recordings on the electroencephalogram (EEG). To facilitate comparison between experiments, a selection of surface electrodes are typically placed on the scalp in accordance with the International 10-20 system (Jasper, 1958) or expanded versions of the system (e.g., Nuwer, 1987). As first described by Jasper (1958), the 10-20 system of electrode placement is based upon measurements from four standard points on the head: the nasion, the inion, and the left and right pre-auricular points. In their review, Cooper Osselton, & Shaw (1980) described how the system could help to ensure that the inter-electrode spacings are equal along any anteroposterior or transverse line and that the electrodes are symmetrical. The surface scalp electrodes are typically referenced to a site, such as the mastoid, nose, or earlobes, from which relatively little of the brain's electrophysiological activity would be recorded (see Cooper et al., 1980 for a detailed description of electrode placement, application, and issues related to referencing).

Each scalp electrode is connected to an amplifier and filter which is then connected to an analogue-digital (A-D) converter, a device for measuring electrical potentials that converts the analogue electrical output from each amplifier to digital numbers to permit plotting and statistical analysis of the data. The potentials, sampled at a frequency ranging from 100 to 10 000 Hz (cycles per second), are then usually stored for subsequent analysis (Fabiani, Gratton, & Coles, 2000).

As described by Fabiani et al. (2000), an averaging procedure is usually used to increase discrimination of the true ERP signal, which is very small (i.e., a few microvolts μV) from the much larger (e.g. 50 μV) background noise of the EEG. Time-locking the segments of EEG to the repeated presentation of a specific type of stimulus permits the electrical neural activity that is consistently time-locked to the stimulus to remain in the average while unrelated background activity becomes progressively attenuated as more trials are added to the average. In this way, the number of samples used in the average is related to the signal-to-noise ratio in the resulting ERP waveform (Fabiani, et al. 2000).

As noted by Luck and Girelli (1998), any measurable event can be used as the time-locking point. For example, ERPs can be synchronised with the onset of a stimulus in any sensory modality (e.g., picture, word, sound, smell, or mild electric shock), with the onset of a behavioural response to a stimulus (e.g., a button press), or with the onset of electromyographic activity. Thus, ERPs can be readily incorporated as on-line electrophysiological correlates of information processing for a wide range of experimental paradigms (Luck and Girelli, 1998).

The Physiological Basis of ERP Generation

The ERP response recorded from the scalp arises as a result of the postsynaptic potentials that are created when neurotransmitters bind with receptors on postsynaptic neurons (Nunez, 1981). The biological events contributing to the generation of an ERP signal have been concisely summarised by Luck and Girelli (1998). According to their account, the binding of excitatory neurotransmitters with receptors on the apical dendrite of a pyramidal cell allows positive ions to enter the neuron, which creates a net negativity outside the cell in the region of the activated synapses. To maintain a complete circuit, the inward current is balanced by a passive outflow of current in the remainder of the cell, causing a net positivity in the region of the cell body and basal dendrites. Together, the positive and negative voltages create a small current dipole. When many similarly oriented cells are activated in this manner, their summed dipoles can be represented as a single, equivalent current dipole. According to Luck and Girelli (1998), this type of summation occurs primarily with cortical pyramidal cells, which are named after the unique pyramidal shape of their cell body. These cells constitute about 70 percent of cortical neurons. They vary widely in size and interact with other cortical and subcortical neurons (Nolte, 1988).

According to Luck and Girelli's (1998) account, the synchronized current produced by the pyramidal neurons passes through the conductive medium of the brain.

The voltage of this current is attenuated and spread by the electrical resistance of the meninges and skull. Nevertheless, some of the resulting current is of sufficient magnitude for reliable recordings from electrodes placed on the scalp (Nolte, 1988). The voltage recorded will vary in amplitude over the scalp with a distribution that depends on the position and orientation of the current dipole which, in turn, depends on the position and orientation of the active neural tissue with respect to the surface of the skull.

ERP Nomenclature

An ERP waveform consists of a set of positive and negative voltage deflections, which are referred to as peaks, waves, or components (Luck & Girelli, 1998). These components may be identified on the basis of their amplitude, measured in microvolts (μV), and latency, measured in milliseconds (*ms*). By convention, some researchers plot ERP waveforms with negative voltages upward and positive voltages downward and others plot ERP waveforms with the polarity of the voltages reversed.

Several nomenclatures have been used for peak identification. Each peak may be given a label, usually a P or N to indicate whether the peak is positive-going or negative-going, followed by a number to indicate the temporal position of the peak within the waveform. The number may be given as a precise latency (e.g., P105 for a positive peak at 105 ms post stimulus) or as a single digit to indicate the ordinal position of the peak within the waveform (e.g. N2 for the second major negative peak) (Luck & Girelli, 1998).

Two well-known examples of components that have been named using these nomenclatures include the P300 (sometimes referred to as a P3) and the N400 (sometimes referred to as the N4). The P300 is sensitive to a variety of cognitive processes involving the recall of information, stimulus significance, recognition of information, and memory context updating (Donchin, 1981; Polich and Kok, 1995). The N400 is sensitive to semantic incongruities within a number of different linguistic paradigms (e.g., Kutas & Hillyard, 1980b; Kutas &Van Petten, 1994). Given the centrality of the P300 in Experiment Two and the N400 in Experiment One of the present dissertation, each of these components will be reviewed in greater detail in subsequent chapters.

As indicated by Luck and Girelli (1998), the use of exact latencies in component labels can be misleading because peak latencies may vary as a function of the stimuli and task used. As an example, Luck and Girelli (1998) pointed out that the P300 component may peak as late as 1000 ms under some conditions. On the other hand, the use of a single digit as an indication of temporal position can also become confusing when additional components are identified or when comparing components with similar names that have been obtained using different experimental methodologies. For example, in a recent study by Verleger, Heide, Butt, Wascher, and Kömpf (1996), the P300 complex was described as being made up of two components that are differentially affected by expectancies. The P3b was described as a parietal component that is enhanced after expected stimuli and the P3f was described as a frontal component that is enhanced after unexpected stimuli.

The particular component elicited in an ERP waveform is determined by the nature of the stimulus presented and certain electrophysiological components have been demonstrated to occur in response to specific deviations in sensory, cognitive, or motor processes. Moreover, each component is unique in terms of its topographical distribution on the scalp, polarity, and for the conditions under which it is elicited (Rugg & Nagy, 1997). For these reasons, other descriptors that can be used in labelling peaks make reference to the scalp locations at which the potential is maximal (e.g., frontal P300) or to the psychological or experimental conditions that control the potential (Fabiani, et al., 2000).

For example, a component identified as the Mismatch Negativity (MMN; Näätänen, 1992, 1995) is sensitive to attentional processes that occur in a variety of circumstances and reflects subtle variation in sustained, divided, and switched attention. As a second example, the Phonological Mismatch Negativity (PMN; Connolly & Phillips, 1994) is a component that reflects the phonological processing of spoken words. The Syntactic Positive Shift (SPS; Osterhout, McKinnon, Bersick, & Corey, 1997; Hagoort, Brown, & Groothusen, 1993) is a component that is sensitive to syntactic violation in sentences being read. The novelty P3 is elicited by deviant stimuli that are exceedingly rare and unexpected most typically within the context of an oddball paradigm (Courchesne, Hillyard, & Galambos, 1975; Yamaguchi & Knight, 1991). As a final example, the Contingent Negative Variation, is a component that occurs between the presentation of the warning and imperative (or target) stimuli in a reaction time task (CNV; Walter, Cooper, Alderidge, McCallum, & Winter, 1964).

ERP Component Classification: The Exogenous Versus Endogenous Distinction

Regardless of the nomenclature used to identify the peaks, ERP components have traditionally been classified as Exogenous or Endogenous based upon the aspects of the stimulus to which the component is most sensitive. The terms used for this classification system are generally now conceptualised as generalisations along a continuum rather than a discreet dichotomy and remain in use for general descriptive purposes (Begleiter, Porjesz, Yerre, & Kissin, 1973; Fabiani et al., 2000).

According to this classification system, an ERP component is referred to as exogenous if it is primarily sensitive to the physical characteristics of a stimulus, such as stimulus intensity, modality, or rate of presentation (Kramer & Donchin, 1987). Exogenous components would be expected to be elicited regardless of whether the subjects are actively attending to the stimuli (Näätänen, 1990). Among the best known examples of exogenous components are the very early waveforms elicited by phase-reversing checkerboards or sinusoidal gratings that have been used to investigate basic sensory processing in the visual modality (see Chiappa, 1997, for a review of basic sensory EP investigations in other sensory modalities).

In contrast, ERP components have been referred to as endogenous when there is evidence that they primarily reflect the psychological effects within the brain of a stimulus manipulation. Endogenous components are associated with longer latencies than are exogenous components. The elicitation of endogenous components is influenced by the processing demands of the task. Moreover, for the elicitation of endogenous components, it is generally believed that the subjects must attend to the stimuli (Kramer & Donchin, 1987). The P300 and N400 have traditionally been referred to as classic examples of endogenous ERP components because they are both sensitive to deviations in expectancy based on some aspect of cognitive processing (Rugg & Nagy, 1997). Information processing speed, attention, effort, movement preparation, linguistic analysis, and memory are but a few of the many different cognitive constructs that have been investigated using a range of different endogenous ERP components (Knight, 1997).

Many components which were traditionally viewed as exogenous or endogenous have more recently been shown to be more mesogenous with both exogenous and endogenous features (Begleiter, et al., 1973; Fabiani et al., 2000; Pritchard, Shappell, & Brant, 1991). For example, the N100 has traditionally been considered an example of an exogenous component because of its sensitivity to various physical properties of the eliciting stimuli (Luck, Heinze, Mangun, & Hillyard, 1990). However, the N100 has also been shown to be sensitive to endogenous manipulations, such as whether or not the stimulus event was to be attended (Fabiani et al., 2000). Sensitivity to attentional manipulations have similarly been reported for other early components that had traditionally been considered to be exogenous because they occurred within the first 25 ms of the ERP waveform (e.g., McCallum & Curry, 1984; Vogel, Luck, and Shapiro, 1998). At the other end of the spectrum, the P300 has been found to be less purely endogenous than it has often been presented. For example, the amplitude of the P300 has been shown to increase automatically in response to intense repeated stimulation as would be expected for an exogenous component (Pritchard, Brant, O'Dell, Shappell, and Barratt, 1985). Thus, many ERP researchers now maintain that that the division between exogenous and endogenous categories of ERPs is not as dichotomous as they have traditionally been presented (Fabiani et al., 2000; Pritchard et al., 1991).

Researchers may disagree about the extent to which different ERP components reflect exogenous or endogenous processing. Nevertheless, the terminological distinctions serve to illustrate a useful classification system when investigating the various stages of information processing in the brain. For example, ERP investigations of cognition in the elderly have provided electrophysiological evidence of major age-related cognitive slowing (i.e., peak latency delays) for the endogenous or cognitive but not exogenous or sensory/perceptual stages of information processing across a number of different experimental paradigms (see Friedman, 1995 for a review). As this example illustrates, ERPs can provide an informative "on-line and continuous" measure with which to investigate different stages involved in the neuroprocessing of information time-locked to the presentation of discreet stimuli (Fabiani et al., 2000).

Comparison of ERPs and Other Experimental Techniques

Compared to behavioural measurements, ERPs have the advantage of providing a continuous measure of processing between the stimulus and the response, allowing precise measurement of the time course of a variety of neurocognitive processes as described above. Moreover, ERPs allow for the covert measurement of information processing without requiring overt responses. This covert measurement is particularly useful for the investigation of patients from whom reliable verbal or motor responses may be impossible (for a review see Connolly & D'Arcy, 2000; Connolly, D'Arcy, Newman, & Kemps, 2000). For example, through the adaptation of traditional neuropsychological measures, response-free computerised ERP paradigms have been developed for the investigation of receptive vocabulary level (Byrne, Dywan, & Connolly, 1995a,b; Connolly, Byrne, & Dywan, 1995); reading comprehension (D'Arcy, Connolly, & Eskes, 2000), as well as speech comprehension, attention, and phonology (D'Arcy & Connolly, 1999; D'Arcy, Connolly, & Crocker, 2000). These measures have been successfully employed in the evaluation of individual patients for whom the ability to provide reliable motor or verbal responses has been compromised, such as children with severe cerebral palsy (e.g., Byrne et al., 1995a) and adults with severe communication difficulties following brain damage (e.g., Connolly, Mate-Cole, & Joyce, 1999). These covert measurements have also useful for assessing the processing of ignored stimuli, as may be encountered in studies of selective attention (e.g., Luck & Girelli, 1998) or when stimuli are presented in the contralesional hemifield of brain damaged patients with unilateral neglect (e.g., Verleger, et al., 1996). ERP investigations of hemineglect will be reviewed in more detail in Chapter Five.

As a measure of neuronal processing, the primary advantages of ERPs recorded from the scalp are that they offer a non-invasive index with precise temporal resolution and, to a lesser extent, the ability to localise the temporal events within a spatial domain (Brandeis & Lehmann, 1986). Single-unit recording techniques offer similar temporal resolution and superior spatial resolution but are far more invasive than recordings obtained from surface electrodes. The noninvasiveness of surface ERP recordings increases the suitability of this technique for investigations of information processing in the human brain (Luck & Girelli, 1998). Furthermore, whereas single-unit recordings are typically restricted to one brain area at a given time, ERP recordings from scalp electrodes allow for simultaneous measurement of many brain areas and neural processes (Luck & Girelli, 1998).

ERP methods are complementary to other methods of measuring neuronal activity, such as positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and magnetoencephalography (MEG) are associated with superior spatial resolution. Pet and fMRI measure relatively slow changes in blood flow, which develop over periods of several seconds. For example, each PET image represents the average activity over a typical minimum of 40 seconds or more. In contrast, ERPs have the advantage of millisecond temporal resolution. According to Luck and Girelli (1998), this temporal resolution enables comparison of the neuroprocessing of different stimuli presented within a single block of trials.

The magnetoencephalogram (MEG), which monitors electromagnetic fluctuations in real time, can be used to record event-related magnetic fields (ERFs) with temporal resolutions that parallel those of ERPs recorded from scalp electrodes. Compared to ERPs, ERFs are superior in their spatial accuracy and ease of use (Näätänen, Ilmoniemi, & Alho, 1994). ERPs generally have superior source detection of dipoles oriented in a radial manner. At a practical level, the recording equipment for ERPs currently remains more readily available and economical than the ERF counterparts.

Potential Methodological Limitations of ERPs

Potential methodological limitations associated with investigations of information processing in the brain using functional measures, such as ERPs have been presented in the literature (see Gevins and Cutillo, 1986 for a comprehensive list). For example, Gevins and Cutillo (1986) provided a reminder that it is the behavioural and neuronal correlates of mental events, and not the mental events themselves that are amenable to measurement. Therefore, information gleaned from these correlates is used to make inferences about the nature and stages of the information processing taking place in the brain.

Several of the criticisms that have historically been made about cognitive ERPs now appear to be dated and fundamentally incorrect (Connolly & D'Arcy, 2000;

Connolly et al, 2000). According to these authors, ERPs have historically been considered to be of limited utility for researchers and clinicians who wish to reliably index cognition at an individual rather than group level because the ERPs 1) require many trials to obtain a reliable waveform; 2) have latency and amplitude variations too great to be reliable indicators of cognitive processing; and 3) require grand averages to differentiate amongst experimental conditions. To refute these criticisms, ERP data collected as part of an Innovative Assessment Methods Program (IAMP) were reviewed (Connolly & D'Arcy, 2000; Connolly et al., 2000). As already described, the goal of this program has been the adaptation of neuropsychological tests for computer presentation and ERP recording. Also as already described in the preceding section, the clinical utility of these adapted measures has been successfully demonstrated for individuals with and without severe motor and verbal communication impairments (e.g., Byrne et al., 1995a,b; Ingles et al., 1996; Connolly, Mate-Cole et al., 1999).

According to Luck and Girelli (1998), the averaging procedure may make ERPs an inappropriate measure for experimental paradigms for which single trials must be examined (e.g. single trial learning). When stimuli are repeated many times in traditional ERP paradigms, the influence of factors such as learning, automatization, and habituation cannot be discounted (Gevins & Custillo, 1986). However, at an individual subject level, the differential response pattern observed for a computerised version of a reading and comprehension test was also reliably elicited in reduced-average (5-trial) waveforms when the data were examined using event-resolution imaging (ERI). Very briefly, the ERI technique involved the formation of response templates based on time, frequency, and spatial distribution for correct and incorrect trials. The resulting templates were then applied to new data sets formed with low numbers of trials (see Newman, Connolly, D'Arcy, Cook, & Cook, 1999 for a full description of this procedure and results). The ability of ERI to discriminate smaller sets of trials than what is currently capable with traditional averaging offers the potential to more accurately denote trial types an gradients of difficulty within the computerised versions of the neuropsychological tests developed as part of the Individual Assessment Methods Program (Connolly et al, 2000). For the present dissertation, ERP waveforms were constructed using traditional methods of sorting and averaging at both a group and individual participant level of analysis and the analysis of reduced-average trials was not undertaken.

Finally, Gevins and Cutillo (1986) described how overlapping components may exist within a single ERP waveform and how careful experimental and analytic methods, such as waveform subtraction (Näätänen, 1995), may be required for the fractionation of the overlapping components. Provided that these potential limitations are addressed, ERPs remain a non-invasive measure of neuronal activity that can be used economically on their own, or with other measures, to provide valuable information about the temporal characteristics, magnitude, and general location of electrophysiological correlates of real-time information processing within the human brain.

CHAPTER THREE

THE P300 AND RELATED LATE POSITIVE COMPONENTS

The P300 and related late positive components (LPCs) have been among the most extensively investigated ERP waveforms. The following review will begin by addressing theoretical and practical reasons why these components have been the focus of extensive investigation. After noting some of the terminological confusion associated with these components, some of the main factors influencing their amplitude and latency will be reviewed. The review will conclude with a brief summary of some of the main models that have been proposed to account for the P300 and related components.

Reasons for their extensive representation in the literature

According to Kutas and Dale (1997), the P300 and related LPCs have been among the most extensively investigated ERP correlates of information processing because they were among the first relatively late components that were found to be influenced by endogenous or subject-based rather than exogenous or stimulus-based manipulations. The classic P300 was initially demonstrated by two independent groups of researchers (Sutton, Braren, Zubin, & John, 1965; Desmedt, Debrecker, & Manil, 1965). Both groups described waveform deflections with a centro-parietal scalp distribution that were labelled P300s based on their positive polarity and approximate peak latencies at 300 ms from the onset of stimuli that were unpredictable. For example, in the paradigm of Sutton et al. (1965), trials consisted of a cue that could be used with either 100 or 33 percent certainty to predict the modality of a subsequent target. The most notable feature of the target waveforms was the P300 component, which was most prominent when the modality of the target could not be predicted with certainty. Sutton, Teuting, Zubin, & John (1967) were among the first to propose that the newly discovered P300 reflected the informational content of a stimulus.

According to Coles and Rugg (1995), the relatively large size (5 to 25 μV) and ease with which these components can be elicited in different experimental paradigms account for their popularity among researchers interested in a wide range of cognitive functions. For example, the range of cognitive activities with which the P300 has become associated includes decision making, signal probability detection, attentional discrimination, uncertainty resolution, stimulus relevance, and information delivery

(Andreassi, 2000). The ease with which these relatively large ERP correlates of endogenous information processing could be incorporated into paradigms of interest to various cognitive investigators resulted in a rapidly expanding body of literature.

Terminological Confusion

Reviewers frequently describe the terminology used to refer to the P300 and related LPCs as confusing. For example, the term 'P300' can be misleading given that the cognitive situations known to produce the component have yielded positive peaks with the classical posterior scalp distribution for latencies ranging from 250 to 900 ms (Donchin, McCarthy, Kutas, & Ritter, 1983). Similarly, the alternative term P3 can be misleading given that under some circumstances, the component can be reliably elicited with latencies that follow those of the typical N4 or N400 (Kutas & Hillyard, 1980b).

Most contemporary reviewers point out that there may be more than one component of the ERP within the latency range of the classical P300 and that the sub-components may often overlap and be difficult to disentangle (Anderassi, 2000; Kutas & Dale, 1997). For example, according to Coles & Rugg (1995), the P300 is not a unitary component. Instead, these authors describe how it more likely represents the activity of a widely distributed system whose constituent parts may be more or less coupled depending on the complexity of the experimental situation.

According to Kutas and Dale (1997), some researchers have typically skirted the issue of whether or not a specific positivity is an example of a P300 by not referring to any positivity after 300 ms as a late positive component (LPC) or a member of the P3 family. Other researchers have placed greater emphasis on the differing peak latencies, topographical distributions, sensitivity to specific experimental manipulations, or some combination of these factors in their generation of distinctive labels for specific sub-components. In their list of examples, Kutas and Dale (1997) included the distinction between the relatively early frontally distributed positivity (P3a) and the relatively later, larger, and posteriorily distributed positivity (P3b) of Squires, Squires, and Hillyard (1975) which has become a frequently cited example of this approach. A fuller description of these and other sub-components has been provided in a subsequent section of this literature review.

According to Andreassi (2000), the many different terms used to describe the P300 and its sub-components did not arise from ambiguity of the components in terms of their physical occurrence. Instead, they arose from the different interpretations offered by investigators who generally used their own labels to describe the relationships found in a wide variety of experimental situations. Andreassi (2000) pointed out that some researchers maintain that a coherent pattern can be observed when careful consideration is given to the circumstances under which the P300 and the sub-components are observed.

Example Paradigms

Whereas the P300 can be elicited in a variety of paradigms, the relationship between the P300 and expectancy has been most extensively investigated using variants of the oddball detection task (Kutas & Dale, 1997). For this paradigm, participants are to detect the target or oddball stimuli that are presented relatively infrequently (5-25%) and unpredictably in a randomised sequence of relatively more frequent non-target, non-oddball, standard, or background stimuli (Kutas & Dale, 1997). As an illustrative example, Vogel, et al. (1998) described an oddball paradigm in which participants were to discriminate between names on the basis of their gender in a randomised series consisting of 85% male and 15% female names. For this example, the amplitude of the P300 would be expected to be larger for the relatively infrequent female rather than relatively frequent male names.

Based on the results of typical oddball paradigms, the P300 has been defined by several researchers as a positive peak occurring around 300 ms after an infrequent or improbable task-relevant stimulus occurring within a regular train of standard stimuli (e.g., Donchin, 1981; Gevins & Cutillo, 1986; Picton, 1992). The frequent citation of this definition has made it easy for individuals new to the literature to lose perspective that relative stimulus probability represents only one of the experimental manipulations to which the P300 is sensitive. When the P300 is used in the paradigms of memory researchers, for example, care is often taken to ensure that relative probability of the stimuli do not serve as a potential confounding variable. Typical recognition memory paradigms (e.g., Johnson, Kreiter, Russo, & Zhu, 1998) might start with the presentation of a list of stimuli that participants are instructed to study. During the testing phase, a second list might be presented with instructions to differentiate between items that were or were not on the study list. Even when an equal proportion of new and old stimuli were presented during the testing phase, the amplitude of the P300 elicited by the targets would generally be larger for those which had previously been studied when compared to those that had not. This example highlights how the relative frequency of a target is not a necessary condition for the elicitation of the P300.

Main Variables Influencing the Amplitude and Latency of These Components

Investigation of the P300 and related LPCs in a range of experimental paradigms has resulted in a fairly comprehensive assessment of the extent to which the amplitude, latency, or both amplitude and latency of these components are sensitive to a wide range of experimental manipulations. Some of the main variables investigated include age, stimulus modality, stimulus probability, task difficulty, available attentional resources, and various forms of arousal.

Stimulus Probability

As already mentioned with respect to the elicitation of the P300, one of the most comprehensively investigated variable manipulations has involved relative stimulus probability. Researchers have consistently reported that the amplitude of the P300 and other LPCs are inversely related to the probability of stimulus occurrence within variants of the standard oddball task or within a variety of other experimental paradigms (Andreassi, 2000; Coles & Rugg, 1995; Kutas & Dale, 1997). In general terms, the rarer the event, the larger the amplitude of the component. Kutas and Dale (1997) summarised how the contribution of relative probability to this inverse relationship can be assessed at a number of levels. For example, it can be assessed temporally, within a given period, globally, across the entire block of trials, and more locally, at the level of an immediate stimulus or within the fine structure of the stimulus sequence. At all of these levels, Kutas and Dale pointed out that it is the subjective and not objective probability that is the more critical determinant for the amplitude modulations. To illustrate this point, they described how in oddball tasks with more than two different stimulus categories, the amplitude of the P300 is determined by the relative probability of the relevant stimulus category rather than the relative probability of each individual stimulus. The sensitivity of the amplitude of the P300 and other LPCs to the manipulation of relative stimulus probability at a subjective rather than objective level has frequently been used to highlight the endogenous processing nature of these components.

Task Relevance

Another comprehensively investigated variable manipulation that demonstrates the endogenous processing nature of the P300 and other LPCs has been task relevance. For the manipulation of task relevance, the important finding across paradigms has been that a stimulus will or will not elicit a P300 or other LPC depending on its information value or content as determined by the experimental task (Kutas & Dale, 1997). For example, in a detection task consisting of high and low tones, a P300 will be elicited by the stimuli that have been assigned as the target regardless of whether it happens to be the high or low tone. In other words, the specific stimuli assigned to the target and non-target conditions are interchangeable. The P300 will be elicited by whatever stimulus has been assigned to the target or P300-eliciting category.

One of the most convincing examples of the importance of task relevance for the production of the P300 and other LPCs has been the demonstration that these components could be elicited for the absence of a physical stimulus that provided information because it was expected. Ruchkin, Sutton, and Stega (1980) used the terms evoked and emitted to differentiate between the P300s elicited by the presence or omission of a stimulus. After demonstrating that both evoked and emitted P300s were similarly influenced by the manipulation of relative stimulus probability, the authors concluded that they essentially reflect identical phenomenon. Results such as these supported the proposal that the P300 and related LPCs reflected the informational content of a task-relevant stimulus or stimulus event.

Response Independence

The P300 and other LPCs are typical of longer latency endogenous ERP components in that they may be elicited in the presence or absence of a required motor response (Johnson, 1986). P300 amplitudes for targets in a typical oddball detection task are generally larger under conditions of active discrimination, when a behavioural response is required for each stimulus rather than under conditions of more passive discrimination, such as target counting, when no behavioural responses are required (Polich & McIsaac, 1994).

In contrast to behavioural measures, however, the peak latency of the P300 has been shown to be disproportionately sensitive to stimulus evaluation (encoding, recognition, classification) and relatively independent of response selection and execution factors (Magliero, Bashore, Coles, & Donchin, 1984). According to Kutas and Dale (1997), the latency of the classic P300 has consequently been taken as an upper limit on the time required to reach the perceptual decision that an information event has occurred. Thus, the peak latencies of the P300 and related LPCs have been used to complement more traditional measures of information processing speed, such as verbal or motor response times.

Moreover, these peak latencies and amplitudes offer a promising way to investigate the brain responses of individuals who might be unable to engage in active discrimination by traditional behavioural means (Connolly & D'Arcy, 2000; Connolly et al., 2000; Polich & McIsaac, 1994). As described in Chapter Two, various ERP components including the P300 have been used successfully within an innovative assessment methods program (IAMP; Connolly et al., 2000). The goal of this program has been the development of computerised and ERP-compatible versions of neuropsychological measures for the assessment of individuals with severe communication impairments who cannot provide reliable verbal or motor responses. To this end, several neuropsychological tests of language function have successfully been adapted for computer presentation and simultaneous ERP recording (for a review, see Connolly & D'Arcy, 2000, Connolly et al., 2000). With these innovative measures, the presence or absence of certain cognitive functions can be determined by the elicitation of a predicted ERP component, such as the P300, which has been shown previously to reflect the cognitive function being assessed. With respect to the P300, the neuropsychological tests that have been successfully adapted to date include tests of acquired vocabulary (e.g., the vocabulary subtest of the Wechsler Intelligence Scale for Children III and the vocabulary subtest of the Wechsler Adult Intelligence Scale-Revised as a Neuropsychological Instrument; Connolly, Major, Allen, & D'Arcy, 1999), speech comprehension (e.g., the Token Test; D'Arcy & Connolly, 1999; D'Arcy, Connolly, & Crocker, 2000), and reading comprehension (e.g., from the Psycholinguistic Assessments of Language Processing in Aphasia or PALPA; D'Arcy, Connolly, & Eskes, 2000). ERP-based assessment measures, such as these, have been clinically useful in helping to establish whether or not individuals are able to perform specific cognitive functions at an age appropriate level despite severe communication impairments that precluded assessment by more traditional means (Connolly et al., 2000).

ERP components, such as the P300, were elicited using standard auditory or visual oddball paradigms to demonstrate the objective assessment of the cognitive activities of fully conscious patients who were unable to move or speak as a result of the "locked-in" syndrome (Onofrj, Thomas, Paci, Scesi, & Tombari, 1997). According to Beaumont, Kenealy, & Rogers (1996), the locked-in syndrome can result from a lesion, such as a vascular or hypoxic lesion of the midbrain or brain stem, which leaves the cortex intact yet interrupts the corticobulbar and spinal pathways. As a result, the patient is unable to speak or to move although occasionally, sufficient movement of the eyes or eyebrows is preserved to permit operation of a communication devise. In these cases, it may be possible to demonstrate that normal or even superior intelligence has been preserved (Beaumont et al. 1996).

In the study by Onofrj et al. (1997), ERPs to the oddball paradigms were recorded in three patients with the locked-in syndrome in the first recording session (3 to 4 days after admission) and in all four patients with the syndrome in the second recording session (7 to 8 days after admission). Compared to the performance of 30 age-matched controls, the amplitude, latency, and topographic distribution of P300 and other ERP components were within normal limits. Once again, these results illustrate how ERPs can be used to facilitate the neuropsychological evaluation of patients who are difficult or impossible to assess because of the severity of their communication difficulties.

Stimulus Modality

The P300 and related components have been most extensively investigated in the visual, and auditory, modalities (Andreassi, 2000). P300s have been elicited in the somatosensory modality using electrical stimulation (e.g., Johnson, Miltner, & Braun,

1991) and in the olfactory modality using different odourant concentrations as stimuli (Pause, Sojka, Kravel, & Ferstl, 1996). According to L'hermitte, Turell, LeBrigand, and Chain (1985), the P300 is not sensory specific in that it is not dependent on the modality of the eliciting stimuli, although some of its sub-components, as defined on the basis of differing scalp distributions, may be (see below).

In his review, Andreassi (2000) noted that some general differences have been reported when the P300s elicited within different modalities have been compared. For example, auditory P300s are generally reported to have shorter peak latencies compared to visual P300s. According to the author, this difference likely reflects the fact that auditory stimuli are generally registered in the brain earlier than visual stimuli because of the extra retinal photochemical activity required in the processing of visual stimuli. According to Andreassi (2000), auditory and somatosensory P300s have generally been reported to have different scalp distributions. In the examples cited by the author, the auditory P300s were reported to have parietal distributions and the somatosensory P300s were reported to have central distributions. Based on this evidence, Andreassi (2000) concluded that the P300 is modality dependent in that there are likely to be different neural generators for each modality.

Kutas and Dale (1997) presented a different point of view. According to these authors, remarkably similar P300s have been recorded in the visual, auditory, and somatosensory modalities in a variety of paradigms. As pointed out by Kutas and Dale (1997), no general consensus on the generator(s) of the P300 has yet been reached, although a number of sites, including the hippocampus, parietal regions, locus coeruleus, and temporo-parietal junction have been proposed, examined, and implicated. However, Kutas and Dale (1997) maintain that it is the presumed functional significance of the positivity and the experimental conditions that lead to its elicitation, rather than the identity of its underlying neural generators, that serve as the criteria for defining a P300 or related LPC.

Manipulations involving Attention

The P300 and related LPCs have been investigated within the context of a number of manipulations involving attention. Whereas task relevance may be considered an example of an attentional manipulation, its relation to the P300 has already been described in this review (see previous section). Within the context of divided attention paradigms, the amplitude of the P300 has been shown to vary inversely with attentional load, and therefore has been thought to be a manifestation of attentional capacity (Israel, Wickens, & Donchin, 1980).

The results of P300 paradigms involving selective attention have led many researchers to conclude that selective attention appears to be a necessary condition for producing the classic P300 (Andreassi, 2000; Kutas & Dale, 1997). For example, in an investigation of selective attention by Johnson et al. (1991), auditory and somatosensory P300s were elicited during the "attend" condition but not under "ignore" instructions when the participants were instructed to complete a word puzzle. As summarised in an earlier review by Pritchard (1981), even low probability stimuli will not produce a P300 if they are not task-relevant and are ignored while a subject engages in another task. According to Kutas and Dale (1997), it is often stated that the P300 will be elicited provided that the participants pay some attention to the stimulus sequence. P300s have been elicited, however, while the subjects were in a non-conscious state of natural sleep. The auditory P300 has been one of the ERP components used to measure information processing during various stages of sleep. More specifically, auditory evoked potentials for target and non-target tones were recorded under two probability conditions from 10 young adults during stages 2, 3/4, and (rapid eye movement) REM sleep (Wesensten & Badia, 1988). The latency of the P300 was found to increase and the amplitude to decrease from wakefulness through the stages of sleep. During each stage, however, the amplitudes of the P300s for the targets were found to be of greater magnitude than the amplitudes of the P300s for the non-targets. According to the authors, the amplitude differentiation suggested that the P300 recorded in sleep indexed cognitive processes similar to those indexed by the P300 recorded in wakefulness although at a slower rate (as indexed by the increased latencies).

In a more recent study by Colrain, Di Parsa, and Gora (2000), the P300 has been elicited with a delayed latency during Stage 2 sleep (see also Pratt, Berlad, and Lavie, 1999; but see Niiyama, Fujiwara, Satoh, and Hishikawa, 1994 who report P300 only during early Stage 1 sleep). Doreen (2000) reported that the P300 was elicited during sleep by infrequent tones presented in a simple oddball task but not in a more complex task that contained a second distracting stimulus dimension.

P300s have also been elicited while subjects have been in coma following a traumatic brain injury. The P300 was, for example, among the prognostic measures examined in a prospective, longitudinal investigation of the three-month outcome of fifty-four patients with severe coma (Glasgow Coma Scale; GCS score < 8) resulting from traumatic brain injury (Kane et al., 1996). Visual and auditory ERPs were elicited from the comatose patients using passive oddball paradigms. The presence of a P300 component was significantly correlated with the GCS outcome score. Unfortunately, variance in the latency of the P300 response, even for the control participants, precluded the establishment of absolute prognostic values. The presence of an earlier-latency mismatch negativity (MMN) component was, however, found to predict return of consciousness for 89.7% of the patients prior to changes in the GCS. All of the patients whose waveforms showed no evidence of an MMN failed to return to consciousness three months later. Although the latency of the P300 elicited during coma was not as good an indicator of three-month outcome from coma as the MMN, this investigation nevertheless demonstrated that the P300 may be elicited during coma when the individual is presumed to be subjectively unaware of the eliciting stimuli.

In a study of 20 patients with coma resulting from causes other than traumatic brain injury, the presentation of standard auditory oddball paradigms with 20% rare tones to 20 patients with non-traumatic coma resulted in the elicitation of the P300 response for thirty percent (6/20) of the patients (Gott, Rabinowicz, & DeGiorgio, 1991). Concurrently obtained scores on the GCS were significantly higher for those patients with a P300 than for those without a P300. Eighty-three percent (5/6) of those with a P300 eventually awoke from the coma (GCS Outcome Score ≥ 3). According to the authors, the presence of a P300 during coma was associated with eventual awakening but absence of the P300 did not preclude it. More generally, the results of this investigation demonstrated again that it was possible to elicit a P300 for stimuli presented during a non-conscious state when participants would presumably be subjectively unaware of the eliciting stimuli.

An oddball paradigm conditioning technique was used by Signorino, D'Acunto, Cercaci, and Pietropaoli (1997) in the investigation of the P300 for 25 adult patients in the early-phase of coma resulting from traumatic brain injury (GCS score of 3 to 10). The paradigm was presented during 3 consecutive phases to study the evolution of the P300 responses. The initial phase consisted of the simple oddball paradigm. An emotional stimulus was then coupled to the pure tones for the conditioning phase. The simple oddball paradigm was repeated during the final phase to determine whether the conditioned response was extinguished.

P300s were recorded for 60 percent of the patients in one or more phase of the experiment with the occurrence of the component significantly associated with the conditioning phase (P300s were elicited for 36% of cases in the passive oddball paradigm, 52% of cases in the conditioning phase, and 16% of cases in the extinction phase). No P300 was detected for the other 40% of the patients, of whom 50% died shortly after the trauma. For the patients who produced a P300, the incidence of mortality was considerably lower (13.3%) and a good cognitive recovery was reported for 76% of the survivors.

These three examples of the investigation of the P300 component during coma illustrate that the component may not be elicited in all cases of coma. While the presence of a P300 may have some predictive validity concerning the outcome of the coma, the absence of a P300 did not preclude recovery. More generally, the results indicate that a participant's conscious or subjective awareness *might* not always be required for the elicitation of the P300. These studies have generally been done with auditory rather than visual stimuli because the eyes of the sleeping or comatose subject are closed.

Task Difficulty

The latency of the P300 and related LPCs has consistently been reported to increase as a function of increased task difficulty or complexity. According to Donchin (1981), for example, the latency of the classic P300 in a standard target detection task may occur as late as 1000 ms from the onset of target stimulus depending on the complexity of the decision process involved (Donchin, 1981). As described by Andreassi (2000), increased difficulty in detecting the stimulus or discriminating between stimuli has generally been associated with an increase in the peak latency and decrease in the peak amplitude of the P300. Using trial by trial studies within a signal detection paradigm, Hillyard, Squires, Bauer, and Lindsay (1971) demonstrated that the P300 is obtained for correctly detected targets and is absent for undetected targets.

Using the Sternberg memory set task (Sternberg, 1966) as an example, Andreassi (2000) provided a second example of how the manipulation of task difficulty can be reflected in the peak latency of the P300. For each trial of a typical Sternberg task, participants are presented with a memory set of up to six items. A probe is then presented after a brief delay and the participants are to indicate whether it was a member of the memory set or not. The time to respond behaviourally generally increases as a function of the number of items in the memory set. The amplitude of the P300 is generally larger for probes that were members of the memory set than for those that were not. The peak latency of the P300 is similar to the behavioural response time measure in that it generally increases as a function of memory set size but with less variability than the response time. In their review of the effects of difficulty of the categorisation on the latency of the P300, Kutas and Dale (1997) drew similar conclusions and added that the latency of the preceding N200 typically varies positively with the difficulty of the discrimination from stimulus categorisation as well. Thus, the P300 is not the only or necessarily first component for which difficulty of the discrimination results in peak latency delays.

Biological Determinants

As described by Polich and Kok (1995), a substantial portion of P300 variation appears to be caused by fluctuation in the arousal-state of the subject (i.e., biological factors that affect the organism's physiological state as a whole and therefore affect its capacity to engage in cognitive operations). In their review of the biological factors that affect an organism's physiological state, Polich and Kok (1995) distinguished between variables that occur naturally and those that are environmentally induced. Some naturally occurring biological factors reviewed by Polich and Kok (1995) included circadian rhythms (e.g., time of day fluctuations in body temperature and heart rate), recency of food consumption, ultradian rhythms (i.e., fluctuations in arousal level that occur in approximately 90 minute cycles throughout the day), seasonal variation in the number of daylight hours, and hormonal changes associated with the menstrual cycle in women. Some of the environmentally induced changes of body state included factors such as physical exercise, sleep deprivation, and common drugs (e.g., caffeine, nicotine, and alcohol).

According to Polich and Kok (1995) most of these naturally occurring and environmentally induced state factors have significant effects on the amplitude, latency, and in some cases topographical distribution of the P300 (see Polich and Kok, 1995, for elaboration). Put in general terms, the global pattern of the effects indicates that when arousal is increased, P300 amplitudes increase and latencies decrease, with the opposite pattern observed when arousal is decreased. In their review, Polich and Kok (1995) maintained that biological factors have typically been underestimated in the information processing models of most cognitively oriented P300 studies. Given that impaired arousal is a common consequence of stroke (Lezak, 1995) and that impaired arousal has been proposed as a potential mechanism of hemineglect (e.g., Heilman et al., 1985), the impact of stroke-induced changes in arousal should not be disregarded when evaluating the P300s elicited for patients with hemineglect resulting from stroke.

Age

Changes in the P300 and other LPCs have been reported to occur as a function of age. For example, for the transition from preadolescence to early adulthood, an increase in the amplitude and decrease in the latency of the P300 have generally been reported (e.g., Katsanis, Iacono, & McGue, 1996). The transition into later adulthood has generally been associated with a decrease in the amplitude and an increase in the latency of late positive components (Picton, Lins, & Scherg, 1995). As described in Chapter Two, Friedman (1995) reviewed the results of ERP investigations in which the waveforms of young and older adults were compared. Friedman (1995) concluded that the major age-related changes associated with cognitive slowing, as indexed by the latency of various ERP components, occurs primarily in the endogenous, or cognitive, stages of information processing, and not in the exogenous, or sensory/perceptual stages. With respect to the latency of the P300, the data from oddball and memory scanning paradigms in which the ERPs and behavioural response times were compared suggested that a major component of the cognitive slowing indexed by the P300 is attributable to response organisation and execution. For example, the evidence of cognitive slowing with age in these studies may in part reflect a more conservative response strategy in the elderly than in younger adults (Friedman, 1995). Another robust age-related finding reported by Friedman (1995) was a shift in the scalp distribution of the P3 from the posterior distribution associated with young adults to a more equipotential scalp distribution across the midline recording sites in older adults. Thus, when using the P300 to investigate a medical condition, such as stroke, that is generally associated with patients who are older than the typical young adult experimental volunteer, age is an important variable to control for when selecting members for a comparison group.

P300 sub-components and other components sensitive to stimulus probability

As mentioned previously, researchers using variants of the oddball detection task have identified specific sub-components of the P300, that appear to reflect the manipulation of stimulus probability in a manner that is distinct from the classic P300 of Sutton et al. (1965). Two examples of these specific sub-components are the P3a (Squires et al., 1975) and the novelty P3 (Courchesne et al., 1975). To emphasize the distinction, Squires et al. (1975) suggested that the classic P300 be renamed the P3b. Both the P3a and novelty P3 are generally characterized as having peak latencies that are earlier and scalp distributions that are more frontal compared to the classic P300 or P3b. Both the P3a and novelty P3 were obtained in the context of variants of the oddball task in which a third category of stimuli was added. This new category of stimuli consisted of relatively low-probability non-targets that were different in some way from either the relatively low-probability targets and from the relatively high-probability non-targets.

Although both the P3a and novelty P3 are elicited by low-probability non-target stimuli embedded in an otherwise standard oddball paradigm, it is not clear that they reflect the same type of processing. For example, as described by Friedman, Kazmerski, and Cycowicz (1998), the scalp distribution of the P3a has generally been found to be more central compared to the more frontal distribution of the novelty P3. Moreover, the low-probability category of non-targets generally consist of the repetition of a single or limited number of unique stimuli for the elicitation of the P3a. In contrast the novelty

P3 is formed on the basis of a series of unique events occurring within the context of an otherwise standard oddball stimulus presentation.

In a review of some of the P300 sub-components, Kutas and Dale (1997) stated that the frontal P3s are similar to the classic posterior P300 in that their P300-like response may be elicited by stimuli even when they are not the explicit focus of the subject's attention. It is not clear, however, if the frontal P3s would emerge for stimuli of which the participant was not subjectively aware.

In a study by Squires, Donchin, Herning, and McCarthy (1977), participants were instructed to ignore or count loud or soft tones whose probability was either high (.90) or low (.10). The three prominent ERP components identified by the authors included a negativity at about 210 ms (N210), a positivity at about 350 ms (P350), and a positive slow wave (SW) over the last 200 ms of the 768 ms recording period. The P350 and SW were found to be enhanced whenever the stimulus was rare and relevant to the task. The N210 was reported to reflect stimulus probability independent of the task requirements because it was most pronounced following rare stimuli regardless of whether they were counted or ignored. The results of this study illustrate how the term SW has been used to refer to potential sub-components of the ERP that are sensitive to the manipulation of relative stimulus probability that are elicited within the time period generally associated with the classic P300. As mentioned in the section on terminological confusion in the literature, slow wave is a term that has been applied by many investigators to any positive component after 300 ms to avoid dealing with whether or not it is the same or different from the classic P300.

The results of the investigation pertaining to the N210 (Squires et al., 1977) highlight that the P300 and related LPCs are not the only components that have been identified as sensitive to manipulations of targetness and relative stimulus probability. According to Kutas and Dale (1997), N200 components, which have often been observed to precede the classic P300, have also been found to be sensitive to manipulations of targetness and relative stimulus probability. As an example, Kutas and Dale (1997) referred to the N2a, which in a passive auditory oddball task has also been referred to as the mismatch negativity (MMN). The amplitude of the MMN is modulated as a function of the degree of mismatch between different standard stimuli even if the stimuli are being ignored (e.g., Näätänen, 1992). According to Kutas and Dale (1997), the P165 and Na (e.g., Goodin, Squires, Henderson, & Starr, 1978; Ritter, Simson, Vaughan, & Macht, 1982) are additional components preceding the typical P300 that have been identified following subtractions of ERPs to target and non-targets in variants of the oddball task with and without attention. Thus, components that occur prior to the P300 have been reported to be sensitive to the manipulation of targetness and relative stimulus probability.

Theoretical Accounts and Models

As previously described, the most popular account of the latency of the P300 has been that it reflects stimulus evaluation and categorisation time independently from more traditional behavioural reaction time measures (Magliero, et al., 1984; McCarthy & Donchin, 1981). The remainder of this review will focus on some of the major theoretical accounts of the amplitude of the P300.

There are a number of theories in which the functional significance of the P300 has been ascribed to a variety of cognitive events with varying degrees of specificity. In drawing up a list of the many different cognitive constructs that have been proposed to elicit and influence the amplitude of the P300, Johnson (1986, 1988) included attention, the orienting response, decision making, uncertainty reduction, processing demand, task relevance and information value. To this list has been added updating of working memory, content closure, and the transfer of information to consciousness (Kutas & Dale, 1997).

To illustrate how some of these specific cognitive constructs have been proposed to account for the amplitude of the P300, the models pertaining to decision making, the orienting response, and context updating will be reviewed. Johnson's (1986, 1988) triarchic model will then be described to illustrate the approach of researchers who reject the notion that a single cognitive process accounts for the P300. After reviewing these theoretical accounts, the extent to which they would have to be modified to accommodate the findings of P300 amplitude responses for auditory stimuli of which participants are presumed to be subjectively unaware during sleep (e.g., Colrain et al., 2000; Doran, 2000; Wesensten & Badia, 1988) and coma (e.g., Gott et al., 1991; Kane et al., 1996) will be considered briefly.

Decision allocation

An early interpretation of the P300 linked the component to decision making in general or more specifically to a decision that involves the allocation of an event to a category. In a review of the relevant literature, Andreassi (2000) illustrated the intuitive appeal of these interpretations. For example, Andreassi (2000) referred to an investigation by Rohrbaugh, Donchin, and Erickson (1974) that supported the general rule that the P300 amplitude was enhanced when participants were required to make a decision about a stimulus. For this investigation, an experimental paradigm was devised in which only the second of two rapidly successive and relevant visual stimuli permitted participants to make a decision. A prominent and enhanced P300 was obtained only for the second of the two stimuli. According to the authors of this investigation, the term 'decision' described the psychological correlate of the participants' activity as processors of information.

As a second example, Andreassi (2000) referred to an investigation by Squires, Hillyard, and Lindsay (1973) to illustrate how P300 amplitude was observed to relate directly to increased confidence in a decision. In the signal detection paradigm used by these investigators, the decision pertained to whether or not a very low-level auditory signal had been detected. As noted previously, when comparing the P300 with traditional behavioural measures of information processing, the P300 components have been reported to be relatively independent of response selection and execution factors, thus allowing a more direct index of cognitive processing associated with stimulus selection and evaluation during the decision making process. Overall, the decision allocation account provided a very broad interpretation of the P300.

Orienting response

Another interpretation, first proposed by Ritter, Vaughan, and Costa (1968), linked the P300 to the orienting response. The orienting response or 'orienting reflex' has been used to describe an attentional response contingent upon the onset of a stimulus (e.g. head turning or any turning of the body with reference to the position of the stimulus). The implication is that the response serves to bring the individual into a position appropriate for optimal exposure to the stimulus (Beaumont et al., 1996). Working in the auditory modality, Ritter et al (1968) found that a frontally distributed

P300 was elicited following unexpected changes in the tone stimuli. More specifically, the component was elicited when the first of a series of tones was presented unexpectedly or when a change in the pitch of a tone was unexpectedly introduced. In contrast, the component was not elicited for predictable changes in the tone. This frontally distributed response was found to habituate after repeated presentation as characterised by a decrease in amplitude and a shift in distribution to more posterior scalp areas. The authors concluded that this P300 component reflected a shift of gaze (attention) associated with the orienting response.

This interpretation stands in contrast to the decision making model. Instead of being a very broad account of the P300, it appears to be an overly narrow interpretation. As described more recently (Friedman et, al., 1998), the orienting response may account for frontally distributed sub-components, such as the novelty P3 rather than the more classic P300 that generally has a more posterior distribution as described earlier. The orienting response, which has generally been conceptualised as an autonomic response, usually habituates quite rapidly. Thus, with continual presentation of the eliciting stimuli, one would anticipate that an electrophysiological correlate would show evidence of similar habituation (Polich, 1989). Whereas the amplitude of the frontal P300s have been reported to habituate quite rapidly with continued presentation of the eliciting stimuli, the more classic P300 has not generally shown substantial amplitude decrement across a large number of trials (Courteous, Courteous, & Hillyard, 1978). In an investigation of the auditory P300 by Polich (1989), no amplitude habituation was observed across the first 15 trials. A decrease in amplitude was observed following presentation of 200 of the relatively infrequent targets and this habituation showed evidence of a reversal when the pitch of the target was changed. The author speculated that the P300 may not be very susceptible to habituation because the participant must continually make use of their attentional resources to perform the task accurately (Polich, 1989).

The investigation of patients with frontal lobe damage (e.g., Knight, 1984, 1991; Woods & Knight, 1986) has supported the idea that the orienting response may account for the production of frontally distributed P300 components elicited by novel stimuli but not the classic P300 components with a more posterior distribution. According to

Knight and colleagues, unilateral dorsolateral prefrontal cortical lesions have been found to result in a disorder in orienting that appears to involve a disproportionately strong *capture* of attention by salient events regardless of the relevance of the events. Moreover, damage to these areas was found to influence the frontal P300s elicited by novel stimuli (e.g., slower habituation) but not the more posteriorly distributed classic P300s. These findings provided support for the idea that the frontal P300s elicited by novel stimuli and the classic P300 must be dependent on the integrity of different brain regions and serve to illustrate a potential limitation in the use of the orienting response as a general model for the P300.

Context Updating and Closure

Context updating represents one of the most influential and widely accepted theories of the (classic) P300 component (Andreassi, 2000; Vogel et al., 1998). The concept was first proposed by Donchin and colleagues (e.g., Donchin, 1981; Donchin & Coles, 1988a). In general experimental terms, the authors proposed that the P300 reflects the endogenous process of context or memory updating elicited by a stimulus event that induces participants to modify or update their current mental representation of the environment (Coles & Rugg, 1995).

The widespread appeal of the model has been its ability to account for several of the standard manipulations to which the P300 has been found to be sensitive in a variety of paradigms. To explain the inverse relationship between P300 amplitude and the relative probability of a target as described previously, it has been proposed that a relatively rare target's mental representation in working memory has been weakened by the relatively more frequent occurrence of non-target stimuli. As a result, the amount of contextual updating in working memory required upon presentation of the target would be directly proportional to its relative rarity in the task. Along the same lines, the model also predicts that the subsequent recall of an experimental stimulus event would increase directly as a function of the amount of contextual updating generated by presentation of the stimulus during the experimental task.

Whereas memory updating has been among the most widely accepted and influential accounts of the P300, it has not been unanimously accepted. For example, Verleger (1988) strongly criticised the hypothesis and proposed the concept of context closure. According to Verleger (1988), the P300 is elicited within the context of highly structured tasks when the participants' expectancies have been fulfilled, not when they require revision. However, this alternative hypothesis has not gained widespread support given that the majority of data are consistent with some form of context updating (Polich & Kok, 1995).

Triarchic Model

After reviewing the similarities underlying many of the constructs that have been proposed by different researchers to influence the occurrence and amplitude of the P300, Johnson (1986, 1988) rejected the notion that the P300 could be accounted for by a single cognitive construct. Instead, he proposed a triarchic model that uses three dimensions, each composed of several factors, to explain the variation in P300 amplitude seen across experimental paradigms.

Subjective probability was identified as the first dimension. It referred to the inverse relationship between P300 amplitude and the subjective probability of a particular stimulus event. Within this dimension, *a priori* probability and sequential expectancies were both factors that contributed to P300 amplitude modulations.

Stimulus meaning was identified as the second dimension. It was proposed to account for the processing of stimulus information not related to probability. The factors within this dimension included task complexity, stimulus complexity, and stimulus value.

Information transmission was identified as the third and final dimension. It was defined as the proportion of available stimulus information relative to the total amount of information contained by the stimulus. The factors within this dimension included the degree of equivocation or uncertainty and the extent of attentional allocation.

According to the author, the first two dimensions (subjective probability and stimulus meaning) each have independent and additive effects on the amplitude of the P300. However, their combined contribution to the amplitude of the P300 would always be proportional to quantity of degradation determined by the stimulus information dimension of the model. In a review of P300 concepts and models, Anderassi (2000) identified the triarchic model as the most systematic model of the psychological processes and their combined effects that affect the amplitude of the P300. As with most predominantly cognitive models of the P300, however, the influence of the naturally occurring and environmentally influenced biological factors listed earlier in this chapter (i.e., Polich and Kok, 1995) have generally been underestimated.

Summary and Conclusions

The P300 appears to be influenced by a range of experimental manipulations that increase the subjective salience of a stimulus within the context of a structured and repetitive task. The outcome of this review is quite similar to the original conclusions of Sutton et al. (1965) who referred to the importance of the information content of the eliciting stimuli.

According to Vogel et al. (1998), virtually all accounts would posit that the P300 is elicited only for stimuli that have reached the level of working memory regardless of whether the mechanism involved context updating, closure, or more generalised cognitive functions. Models that address the influence of reduced attention on the P300 generally predict amplitude attenuation. All of the major models proposed to date would require revision to account for demonstrations of the P300 elicited by stimuli for which the subject has presumably demonstrated no subjective awareness, as described within the context of sleep (e.g., Colrain et al., 2000; Doran, 2000; Wesensten & Badia, 1988) and coma (e.g., Gott et al., 1991; Kane et al., 1996) studies. Non-conscious states, such as sleep and coma, may provide a context in which to demonstrate the sensitivity of the P300 to stimuli of which the subject is subjectively unaware. They do not, however, provide a context in which to determine whether these demonstrations might also generalise to the visual modality given that the eyes are closed during both of these altered states of consciousness. Patients with unilateral visual neglect, however, are reported to be aware of visual stimuli presented to the ipsilesional but not contralesional visual field. For this reason, these patients may be able to serve as their own controls for a P300-based investigation of the implicit and explicit processing of visual information.

CHAPTER FOUR

THE N400 COMPONENT AND ITS DISCOVERY

The N400 is a robust negative ERP component that has been firmly linked to violation of semantic expectancies in a variety of priming paradigms. It has been described as a default component elicited by meaningful stimuli that are unrelated to or not predicted by the context established by preceding stimuli (Coles & Rugg, 1995). Priming, whether semantic or contextual, results in attenuation of the component.

The N400, has an onset of about 200-250 ms and a peak latency of about 380 to 440 ms (Curran, Tucker, Kutas, & Posner, 1993; Kutas & Iragui, 1998). Kutas and Van Petten (1994) reported that the scalp distribution of the N400 is broadly distributed over the right parietal, posterior temporal, and occipital sites possibly due to a left hemisphere generator oriented towards the right hemisphere. Whereas this right-lateralized centro-posterior maximum is consistent with several initial reports of the N400 elicited using predominantly visual language processing paradigms (e.g., Kutas & Van Petten, 1988), less marked or even reversed lateralisation (e.g., Holcomb & Neville, 1990) and more anterior distributions have been reported depending on the experimental paradigm used and the sensory modality or surface form of stimulus presentation (Connolly, Phillips, et al., 1995; Holcomb, Coffey, & Neville, 1992). Using MEG to localise N400 generalisation, Helenius, Salmelin, Service, & Connolly (1998) found cortical activation that differentiated between semantically congruous and incongruous sentence-ending words that was in most subjects localised in the left hemisphere, particularly in the left superior temporal cortex. Comparable results were obtained when ERPs were elicited using implanted rather than surface electrodes (Nobre & McCarthy, 1994, 1995).

The N400 was first identified by Kutas and Hillyard (1980c) in an ERP investigation of semantic incongruity in a sentence-processing context. Evidence of the P300's sensitivity to unexpected events in a stimulus set (see previous section) led Kutas and Hillyard (1980c) to hypothesise that the P300 might also be sensitive to deviations in language. In their landmark investigation, participants silently read sentences presented one word at a time. In the physically deviant version, 25% of the sentences had terminal words in a larger font than had been used for the preceding words. For the two semantically deviant versions, 25% of the terminal words deviated semantically, but not physically from the preceding words. For one of these versions, the semantic incongruity was moderate (e.g., He took a sip from the waterfall). For the other version, it was strong (e.g., He took a sip from the transmitter).

The authors predicted that a P300 component would be elicited by both the physically and the semantically deviant terminal words. They further predicted that the timing of word recognition for the semantically deviant terminal words might be reflected in P300 latency. As expected, the physically deviant terminal words evoked the P300 component, which peaked at about 560 ms. No P300 component was elicited by the semantically incongruent sentence endings. Instead, a negative component with a central-posterior distribution and peaking at about 400 ms from the onset of the terminal words was elicited. The amplitude of this negative component was directly related to the degree of semantic incongruity of the terminal word. More specifically, N400 negativity was greater for high than for moderate incongruity. The newly discovered ERP component, which was found to be sensitive to semantic but not physical deviations in sentence processing, was identified by Kutas and Hillyard (1980a,c) as an N400.

Incorporation of the N400 into Behavioural Priming Paradigms

To investigate the processing nature of the N400, it was incorporated as a dependent measure in variations of the priming paradigms upon which influential models of psycholinguistic and memory processing have been based (see Kutas & Van Petten, 1988 for a review). In behavioural paradigms, priming effects are represented by facilitation in task performance for targets preceded by identical or related primes (see Neely, 1991 for a review). Behaviourally, response facilitation may take the form of increased speed or accuracy. Thus, for example, a response to the target word 'nurse' would be faster if preceded by the same word (repetition priming) or by a related word, such as "doctor" (semantic priming). In this example, the modality of stimulus presentation may be visual, auditory, or crossed. Within or between modalities, the targets and primes may take different surface forms. In the above example, for instance, similar response facilitation would be obtained if the target, prime, or both target and prime were presented as pictures rather than words (see below for specific examples of studies in which non-word stimulus were used, e.g., Stelmack & Miles, 1990; Nigram, Hoffman, & Simons, 1992). Moreover, priming effects are not limited to single words or pictures. For example, as with the paradigm used by Kutas and Hillyard, (1980a,b,c), the contextual information provided by a sentence or a phrase can serve as a prime (see also Stanovich & West, 1983). Thus, many behavioural priming paradigms were available for researchers seeking to determine the nature of the processes responsible for the elicitation of the newly identified N400 component.

The results of these investigations revealed the N400 to be a robust component that could be elicited reliably in different sensory modalities with a variety of stimulus forms. For example, within the context of sentence processing, elicitation of the N400 was replicated in the visual (Besson & Macar, 1986; Connolly, Phillips et al., 1995; Kutas & Hillyard, 1980a,b,c; Kutas & Van Petten, 1988; Polich, 1985b; Van Petten, 1993) and auditory modalities (e.g., Connolly & Phillips, 1994; Connolly, Phillips, Stewart, & Brake, 1992; Connolly, Stewart, & Phillips, 1990; Holcomb & Neville, 1991; McCallum, Farmer, & Pocock; 1984; O'Halloran, Isenhart, Sandman, & Larkey, 1988). It has been elicited by the semantically anomalous endings of sentences when the probability of anomaly has been manipulated (Kutas & Hillyard, 1982).

As previously described for behavioural priming effects, the priming stimuli used for the elicitation of N400 priming effects need not take the form of complete sentences. It has been elicited when the semantically anomalous word has been presented prior to the end of the sentence (Herning, Jones, & Hunt, 1987) or when the primes were presented in the form of word phrases (Neville, Kutas, Chesney, & Schmidt, 1986). The N400 can also be reliably elicited for single words presented in a list or as a series of pairs. For example, a categorical mismatch with a previous series of category exemplars will elicit an N400 (Barrett & Rugg, 1987; Harbin, March, & Harvey, 1984; Polich, 1985a,b) and N400 amplitudes are attenuated when target words are preceded (primed) by semantically related words (Bentin, 1987; 1989; Bentin, Kutas, Hillyard, 1993, 1995; Bentin, McCarthy, & Wood, 1985; Holcomb & Neville, 1990; Koyama, Nageishi, & Shimokochi, 1992; Nobre & McCarthy, 1994).

Non-word stimuli which carry meaning, such as pictures (Barrett & Rugg, 1990; Brown & Hagoort, 1993; Nigram et al., 1992; Rugg, 1990) or sign-language gestures

(Neville et al., 1997) have also been used as the primes, targets, or primes and targets in paradigms for which the N400 was successfully elicited. For example, visual N400 amplitudes for words preceded by semantically associated pictures were attenuated compared to those elicited by words preceded by semantically non-congruent pictures (Stelmack & Miles, 1990). With reference to pictorial stimuli, the use of line drawing or photographic exemplars does not appear to influence the pattern of the N400 effects obtained (Holcomb & McPherson, 1994; McPherson & Holcomb, 1999). Thus, the successful elicitation of the N400 by researchers using a wide range of semantic priming paradigms indicated that this newly discovered component was extremely robust.

Processing Nature of N400

In addition to demonstrating the robustness of the N400 component, the elicitation of the N400 in different priming paradigms helped to build an understanding of the processes for which the newly discovered component was sensitive. Within a sentence-processing context, for example, Kutas and Hillyard (1984) demonstrated how N400 amplitudes can be manipulated by altering semantic expectancies even in the absence of semantic incongruity. The participants read semantically congruent sentences of high, medium, and low contextual constraint (the predictability of the terminal word or the extent to which the subjects could anticipate a particular terminal word). These sentences were completed by semantically congruent words of high, medium, or low cloze probability (as defined by the relative frequency with which the word was used to complete each sentence by a representative group of individuals). N400 amplitudes elicited by the terminal words were sensitive to both manipulations independently. The amplitude of the N400 to violations of semantic expectancy was directly related to the semantic constraint of the sentence and inversely related to the close probability of the terminal word. The authors reported that the amplitude of the N400 was more sensitive to the manipulation of cloze probability than to the manipulation of contextual constraint based on the observation that the amplitudes for terminal words of low cloze probability did not differ significantly for sentences of differing contextual constraint. Overall, these results provided strong support to the now generally agreed upon view that N400 amplitudes are sensitive to the degree of semantic mismatch between a given stimulus and what was expected or anticipated to occur and not simply to the presence of a semantic incongruity *per se* (Connolly et al., 1990, 1992; Hagoort & Brown, 2000; Kutas et al., 1984; Van Petten & Kutas, 1990).

Still within the context of sentence processing, N400 amplitudes were found to be larger in response to open versus closed class words (Kutas & Hillyard, 1983; Kutas, Van Petten & Besson, 1988; Van Petten & Kutas, 1991). Open-class (sometimes loosely referred to as content words) denotes a category of words to which new items can be added to reflect changes in culture over time (e.g., nouns, verbs, and adjectives). In contrast, closed-class (sometimes loosely referred to as functional words) denotes a category of words that primarily serve grammatical functions and that normally do not allow for new membership (e.g., pronouns, propositions, conjunctives, and modals).

N400 amplitudes were not sensitive to violations involving physically aberrant words appearing in a different letter size or font (Kutas & Hillyard, 1980a), unpronounceable orthographically legal and phonologically illegal non-words (Holcomb, 1993; Rugg, 1984a), or manipulations of grammatical features (Kutas & Hillyard, 1983). Within a sentence processing context, N400 amplitudes are normally found to be insensitive to manipulations involving syntactic construction (Friederici, Pfiefer, & Hahne, 1993; Gunter, Stowe, Mulder, 1997; Mündt, Heinz, & Mangun, 1993; Rosler, Putz, Friederici, & Hahne, 1993; Van Petten & Kutas, 1991).

N400 amplitudes have been reported to be sensitive to orthographic and phonological representations of words when these codes are task relevant in a sentence processing context (Kutas & Van Petten, 1988; Polich, McCarthy, Wang, & Donchin, 1983). For priming paradigms involving lists of single words, N400 amplitudes have been elicited in response to pseudo-words (pronounceable orthographically legal non-words) (Benton, 1987; Connolly, Service, D'Arcy, Kujala, & Alhu, 2001; Nobre & McCarthy, 1994; Rugg, 1984a).

The elicitation of the N400 in priming paradigms in which semantically meaningful non-word stimuli were used as primes, targets, or primes and targets (as briefly cited above) also supported the semantic nature of the processing for which N400 amplitudes are sensitive. For example, Stelmack and Miles (1990) found that visual N400 amplitudes were reduced when words were preceded by semantically associated pictures rather than unrelated pictures. In reading tasks, visual N400s have been elicited by semantically anomalous sentence endings presented in the form of words or pictures (Ganis, Kutas, & Sereno, 1996; Nigram et al., 1992). These demonstrations of N400 amplitude sensitivity to semantically meaningful stimuli regardless of their different surface forms within the visual modality support the idea that the N400 reflects activity in a common conceptual system rather than in a specific word-based domain of language. According to this view, semantic representations would be equally accessible by words and pictures in priming studies although different regions of the brain may be involved (Kutas, 1997).

Additional support for the conceptual system interpretation of the N400 has been demonstrated in priming paradigms in which both the surface form and sensory modality of the prime and target stimuli were crossed. For example, auditory N400s were elicited in a paradigm in which spoken words primed photographic slide targets (Pratarelli, 1994). N400 amplitude priming effects were also reliably obtained for children (Byrne et al., 1995a,b) or adults (Connolly, Byrne et al., 1995) who were administered a computerised version of a form of the Peabody Picture Vocabulary Test-Revised (PPVT-R). The primes consisted of line-drawing exemplars from the PPVT-R which were correctly or incorrectly named by spoken word targets. The auditory N400 amplitudes elicited by words which misnamed the pictures were reliably larger compared to those elicited by words which correctly named the pictures but only for trials that were psychometrically pre-determined to be within the participants' acquired range of receptive vocabulary, as assessed using the alternative form of the PPVT-R. It is noteworthy that the N400 amplitudes were high for all trials psychometrically determined to be above the participants' acquired level of receptive vocabulary regardless of the congruency manipulation. In other words, when the level of receptive vocabulary involved was above the participant's acquired range, N400s for semantically congruent and non-congruent conditions were equally elevated. While supporting the idea that the amplitude of the N400 reflects semantic activity that is common to both pictures and words regardless of sensory modality, the sensitivity of the N400 to the manipulation of level of receptive vocabulary suggested that N400 amplitudes reflect the uncertainty experienced when one's semantic expectations have not been met even in the absence of incongruity *per se*.

N400-like components have been recorded in sentence verification paradigms. For example, in one such paradigm used by Fischler, Bloom, Childers, Roucos, and Perry, (1983), sentences were presented in segments (e.g., "A sparrow / is / a bird"), and two dimensions of the sentences were orthogonally manipulated. The dimension involved whether the sentences were positive (i.e., 'is') or negative (i.e., 'is not'). The second dimension involved whether the sentences were true (as in the example give above) or false (e.g., "A sparrow / is / a vehicle). Participants were to indicate whether the sentence was true or false. A large negativity in the region of about 250 to 450 ms following presentation of the sentence object was elicited by false affirmative (e.g., "a sparrow / is / a car") and true negative (e.g., "a sparrow / is not / a car") sentences. In other words, the N400-like component was elicited by sentences in which the first and last elements were semantically unrelated regardless of the truth-value of the sentence. Thus, the N400-like negativity reflected a semantic mismatch between terms at a preliminary stage of sentence comprehension, rather than the truth or falseness of the sentence taken as a whole. Similar results were obtained when the semantic manipulation involved the relationship between a category and an exemplar (Kounios & Holcomb, 1992).

Comparison of the amplitude of the N400-like components and the behavioural reaction times from these sentence verification studies was informative. Both the electrophysiological and behavioural data were sensitive to the predictability of a word in a sentence based on a mismatch between the subject and predicate (e.g., Fischler et al., 1983) or category and exemplar (e.g., Kounios & Holcomb, 1992). However, only the behavioural and not the electrophysiological data were sensitive to the truth-value of the sentence as a whole.

The results of a similar sentence-verification study demonstrated that the amplitude of the N400-like component is sensitive to violations of recently acquired semantic knowledge (Fischler, Childers, Achariyapaopan, & Nathan, 1985). Participants in this investigation studied made up facts about fictitious people (e.g., Matthew is a – lawyer). They subsequently read correct and incorrect statements, which were presented one word at a time (e.g., Matthew is a – lawyer/dentist). ERPs were recorded for each terminal word. Regardless of whether or not an active response to the validity of the statements was required, the amplitudes elicited 200 to 420 ms following onset of the terminal words were more negative for the incorrect than for the correct statements.

The results of a similar study were used to demonstrate the potential utility of the N400 as an auxiliary to current lie-detection techniques (Boaz, Perry, Raney, & Fischler, 1991). In this investigation, participants viewed videotape of either an enacted burglary (guilty condition) or scenes from the city of New York (innocent condition). They then read crime-related phrases that had true or false completions but were not required to make any overt response as to the statements' truth. Post hoc analyses indicated that 78% of the participants could be correctly classified as "guilty" or "innocent" with respect to knowledge of the "crime" based on the N400 amplitude data.

In a more clinical context, it has recently been demonstrated that the amplitude of the N400 could be used to reveal evidence of spared knowledge for patients with Alzheimer's Disease (Ford, Askari, Gabrieli, Mathalon, Tinkleberg, Menon, & Yesavage, 2001). The priming paradigm was similar to the cross-modality cross-form paradigm developed by Connolly and his colleagues in their investigations of the receptive vocabulary of patients with cerebral palsy (Connolly, Byrne et al., 1995; Byrne et al., 1995a,b). The patients in the Ford et al. (2001) study were to indicate whether or not a spoken word correctly named the preceding picture. A week earlier, the patients had been pre-tested with a confrontation-naming task to identify pictures that they could not name. The expected N400 semantic priming effect, characterised by greater amplitude negativity for incorrectly than for correctly named pictures was obtained and was not affected by the pre-assessed ability to name the pictures correctly. As described by the authors, the ERP evidence of spared knowledge was complemented by 80% performance accuracy on the experimental measure. The authors concluded that the N400 group effect, like those for the implicit behavioural measure, demonstrated that the patients' knowledge was intact enough to prime cortical responses even though the name of the item had been inaccessible in confrontation testing. Moreover, in the studies by Byrne et al. (1995a,b) and Connolly, Byrne et al. (1995), such N400 amplitude discrimination was evident at the individual participant as well as group level, which is a critical concern for the Innovative Assessment Methods Program (IAMP) outlined in Chapters Two and Three (Connolly et al., 2000).

N400 Repetition Priming

In a variety of behavioural paradigms, stimulus repetition results in facilitation of task performance (Bentin & McCarthy, 1994). Electrophysiologically, stimulus repetition has most typically been associated with a significant increase in amplitude and decrease in latency of the P300. However, as described by Bentin and McCarthy (1994), it has also been associated with attenuation of N400 amplitudes. For example, in word repetition paradigms, N400 amplitudes are smaller for the second (and subsequent) presentations of a word than for the first presentation (Okita & Jibu, 2000). In the word recognition paradigms used by memory researchers, the amplitude of the N400 for words presented during the testing phase is smaller for words presented during an initial study phase than for novel words (Neville et al., 1986; Smith, Stapleton, & Halgren, 1986). As a third example, for words presented individually from a list, the N400 amplitudes were attenuated for those that had appeared in a previously read magazine article compared to the amplitudes of those elicited by words that had not been in the article. Moreover, the N400 repetition priming effects were stronger for low rather than high frequency words (Van Petten, Kutas, Kluender, Mitchiener, & McIsaac, 1991).

As described for the N400 semantic priming effect, the N400 repetition priming effect has been elicited for priming paradigms with stimuli from different sensory modalities (e.g., Holcomb & Neville, 1990; Rugg, Doyle, & Melan, 1993) or with different surface forms within the same sensory modality. For example the N400 amplitude elicited by words which named objects in the second phrase of semantically valid two-phrase statements was smaller when an image of the object had been viewed previously on videotape (Fischler & Raney, 1991).

Repetition priming can be conceptualised as an extremely congruent form of semantic priming. Electrophysiologically, both forms of priming are associated with N400 amplitude attenuation. However, it has been suggested that repetition priming may reflect different cognitive processes (Rugg, 1985a,b, 1987). For example, using a lexical decision task, Rugg (1985) demonstrated that both the behavioural and electrophysiological effects of repetition priming are stronger than semantic priming. In this investigation, the participants' behavioural responses were faster for primed than for unprimed stimuli and significantly faster responses were made for the words primed by the same word than for words primed by a semantically related word. N400 amplitudes for primed stimuli were attenuated compared to those for unprimed stimuli with the greatest attenuation associated with the repetition rather than the semantic priming condition (see also Dannenbring & Briand, 1982; Wilding, 1986 for similar reports). Repetition priming effects have also been reported to be more persistent than semantic priming effects (Jacoby & Dallas, 1981; Scarborough, Cortese, & Scarborough, 1977). Moreover, a dissociation between repetition priming and associative or semantic priming has been reported under conditions of masked prime presentation (Carr & Dagenbach, 1990). Whereas masking of a prime word to prevent subjective awareness has been found to decrease associative or semantic priming, it has in contrast been found to increase repetition priming, possibly because it reflects a lower level function, such as identity matching.

Using an ERP-compatible sentence reading task, Besson, Kutas, and Van Petten (1992) examined the relationship between semantic and repetition priming. Participants read sentences that ended with semantically congruous or incongruous words. For one version of the task, the sentences were repeated once. For a second version of the task, the sentences were repeated twice. As expected, the amplitudes of the N400 for terminal words that were incongruous were larger than were those for congruous words. For the congruous sentence endings, no repetition effect was obtained: the amplitude of the N400 elicited by the first and second presentation of the congruent endings did not differ significantly. For incongruous sentence endings, a significant repetition effect was obtained: the amplitude of the N400 for the second presentation of the incongruent terminal words was attenuated compared to the amplitude elicited by the first presentation of the incongruent terminal words. The amplitude elicited by second presentation of the incongruent endings did not differ from the amplitude elicited by the congruous terminal words. The N400 amplitudes elicited by the second and third presentation of the incongruent sentence endings did not differ significantly from each other or from the amplitudes elicited by congruous endings. Thus, the repetition effect interacts with target congruity in that it is more marked for incongruous than congruous sentence endings (see also Mitchell, Andrews, & Ward, 1993).

N400 topographical distribution and timing

Whereas N400s have been reliably elicited by manipulation of semantic congruity, its topographical distribution and timing have been reported to vary depending on the sensory modality or surface form of the eliciting stimuli or by the task requirements of the experimental paradigm used (Bentin & McCarthy, 1994; Connolly & Phillips, 1994; Connolly, Phillips, and Forbes, 1995). The N400 was initially reported to have a centro-parietal maximum that is also right-lateralized (Kutas & Van Petten, 1988, 1994). This distribution was generally reported for paradigms in the visual modality. Similar posterior distributions have been reported for N400s elicited in the auditory modality and particularly within the context of sentence processing paradigms. However, auditory N400s have also been reported to show a more equipotential or even fronto-central distributions that may be symmetrical or left-lateralized (Bentin et al., 1995; Connolly & Phillips, 1994; Connolly et al., 1990, 1992; Hagoort & Brown, 2000; Holcomb & Neville, 1990; Pritchard, et al., 1991). In memory-related tasks, frontal or equipotential distributions have been observed (Benton et al., 1993). In speeded lexical decision tasks temporo-parietal distributions have been reported (Holcomb & Neville, 1990). Comparison of the topographical distributions for semantic and repetition priming revealed an anterior distribution for semantic priming and a more widely spread distribution for repetition priming (Rugg, 1987).

Several factors influence the timing of the N400. For example, within the visual modality, N400 latency is sensitive to word presentation rate with faster presentation rates associated with a delay in N400 onset and peak latency by up to 100 ms (Kutas, 1987). Even when visual and auditory N400s elicited from sentence processing paradigms share similar posterior topographies, the auditory N400s have generally been characterised by earlier onset and longer duration times (Hagoort & Brown, 2000; Holcomb & Neville, 1991; McCallum et al., 1984; Osterhout & Holcomb, 1992). The apparently monophasic early-onset auditory N400 is comprised of two separate negative components of which the second is the N400 with the same latency range as the visual N400 (Connolly et al., 1990, 1992; Friederici et al., 1993; Hagoort & Brown 2000;

Kutas, 1997; Van Petten, Coulson, Rubin, Plante, & Parks, 1999). The biphasic nature of the negativists may not be reported consistently across studies because it has been observed most distinctly in individual subtraction waveforms rather than in overall averaged waveforms (Connolly et al., 1990, 1992; Connolly & Phillips, 1994). The earlier of the two components has been reported to be sensitive to phonological processing of the beginning of the target word and has been identified as the N200 (Connolly et al., 1992) or more recently, the Phonological Mismatch Negativity (PMN; Connolly & Phillips, 1994; Connolly, Byrnes et al., 1995). It has also been reported to be sensitive to lexical selection and has been identified as the N200 (Hagoort & Brown, 2000).

Within the visual modality, the topographical distribution and timing of N400s elicited by different surface forms have been reported to differ. For example, when semantically anomalous sentence endings took the form of words or pictures, the N400s for the pictures had a more frontal scalp distribution and earlier peak latency compared to the classical N400 response associated with words (Ganis, Kutas, & Sereno, 1996; but see Nigram et al., 1992, for the results of a similar investigation for which no differences were obtained in the N400 response elicited by semantically anomalous sentence endings which took the form of pictures or words).

Automatic and Controlled N400 Processing Mechanisms

One key area in the study of attention has been the role of physiological resources in the automatic and controlled processing of information (e.g., Posner & Snyder, 1975; Shiffrin & Schneider, 1977). Automatic mechanisms have typically been characterised as fast-acting parallel processes that do not involve subjective awareness, are not influenced by strategy, and do not utilise a limited pool of attentional resources. Controlled mechanisms, in contrast, have generally been characterised as slower serial processes that utilise limited attentional resources, involve subjective awareness (or reflection in subjective consciousness), and are influenced by expectancies or strategies (Benjafield, 1992; Kolb & Whishaw, 1995; Pashler, 1998; Posner & Snyder, 1975; Rogers, Bertus, & Gilbert, 1994; Shiffrin & Schneider, 1977). Moreover, whereas automatic processes have been conceptualised as bottom-up processing, controlled or attentive processes have been conceptualised as top-down processing (Kolb & Whishaw, 1995). For this distinction, bottom-up processing is data-driven in that it relies almost exclusively on the stimulus information being presented in the environment. In contrast, top-down processing is conceptually driven in that it relies on the use of information already in memory, including whatever expectation there might be regarding the task at hand (Kolb & Whishaw, 1995). These terminological distinctions are very similar to the endogenous versus exogenous classification of ERP components described in Chapter Two.

Also, as described in Chapter Two, the N400 has been referred to as an endogenous ERP correlate of semantic processing because of the sensitivity of its amplitude to manipulations involving controlled or top-down forms of processing. The extent to which it is possible to elicit an N400 semantic priming effect that may be attributed to automatic rather than controlled processing mechanisms remains unresolved (Okita & Jibu, 2000; Sternberg et al., 2000). Whereas some researchers have argued that N400 priming effects may reflect entirely automatic mechanisms under certain circumstances, others have maintained that N400 amplitude modulations are determined at least in part by more controlled mechanisms (Gunter & Friederici, 1999; Osterhout & Holcomb, 1995; Silva-Pereyra, et al., 1999).

Electrophysiologists interested in the extent to which N400 amplitude modulations reflect automatic or controlled processing have generally adopted models of information processing developed by researchers, such as Neely & Keefe (1989) to account for behavioural semantic priming (Brown & Hagoort, 1993; Kellenbach & Michie, 1996; Stenberg et al., 2000). Most comprehensive accounts of semantic priming identify several automatic and controlled mechanisms that operate in a complimentary fashion to account for the spectrum of priming effects. For example, as articulated by Neely and Keefe (1989), the automatic mechanism involve a spreading of activation in semantic memory and the more controlled post-lexical mechanisms involve expectancy priming and checking.

Automatic Spreading Activation

Despite differing terminology, an automatic spread of activation within semantic memory (e.g. Collins & Loftus, 1975; Quillian, 1969) has been one of the most popularly described automatic mechanisms of semantic priming (for recent reviews see

Okita & Jibu, 2000; Kellenbach & Michie, 1996). In these accounts, semantic memory consists of a network of conceptual representations of meaningful stimuli sometimes referred to as nodes (Collins & Loftus, 1975) or logogens (Morton, 1969). With respect to the amount of processing resources required for its activation, each representation within semantic memory is believed to have a certain resting level of activity. As the degree of association between the representations within semantic memory become stronger, the links between them are believed to become stronger, shorter, or otherwise more direct.

For this mechanism to account for semantic priming, the presentation of a prime is believed to automatically increase the activity of a corresponding representation in semantic memory. This temporary increase in activation spreads automatically within the semantic network to the representations of stimuli that have become associated with the prime. Subsequent processing of a target will require less time or resources if the target's representation is among those in semantic memory that were temporarily activated by the prime. Thus, the activity level of a target's representation in semantic memory can be temporarily increased through the prior presentation of identical or semantically related priming stimuli.

Behaviourally the priming effect may be observed as response facilitation. Electrophysiologically, it may be observed as amplitude attenuation of the N400 (Fischler & Raney, 1991). More specifically, presentation of a target would be associated with the production of an N400 of attenuated amplitude when the activity level of the target's representation within semantic memory has been increased above resting level by the prior presentation of a semantically related or identical prime. According to Okita and Jibu (2000), however, attentionally controlled post-lexical processes, rather than automatic lexical access *per se* have typically been called upon in recent interpretations of the N400 amplitude modulations elicited in repetition or other semantic priming paradigms.

Controlled Processing Mechanisms

Whereas spreading activation within semantic memory has typically been identified as the automatic processing mechanism in most comprehensive models of semantic priming, a range of controlled processing mechanisms have also been described. According to Kellenbach and Michie (1996), the controlled processing mechanisms generally involve the integration of meaningful stimuli into meaningful contexts, which are built up from multiple sources. The integration is typically facilitated by congruous contexts and impeded by incongruous contexts. For the controlled mechanisms to operate, it is generally believed that the context and target must be identified and that the context must be processed to the extent that it may be maintained in working memory. Expectancy-induced priming and semantic matching are two of the controlled processing mechanisms that have been described in investigations of N400 semantic priming effects.

Recent descriptions of the expectancy-induced priming mechanism (e.g., Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995; Kellenbach & Michie, 1996; Stenberg et al., 2000) have typically been based on the accounts of Becker (1985) or Posner and Snyder (1975). In contrast to the automatic spreading activation mechanism, which predicts only response facilitation, this more controlled expectancy-induced priming mechanism predicts facilitation and inhibition due to the assumption of a limited attentional processing resource. More specifically, expectancy induced priming involves a predictive strategy in which participants make use of the information provided by a recognised prime to direct the focus of their attentional resources to the generation of a set of representations within semantic memory of potentially related targets. The processing of representations within this attentional focus is facilitated and the processing of those outside the focus is inhibited (slowed down). Thus, as described by Stenberg et al. (2000), processing is facilitated for related or expected stimuli and inhibited for unrelated or unexpected stimuli.

As summarised by Brown and Hagoort (1993), the circumstances that bring about expectancy-induced priming may be specific to the experimental prime-target paradigm and may not represent part of the normal comprehension process. To be effective, this mechanism requires a long stimulus onset asynchrony or conditions allowing for the generation of a useful expectancy-based strategy. For example, it can be influenced by experimental instructions and by a list structure containing a high proportion of related word pairs (Chwilla et al., 1995).

Semantic matching, as based on the accounts of de Groot (1984) and Neely and Keefe (1989), is a second controlled mechanism referred to in recent investigations of the N400's processing nature (Brown & Hagoort, 1993: Chwilla et al., 1995). This mechanism has been used to explain semantic priming primarily in lexical decision paradigms where a yes or no response is required. For this mechanism, it is assumed that participants in lexical decision tasks compare the prime and target letter strings for semantic similarity and then bias their decision on the results of this comparison. Detection of a relationship between a prime and target word leads to a bias to respond 'yes' which results in facilitation for the related target word. When no relationship is detected, a bias to respond 'no' results in the inhibition of the required 'yes' response for unrelated target words. Whereas this controlled matching mechanism may operate within dichotomous lexical decision tasks and possibly in more common fluent reading situations (Brown & Hagoort, 1993) it cannot account for the semantic priming effects obtained when naming is required because naming is not necessarily involved in a task requiring only a yes or no response.

In their review of N400 priming effects within the context of spoken word repetition, Okita and Jibu (2000) cited the accounts of researchers who have attributed N400 amplitude modulations to controlled post-lexical processes rather than to automatic lexical access *per se*. According to Bentin and McCarthy (1994), for example, the N400 may reflect processes of integrating an item with ongoing context with, N400 amplitude inversely proportional to the ease of contextual integration. Bentin and McCarthy (1994) have also proposed that N400 attenuation may reflect an interruption of semantic processing that items trigger automatically. As summarised by Okita and Jibu (2000), the attenuation of the N400 associated with the repetition effect occurs because the processing required to access an item's semantic representation upon repetition is forestalled by the availability of the processing that results from the item's initial presentation.

N400 amplitude modulations as a reflection of automatic processing

Researchers have manipulated the amount of attentional processing available within semantic priming paradigms to investigate the extent to which N400 amplitude modulations reflect automatic processing apart from controlled processing. The following sections contain reviews of this literature, which has generally yielded mixed or conflicting results.

Sleep Studies

The role of automatic and controlled processing for the N400 has been investigated within the differing attentional states of various stages of sleep and wakefulness. Auditory N400 semantic priming effects have been demonstrated for single spoken words presented during sleep (Brualla, Romero, Serrano, & Valdizan, 1998). In this case, the auditory semantic priming paradigm consisted of pairs of words, of which half were related. The paradigm was presented while the participants were awake and during various stages of sleep. Compared to the peak amplitudes of the N400s obtained when participants were awake, the peak amplitudes of those obtained during stage II and REM sleep were delayed. Despite this delay, similar N400 semantic priming effects, characterised by amplitude attenuation for related relative to the unrelated pairs were obtained. These results provide evidence that the N400 semantic priming effect reflects the automatic processing of information presented specifically in the auditory modality. A similar design cannot be used to determine whether these results would generalise to the visual modality, however, given that eye closure during sleep precludes the presentation of visual stimuli.

Stimulus Timing

To investigate the roles of automatic and controlled processes in the N400 semantic priming effect, ERP researchers have varied the duration of the prime to target interval. According to Kiefer, Weisbrod, Kern, Maier, and Spitzer (1998), it has traditionally been maintained that automatic processing mechanisms, such as spreading activation, may account for semantic priming effects at short prime-target intervals. More controlled processing mechanisms have generally been thought to become engaged only at prime-target intervals of 400 ms or more (see Neely, 1977). N400 semantic priming effects have been elicited, however, for stimulus onset asynchronies (SOAs) of 200 ms (Besson, Fischler, Boaz, & Raney, 1992) and even when the prime and target have been shown simultaneously (Anderson & Holcomb, 1995). The magnitude of the effect may be attenuated when short rather than long SOAs are used, but the presence of reliable effects for short SOAs has been put forward as evidence that the N400 may be elicited by automatic processing. However, some researchers have noted that the N400s in these investigations have generally occurred later at the short than at the long SOAs (Kutas, 1987; Stenberg, Lindgren, Johansson, Olsson, & Rosén, 2000). This delay might suggest the involvement of controlled processing for the elicitation of the N400 component even when short SOAs were used.

Perceptual Thresholds

Researchers interested in the processing nature of the N400 in semantic priming paradigms have incorporated techniques, such as stimulus masking, to reduce or prevent perceptual awareness of the prime or target stimuli. These techniques are believed to reduce or eliminate the influence of controlled processes so that the remaining automatic processes, such as lexical access, may be assessed.

Masking of the primes has been reported to eliminate N400 semantic priming effects elicited by unmasked targets. For example, in a lexical decision task, Brown and Hagoort (1993) obtained both behavioural and N400 semantic priming effects when the target letter strings were preceded by unmasked primes and only behavioural semantic priming effects when the targets were preceded by masked primes. In a similar study by Mündte and Heinz (1991), neither behavioural nor N400 semantic priming effects were obtained for target words that were preceded by the masked primes (both types of priming were obtained for the unmasked primes). According to Schnyer, Allen, and Forster (1997), data such as these have been used to support the idea that obtaining an N400 priming effect requires conscious perception of the stimuli. Based on the results of their own study, Brown and Hagoort (1993) suggested that the amplitude modulations of the N400 reflect the controlled processes of integrating an identified word into the previous contextual information of the prime rather than the more automatic semantic processing associated with lexical access *per se*.

In a series of word repetition paradigms, however, masked primes that left no episodic memory trace showed N400 repetition effects when repeated after a brief interval as unmasked targets (Schnyer et al., 1997). The first phase of the experimental paradigms consisted of a lexical decision task. The stimuli were presented for 300 ms each with no time between stimuli and two-buttons were used to indicate when a word or non-word appeared. After a five-minute break, participants completed a second lexical decision task. They were not informed that some of the words were repeated from the first task. The stimuli were presented for 2400 ms each with no time between stimuli. Embedded in the list were masked primes, which consisted of a single novel word that appeared for 48 ms before it was replaced by one of the fully visible stimuli. Each masked prime was repeated as an unmasked target after a brief interval (the first word following the masking stimuli) or after a slightly longer interval (the second word following the masking stimuli). N400 word repetition effects relative to novel words were elicited by the targets that repeated unmasked primes from the first lexical decision task and by the targets that repeated masked primes by only the briefer of the two intervals within the second lexical decision task.

According to Schnyer et al (1997), it is possible that the investigations with masked primes that failed to find N400 semantic priming effects might reflect insufficient signal-to-noise ratios. Alternatively, they proposed that conscious or subjective awareness of the stimuli might be required for N400 amplitude modulations when the priming manipulations involve semantic associations but not when they involve the activation of a word's pre-existing representation through more direct means, such as identity priming or stimulus repetition. However, whereas no data were specifically provided for the version of the paradigm reported above, during an interview conducted during the debriefing of a similar version of the paradigm, 79% reported that they could occasionally tell that the masked primes were words. Therefore, it is possible that the masking procedures did not consistently prevent subjective awareness of the primes.

N400 semantic priming effects were not eliminated when the target was masked in an auditory sentence processing task (Connolly et al., 1992) or when the target was visually degraded in a speeded lexical decision task (Holcomb, 1993). For example, in the study by Holcomb (1993), the participants' lexical decision speed and accuracy were greater for the target words that had been primed by related rather than unrelated words. Moreover, as predicted, the magnitude of these behavioural semantic priming effects were greater when the targets were physically degraded, mostly due to slower responses and more errors for the unrelated targets that were visually degraded. In contrast, analysis of the average amplitude and peak latency of the N400 and two kinds of difference waves indicated that there were no differences in the size of the N400 semantic priming effects elicited by the intact and degraded targets. Degrading the target generally delayed the time course of the N400 but equally for those targets that followed the related or unrelated primes. The absence of increased N400 semantic priming effects for the degraded rather than intact targets stands in contrast to the behavioural results. The authors therefore concluded that the behavioural and electrophysiological measures appear to be tapping into different components of the processes involved in semantic priming.

According to Kellenbach and Michie (1996), the results of these investigations might suggest that controlled processing of the priming context and not the target is necessary for the elicitation of N400 amplitude modulations in semantic priming paradigms. However, the stimulus masking and degrading procedures used in these investigations were intended to increase task difficulty and not to eliminate perceptual identification or subjective awareness of the targets. For example, the visual degradation techniques used by Holcomb (1993) for the targets in the speeded lexical decision task involved the overlay of a random pattern of dots or by the removal of a random 33% of the pixels form each letter position. Therefore, the effects of controlled processing of the targets cannot be ruled out in these investigations.

In a comparable paradigm developed by Vogel et al. (1998), target words that were semantically related or unrelated to an initial context word were presented with incremental amounts of visual noise to perceptually degrade the probe word. As expected, as the luminance of the visual noise increased, the accuracy in reporting the semantic relationship between the target word and the context word decreased. The amplitude of the N400 was closely related to the behavioural accuracy. As the intensity of the visual noise increased, the amplitude of the N400 observed in difference waves constructed by subtracting the unrelated target condition from the related target condition declined. According to the authors, these results indicate that the N400 component is highly sensitive to manipulations of perceptual quality.

A more recent N400 semantic priming investigation with masked targets was designed with more direct measures of whether each target was detected or not (Stenberg et al., 2000). In this investigation, the primes were clearly visible category labels. The target words, which were marginally perceptible due to the masking procedures, were either members or not members of the cued category. The duration of target exposure was varied so that some targets would be identified and others would not. Trial-by-trial behavioural measures of target identification ensured that the N400 semantic priming effects for targets that had or had not been perceived could be compared. For each trial, participants were to indicate on a response pad if the target belonged or did not belong to the preceding category. They were also to read each target aloud, if possible. Following each trial, participants completed a forced choice selection of the target from an array of alternatives (two or six alternatives were used for different experimental runs). For all of these measures, participants were encouraged to guess. According to the authors, one of the main strengths of this investigation was that the ability or inability to identify each target could be determined subjectively on the basis of the participants' verbal reports and more objectively on the basis of the forced-choice categorisation or recognition procedures that required manual responses.

As expected, marked N400 semantic priming effects with defined peaks were obtained for the above-threshold, verbally-identified words. Among the sub-threshold, verbally unidentified words, there were similar although smaller effects with less characteristic wave shapes. Moreover, the N400 priming effects obtained when the sub-threshold criteria were determined on the basis of the more objective (more conservative) measures were similar. As summarised by the authors, the amplitudes of the N400s for unidentified sub-threshold words showed evidence of semantic processing regardless of whether the participants' awareness was defined using verbal report or the more conservative measures (the authors spoke in terms of conscious awareness rather than subjective awareness).

According to the authors, the results of this N400 semantic priming study demonstrated high-level word processing for masked targets of which the participants were subjectively unaware. Masked targets about which participants professed ignorance, nevertheless evoked N400 amplitude modulations that reflected the targets' semantic qualities in relation to preceding full-view primes.

Attentional Blink Paradigms

Within the context of a rapid stream of briefly presented visual stimuli, the attentional blink refers to a 400 to 600 ms period of time following the successful detection of an attention-catching target during which subsequent target detection is typically impaired. N400 semantic priming effects have been demonstrated for *target* words that could not be reported in an attentional blink paradigm (Luck, Vogel, & Shapiro, 1996; Vogel, et al., 1998). In this investigation, each trial began with the presentation of a context word followed by a series of twenty letters or number strings at a rate of one string every 83 ms. Most were distracters consisting of randomly selected consonants drawn in blue. Either the 7th or 10th string served as the first target and consisted of seven repeated blue digits. The second target, a red probe word, was semantically related or unrelated to the initial context word (words of less than seven letters were flanked by red Xs so that all strings would have a total of seven characters). The probe word followed the first target by a lag of 1, 3 or 7 strings. These lags were chosen because the attentional blink impairment is typically strongest at lags of 2-3 stimuli. There is generally little or no impairment in detection accuracy at a lag of 1 stimulus and the impairment usually ends by lags of 6-8 stimuli. Following each trial, the participants used a two-button response pad to indicate whether the first target was an odd or an even digit and whether the probe word was semantically related or unrelated to the context word for that trial.

On trials for which the response to the initial target response was correct, there was a substantial decrease in the accuracy of the semantic relatedness response for the lag 3 probe words (66% correct) compared to the accuracy of the semantic relatedness responses for the lag 1 or 7 probe words (87-90% correct). However, analysis of the N400 component from the ERP difference waves (waveforms for the related condition were subtracted from those for the unrelated condition) revealed no significant effect of lag on N400 amplitude despite the large drop in accuracy associated with the attentional blink at lag 3.

According to the authors, these results indicate that the meaning of a word can be extracted and compared with other semantic information without reaching a stage at which the results of this comparison can be retained for even 1 to 2 seconds. They concluded that substantial semantic processing may occur in the absence of awareness, although they admitted that it is difficult to determine whether the probe words were identified without reaching awareness or if they momentarily reached awareness and were then rapidly forgotten.

Missed *prime* words within the attentional blink have recently been found to elicit an N400 semantic priming effect (Rolke, Heil, Streb, & Hennighausen, 2001). The participants were to identify three target words among distracters in a rapid serial visual presentation task. The strength of the association between the prime (second target) and probe (third target) was varied. As expected, detection of the prime was impaired. The authors interpreted the presence of a P300 for the detected primes and the absence of a P300 for the missed primes as evidence that the missed primes had not been explicitly recognised. Despite this difference, an N400 amplitude effect was elicited for the targets regardless of whether the preceding primes had been detected or missed. The authors concluded that the automatic spread of activation can be evoked by missed primes within the attentional blink and that this automatic spread of activation is sufficient to elicit the N400 semantic priming effect.

Task Demands

To investigate the relative roles of automatic and controlled processes in the N400 semantic priming effect, ERP researchers have manipulated the depth of the attentional processing demands within their semantic priming paradigms. For example, relatively shallow processing conditions have been created by instructing participants to attend to orthographic (Kutas & Hillyard, 1989) or physical (Besson, Fischler et al., 1992) rather than semantic properties of the stimuli. Sometimes shallow processing instructional sets have been combined with a decrease in the proportion of related word pairs within the paradigm (Holcomb, 1988). As noted by several authors, the results of these investigations have been inconclusive (Chwilla et al., 1995; Kellenbach & Michie, 1996). Robust N400 semantic priming effects have generally been elicited for semantic-priming tasks that require deep, active, or controlled processing. In some of these investigations, reliable although somewhat attenuated N400 semantic priming effects have been obtained for the conditions designed to engage only shallow, passive, or automatic processing (Bentin et al., 1993; Besson, Fischler et al., 1992; Holcomb, 1988; Kutas & Hillyard, 1989).

For example, Holcomb (1988) compared results from two versions of a lexical decision task in which the proportion of related word pairs and task instructions were manipulated simultaneously to assess the extent to which the N400 semantic priming effect reflects automatic processing in the absence of controlled processing. For one version, controlled processing of the primes was induced by using a high proportion of related word pairs with instructions to attend to the semantic relationship within each pair. For another version, automatic processing of the primes was induced by using a low proportion of related word pairs with instructions to ignore the semantic relationship within each pair. For this investigation, N400 priming effects took the form of amplitude attenuation for target words that followed semantically related rather than neutral primes. Whereas N400 semantic priming effects were obtained for both versions of the task, the magnitude of the effect was larger for the version designed to induce controlled rather than automatic processing of the primes. Although attenuated relative to the controlled processing version, Holcomb (1988) maintained that the elicitation of an N400 semantic priming effect using the automatic processing version of the task demonstrated that the amplitude of the N400 can reflect automatic processes apart from controlled processes. According to Brown and Hagoort (1993), however, both of the manipulations upon which this investigation was based represented ways of assessing the impact of expectancy-induced priming but not necessarily other forms of controlled processing, such as semantic matching. Consequently, the N400 amplitude modulations for the automatic processing version might be attributed to this other form of controlled processing rather than to the automatic spreading activation *per se*.

As a second example, Kutas and Hillyard (1989) used a semantic priming paradigm with a delayed letter detection task to direct attention toward orthographic rather than semantic properties of the primes and targets. For each trial, a prime and target word were presented one at a time with an onset asynchrony of 700 ms. The words were either semantically related or unrelated and were followed after 1200 ms post-target by a single letter. The task was to indicate whether the letter appeared in the words. Despite the shallow processing nature of the task, the N400s elicited by the targets showed N400 semantic priming effects with amplitude attenuation for targets that were semantically related to the primes. This N400 effect was obtained regardless of whether the target EEG signals were sorted on the basis of established word association norms or the participants' expectancy ratings for each word pair, which had been obtained following presentation of the paradigm. Kutas and Hillyard (1989) suggested that these results support the idea that automatic processes are reflected in the N400 semantic priming effect. They did, however acknowledge that awareness of the deeper semantic relationship within the word pairs may not have been excluded by the more superficial processing nature of the orthographic task. In a critique of this investigation, Brown and Hagoort (1993) agreed with the authors that performance of the task might not have required semantic processing. However, given the long stimulus onset asynchrony between the prime and target and the lengthy response delay, Brown and Hagoort (1993) reasoned that there was ample opportunity for controlled processing to have been performed, perhaps in the form of semantic matching. Consequently, the observed N400 semantic priming effects may have been a reflection of these other forms of controlled processing that had not been excluded from the semantic priming paradigm using the orthographic task (Brown & Hagoort, 1993).

As a third example, Besson, Fischler et al. (1992) compared the amplitudes of the N400s for word pairs presented with task instructions intended to induce deep or shallow semantic processing during the study phase of a memory investigation. The deep processing instructions involved making a semantic decision about the word pair. The shallow processing instructions involved making an orthographic decision in the form of whether the first and last letter of the two words were the same or different. A stimulus onset asynchrony of 300 ms was used for both versions of this semantic priming paradigm. Analysis of the participants' behavioural reaction times revealed reliable semantic priming effects for the deeper processing semantic version of the paradigm only. In contrast, analysis of the amplitude of the participants' N400s revealed reliable semantic priming effects for both versions of the paradigm although the magnitude of the difference was attenuated when the shallow processing orthographic rather than deeper processing semantic processing instructions were used. The authors attributed the small N400 priming effect elicited in the shallow processing version of the task to automatic processing. However the word pairs were presented within the context of the study phase of an investigation of memory. Therefore, attention to the meaning of the words might have been reinforced by the experimental design and controlled processing would not have been entirely absent during the performance of the shallow processing orthographic task.

As a final example, Bentin et al. (1993) used lists of spoken words with shallow or deep processing instructions to examine the extent to which N400 amplitude modulations are influenced by the level of processing afforded the stimuli. An SOA of 1750 ms was used and the inter-stimulus interval (ISI) varied with stimulus duration. For the shallow processing lexical decision task, participants were asked to silently count the number of non-words occurring in the list. For the deeper processing task, participants were asked to study the words in anticipation of a subsequent recognition task. Within each list, target words were either semantically related or unrelated to the immediately preceding word. Reliable N400 semantic priming effects were obtained regardless of the depth of processing associated with the task instructions, although the effects were attenuated under the shallow rather than deeper processing conditions. According to the authors, these data, which are consistent with the results of comparable investigations in the visual modality, support the view that the sensitivity of the amplitude of the N400 to semantic relatedness can be modulated by task variables that manipulate depth of processing. These data, however, do not address whether it is possible to elicit N400 amplitude modulations that reflect a purely automatic level of semantic processing.

In contrast to these examples, some investigations have reported no reliable semantic priming effects for the N400 under shallow processing conditions. For example, in a study that was principally designed to compare the N2 and the N400, Deacon, Breton, F., Ritter, W., & Vaughan, H. (1991) did not observe N400 effects in a semantic priming paradigm when the task instructions induced shallow processing of the stimuli. The participants were presented with sets of word strings that contained infrequent deviations. In one set, infrequent deviations took the form of change in the size of the letter strings. In another set, infrequent deviations took the form of change in the semantic category of the letter string. In a final set, infrequent deviations involved both the size and semantic category manipulations simultaneously. The infrequent deviations in semantic category elicited an N400 that peaked around 400 ms but only when the participants were instructed to discriminate on the basis of the semantic features of the letter strings (i.e., a semantic category discrimination task). When participants were instructed to discriminate on the basis of the size of the letters (i.e., a size discrimination task), an N400 was not elicited by the semantic deviations. The infrequent deviations in size elicited an N2 that peaked at around 320 ms. According to the authors, the N2 and N400 were generally similar in scalp distribution, hemispheric asymmetry, and sensitivity to stimulus probability.

In a more recent study by Chwilla et al. (1995) demonstrated that N400 semantic priming effects reflect controlled rather than automatic processing using a semantic priming paradigm with different levels of processing demands. Each trial of the semantic priming paradigm consisted of a pair of letter strings that were presented in rapid succession. There were two different levels of task instruction (lexical versus physical) and two proportions of related word pairs (high versus low), which resulted in a total of four versions of the paradigm, which were administered to four different groups of participants. All participants were instructed to pay attention to the second letter string, the target stimulus. Participants given the lexical instructions were to decide whether the target was a word or not to induce processing that was described as deep, active, and controlled (e.g., semantic matching). Participants given the physical instructions were to decide whether the target appeared in uppercase or lowercase letters to facilitate processing that was described as shallow, passive, and automatic (e.g., spreading activation).

According to the authors, words were responded to more quickly than non-words for the lexical versions of the task, which confirmed that the task was performed lexically. For the physical versions of the task, there were no significant differences in the mean reaction times for words and non-words, which confirmed that this task was performed on the basis of non-lexical form information only.

Analysis of the reaction time and N400 amplitude data revealed significant semantic priming effects for the lexical versions of the task only. More specifically, when the lexical instructions were given, the targets paired with related primes were generally responded to more quickly and had attenuated N400 amplitudes when compared to the values obtained for the targets paired with unrelated primes. In contrast, N400 semantic priming effects were absent for the physical versions of the task.

According to the authors, these results demonstrated that modulation of the N400 amplitude required the explicit identification of the words, including their meaning. Once it can be determined that for task-related performance, the target words are processed non-lexically, N400 priming effects are no longer observed. Consequently, they concluded that N400 semantic priming effects primarily reflect controlled processing in the form of lexical integration as mediated by semantic matching rather than automatic processing in the form of lexical access as mediated by spreading activation.

According to Chwilla et al. (1995), the demonstration of N400 semantic priming effects for shallow processing tasks has been presented by other researchers (e.g., Bentin et al., 1993; Besson, Fischler et al., 1992; Holcomb, 1988; Kutas & Hillyard, 1989) to support the idea that the amplitude of this component is sensitive to automatic processing. However, they caution that the conclusions of the other researchers depend critically on the claim that the observed effects cannot be attributed to more controlled mechanism. Consequently, the extent to which controlled processing has been successfully eliminated from the shallow processing conditions has been debated.

Selective Attention Paradigms

Another approach used by researchers to investigate the contribution of controlled and automatic processing on modulation of N400 amplitudes in semantic priming paradigms has involved incorporation of a variety of selective attention techniques. In these paradigms, it is assumed that the stimuli presented within the attended focus reach conscious or subjective awareness and receive controlled processing whereas the stimuli presented out of the attended focus do not. Once again, with respect to the demonstration of N400 amplitude modulation for unattended stimuli, the results of these investigations have been mixed.

Based on the results of some of these investigations, some researchers have concluded that elicitation of N400 priming effects requires attentional or controlled processing. One of these investigations was conducted using lists of words that were presented dichotically during an investigation of memory in the auditory modality

(Bentin et al., 1995). During the study phase, different word lists were presented to each ear simultaneously and the participants were instructed to memorise the words presented to a designated ear and to ignore those presented to the other ear. Participants were not informed that both lists contained target words that followed semantically related or unrelated primes.

According to the authors, subsequently administered indirect tests of memory revealed that the semantic representations of both the attended and unattended words had been activated during the study phase. For example, the incremental increase in the percentage of false-positive responses for novel words that were semantic associates of the attended or unattended words did not differ significantly. Moreover, lexical decision reaction times were shortened equally by stimulus repetition whether the first presentation of the words had been attended or unattended. In contrast, the participants' recognition was better for the attended rather than unattended words. The authors interpreted these behavioural results as evidence that the meaning of both the attended and unattended words had been processed but that the processing of the attended words had been relatively more extensive. In other words, the behavioural data suggested that the manipulation of selective attention did not prevent the unattended words from accessing semantic memory, although it did appear to influence the manner in which words were processed and the nature of the memory traces they formed.

Analysis of the amplitudes of the N400s elicited by the target words revealed reliable semantic priming effects for stimuli presented to the attended ear only. According to the authors, the apparent contradiction in the behavioural and electrophysiological data can be reconciled by assuming that at least some aspects of behavioural semantic priming for the unattended words were automatic and that N400 was not sensitive to these aspects. Based on this assumption, the results would therefore suggest that the amplitude of the N400 in this paradigm reflected controlled attentional, rather than automatic, components of semantic priming.

Similar conclusions were reached for a more recent investigation conducted in the auditory modality (Okita & Jibu, 1998). These researchers also investigated the influence of selective attention on the N400 repetition effect for spoken words using a dichotic-listening paradigm but with a lexical decision task. For each trial, a word or non-word was presented to one ear while a different word or non-word was simultaneously presented to the other ear. Participants were instructed to selectively attend to a designated ear for occasional non-words and to ignore the stimulus presented simultaneously to the other ear. N400 repetition effects were measured for stimuli presented to the attended ear (AA condition), to the unattended ear (UU condition) and across the ears (AU and UA conditions). Word repetition in the attended ear (AA trials) resulted in attenuation of the N400. In contrast, no statistically significant N400 repetition effects were obtained for word repetition within the unattended condition (UU trials) or across attentional conditions (UA or AU trials). These results led the authors to conclude that modulation of N400 amplitudes is attentionally controlled and is therefore not reflective of automatic processes.

Both of the preceding investigations were conducted in the auditory modality. Similar conclusions have been based on investigations involving selective spatial attention conducted in the visual modality. For example, McCarthy and Nobre (1993) presented single words vertically to the left or right of central fixation and instructed the participants to attend to those on one side while ignoring those on the other side. Words presented to the attended side generally elicited N400 amplitudes of greater magnitude compared to those presented to the unattended side. Moreover, analysis of the N400 amplitude data for words presented to the attended side revealed evidence of semantic and repetition priming effects whereas analysis of the N400 amplitude data for words presented to the unattended side did not. These results were interpreted as evidence that N400 priming effects are elicited only in response to stimuli that are presented in a selectively attended space and that modulation of the amplitude of this component reflects controlled rather than automatic processes (McCarthy & Nobre, 1993).

In contrast to the above reports, some researches have reported N400 priming effects when at least one of the prime or target stimuli was presented within the focus of attention. For example, in an investigation by Otten, Rugg, and Doyle (1993), the N400 repetition effect was examined in the visual modality using a selective spatial attention paradigm in which the focus of attention was also manipulated through the use of colour.

Each trial involved the simultaneous presentation of a red and a green horizontal letter string, close by and equidistant above and below fixation. The horizontal presentation of the coloured words was chosen to allow the stimuli to be read relatively naturally. The task was to attend to the string presented in the designated colour and to respond to it if it was a non-word. A positive shift in the ERPs, including N400 attenuation, was obtained for word repetitions within the attended colour but not for word repetitions within the unattended colour. A small but reliable N400 repetition effect was also obtained when the first occurrence of the word was presented in the attended colour and the second occurrence was presented in the unattended colour. When trying to account for this result, that authors noted that the participants' selectivity of processing may have been less than perfect given the slight but significant excess of false alarm responses on trials containing an unattended non-word. Moreover, Otten et al. (1993) pointed out that the filtering costs in this experiment were high, as indexed by the relatively late onset of the N400 repetition effect compared to previous investigations.

A second version of the paradigm, containing the addition of a pre-stimulus spatial cue, was developed to remove uncertainty about the location of the relevant letter string. For each trial, the fixation point consisted of an arrowhead pointing upward or downward to indicate whether the stimulus in the intended colour would appear above or below central fixation. According to the authors, addition of the cue permitted the joint effects of attention and repetition to be assessed when selective processing was not contingent on an initial analysis of a sensory feature of the stimuli. When the focus of attention was manipulated by colour and the pre-cue, the N400 repetition effect was obtained whenever at least one of the word repetitions was within the focus of attention. The magnitude of the effect was smaller when only one rather than both members of the repeated word was in the focus of attention. According to Otten et al. (1993), these results indicated that visual selective attention might act more to attenuate than to eliminate the processing of unattended items. They further suggest that elicitation of the N400 repetition effect may require that only one, rather than both, of the words undergo controlled processing. However, features of the experimental protocol, such as the location of the stimuli (close-by and equidistant above and below central fixation), the standard rather than vertical presentation of the letter strings, and the extremely easy nature of the task in the attended location may have permitted some controlled processing of the words in the unattended location.

Based on the results of their selective attention paradigms, researchers such as Kellenbach and Michie (1996) have suggested that selective attention to the prime rather than the target might be critical for the elicitation of the N400 semantic priming effect. In the semantic priming paradigm used by Kellenbach and Michie (1996), selective attention was manipulated the on the basis of colour only. The paradigm consisted of a series of word and non-word letter strings that were presented foveally one at a time in red or green. Participants were instructed to make lexical decisions for the stimuli presented in a designated colour. Within the list of stimuli, target words appeared in the attended (A) or unattended (U) colour. Each target word was preceded by a semantically related or unrelated prime in either the attended (A) or unattended (U) colour. The presence and magnitude of the N400 semantic priming effect was examined when both the prime and target were in the attended colour (AA), when only the prime or target were in the attended colour (AU, UA), and when both the prime and target were in the unattended colour (UU).

N400 semantic priming effects were reliably elicited when the prime and target were within the attended colour (AA condition). A smaller but reliable N400 priming effect was elicited when the prime but not the target was in attended colour (AU condition). In contrast, reliable semantic priming effects were not elicited whenever the prime was not attended (i.e., in the UU condition when neither the prime nor the target was in the attended colour or UA condition when the target but not the prime was in the attended colour). When reviewing the results of this experiment, it is interesting to note how the results were consistent with those for the first but not second study by Otten et al. (1993). According to Kellenbach and Michie (1996), the sensitivity of the N400 semantic priming effect to the colour-based attentional manipulations was demonstrated by the lack of robust priming effects in the UU and UA conditions and is consistent with the view that N400 amplitude modulations reflect controlled rather than automatic processing mechanisms. Moreover, they concluded that attentional processing of the primes rather than the targets was necessary for activation of the controlled processing mechanisms indexed by N400 amplitude modulation. This conclusion was based on the contrast between the lack of reliable N400 amplitude modulation in the UU and UA conditions and the presence of reliable N400 modulation in the AA and AU conditions. In summary, the results of this colour-cued selective attention study, N400 semantic priming effects were obtained in a lexical decision task for primed target words irrespective of whether the targets were within the focus of attention provided that the preceding primes were attended. According to the authors, these results indicated that controlled processing of the prime and not necessarily the target is required for the elicitation of reliable N400 amplitude modulation in semantic priming paradigms. Once again, these results stand in contrast to those from the second study of Otten et al. (1993) in which somewhat attenuated N400 repetition effects were elicited provided either the prime or target were in the attended condition.

Summary and Conclusions

A review of the literature confirms that the N400 is a robust component linked to violations of semantic or contextual expectancies in a wide range of priming paradigms. Although typically defined as an ‘endogenous’ ERP component (i.e., sensitive to the psychological effects within the brain in response to a stimulus manipulation), the extent to which the amplitude of the N400 is sensitive to automatic processing in the absence of the controlled forms of processing associated with subjective awareness remains controversial. As suggested with respect to the P300 component, one way to investigate this question could involve the testing of patients with visual hemineglect who are reported to be aware of information in their ipsilesional but not contralesional visual field. Once again, the patients would be able to serve as their own controls in an investigation of the implicit and explicit processing of visual information presented in an ERP-compatible semantic priming paradigm with the N400 as the electrophysiological correlate of information processing. As described in Chapter 2, behavioural measures have been used to demonstrate implicit semantic processing of contralesional visual information of which patients with visual hemineglect remain subjectively unaware. In the light of these findings, it is likely that similar implicit N400 semantic priming effects will also be obtained for patients with visual hemineglect.

CHAPTER FIVE

ERP INVESTIGATIONS OF HEMINEGLECT

Animal Studies

One of the first ERP investigations of neglect was conducted by Watson, Miller, and Heilman (1977) using three adult monkeys (Macaca speciosa). Several early (P1, N1, and P2) and relatively late (N2 and P3) somatosensory ERP components were examined before and after the monkeys received right unilateral frontal arcuate lesions that were verified histologically. Post-operatively, the animals exhibited the behavioural phenomena typical of somatosensory neglect in monkeys. For example, they generally preferred to use their extremities ipsilateral to the lesion for all unilateral tasks. Their contralateral limbs generally hung at their sides. In contrast, they displayed symmetrical strength and co-ordination if vigorously stimulated to use their contralesional sides. Similarly, in tasks, such as climbing, which required use of both sides, they generally showed no side preference or dependence.

ERPs were collected for 7 consecutive days prior to surgery and for 7 consecutive days after surgery. The somatosensory stimuli for which the ERPs were elicited involved averaging across 64 mild electrical stimulations of .15 ms duration each applied to the peroneal nerve of the monkeys' legs. The electrical stimulation was of sufficient strength to produce a minimal foot dorsoflection. The ERPs were recorded for each leg separately using lateralized recording sites positioned over the ipsilesional and contralesional hemispheres.

The results of this animal study demonstrated that frontal lesions inducing neglect did not alter the early components of the somatosensory ERP (i.e., P1, N1, P2). Significant ERP changes associated with neglect were, however, seen in the later components (N2, P3). Compared to the N2 and P3 components elicited by stimulation of the normal hemispace, those elicited by stimulation of the neglected hemispace had longer peak latencies and the P3 component also showed increased amplitude.

In their interpretation of these results, the authors pointed out that the early ERP components are associated with specific sensory conduction and the later components reflect more non-specific arousal, alerting, or attentional neural activities. Thus, they concluded that the selective alteration of late ERP components provided evidence against purely sensory accounts of the mechanisms underlying the neglect in favour of accounts involving an attentional deficit. The authors acknowledged that their finding of increased P3 amplitude following the onset of a syndrome postulated as secondary to decreased attention is difficult to interpret given that most studies have indicated an increase in amplitude with increased attention. They speculated that the increased P3 amplitude might be related to higher voltages and greater synchrony in the background EEG. Exactly how this would happen, however, was not clear.

The primary advantage of investigations of neglect using animal instead of human subjects is the collection of ERPs before and after specific neglect-inducing lesions in the animals' brains. For an understanding of the information processing fate of stimuli presented to the neglected visual hemispace that escapes subjective awareness, however, this study in particular, and other animal studies in general are associated with several major disadvantages. Because only somatosensory ERPs were investigated in this study, the results may not apply to neglect in the visual modality. Regardless of the modality of stimulus presentation, it cannot be determined whether the animals consciously perceive the stimulation of the contralesional hemifield. Finally, the extent to which the results of ERP investigations of neglect generalise from animal to human subjects is questionable given that the post-sensory (exogenous) ERP components, particularly those linked to language, are unlikely to have the same functional significance across species. In the light of these inherent limitations, the focus of the remainder of this review has been limited to ERP investigations of neglect using human rather than animal subjects.

Human Studies

The number of studies in which ERPs have been used to investigate visual processing in humans with contralesional neglect is limited. Conclusions concerning the degree to which various stages of information processing remain intact for stimuli presented in the neglected visual field have been mixed, likely as a result of differing ERP methodologies and paradigms. Whereas most of these studies investigated the processing of stimuli presented to the neglected visual field, few were designed to collect data for stimuli processed outside of conscious awareness, as assessed by the patients' failure to report the stimuli verbally or by means of a motor response. In an attempt to evaluate the mixed conclusions derived from these early ERP investigations of Neglect, a review of the literature with attention to methodological considerations has been undertaken.

Early Sensory Processing

In a study principally designed to investigate the P300 in the visual processing of patients with unilateral neglect, L'hermitte et al. (1985) reported that the primary visual evoked potentials (VEPs) elicited by reversing checkerboards presented in the centre of a screen were evidently normal. This qualitative report was made to back up their conclusion that neglect of the hemispace contralateral to parietal lesions was not associated with sensorial deficiencies in a group of patients with neglect who were not also affected by hemianopia. Unfortunately, no quantitative data were provided upon which to substantiate this report and the specific methodology used to collect the primary VEPs was not specified. Given that the eliciting checkerboard stimuli were presented centrally, rather than separately to the neglected and intact visual hemifields, this qualitative report does not specifically address the processing fate of information presented to the neglected visual hemifield.

In a study based on two right hemisphere damaged patients with contralesional visual neglect, Valler, Sandroni, Rusconi, and Barbieri (1991) demonstrated that stimulation of the neglected visual field may elicit normal early sensory ERPs even when the patients' verbal report reveals no subjective awareness of the eliciting stimuli. Patients ($N = 3$) with damage involving the primary sensory areas of the left hemisphere resulting in hemianopsia without neglect served as controls. In this study, monocular phase-reversing checkerboards were presented to the left or right visual fields of each patient. The visual ERPs were recorded ipsilateral to the stimulated visual hemifield at lateral occipital scalp recording sites (O1 and O2) referenced to the contralateral ear lobe.

The patients' verbal report of the checkerboard stimuli was used as an index of conscious perception (subjective awareness). Neither patient group had difficulty reporting when the checkerboards appeared in the ipsilesional visual hemifield. Both patient groups failed to report having seen the checkerboards when they were presented to the contralesional visual hemifield.

Analysis of the electrophysiological data was based on 3 early sensory visual ERP components, the P75, N100, and P145. For the patients with hemianopsia, recognisable early sensory ERP components were obtained following stimulation of the ipsilesional but not contralesional visual hemifield. For the patients with neglect, however, the early sensory components of the ERPs obtained following contralesional visual stimulation were reported to be within normal limits and were comparable to those obtained following the ipsilesional visual stimulation. Thus, for the patients with neglect, there was electrophysiological evidence of preserved early sensory processing outside of conscious awareness following stimulation of the neglected visual hemifield.

According to the authors, this dissociation is consistent with speculation that deficits at more complex stages of information processing (e.g. attentional factors) may serve as important determinants of the spatial deficits of patients with neglect. The authors speculated that the visual field deficits of patients with neglect may arise from defective access of the outputs of preserved primary sensory analysis to the successive processes involved in conscious perception and in overt verbal report. They further speculated that this defective access may result from damage to the neuronal structures subserving perceptual awareness or their disconnection from primary sensory areas. It is important to note that the speculations concerning the later stages of information processing were not directly tested in this study of basic visual processing.

In several studies by Spinelli and her colleagues, steady-state ERPs elicited by phase-reversing checkerboards or sinusoidal gratings have been used to investigate basic visual processing for patients with contralesional neglect (Angelli, De Luca, & Spinelli, 1996; Spinelli, Burr, & Morrone, 1994; Viggiano et al., 1995). In these studies, the spatial, temporal, or both spatial and temporal characteristics of the eliciting pattern-reversing stimuli have been manipulated to determine whether patients with neglect might have deficit patterns restricted to certain ranges that might differentiate them from other brain-damaged patients without neglect or from normal controls. The extent of early sensory impairment reported in the visual ERPs of the patients with neglect has varied, likely as a result of methodological differences between the studies, including sample size, choice of comparison groups, and the selection of amplitude, latency, or both amplitude and latency as dependent variables.

This review will focus on a summary of the most recent of these investigations, which was based on the largest number of patients with contralesional visual neglect (Angelli et al., 1996). For this investigation, steady-state VEPs were obtained from 19 right hemisphere damaged patients with contralesional visual neglect, 12 right hemisphere damaged patients without neglect, 15 left hemisphere damaged patients without neglect, and 2 left hemisphere damaged patients with contralesional visual neglect. Of the 3 studies, this was the only one for which data were not collected from a healthy comparison group. The eliciting stimuli were sinusoidal gratings, which were phase reversed at various temporal frequencies in the left or right visual field. For this investigation, the analysis involved the amplitude and latency of the VEPs differentially recorded at midline central (Cz) and occipital (Oz) scalp sites, with a ground located half way between these sites.

Stimulation of the contralesional hemifield elicited VEP amplitudes that were smaller than those elicited by stimulation of the ipsilesional visual hemifield for all of the patient groups with the exception of the left hemisphere damaged patients without neglect. For this last group of patients, stimulation of the contralesional or ipsilesional hemifields elicited VEPs of comparable amplitudes. In contrast, the results of other investigations by Spinelli and her colleagues based on smaller samples of patients ($N = 9$ or 10) with contralesional neglect have reported comparable VEP amplitudes following stimulation of the contralesional and ipsilesional hemifields (Spinelli et al., 1994; Viggiano et al., 1995).

A more distinct pattern of results for patients with neglect was obtained when the latencies of the VEPs were analysed. Stimulation of the contralesional hemifield elicited VEP latencies that were longer than those elicited by stimulation of the ipsilesional hemifield for patients with neglect regardless of the laterality of the brain lesion. In contrast, there were no delays in the VEP latencies following contralesional stimulation for either the left or right hemisphere damaged controls without neglect. The lack of a non-brain damaged control group limits the extent to which these results based on the amplitude of the VEP can be classified as abnormal. However, compared to the mixed results based on VEP amplitudes, the results based on VEP latencies appear to be more consistent across studies (see Spinelli et al., 1994; Spinelli, Angelelli, De

Luca, & Burr, 1996; Spinelli & Di-Russo, 1996; Pitzalis, Spinelli, & Zoccolotti, 1997). These data support the view that the early sensory processing of stimuli presented to the neglected visual hemifield may be abnormal.

In an investigation of 10 patients with right hemisphere damage and contralesional visual neglect, Spinelli et al. (1996) reported a delay in VEP latency in the contralesional hemifield for sinusoidal gratings of luminance contrast modulated over relatively high temporal frequencies (4-10.5 Hz) and recorded differentially at Oz and Cz with a ground located half way between these scalp sites. In contrast, no delay in VEP latency in the contralesional hemifield was elicited for equiluminant stimuli of chromatic contrast modulated over relatively low temporal frequencies (1-4 Hz). These results were interpreted as evidence of selective damage to the fast-responding magnocellular pathways and sparing of the slower-responding parvocellular pathways.

In an investigation based on 16 patients with right hemisphere damage and contralesional visual neglect, Pitzalis, et al. (1997) used steady-state and transient VEPs recorded at Oz and Cz to investigate the horizontal and vertical dimensions of the patients' neglect deficits. The stimuli were horizontal sinusoidal gratings phase reversed at 8 temporal frequencies (4-11 Hz). There were 4 bright red LEDs placed 1 degree out of the corners of the screen to serve as fixation points and 4 experimental conditions. For each condition, patients were instructed to fixate on one of the 4 fixation points. In this way, the authors reasoned that the upper left, upper right, lower left, and lower right portions of the visual field would be stimulated separately. The authors' prediction that the patients' VEP latencies would be longest in the lower left quadrant when compared to all other quadrants was supported. In the design of this experiment, it is noteworthy, however, that the 4 quadrants of the screen may not correspond to the 4 quadrants of the patients' visual field. Each quadrant contained a fixation point upon which the patients were instructed to direct the centre of their visual focus. Thus, it would be interesting to determine whether similar results would be obtained if the patients had been instructed to maintain central fixation while the eliciting stimuli were presented in the quadrant to be tested.

In a study by Spinelli and Di-Russo (1996), the steady-state VEP delay recorded at Oz and Cz for sinusoidal grating stimuli presented in the left visual field of 4 patients with right hemisphere damage and neglect was reduced by rotation of the patients' trunk 45 degrees to the left while their heads faced the monitor. For patients from whom transient VEP recordings were collected (*N* = 3), similar results were obtained from analysis of the P100 latencies. According to the authors, these electrophysiological results parallel behavioural data obtained from other patients with unilateral left neglect, which showed a decrease in the neglect deficit as a temporary consequence of the neck torsion resulting from this form of head-trunk rotation or from vibration of the left posterior neck muscles. The behavioural data, which was not obtained from the same patients, from whom the electrophysiological data were obtained, involved improved rates of identification for figures presented tacthistoscopically to the left visual field and increased frequency and speed of saccades used for scanning the left space. According to the authors, trunk rotation was effective only in the particular case of the delayed response of patients with neglect. No similar effect was observed in the data of left brain damaged patients without neglect or of normal subjects.

Together, the reports of Spinelli and her colleagues support the view that the early sensory processing of stimuli presented to the neglected visual hemifield may be abnormal. However, because no behavioural index of the patients' subjective awareness of the eliciting stimuli were obtained, these data do not directly address the information processing fate of stimuli presented to the neglected visual hemifield which may be processed outside of the patients' subjective awareness. Also, these data do not assess the effect of alterations in the early sensory processing on later ERP components.

Later ERP Components

L'hermitte et al. (1985) obtained behavioural response time and ERP data from 9 patients with unilateral brain damage involving the right (*n* = 7) or left (*n* = 2) parietal lobe and contralesional neglect in the absence of hemianopsia. Two comparison groups consisted of healthy subjects (*n* = 14) and brain damaged patients without neglect (LHD, *n* = 3; RHD, *n* = 1). Participants were instructed to press a button as quickly as possible to peripheral light flashes (green diodes) that appeared randomly 20 degrees to the left or right of a central fixation point (laser beam) on a screen where an illuminated checkerboard was phase-reversed every 600 ms.

Analysis of the behavioural data revealed that the lateralized targets were generally detected more slowly by the patients with neglect than by the members of either comparison group, possibly because the three groups were not matched on basic demographic variables, such as age. Whereas no demographics were given for the patient controls, the healthy controls were significantly younger than were the patients with neglect. For both control groups, the rate of target detection did not differ significantly as a function of the visual field in which they appeared. As expected for the patients with neglect, however, contralesional targets were detected more slowly than ipsilesional targets.

The electrophysiological data were recorded from four midline (Fz, Cz, Pz, Oz) and two lateral (P3, P4) scalp sites referenced to linked mastoids. Analysis of the electrophysiological data for the control groups revealed no significant difference in the amplitude or latency of the P300 elicited by targets as a function of the visual field in which they appeared. For the patients with neglect, however, the peak amplitudes of the P300s elicited by the contralesional targets were attenuated and delayed compared to those elicited by ipsilesional targets. As mentioned in the preceding section, L'hermitte et al. (1985) reported that the steady-state VEPs elicited by the checkerboard stimuli for the patients with neglect were "apparently normal" but presented no data upon which to evaluate this claim.

The authors took the attenuated and delayed peak amplitude of the P300 elicited by the contralesional targets as evidence that the neglect deficits arose as a consequence of damage to brain areas involved in stimulus discrimination and evaluation. However, neither of these psychological processes were directly manipulated. The targets (green diodes) appeared to the left or right of centre in the patients neglected and intact visual fields respectively. No statistical comparison of the electrophysiological data elicited by the targets and "frequent background stimuli" (checkerboards upon which the targets were superimposed and which differed from the targets with respect to size, colour, form, intensity, and location) were performed. The abnormalities in P300 amplitude reported in this study could simply reflect increased difficulty in the detection of targets presented in the neglected visual field without calling upon other psychological processes such as stimulus discrimination or evaluation.

In the L'hermitte et al. (1985) investigation, all analyses were based on trials during which a behavioural response to the targets was made. Therefore, the results do not address the information processing fate of stimulation of the neglected visual field for which no response was elicited. The authors did not report on the detection accuracy of the patients with neglect apart from the observation that many stimuli did not prompt any motor response at all. Presumably, the proportion of misses was greater for contralesional than for ipsilesional stimuli for the patients with visual hemineglect.

The closest that the authors got to looking at the information processing fate of stimuli that were omitted due to neglect was an analysis in which the P300s corresponding to the shortest 25 RTs were compared with those corresponding to the longest 25 RTs. This analysis showed that in 8 of the 9 patients, P300 wave for the fastest 25 RTs was clearly identifiable during stimulation of the visual field contralateral to the lesion but it's average latency was longer than in normal subjects. The P300 wave corresponding to the slowest 25 RTs was still clearly identifiable in one patient was of weak amplitude and spread out in 7 patients, and did not exist in 1. In all 9 patients, P300 was clearly identifiable with an average latency close to normal after stimulation ipsilateral to the lesion.

In a study by Verleger, et al.(1996), ERPs were recorded during the administration of a visual cueing task to 10 patients with lesions of the right posterior parietal cortex and 10 age-matched controls. The recordings were made from nine sites (Fz, Cz, Pz, C3, C4, P3, P4, O1 and O2) with the mastoids as reference. The patients were not selected on the basis of functional impairment on clinical measures of neglect or extinction. Instead, they were selected neuroanatomically on the basis of a CT- or MRI-verified lesion involving the parietal cortex. A composite neglect score was derived from the patients' performance on about 11 clinical measures of neglect and extinction. Two of the patients obtained a total neglect score of zero (out of a possible 30 points, which was not reached by any patient) indicating that neither neglect nor extinction were present in the qualitative or quantitative measures. Scores for the other eight patients ranged from 1 to 18.

The visual cueing task was originally developed by Posner (Posner, 1980; Posner et al., 1980) and has been useful in the study of visual extinction. Each trial began with the onset of a central grey fixation cross, flanked horizontally by the grey outlines of two rectangles. After 500 ms, a cue appeared. More specifically, the frame of one of the rectangles turned yellow and remained yellow until clearing of the screen at the end of the trial. Then, 150 ms after illumination of the cue, the target, a grey diagonal cross, appeared in one of the rectangles[1]. The targets, which appeared to the left or right of the central fixation point, were cued either validly (cue on the side on which the target will appear) or invalidly (cue on the side opposite to where the target will appear). In total, there were 4 cue/target pairings which were presented randomly and with equal probability of occurrence (i.e., left cue/left target, right cue/right target, left cue/right target, and right cue/left target). In response to every target, participants were instructed to press a key, which triggered clearing of the screen in preparation for the next trial.

As expected, based on the location of their right parietal lesions, the patients' key press responses were delayed when the contralesional (left) targets were invalidly cued on the right. The magnitude of this delay was correlated with the composite clinical neglect score.

Analysis of the ERP waveforms elicited by the cues was limited to the N1 due to the short cue-target interval. Analysis of the ERP waveforms elicited by the targets included the N1, Nd, P3b, and P3f. According to the authors, evidence of the patients' neglect disorder was found as early as the N1 component elicited by the lateralized cues. The N1 is a posterior ERP component peaking at about 180 ms which is considered a correlate of visual perception that can be modulated by the manipulation of selective attention. The N1 amplitudes elicited by the lateralized cues and recorded at the left and right parietal sites showed the anticipated contralateral enhancement for the control group. For the patients, however, contralateral enhancement of N1 amplitude was seen for right but not left cues. Thus, whereas the N1 amplitudes of the controls' were equal for left and right cues, those of the patients' were smaller for contralesional (left) than for ipsilesional (right) cues. The authors offered two interpretations of these results.

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[1] The short SOA (150 *ms*) between cue and target restricted the investigation to automatic reflexive shifts of gaze (attention) triggered by the lateral cue. More voluntary shifts would be expected with longer SOAs.

The results suggest degraded perception of left stimuli (possibly due to impaired perceptual pathways or as a consequence of a lesion to the cortical area that generates N1) resulting in weaker visual input. Alternatively, the results suggest a relative difference in the patients' ability to orient or engage attention toward the left and right cues.

The amplitude of the N1 evoked by the lateralized targets did not differ between the control and patient groups and was not affected by the laterality[2] or validity[3] of the cues. Based on these results, the authors concluded that the patients' response delay for left targets that were invalidly cued did not arise at the perceptual level as indexed by the amplitude of the N1.

The Nd is a negative shift elicited 130 and 300 ms after the onset of validly cued targets in choice-response tasks. The Nd effect has been interpreted as a sign of enhanced processing of same-location targets. As predicted, the amplitude of the patients' Nd (160 to 280 ms after target onset) served as a reliable correlate of the patients' deviant pattern of delayed response times for left targets that have been invalidly cued on the right. More specifically, the amplitude of the patients' Nd was attenuated most for the left targets that were invalidly cued on the right and for which the patients' behavioural responses were slowest as well. The authors concluded that the lack of negativity for invalidly cued left targets suggested a reduction in processing. They went on to suggest that the Nd may provide the most direct estimate about the time at which the pathology of information processing occurs in neglect patients. According to their account, the manifestation of the information processing pathology as early as 200 ms after target onset indicates that the neglect occurs within the very processing of perceptual input. Neglect pathology is therefore not simply the result of an extraneous re-evaluation of otherwise uncorrupted results of intact perceptual processing.

Two components of the P300 complex that are differentially affected by expectancies were also analysed. The P3b is a parietal component, which is enhanced

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[2] As with the cue-evoked N1, the authors predicted that the target-evoked N1 might also be smaller in amplitude for left than for right targets.

for expected stimuli. The P3f is a frontal component, which is enhanced after unexpected stimuli. The authors predicted that any target should evoke a P3b. Based on previous work, the authors also predicted an unspecific reduction of the P3b in the patients' data (at least for those patients whose temporo-parietal junction was affected) compared to the control's data. For invalidly cued targets a P3f was anticipated in addition to the P3b. The P3f effect was expected to be greater the more that the invalid cueing had a measurable effect on the participants' response times. Thus, for patients', it was predicted that the P3f effect should be largest for left targets that were invalidly cued on the right (the pairing of cues and targets for which the patients' responses were expected to be slowest).

As expected, the amplitude of the P3b was reduced in the patients' data and was not affected by specific cue/target sequences[4]. Also as expected, the amplitude of the patients' P3f was sensitive to the validity of the cue/target sequences. It was largest for the invalidly cued left targets. The authors interpreted this result as a reflection of the patients' reorienting of attention and speculated that the patients may not initially have consciously perceived the invalidly cued left targets. Therefore, they initially behaved as if there was no target present and were only able after some reorientation of attention to respond to the target. The authors proposed that this assumption may be tested in future research by comparing the potentials evoked by the invalidly cued left targets that were detected with those evoked by invalidly cued left targets that were omitted.

In summarising their results, the authors pointed out that the amplitude of different ERP components were sensitive to different aspects of the patients' neglect disorder. They did not report results for any analysis of the latency component of the ERP data. The patients' N1 component evoked by left cues was reduced at the right parietal recording site. Thus, there was a perceptual asymmetry in the form of a general impairment in the processing of left visual input or a reduction in the patients' ability to orient or engage attention to stimuli on the left. Analysis of the ERPs elicited by the

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[3] Only the patients' but not controls' reaction times were expected to be sensitive to invalid cueing. The authors therefore predicted that a differential effect of cue validity might be seen in the amplitude of only the patients' target-evoked N1s with smaller amplitudes for targets cued invalidly compared to those cued validly.

targets revealed two correlates of the RT delay for left targets that were cued invalidly on the right side. For this condition, the mean amplitude 160-280 ms after target onset (Nd) was less negative than with other combinations of cue and target. This Nd reduction was interpreted as an on-line measure of the patients' momentary decrease of attention for the left visual hemifield. The following P3f that was enhanced for these left targets that were invalidly cued on the right might reflect a mechanism of compensation in the patients' reorienting of attention.

Summary and Conclusions

ERP investigations of visual information processing in humans with contralesional hemineglect have been limited in number to date. However, as stated by Verleger et al. (1996), ERPs offer a promising on-line measure of the various stages of neurocognitive processing for information presented to the neglected visual hemispace of humans with contralesional visual neglect. As reviewed, researchers to date have examined ERP correlates for relatively low-level stimuli. ERP correlates for stimuli that can be differentiated on the basis of a higher order, categorical, or symbolic identity have not yet been undertaken for patients with contralesional neglect. Furthermore, the question concerning the information processing fate of stimuli that are not subsequently reported due to neglect remains largely unexplored.

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[4] The unspecific reduction in amplitude of the P3b was obtained with the same group of patients in two other tasks (Verleger et al., 1996).

CHAPTER SIX

EXPERIMENT ONE: N400 AND IMPLICIT SEMANTIC PRIMING IN VISUAL HEMINEGLECT

INTRODUCTION

On tests requiring overt responses, patients with visual hemineglect may appear unaware of contralesional but not ipsilesional stimuli (Heilman et al., 1985). This lateralized deficit has provided opportunities to compare the implicit and explicit processing of information using a within subject design with participants as their own controls. As described in the introductory chapters, previous investigations have demonstrated extensive implicit processing up to the level of object identification and semantic categorisation for neglected information that remains inaccessible to subjective awareness. Demonstrations of implicit semantic or repetition priming have been among the most convincing evidence of the residual processing to date (Berti & Rizzolatti, 1992; D'Esposito et al., 1993; Ladavas et al., 1997; McGlinchey-Berroth et al., 1993, McGlinchey-Berroth & Milberg, 1996; Schweinberger & Stief, 2001). As noted in an earlier chapter with respect to the level of implicit processing attained, these two forms of priming do not likely represent entirely equivalent phenomenon although the N400 is sensitive to both forms.

As noted by Sweinberger and Steif (2001), the reaction times from these investigations cannot precisely determine the point at which priming influenced target processing. In contrast, within a covert cueing paradigm, Verleger et al. (1996) have demonstrated that the amplitudes of different ERP components can be sensitive to different aspects of the hemineglect disorder. This demonstration confirms the suitability of electrophysiological measures, such as ERPs, to elucidate the time course of selection and priming in relation to visual awareness for patients with hemineglect (Sweinberger & Stief, 2001). For the present experiment, an ERP-compatible priming paradigm was developed to determine whether the N400 could be used as an electrophysiological correlate of the implicit semantic priming previously reported for patients with visual hemineglect.

The experimental paradigm was fashioned on the categorisation paradigms of Berti and Rizzolatti (1992) and McGlinchey-Berroth et al. (1993); McGlinchey-Berroth &

Milberg (1996). The participants were to categorise target pictures (green line drawings of animals or clothing), which appeared at central fixation. Each green target was preceded by a semantically congruent or non-congruent picture prime (presented in red) which appeared to the left or right of centre. The participants' categorisations were made using a two-button response pad. No response was required for the primes. Note that in the experimental paradigm just described, neglect of the contralesional primes had to be inferred. Therefore, a 25-trial pre-experimental version of the paradigm was used. Instead of categorising the central target only, for the pre-experimental version of the paradigm, the patients were to verbally report everything seen during each trial (i.e., the prime, target, or both prime and target). The subjective manifestation of hemineglect on this pre-experimental verbal-report version of the paradigm was expected to take the form of an impaired detection of the contralesional but not ipsilesional primes.

Once the patients' subjective neglect of the left-sided primes had been demonstrated on the pre-experimental verbal-report version of the paradigm, the button press categorisation times on the longer experimental version of the paradigm could then be analysed to confirm that the subjectively neglected left-sided primes had nevertheless been processed implicitly. To support this conclusion, the target categorisation times on the experimental motor-response version of the paradigm were expected to be faster for the congruently rather than non-congruently primed targets regardless of whether the primes appeared in the patients' contralesional (right) or ipsilesional (non-neglected) visual field. These behavioural results would be consistent with previous demonstrations that neglected information that has escaped subjective awareness may be implicitly processed semantically (Berti & Rizzolatti, 1992; D'Esposito et al., 1993; Ladavs et al., 1997; McGlinchey-Berroth et al., 1993; McGlinchey-Berroth & Milberg, 1996; Schweinberger & Stief, 2001). The successful demonstration of implicit semantic processing in the behavioural data would suggest that the high-level processing of subjectively neglected information represent a general phenomenon of hemineglect rather than a specific characteristic of the patient participants in previous investigations.

The N400s elicited by the targets were the electrophysiological correlate of primary interest. As described in the introductory chapters, the amplitude of this component is inversely related to the degree to which semantic expectancy is violated within a variety of priming paradigms. Whether or not the amplitude of the N400 is sensitive to the implicit semantic processing that would take place in the absence of the more controlled processing associated with subjective awareness remains controversial (Behrman & Tipper, 1994). If N400 amplitude priming effects are obtained regardless of the laterality of the prime for patients with hemineglect, these results would provide support for the idea that the amplitude of the N400 can be modulated by automatic levels of semantic processing (e.g. Automatic Spreading Activation; ASA) in the absence of controlled processing. This result would suggest that the N400 is not an exclusively endogenous component, which in turn has implications for how the component is modelled and for the way in which the elicitation of the N400 priming effect may be interpreted in different contexts. With respect to the patients with hemineglect, these results would provide electrophysiological support for the implicit behavioural semantic priming effects. An age-matched healthy comparison group was used to ensure that presentation of the primes in unattended spatial locations and in an unattended colour did not interfere with the expected semantic priming effects.

The within-subject comparison of the patients' target N400 amplitudes is expected to reveal evidence of implicit (contralesional) and explicit (ipsilesional) semantic processing of the primes. If this is the case, then inspection of the amplitude and latency of the N400 and earlier components of the target waveforms may provide insight into the relative intensity or rate with which the preceding primes were processed when available or unavailable to subjective awareness. In other words, examination of the amplitudes and latencies of the sensory, perceptual, and cognitive correlates of information processing for the targets may determine the point in time at which the implicit or explicit processing of the primes begins to influence the subsequent processing of the targets. ERP data were also obtained for the picture primes presented to the patients' ipsilesional and contralesional visual fields. Compared to the relatively low-level visual stimuli presented in previous ERP investigations (see Chapter 5 for a review of these studies in which reversing checkerboards, sinusoidal gratings, light flashes, or simple shapes were used as stimuli), the pictures used as lateralized cues in the present experimental protocol were much more complex. Thus, the present experiment permitted an opportunity to examine the electrophysiological correlates of stimuli that potentially carried more meaning for patients with visual hemineglect.

Of the limited number of investigations of hemineglect in which electrophysiological measures, such as ERPs or VEPs were used to assess the residual information processing of these patients, none have examined the N400 component as a potential correlate of implicit or explicit processing. The conclusions concerning the degree to which various stages of information processing remain intact for contralesional stimuli have been mixed, likely as a consequence of the different paradigms and methodologies used, aspects of the components examined, or even variability within the very nature of hemineglect. As described in the introductory chapters, the investigation of electrophysiological correlates of information processing in the neglected field has mostly reported on early visual EP or ERP components rather than on later visual ERP components. With two exceptions in which amplitude attenuation was reported at a contralateral recording site (Angelelli et al., 1996; Verleger et al., 1996), the amplitudes of these early components have typically been reported to be within normal limits (e.g., Spinelli et al., 1994; Vallar et al., 1991; Verleger et al., 1996; Viggiano et al., 1995; Watson et al., 1977), although no data upon which to evaluate these claims were provided in some reports (e.g., L'hermitte et al., 1985). While the lack of amplitude attenuation has been interpreted by some authors as evidence of normal early level processing of contralesional information, investigators who have examined the latencies of these components have typically reported significant latency delays (Angelelli et al., 1996) particularly in the lower left visual field of patients with left visual hemineglect (Pitzalis et al., 1997), with improvement associated with rotation of the patients' trunks but not heads toward the contralesional stimuli (Spinelli & Di-Russo, 1996). The number of investigations conducted in which later components elicited by stimuli within the contralesional visual field were studied has been even more limited. In all cases, the abnormalities reported took the form of latencies that were delayed, amplitudes that were attenuated or even increased, or some combination of these abnormalities (L'hermitte et al., 1985; Verleger et al., 1996; Watson et al., 1977). In most of these investigations, electrophysiological correlates were obtained for contralesional stimuli that were available to subjective awareness (as indicated by the elicitation of delayed behavioural responses) but not to those unavailable to subjective awareness or the degree of subjective awareness was simply not assessed.

As just summarised, a review of the literature pertaining to ERPs and hemineglect provides few consistent findings upon which to base specific hypotheses concerning the amplitude and latencies of the early or late ERP components elicited by centralised targets that follow lateralized cues. For most visual ERP components, neurological damage is generally associated with peak amplitude attenuation, peak latency delay, increased peak latency variability (latency jitter), or a combination of these features which all indicate disruption of normal information processing. However, under normal circumstances, the automatic nature of implicit processing is generally thought to be faster than the more controlled forms of information processing that are associated with subjective awareness. In the formulation of hypotheses, it is important to keep in mind that the central hypothesis concerning the N400s elicited by the centralised targets was that evidence of implicit semantic processing of the preceding contralesional prime would be evident in the form of amplitude attenuation for congruently relative to non-congruently primed targets regardless of whether overall comparison of the N400 revealed latency delay or amplitude attenuation relative to controls. Relative to control data, it was anticipated that there would be non-specific amplitude attenuation and delay in the N400 and possibly earlier components elicited by the targets. If patient data reveals significant differences in the amplitudes or latencies of the N400 or earlier components on the basis of information presented in the preceding primes, these differences might help to determine the time at which the implicit or explicit processing of the lateralized primes begins to influence the subsequent processing of the centralised target.

With respect to the early ERP components elicited by the lateralized primes, the demonstration of no significant amplitude attenuation or latency delay for the contralesional relative to the ipsilesional primes would indicate that the early stages of information processing are preserved for information presented in the contralesional visual field. This result would suggest that the deficits associated with hemineglect are caused exclusively by impairment at later stages of information processing. If, on the other hand, the amplitude, latency, or both of these features of the early ERP components elicited by the contralesional primes are significantly different from those elicited by ipsilesional primes, these results would suggest that early level impairments are present that likely contribute to or interact with the impairments that would be expected in the later stages of information processing for contralesional stimuli.

METHODS

PARTICIPANTS

Patients

Fifteen English-speaking, right-handed patients (9 men, 6 women) were recruited using standard methods of informed consent from the Stroke Service and Rehabilitation Program of the Queen Elizabeth II Health Sciences Center. All had been admitted with a primary diagnosis of right hemisphere stroke and were considered by their health-care providers to exhibit evidence of left visual-spatial neglect. Four of the patients (3 men, 1 woman) who began the experimental protocol did not remain well enough to complete it.

Data were obtained from the remaining 11 patients (6 men, 5 women) whose demographics appear in Table 1. On average, the patients were 72 years old and ranged in age from 51 to 86 years. They achieved between 8 and 14 years of education ($M = 10.7$, $SD = 1.9$ years). Prior to stroke onset, 63.6% of the patients were retired, 9.1% were working, and 27.3% described themselves as a homemaker who had never worked outside the home. A total of 90.9% of the patients would be retired if the standard retirement age of 65 years was applied to the homemakers. The highest level of employment attained by the patients (excluding homemakers; 27.3%) could be categorised as blue collar (27.3%), clerical (18.2%), civil servant (18.2%), and education or health care (9.1%).

Clinical stroke features from chart review are in Table 2. The strokes were all diagnosed as due to obstruction of the blood supply to part of the brain (ischemic) with the exception of one, which resulted from an internal bleed (hemorrhagic). One of the ischemic events was complicated by hemorrhagic transformation. A second ischemic event was complicated by hemorrhagic transformation and an increased accumulation of cerebral spinal fluid within the ventricles of the brain (hydrocephalus). Chart reviews confirmed that all patients were diagnosed with right hemisphere cerebral vascular accidents (CVAs) resulting in evidence of contralesional visual neglect (see Table 2). Although the present investigation was focused on visual hemi-neglect, documentation of hemi-neglect (sometimes referred to as hemi-inattention) in other modalities (auditory or tactile) or contralesional sensory extinction under conditions of double simultaneous stimulation (i.e., when only the more contralesional of the two stimuli is reported, although each would be reported if presented alone) is included in Table 2. The resulting list may underestimate the prevalence of these deficits given that they were not always the primary focus of clinical assessment. Nevertheless, as noted by clinicians, sensory neglect and extinction can arise independently of one another following stroke and each modality can be affected independently (Bisiach & Vallar, 1988).

In Table 2 are summaries of the main brain regions affected by the stokes as reported in the interpretation of the CT scans used as part of routine patient care at the hospital. These CT scans were interpreted by the staff radiologists involved in the care of these patients. Two of the scans showed no clear evidence of brain abnormalities despite the onset of neurological symptoms consistent with the diagnosis of a significant CVA. The remainder of the scans revealed a range of brain region involvement in the strokes. The radiologists' interpretation of the CT scans has been summarised in Appendix A.

During experimental testing, all of the patients showed some of the general attention difficulties, increased fatigue, and decreased stamina associated with recovery from stroke. Chart review indicated that there were no severe comprehension difficulties (e.g., global aphasia) or dementia but mild to moderate confusion was commonly noted. Within the context of experimental testing, the patients' confusion was evident. For example, in contrast to the controls, the patients generally required more frequent repetition of the instructions during acquisition of the experimental task and more frequent reminders during the task. Chart review revealed many instances of specific stroke-related cognitive impairment involving attention, concentration, memory, learning, executive functions, judgement, disinhibition, perseveration, awareness of deficit, disorientation, thought organisation, and confusion (see Table 2). The patients' sensory motor symptoms were consistent with lesion localisation. A review of the visual symptoms revealed that hemianopsia and hemineglect co-existed for about half ($n = 5$) of the patients. Although a potential confound in a study of visual processing in neglect, hemianopsia on its own does not produce neglect (Halligan et al., 1990). Other notable changes attributed to the strokes included depressed mood ($n = 1$), disturbing auditory and visual hallucinations ($n = 1$), and paranoid delusions or ideation (*n* = 2). Although noted in the chart, no evidence of the hallucinations or paranoia were observed at the time of testing.

The extent of behavioural visual neglect was determined using the Sunnybrook Neglect Battery (Black et al., 1990). This standardised battery of paper-and-pencil examinations consists of a drawing and copying task, a line bisection task, a line cancellation task, and a figure cancellation task. A score was assigned for each sub-test reflecting the degree of neglect relative to the performance of a group of age-matched normal controls (Black et al., 1994; Black et al., 1990). Total scores on this screening battery range from 0 to 100. Scores under 5 suggest the absence of neglect. Those above 5 and below 31 indicate mild neglect. Those above 30 and below 75 indicate moderate neglect. Those of 75 or above of 40 represent severe neglect. Example test forms completed by patients with neglect who participated in the present experiments have been presented with a summary of how to administer and score each subtest in Appendix B. Of note, this standardised battery was easily administered at patients' bedsides when necessary. The patients completed each subtest using the hand unaffected by stroke paralysis while the paper was positioned directly in front of them at their midline. Initial scores have been presented in Table 3. As a group, the mean Total Neglect Score indicated the presence of moderate visual-spatial neglect deficits (*M* = 43.1, *SD* = 25.8). However, individual scores ranged from the mild (*n* = 5) to severe (*n* = 6) deficit range.

The total number of days from stroke onset to the time when each patient was first contacted to participate in this research ranged from 4 days to 2.3 years (see Table 4). The total number of days from stroke onset to the completion of different components of the paradigms for Experiments One and Two along with the number of sessions required to complete ERP testing have also been presented in Table 4. As indicated in the table, the time from stroke onset to the completion of all experimental testing varied from less than 2 weeks (*n* = 3) to greater than 1 year (*n* = 2). For patients from whom ERP data were collected over a number of days, the screening battery was re-administered to determine whether the deficits had resolved (see stimulus presentation section of Experiments One and Two for elaboration on the number of sessions required to complete ERP testing). As measured by the neglect screening battery, all patients continued to show at least a mild deficit at the end of their participation in the project. In no case did the neglect fully resolve by the end of testing.

Most patients had a pre-stroke medical history commensurate with their age. They included conditions such as hypercholesterolemia, hypertension, heart disease (e.g., mostly ischemic and/or atrial fibrillation but also congenital heart disease and a heart murmur), cancer in remission (e.g., lungs, bowel, endometrial), diverticulitis (an intestinal condition), thyroid conditions, peripheral vascular disease, respiratory conditions (legionella pneumonia, pulmonary embolism), acute polyneuritis, and chronic labyrinthitis. Previous CVAs experienced by 2 of the patients had been mild with excellent recovery of function and no hemispatial neglect deficits. Apart from this pair of CVAs, none of the pre-stroke health conditions would be expected to produce unilateral attention deficits. No major head injuries, prolonged periods of unconsciousness, or seizures had been reported by the patients or documented in their charts.

As mentioned above, those patients who remained or became too ill following stroke onset for neurological testing were excluded from participation in this research project. Corrected visual acuity less than 20/40 was another exclusionary criteria. One patient had a history of glaucoma and another had a minor cataract affecting the left eye but care was taken to ensure that these and all patients were able to see the stimuli. A documented history of psychiatric or neurological illness (other than current) was a third exclusionary criteria. The only psychological history of note was one case of depression which had been successfully treated with medication many years earlier and the individual had been experiencing good mental health prior to stroke onset. None required Thiamine upon admittance for the treatment of current alcohol abuse. All denied any history of problem drinking or substance abuse. Health screening data for the patients have been presented in Appendix C.

Controls

Healthy, English-speaking, right-handed, elderly volunteers were recruited through public announcement to serve as members of a comparison group for a project concerned with changes in vision following stroke. Of those who expressed interest, 24 volunteers (11 men, 13 women) initially appeared to satisfy the exclusion criteria on a screening questionnaire. Informed consent was obtained from each volunteer prior to the collection of the data. During the course of the experiment, it was discovered that several of the volunteers did not meet some of the exclusionary criteria. One volunteer had a notable tremor. Others recalled that they had experienced a CVA (*n* = 2) or an extended period of unconsciousness following a head injury (*n* = 2). Thus, the data collected from the remaining 19 volunteers (7 men, 12 women) were representative of a normatively healthy and age-appropriate comparison group. One of these volunteers, however, was unable to complete the experimental protocol because of very dry eyes and the onset of a severe headache. In addition, technical difficulties disrupted collection of the electrophysiological data for 4 of the volunteers.

Demographics for the remaining 14 controls (6 men, 8 women) have been presented in Table 5 and comparisons on these variables between the control and patient group have been presented in Table 6. As indicated on Table 6, the ratio of men to women did not differ significantly between the controls (6 men, 8 women) and patients (6 men, 5 women), $X^2 = 0.32, p > .05$. The controls ranged in age from 53 to 79 years. On average, there was no significant difference in the age of the controls ($M = 66$ years, $SD = 6.9$) compared to the patients ($M = 72$.years, $SD = 11$), $t\,(16.02) = 1.59, p = 0.13$. The controls had between 9 and 25 years of schooling and were on average better educated ($M = 15.6$ years, $SD = 4.97$) than were the patients ($M = 10.7$, $SD = 1.9$), $t\,(17.51) = 3.4, p = .003$). At testing, 64.3% of the controls were retired, 21.4% maintained employment, and 14.3% had not worked outside of the home. A total of 71.4% of the controls would be considered retired if the standard retirement age of 65 years were applied to those controls who described themselves as home-makers. As indicated on Table 6, the proportion of participants who described themselves as retired did not differ significantly between the two groups, $X^2 = 1.45, p > .05$. Half of the controls (50%) held professional level jobs in education or health care. The remainder worked in civil service (21.4%) or clerical (14.3%) jobs. None of the controls held blue-collar jobs. As indicated on Table 6, visual inspection of the level of employment data for the patients and controls revealed a disproportionate representation among the education and healthcare workers for the controls and a disproportionate absence of blue collar workers for the controls relative to the representation within these categories for the patients. This pattern of disproportionate representation was confirmed using a 2

(Patient, Control) by 5 (Education and Health Care, Civil Service, Clerical, Blue Collar, Homemaker) Chi Square Test of Independence, $X^2 = 9.87, p < .05$.

Current medical conditions reported by the controls (see Appendix C) included, thyroid conditions ($n = 2$), hypercholesterolemia ($n = 2$), hypertension ($n = 2$), hiatus hernia ($n = 1$), and arthritis ($n = 1$). Their various disorders were successfully under medical control. A majority of the controls reported no current or past medical conditions of note. No post-surgical complications were reported for a variety of routine surgical procedures including gall bladder, hysterectomy, varicose vein stripping, tonsillectomy, appendicitis, hernia, and cosmetic surgery. Three volunteers reported mild concussion and one reported a brief loss of consciousness following a motor vehicle accident. In all cases, the trauma took place between 10 and 56 years ago and there were no obvious functional impairments afterwards. No CVAs or seizures were reported. One person reported a brief episode of unexplained weakness and tiredness within the past year. No other episodes of fainting, paralysis or co-ordination problems were reported. The only psychiatric history of note involved the report of a brief conversion disorder that was successfully treated during childhood. One individual was successfully treated about 12 years ago for a drinking problem that had not recurred.

All volunteers wore prescription glasses during testing. One person had cataracts and one person reported a possible history of colour blindness. Special care was taken in each case to ensure that the experimental stimuli could be seen and that their colours could be differentiated. Of note, the participant who reported possible colour blindness had no difficulty differentiating between the red and green stimuli prior to testing.

In summary, the community volunteers did not differ from the patients in terms of average age. The controls were, however, better educated relative to the patients and appeared to have acquired employment consistent with their higher educational status. Despite a relatively higher (although not statistically significant) incidence of minor head injury in the past for the controls (Controls = 3.1%, Patients = 0%; $X^2 = 3.74, p > .05$), a review and comparison of the community volunteers' medical histories suggests that they enjoyed better health compared to the patients prior to the onset of their CVAs. It is likely that individuals with higher levels of education, employment status, and overall health would take the initiative to volunteer for a research investigation.

PROCEDURES

The Semantic Priming Paradigm

Stimuli. The experimental paradigm consisted of a randomised 120-trial target categorisation task with semantically congruent or non-congruent primes. Pictures served as the target and priming stimuli. The pictures ($N = 30$) were exemplars of common animals ($n = 15$) or clothing ($n = 15$) selected mostly from the line drawings of Snodgrass and Vanderwort (1980). The semantic relationship between the primes and targets was manipulated. For Congruent trials ($n = 60$), 2 exemplars from the same category were selected. For Non-Congruent trials ($n = 60$), 2 exemplars from different categories were selected. Each picture appeared equally often as a prime and as a target in the Congruent and Non-Congruent conditions. Whereas primes were randomly lateralized to the left ($n = 60$) or right ($n = 60$) visual field, all of the targets ($n = 120$) appeared centrally. Thus, the 4 target priming conditions were: Left Congruent ($n = 30$), Left Non-Congruent ($n = 30$), Right Congruent ($n = 30$), and Right Non-Congruent ($n = 30$). Examples of these priming conditions have been presented in Table 7.

Stimulus Presentation. Each participant was tested individually in a quiet hospital research laboratory. In the darkened lab, stimuli were rear-projected onto a large screen using a high-resolution computer data pad and overhead projector. The participants sat in a padded armchair approximately 150 cm from the screen (some patients preferred to remain in their wheel chairs). All pictures subtended visual angles that were approximately 5 degrees wide and 5 degrees high. Against the white background, the primes were red and appeared with equal frequency to the left ($n = 60$) or right ($n = 60$) of the continually illuminated central fixation point by 5 degrees, if measured to the prime's nearest edge, or 7 degrees, if measured to the prime's mid-point. In contrast, the centrally presented targets were green.

The paradigm consisted of 120 trials, divided into 6 blocks of 20 trials each. The order of trial presentation was randomised for both Congruency and for Prime Laterality, with the stipulation that the same picture never appear twice in immediate succession and that the primes never appear more than 3 times in succession on the same side.

Prior to each trial, the word "READY" appeared on the screen in capital black letters to remind participants to get ready for the next trial by blinking their eyes and then directing them toward the continuously illuminated central fixation point (plus sign). After ensuring that the participant was ready, the examiner would initiate the trial by depressing a hand-held button. The screen would then clear for 500 ms before a red prime would appear for 200 ms to the left or right of centre. Then, after an interval of 200 ms during which the screen remained blank, a green target would appear in the centre until it was categorised by the participant by means of a button press[5]. The participants' response pad contained two buttons in vertical alignment to minimise any rightward response bias attributable to the patients' neglect. Response accuracy and latency (in *ms* from target onset) were recorded on the computer.

During the experiment, participants were closely monitored to ensure that they maintained gaze on the task and to minimise any discomfort associated with post-stroke fatigue or postural impairments. Data collection was generally completed within a 2 hour session for controls (along with other testing) and across several sessions for patients depending on their fatigue. The number of sessions required to complete ERP testing for the patients in Experiment One ranged from 1 to 4 ($M = 1.4$ sessions, $SD = .97$; see Table 4). For patients who were unable to complete testing within a single session, testing typically resumed the following day (maximum time interval = 3 days).

Task Instructions. Participants were informed that green and red pictures would appear on the screen in different locations. Using a response pad with buttons in vertical alignment, they were instructed to categorise the green targets, which would always appear in the centre of the screen, by pressing the button labelled "animal" or "clothing". They were reminded that no response was required for the red pictures that they might see on other parts of the screen.

Flash cards depicting animals or clothing were used to familiarise the participants (particularly the patients) with the response pad so that their responses could be made without looking at the buttons. The patients were not taken from the ward to the ERP laboratory until it had been established that they could reliably categorise the flash cards

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[5] Initially, the paradigm was designed with a 200 *ms* exposure time for the targets to minimise the influence of

using the response pad. All participants were encouraged to respond as quickly and accurately as possible. Participants were also instructed (and reminded) to return their finger to the space between the buttons after responding.

To facilitate the collection of the ERPs, the participants were requested to maintain their gaze on the central red fixation point and to avoid blinking or moving except when the word "READY" appeared on the screen to let them know that the trial was over. They were assured that longer breaks would be provided after every 20 trials and that additional breaks could be taken if needed.

Practice and Neglect Verification Tasks. Flash cards and 3 brief introductory versions of the experimental paradigm were constructed to ensure familiarisation with the experimental protocol prior to the acquisition of the ERPs. The first 5-item introductory version started off with very slow trials that were useful as a demonstration when giving the task instructions. Two 24-trial versions were also developed. The first was identical in format to the longer experimental versions and it was used with the behavioural response pad as a practice version of the experimental task. The second was administered only to the patients as a neglect verification task. For this version of the paradigm, the duration of the prime and target was limited to 200 ms each. At the end of each trial, a verbal report of everything that had been seen on the screen was requested. All participants were encouraged to practice until they felt comfortable with task requirements. Controls generally performed well during the first few trials and were, therefore, not required to complete all of the 24 practice trials. In contrast, most of the patients required all of the 24 practice trials and sometimes several repetitions of the practice task before being able to begin the experimental paradigm.

Electrophysiological Data

EEG Recordings. While participants completed the semantic priming paradigm, their EEG activity was recorded using a grounded cap containing tin electrodes at Fz, Cz, Pz, P3, P4, T3, T4, O1, and O2 (International 10-20 system, Jasper, 1958) with linked ears as a reference. Vertical and horizontal electro-oculographic (EOG) activity was recorded using electrodes placed supraorbitally and at the outer canthus of the left eye (Connolly &

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saccadic eye movements but this exposure time was too challenging for most of the pilot patients.

Kleinman, 1978). Continuous analogue recordings were obtained using a half amplitude bandpass of 0.01 to 100 Hz (with a 60 Hz notch filter) and a digital sampling rate of 500 Hz while inter-electrode impedance was maintained at or below 5 KΩ.

ERP Averaging. For each centrally presented target, the continuous EEG data were epoched from 100 ms before to 1000 ms after stimulus onset. For each lateralized prime, the data were epoched from 100 ms before to 500 ms after stimulus onset[6]. A low pass digital filter set at 30 Hz was applied to all epochs. Those EEG epochs contaminated by EOG greater than 75 μV were automatically tagged for rejection. Further visual inspection ensured that epochs contaminated by other forms of artefact, such as amplitude saturation, were also rejected. When the ocular rejection procedure yielded insufficient artefact-free epochs for ERP averaging (i.e., < 10 trials in any condition), the participant's eye blink artefact was removed by means of a regression algorithm (Semlitsch, Anderer, Schuster, & Presslich, 1986) after all epochs contaminated by other forms of artefact had been rejected.

The EEG epochs for targets that participants categorised incorrectly were eliminated from further processing. The EEG epochs for primes were not associated with a behavioural response and could not, therefore, be behaviourally corrected. For each participant, ERPs from each electrode site were obtained by averaging the EEG epochs within each priming condition for the centralised targets (i.e., Left Congruent, Left Non-Congruent, Right Congruent, Right Non-Congruent) and within each visual field condition for the lateralized primes (i.e., Left, Right). For each group of participants, the individual ERPs were then averaged within each stimulus condition to obtain grand average waveforms that reflected the general ERP patterns for the patient and control groups.

ERP Scoring. For the manipulation of semantic congruency, the ERP component of primary theoretical interest was the N400, which was anticipated to occur about 400 ms from onset of the centralised targets. Scoring of earlier components (e.g., N100, P200, N200, P300) elicited by the targets, by the primes, or by both targets and primes was intended to address hypotheses related to earlier stages of visual processing in individuals with and without neglect. Visual inspection of the grand average

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[6] Five-hundred *ms* were available prior to onset of the centralized target.

waveforms was used to identify the presence and latency ranges of the N400 and other potentially scoreable components. The ERP amplitude of each component was calculated as the voltage difference between the mean activity for the 100 ms period before stimulus onset and the point scored as most positive or negative within the relevant latency range. The corresponding ERP latencies were calculated as the time from stimulus onset to the point scored as most negative or positive.

Statistical Procedures

The statistical procedures for analysis of the behavioural response data included: Chi-Square Tests of Independence, Sign Tests, Pearson Product-Moment Correlational Analyses, Independent Samples *t*-tests, Levene's Test for Equality of Variances, and Mixed-factorial Analyses of Variance (ANOVAs) with Group (Patient, Control) as a between-subjects factor and within-subjects factors that included Congruency of Prime (Congruent, Non-Congruent), Laterality of Prime (Left, Right), or both of these factors when appropriate. The statistical procedures used for analysis of the electrophysiological data included Mixed-factorial ANOVAs with Group (Patient, Control) as a between-subjects factor and within-subjects factors that included Congruency of Prime (Congruent, Non-Congruent), Laterality of Prime (Left, Right), Scalp Recording Site (Fz, Cz, Pz) or a combination of these factors when appropriate. Unidirectional Independent *t*-tests were also used for analysis of the electrophysiological data of individual participants. The results of all ANOVAs have been presented with conservative Greenhouse and Geisser (1959) degrees of freedom whenever statistical significance was met on tests of sphericity. All significant main effects involving 3 or more levels and significant interactions were submitted to further post hoc analysis using the Tukey Honestly Significant Differences (HSD) Test. All analyses required an alpha level of $p \leq .05$ before statistical significance was met. Throughout the Results section, the statistical procedures have been presented within a context in which the specific goals of each analysis have been outlined and significance has been used to denote statistical significance unless otherwise indicated.

RESULTS

BEHAVIOURAL RESULTS

Neglect Verification Task

Patient neglect of left primes on the experimental measure was verified using a 24-item version of the Lateralized Semantic Priming Paradigm. For this version, each lateralized prime appeared for 200 ms followed 200 ms later by a centralised target, which also appeared for 200 ms. Patients were instructed to maintain gaze on the central fixation point. After each trial, patients were to *verbally* report everything that they saw during the trial. Detection of the lateralized primes and centralised targets was operationally defined as the correct identification or categorisation of the pictorial stimuli (animals or clothing). Detection accuracy for each patient has been summarised in Table 8.

Of the centralised targets (*N* = 24), an average of 85.6% (*SD* = 17.10) were detected accurately, 0.4% (*SD* = 1.3) were detected inaccurately, and 14.0% (*SD* = 17.6) were not detected. As indicated in the table, inaccurate target detection was evident for only two cases. For one of these cases (P101), the incidence of inaccurate target categorisation was very rare (4.2%). The other case (P105), for whom the incidence of inaccurate target detection was relatively high (45.8%), was subsequently excluded from further data analysis as described in a subsequent section.

It is noteworthy that all but one of the missed targets were from the right-primed condition. This tendency to miss the centralised targets that followed right but not left primes suggested that the patients may have had difficulty redirecting their attention to a central target after it was drawn to a preceding right but not left prime. This pattern would be consistent with the perceptual salience hypothesis for the deficit, which posits that neglect is associated with the involuntary capture of attention by stimuli in the ipsilesional visual field (e.g., De Renzi et al., 1989). Overall, the centrally presented targets were adequately perceived by the patients in this study.

Of the primes (*N* = 12) presented in the patients intact (right) visual field, an average of 85.6% (*SD* = 13.0) were detected correctly, 2.3% (*SD* = 5.4) were detected incorrectly, and 12.1% (*SD* = 10.1) were not detected. Of the primes (*N* = 12) presented to their neglected (left) visual fields, an average of 40% (*SD* = 37.0) were detected accurately, 0.8% (*SD* = 2.5) were detected inaccurately, and 60.1% (*SD* = 37) were not detected. A non-parametric 2 (Left Prime, Right Prime) x 2 (Detected Accurately, Not Detected) Chi-Square Test of Independence (see Table 8) was used to assess the degree of leftward neglect displayed by each patient on this task[7]. Of the 11 patients, 81% (*n* = 9) showed evidence of a detection asymmetry consistent with the symptoms of left hemispatial neglect. Of these positive asymmetries, 7 were statistically significant. Of the patients, who showed no significant detection asymmetry, one (P109) missed a prime on each side and the other (P101) missed a right prime and no left primes. A Sign Test indicated that the number of patients (*n* = 9) who missed more primes on the left than right was significantly greater than the number of patients (*n* = 1) who missed a prime on the right but not on the left ($p < .001$).

A 1-tailed Pearson Product-Moment correlation analysis was used to assess the degree of convergent validity for the above Chi-Square behavioral index of visual neglect and the Total Neglect Score from the Sunnybrook Neglect Battery. For the patients in this experiment, a moderate positive linear relationship was obtained for the experimentally and clinically based measures of neglect, $r\,(N = 11) = .55, p = .04$ (see Column F of Table 9 for the data and Figure 1 for a scatter plot of the correlation). As indicated in Column G of the table, a similar positive linear relationship was obtained when the battery's neglect severity rather than total neglect score was used, $r\,(N = 11) = .65, p = .015$. As indicated in Columns A to E of Table 9, the only subtests of the battery with which the pre-experimental neglect verification task was significantly correlated was the Drawing and Copying Subtest, $r\,(N = 11) = .56, p = .04$. There was a non-significant trend with the line cancellation subtest, $r\,(N = 11) = .45$, $p = .08$. The correlations between the neglect verification task and the line bisection or figure cancellation subtests did not reach statistical significance. Taken together, these results verify the existence of the patients' visual neglect. They also indicate that the 24-item version of the experimental paradigm was behaviorally sensitive to the patients' neglect, and by implication, the same should be true for the longer experimental paradigm.

The Experimental Semantic Priming Paradigm

Accuracy. For the experimental Semantic Priming Paradigm, the percentage of correct target categorisations was used as a measure of task difficulty on which group

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[7] Data for primes that were detected inaccurately were not included because of their interpretative ambiguity for determining the presence of visual neglect relative to the other two conditions. Across all

and individual performance were compared. On average, target categorisation accuracy was significantly higher for controls (*M* = 99%, *SD* = .98) than it was for patients (*M* = 78.3. *SD* = 16.67), *t* (10.05) = -4.13, *p* = .002.

Looking within the groups, all controls performed well (minimum score = 97.5%). In contrast, 3 patients performed relatively poorly (i.e., P106 at 54.2%, P116 at 55% and P105 at 58.9%). For one of these patients (P105), inspection of the categorisation data revealed an unusual performance pattern that likely resulted from the extreme severity of the patient's unilateral neglect deficits. The centralised targets were categorised with reasonable accuracy when they followed left primes regardless of whether they were from the Congruent (72% accuracy) or Non-Congruent (75% accuracy) conditions. When the targets followed right primes, however, they appeared to be categorised very accurately for the Congruent condition (80.6% accuracy) and very poorly for the Non-Congruent condition (10.5% accuracy). The behavioural and electrophysiological data for this patient were not included in the subsequent group-based analyses due to near empty data cells and because of concern about how to interpret the patient's performance on the experimental measure[8]. On average, target categorisation accuracy remained significantly higher for the controls *(M* = 99%, *SD* = .98) than for the patients *(M* = 80.2%, *SD* = 16.2) after data from P105 was excluded *t* (9.05) = 3.67, *p* = .005.

Practice Effects. It was anticipated that healthy elderly controls would master the picture categorisation component of the Semantic Priming Paradigm more easily than the patients who were recovering from the neurological insults associated with a CVA. For this reason, patients were provided with extensive training on the task (minimum of 50 practice trials). In contrast, the controls rarely completed more than 10 practice trials after having been encouraged to practice until they felt comfortable with

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patients, there were only four inaccurately detected primes (a left and a right prime for P110 and two right primes for P107).

[8] The pattern of accuracy suggests that the severity of the patient's left visual neglect caused her to neglect the left primes, as predicted, and to neglect the centralized targets when they appeared to the left of the preceding primes. Categorisation of the prime instead of the neglected target would explain the inflated accuracy of target categorisation following Congruent primes and the extremely poor accuracy following Non-Congruent primes. A review of the patient's verbal responses on the neglect verification version of the paradigm supported this interpretation.

the task requirements. A review of the participants' testing notes revealed that the controls' data likely contained practice effects due to insufficient exposure to the experimental protocol prior to testing. For example, near the beginning of the experimental run, most of the controls expressed surprise, self-doubt, frustration, and embarrassment about the difficulties that they encountered on a task that they believed any child could easily master. Within the first block of trials, most of the controls expressed relief over their ability to have finally begun to master the experimental task. For this reason, the distribution of errors across sequential trials and the response latency data were inspected for evidence of practice effects. Of the controls' missed or inaccurately categorised targets, over ¾ (76.9%) occurred within the initial 22% of the trials[9]. Similarly, most behavioural outliers[10] occurred disproportionately during these early trials. Similar patterns of uneven error or outlier distribution did not characterise the patients' data. Taken together, these observations suggest that the reliability of the data collected during the controls' first block of trials may have been affected by insufficient practice with the experimental task. To correct for the practice effect, data collected during the first 26 trials was considered practice for each control and was excluded from further analysis. This correction procedure had the effect of making the controls' data more representative of their ability and also reduced excess error variance in their behavioural reaction time data.

Response Latencies. The time taken to correctly categorise the centralised targets by pressing one of two buttons was analysed to determine whether the present data supported previous reports of semantic priming elicited by visual primes that had been behaviourally neglected (Berti & Rizzolatti, 1992; McGlinchey-Berroth, et al., 1993). The data of one patient (P105) was excluded from this analysis due to the empty and unreliable data cells, which resulted from the extreme severity of her leftward visual neglect (see Response Accuracy section for a complete explanation). For comparative interpretation, analysis of the behavioural and electrophysiological data should be conducted on the same participants. Unfortunately, technical difficulties encountered

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[9] These trials were defined sequentially as the first 13 Congruent and first 13 Non-Congruent trials.

[10] Within each stimulus condition, a trial was an outlier if its response latency exceeded the mean of the condition by at least 2 *SD* (see next section).

during the administration of the Semantic Priming Paradigm for one patient (P116) and one control (C214) resulted in electrophysiological recordings that were incomplete or unreliable. To ensure maximal compatibility with the electrophysiological analyses, the data of these 2 participants were excluded from analysis of the behavioural response latencies.

Several steps were taken to correct for the positive skew associated with behavioural reaction time data of the remaining 9 patients and 13 controls. First, each participant's mean and median response latencies for correct target classifications were calculated within each of the 4 prime conditions (Left Congruent, Left Non-Congruent, Right Congruent, Right Non-Congruent). As expected, the medians within each condition and for both groups were consistently elevated compared to the means. To normalise the distribution, a log transformation was applied to each participant's data. Within each of the 4 priming conditions, response latency outliers greater than 2 standard deviations above the mean were identified and eliminated from each participant's log transformed data. No other main effects or interactions reached statistical significance. Thus, the percentage of data points identified as outliers and excluded per condition did not differ within each group.

The average number of outlier data points identified per condition in the patients' and controls' target categorisation data have been presented in Table 10. To correct for a practice effect, the reaction time data collected during the first block of 26 trials had been excluded (see previous section). Therefore, as indicated in Table 10, the average percentage of data points excluded as outliers from each condition was analysed by means of a mixed-factorial ANOVA with Group (Patient, Control) as a between subjects factor and Laterality of Prime (Left, Right) and Target/Prime Congruency (Congruent, Non-Congruent) as within-subjects factors. The analysis revealed a main effect of Group, $F\,(1, 20) = 10.6, p = .004, \eta^2 = .374$. On average, after correction for the practice effect, a greater percentage of outlier data points were identified and removed from the controls' data ($M = 5.15\%$, $SD = .58$) than from the patients' data ($M = 2.21\%$, $SD = .69$).

The corrected target response latency means were then analysed using a 2 x 2 x 2 mixed-factorial ANOVA with Group (Patient, Control) as a between-subjects factor and

Congruency (Congruent, Non-Congruent) and Laterality of Prime (Left, Right) as within-subjects factors (see Table 11). The analysis yielded a significant main effect of Group $F(1, 20) = 8.70, p = .008, \eta^2 = .30$. As expected, categorisation of the targets was performed more slowly by the patients ($M = 1050$ ms, $SD = 1096$) than by the controls ($M = 735$ ms, $SD = 1081$). There was also a significant main effect of Congruency, $F(1, 20) = 8.67, p = .008, \eta^2 = .303$. Congruently primed targets were categorised more quickly ($M = 858$ ms, $SD = 1064$) than non-congruently primed targets ($M = 899$ ms, $SD = 1062$). The effect of prime laterality was not significant, which indicated that the visual field in which the primes appeared did not affect target categorisation times. None of the interactions reached statistical significance. The lack of statistical significance for an interaction between Group, Prime Laterality and Congruency was of particular relevance to the experimental hypothesis because it indicated that the magnitude of the semantic priming effect was not influenced by the visual field in which the primes appeared among patients (see Table 11). Thus, in support of the primary behavioural hypothesis, the patient and control groups showed semantic priming effects characterised by faster responses for targets that were primed congruently compared to those that were primed non-congruently regardless of the visual field in which the primes appeared.

Each participant's behavioural reaction times for the categorisation of the centralised picture targets has been summarised in Appendix C3 for the patients and in Appendix C4 for the controls. For each participant, a mean reaction time N400 difference score was calculated for each side of prime presentation by subtracting the mean categorisation time of the Congruent condition from the mean categorization time of the Non-Congruent condition. For each of these comparisons, a positive difference score indicated that the predicted pattern of the semantic priming effect was present. As indicated in the Appendices, 1-tailed independent *t*-tests were used to determine the significance of each reaction time comparison for each participant.

The results of these comparisons have been summarised in Table 14. Inspection of the table revealed that the categorisation times for a majority (69.2%) of the controls showed the pattern of the predicted semantic priming effect differentiation for both the left and right priming conditions. Few of the comparisons, however, reached statistical significance (23.1 to 30.8 % depending on the priming condition). Moreover, these percentages remained low even when a more lenient rejection criteria (i.e., $p < .1$) was employed to permit inclusion of comparisons that reached the level of a statistical trend (30.8 to 38.5 % depending on the priming condition).

Inspection of Table 14 also revealed that the categorisation times for a minority of the patients showed the pattern of the predicted semantic priming effect for the right priming condition (44.4 %). In contrast, all of the patients' categorisation times showed the pattern of the predicted semantic priming effect for the left priming condition. As with the control data, however, very few of these patterns were of enough magnitude to attain statistical significance (i.e., 22.3 to 33.3 % depending on the laterality of the priming condition). Moreover, the percentages remained low (44.4%) even when the more lenient rejection criteria (i.e., $p < .1$) was employed to permit inclusion of comparisons that reached the level of a statistical trend. Thus, for the patients with visual hemineglect and age-matched controls, the behavioural categorisation times for the centralised targets were sensitive to the manipulation of semantic congruity regardless of the laterality of the primes when the data were analysed at a group rather than individual level.

ELECTROPHYSIOLOGICAL RESULTS

The Semantic Priming Paradigm yielded ERPs for the lateralized picture-primes and for the subsequent picture-targets that were presented centrally. Unless otherwise specified, all analyses used ERP data obtained from three midline sites (Fz, Cz, Pz). The ERP waveforms elicited by the lateralized primes were examined first. ERP components elicited by the centralised targets were then analysed with priority given to the amplitude of the N400 component. Finally, as a follow up to the group-based analysis of the N400 amplitude data, the sensitivity of the experimental measure for individual participants was then investigated through separate analysis of each participant's N400 amplitudes.

ERPs Elicited by the Lateralized Primes

The grand average ERPs elicited by the lateralized picture primes have been presented in Figure 2 for controls and in Figure 3 for patients. For each group of participants, the mean number of trials of EEG averaged per condition (with the corresponding standard deviation and range) has been presented in Table 13. As indicated in the table, no average contained fewer than 25 trials for the patients or 38 trials for the controls.

The percentage of EEG trials rejected per condition due to artefact has also been presented in Table 13. These data were analysed using a mixed-factorial ANOVA with Group (Patient, Control) as a between-subjects factor and Laterality of Prime (Left, Right) as a within-subjects factor. The analysis yielded no statistically significant main effects or interactions.

As indicated in Figures 2 and 3, the constraints of the paradigm (400 ms of recording time before onset of the centralised target pictures) restricted the investigation to an examination of the early ERP components elicited by the lateralized picture primes. Visual inspection of the controls' grand average waveforms at each recording site revealed nearly identical morphologies for left and right primes. The waveforms contained 4 peaks, which could be the P1, N1, P2, and possibly the beginning of a N2 or Contingent Negative Variation (CNV) in anticipation of the centralised target. Unfortunately, corresponding components were readily identifiable in only about half of the controls' ERPs, which suggested a weak signal-to-noise ratio for these early components.

Visual inspection of the patients' grand average waveforms revealed much flatter morphologies overall at each of the recording sites, with no readily identifiable components, except possibly a P2 elicited by left primes at approximately 250 ms. However, this component could be reliably identified in only one patient's ERP data. Therefore, no further analysis of the data in these apparently weak early components was undertaken.

ERPs Elicited by the Centralised Targets

Grand average ERPs for the centralised targets from three midline recording sites have been presented in Figure 4 for the controls and in Figure 5 for the patients. For each group of participants, the mean number of trials of EEG averaged per condition (with corresponding standard deviations and ranges) have been presented in Table 15. As indicated in the table, no average contained fewer than 14 trials for either group of participants.

The percentage of EEG trials rejected per condition due to artefact has also been presented in Table 15. These data were analysed using a mixed-factorial ANOVA with group (Patient, Control) as a between–subjects factor and Prime Laterality (Left, Right) and Congruency (Congruent, Non-Congruent) as within-subjects factors. The analysis yielded a significant main effect of Group $F(1, 20) = 11.8, p = .003, \eta^2 = .371$. On average, a greater percentage of trials were rejected due to artefact for the patients (M = 24.1, SD = 3.32) than for the healthy age-matched controls (M = 9.3, SD = 2.76). No other main effects or interactions reached statistical significance. There was some evidence that a greater percentage of trials were rejected due to artefact contamination for the Non-Congruent (M = 18.43%, SD = 2.47%) than for the Congruent (M = 15.02%, SD = 2.14%) condition, $F(1, 20) = 4.25, p = .053, \eta^2 = .175$. However, neither this main effect nor the interaction between this variable and Group or Prime Laterality reached statistical significance.

Visual inspection of the waveforms in Figures 4 and 5 revealed four scoreable components. Following onset of the eliciting stimuli, a P200 was the most positive peak between 100 and 200 ms, a N200 was the most negative peak between 150 and 300 ms, a P300 was the most positive peak between 250 and 400 ms, and a N400 was the most negative peak between 300 and 600 ms. There was some evidence of an early N100-type component in the averaged waveforms, but it was generally not consistent enough across the individual control or patient waveforms to score with any degree of certainty.

Within the context of semantic priming, N400 peak amplitudes were of primary theoretical interest. The N400 amplitudes were analysed first to determine whether they could be used to differentiate non-congruently primed targets from congruently primed targets regardless of the laterality of prime presentation for the participants with and without left visual neglect. The corresponding N400 latencies were then analysed to address the temporal characteristics of the N400 as a correlate of visual information processing in individuals with and without unilateral neglect. Finally, the peak amplitudes and latencies of the 3 earlier identified ERP components were analysed to investigate earlier levels of visual processing that preceded the elicitation of the N400 in both groups of participants. The mean peak amplitude and latency values for each of the 4 ERP components were therefore analysed using 2 x 2 x 2 x 3 mixed-factorial

ANOVAs with Group (Patient, Control) as the between-subjects factor and Congruency (Congruent, Non-Congruent), Laterality of Prime (Left, Right), and Recording Site (Fz, Cz, Pz) as the within-subjects factors (see Tables 16 to 29).

N400 Amplitudes. Analysis of the N400 amplitudes elicited by the centralised picture targets (see Table 15) yielded a significant main effect of Group, $F\,(1, 20) = 6.70, p = .018, \eta^2 = .25$. Overall N4 amplitudes were more negative for the patients ($M = -2.02$ µV, $SD = .76$) than for the controls ($M = .54$ µV, $SD = .63$). The main effect of Congruency was also significant, $F\,(1, 20) = 11.82, p = .003, \eta^2 = .37$. As expected, N400 amplitudes were more negative in the Non-Congruent ($M = -1.49, SD = .55$) than in the Congruent ($M = .005$ µV, $SD = .53$) condition. The main effect of Recording Site was also significant, $F\,(1.4, 40) = 10.01, p = .001, \eta^2 = .33$. Post hoc analysis revealed that the amplitudes at Pz ($M = -1.85$ µV, $SD = .46$) were more negative than those at Fz ($M = -.01, SD = .63$) or Cz ($M = -.23, SD = .56$).

The main effects of Group and Recording Site were qualified, however, by a significant Group x Recording Site interaction, $F\,(2, 40) = 13.36, p < .001, \eta^2 = .40$ (see Table 17 for the data and Appendix D1 for a graph of the interaction). Post hoc analysis revealed greater amplitude negativity for the patients compared to the controls at Fz and Cz but not at Pz. Moreover, whereas the controls' N400s showed statistically significant evidence of a posterior distribution (i.e., greater negativity at Pz than at Cz or Fz), the patients' N400s showed no significant difference in amplitude across the three sites.

The preceding main effects and 2-way interaction were further qualified by a significant 3-way Group x Congruency x Recording Site interaction, $F\,(2, 40) = 3.83, p = .03, \eta^2 = .16$. Post hoc analysis revealed the predicted effect of Congruency (i.e., N400 amplitudes that were more negative for targets that were primed non-congruently rather than congruently) most robustly (i.e., met statistical significance) at Pz and Cz for controls and at Fz and Cz for patients (see Table 18 for the data and Appendix D2 for a graph of the interaction). As indicated in Table 16, neither the main effect of Prime Laterality nor any of the remaining interactions involving this factor reached statistical significance.

Thus, in support of the primary electrophysiological hypothesis, patients and controls showed the expected N400 semantic priming effect characterised by greater amplitude negativity for targets that were primed non-congruently compared to those that were primed congruently regardless of the visual field to which the primes were presented. Moreover, the predicted pattern of amplitude differentiation was elicited most robustly at the expected centro-posterior sites for the controls and at more centro-frontal sites for the patients.

N400 Latencies. Analysis of the N400 latencies elicited by the centralised picture targets (see Table 19) yielded a significant main effect of Group, $F\,(1, 20) = 11.03, p = .003, \eta^2 = .36$. Overall the patients' N400 latencies (M = 455 ms, SD = 15.63) were delayed compared to those of the controls (M = 387 ms, SD = .13.0). As indicated in Table 19, no other main effects reached statistical significance. However, the 3-way Congruency x Laterality of Prime x Recording Site interaction, $F\,(2, 40) = 4.53, p = .017, \eta^2 = .185$, and the 4-way Group x Congruency x Laterality of Prime x Recording Site interaction, $F\,(2, 40) = 4.0, p = .026, \eta^2 = .167$, were statistically significant (see Appendix D3 for a graph of the 4-way interaction and D4 for a graph of the 3-way interaction).

To follow up on the 4-way Group x Congruency x Laterality of Prime x Recording Site interaction, repeated measures ANOVAs with Congruency (Congruent, Non-Congruent), Laterality of Prime (Left, Right), and Recording Site (Fz, Cz, Pz) as within-subjects factors were run separately for the Patient and Control N400 latency data. These follow up tests revealed the same significant 3-way Congruency x Laterality of Prime x Recording Site interaction effect as reported above for the Patient (see Appendix D4a) but not Control data, $F\,(2, 16) = 11.80, p = .001, \eta^2 = .596$, with no other statistically significant main effects or interactions[11].

The presence of the statistically significant 3-way Congruency x Laterality of Prime x Recording Site interaction in the patient but not control data suggested that the differences in N400 latencies across conditions and sites were greater in the patient rather than control data. At this point, the pattern of significant differences among the means during post-hoc analysis remained difficult to interpret. The only latency effect

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[11] A separate graph of the interaction in the patient data is provided (Appendix D4a) even though the pattern was identical to the patient data in Appendix D4.

that would derive from theory is that the patients might be expected to have longer latencies in the left-primed condition than in the right-primed condition whereas the controls would be expected to show no difference. As indicated in Table 19, however, this Group by Laterality of Prime interaction was not significant ($F < 1$).

Further follow up on the 3-way interaction involving Congruency, Laterality of Prime, and Recording Site in the patient N400 latency data involved two sets of analyses. The first follow up analyses involved a separate repeated-measures ANOVA for each recording site (Fz, Cz, Pz) with Congruency (Congruent, Non-Congruent) and Laterality of Prime (Left, Right) as within-subjects factors. These analyses yielded no statistically significant main effects or interactions.

The second follow up analyses involved a separate repeated-measures ANOVA for each of the experimental conditions (Left Congruent, Left Non-Congruent, Right Congruent, Right Non-Congruent) with Recording Site (Fz, Cz, Pz) as a within-subjects factor. Again there were no statistically significant main effects or interactions. In the analysis of the N400 latency data for the right congruent condition, however, the recording site factor showed evidence of a non-significant trend with longer latencies recorded at Pz than at either Fz or Cz, $F\,(1, 16) = 4.19, p = .07, \eta^2 = .34$. Thus, the statistically significant 3-way interaction might reflect greater variability in the patient then in the control N400 latency data possibly in relation to differences obtained within the right congruent experimental condition across the three recording sites. Overall, this statistically significant 3-way interaction appears to add little to an evaluation of the present experimental hypothesis.

In summary, the latencies of the patients' N400s were generally delayed relative to those of the controls. There also appeared to be more variability in the latency of the N400 across conditions for the patients than for the controls. The variability across conditions in the patient data was not characterised by longer latencies in the left rather than right prime conditions. It may have been most evident in the right congruent condition across recording sites.

P200 Amplitudes. Analysis of the P200 amplitudes elicited by the centralised picture targets (see Table 20) yielded a significant Group by Congruency interaction, $F\,(1, 20) = 4.86, p = .04, \eta^2 = .196$ (see Table 21 for the data and Appendix D5 for a graph of the interaction). Compared to patient performance, post hoc analysis revealed that the controls' P200 amplitudes were more positive in the Congruent ($M_{patient}$ = 2.19 μV, *SD* = .91, $M_{control}$ = 4.29 μV, *SD* = .76) but not Non-Congruent condition ($M_{patient}$ = 2.85 μV, *SD* = .63, $M_{control}$ = 3.02 μV, *SD* = .52). With reference to the main hypothesis of this investigation, these results suggests that there was a non-significant trend for the amplitude of the P200 of controls but not patients to have been influenced by the manipulation of semantic congruency. As indicated in Table 20, no other main effects or interactions reached statistical significance.

In summary, there was a statistically significant Group by Congruency of Prime interaction in the P200 amplitude data. However, the only significant difference revealed by post hoc analyses involved attenuation of the patients' P200 amplitudes relative to those of the controls for one of the experimental conditions (the congruent condition) regardless of the laterality of the prime. Therefore, analysis of the P200 amplitudes revealed no statistically significant semantic priming effects in response to the experimental manipulation of semantic congruency for either the patient or control groups.

P200 Latencies. Analysis of the P200 latencies elicited by the targets (see Table 22) yielded a significant main effect of Recording Site, F (2, 40) = 6.22, p = .01, η^2 = .237. The P200 peak latencies were significantly earlier at Pz (M = 125.9 μV, *SD* = 2.28) than they were at Fz (M = 131.8 μV, *SD* = 2.59) or Cz (M = 132.2 μV, *SD* = 2.24). As indicated in Table 22, no other main effects or interactions reached statistical significance. Thus, for both patients and controls, the P200 latencies occurred earliest at the posterior recording site and were not significantly influenced by the experimental manipulation of semantic congruency.

N200 Amplitudes. Analysis of the N200 amplitudes elicited by the targets (see Table 23) yielded a significant main effect of Recording Site, F (1.6, 40) = 12.19, p <.001, η^2 = .379. On average, amplitudes at Pz (M = -1.31 μV, *SD* = .54) were more negative than those at Cz (M = .37, *SD* = .59) or Fz (M = .83, *SD* = .52). This effect was qualified by a significant Group by Recording Site interaction, F (2, 40) = 7.48, p = .002, η^2 = .272. In contrast to the patients' amplitudes, which showed no significant difference across recording sites, the controls' amplitudes were significantly more negative at Pz than at Cz or Fz (see Table 23 for the data and Appendix D6 for a graph of the interaction). In the visual modality, it is not unusual for the N200 to have a posterior scalp distribution (e.g., Deacon et al., 1991). As indicated in Table 23, no other main effects or interactions reached statistical significance.

In summary, the N200 amplitudes were maximal at Pz for the controls and did not differ significantly across the three midline recording sites for the patients. Regardless of this difference in the topographical distribution of the component for the two groups of participants, the amplitude of the N200 in this data set was not significantly influenced by the experimental manipulation of semantic congruency for either group.

N200 Latencies. Analysis of the N200 latencies elicited by the targets (see Table 25) yielded a significant main effect of Group, F (1, 20) = 7.32, p = .014, η^2 = .27, characterised by significantly longer latencies for patients (M = 200.7 ms, SD = 7.4) than for controls (M = 174.6 ms, SD = 6.2). There was also a significant Laterality of Prime by Recording Site interaction, F (2, 40) = 3.35, p = .045, η^2 = .14. Post hoc analysis revealed that the latency of the N200 did not differ significantly across the three recording sites for left primes. For right primes, however, the N200s were significantly later at Pz than they were at the other two sites (see Table 26 for the data and Appendix D7 for a graph of the interaction). Although statistically significant, this interaction does not address the hypotheses of the present investigation. As indicated in Table 25, no other main effects or interactions reached statistical significance.

In summary, the patients' N200s were significantly delayed relative to those of the controls. However, they were not significantly influenced by the experimental manipulation of semantic congruency for either group.

P300 Amplitudes. Analysis of the P300 amplitudes elicited by the targets (see Table 27) yielded a significant main effect of Group, F (1, 20) = 76.97, p = .021, η^2 = .24. The P300 amplitudes of the patients *(M = 3.5 μV, SD = .87)* were significantly attenuated compared to those of the controls (M = 6.4 μV, SD = .73). There was also a significant main effect of Recording Site, F (1.5, 40) = 4.32, p = .03, η^2 = .18. Post hoc analysis revealed that the P300 amplitudes were significantly greater at Cz (M = 5.62 μV, SD = .62) than they were at Pz (M = 4.37 μV, SD = .56) while the mid-range amplitudes at Fz (*M* = 4.92 µV, *SD* = .67) did not differ significantly from those at the other 2 sites. These main effects were qualified by a significant Group by Recording Site interaction, *F* (2, 40) = 5.13, *p* = .01, η^2 = .20. Post hoc analysis revealed that the controls' P300 peak amplitudes were significantly less positive at Pz than they were at Fz or Cz. Whereas the P300 typically is associated with a posterior distribution in young healthy subjects, the more fronto-central distribution of the P300 in this sample of controls is consistent with the more frontal distributions observed in other samples of elderly subjects (e.g., Fabiani, Friedman, & Cheng, 1998). In contrast to the centro-frontal distribution of the P300 amplitudes in the Controls' data, no significant differences were revealed in the Patients' P300 amplitudes at the different recording sites possibly due to the presence or even location of their brain damage (See Table 28 for the data and Appendix D8 for a graph of the interaction). While statistically significant, this group by Recording Site interaction does not relate to the hypotheses of the present investigation pertaining to the manipulation of Semantic Congruity. As indicated in Table 27, none of the other main effects or interactions reached statistical significance.

In summary, the controls' P300 amplitudes were maximal at the frontal and central sites and those of the patients' did not differ significantly across the three recording sites. However, they were not significantly influenced by the experimental manipulation of semantic congruency for either group.

P300 Latencies. Analysis of the P300 latencies elicited by the targets (see Table 29) yielded a significant main effect of Group, *F* (1, 20) = 13.48, *p* = .002, η^2 = .40. On average, the P300 peak latencies for the patients (*M* = 324.4 ms, *SD* = 9.52) were significantly delayed compared to those for the controls (*M* = 278.9 ms, *SD* = 7.92). As indicated in Table 29, no other main effects or interactions reached statistical significance.

In summary, the patients' P300s were delayed relative to those of the controls. However, they were not significantly influenced by the experimental manipulation of semantic congruency for either group.

N400 Amplitudes and Experimental Task Sensitivity at the Level of the Individual

As predicted, group-based analyses revealed significant N400 amplitude differentiation of congruently and non-congruently primed pictures regardless of the laterality of prime presentation for participants with and without left visual hemineglect. Separate analysis of each participant's N400 amplitudes was undertaken to determine the sensitivity of this component for the evaluation of individual performance on the Lateralized Semantic Priming Paradigm.

Each participant's N400 amplitude data has been summarised in Appendix E1 for the controls and in Appendix E2 for the patients. For each participant, an N400 amplitude difference score was calculated for each side of prime presentation by subtracting the mean amplitude of the Non-Congruent condition from the mean amplitude of the Congruent condition. For each of these waveform comparisons, a positive difference score indicated that the predicted pattern of N400 differentiation was present. As indicated in the Appendices, 1-tailed independent *t*-tests were used to determine the significance of each waveform comparison for each participant.

The results of these comparisons have been summarised in Table30. Inspection of the table revealed that the waveforms for a majority of the controls showed the predicted pattern of N400 amplitude differentiation at Pz for both the right (92.3%) and left (84.6%) priming conditions. Few of the comparisons, however, reached statistical significance (< 7.7% for each priming condition). Inspection of the table also revealed that the waveforms for a majority of the patients showed the predicted pattern of N400 amplitude differentiation at all 3 sites for both the right and left priming conditions (i.e., 55.6 to 88.9% depending on site and laterality of prime). Once again, however, few of these comparisons attained statistical significance (< 22.2 % for each priming condition).

ERP waveforms have been presented in Figure 6 for a control (C217) whose waveform comparisons showed the predicted pattern of N400 amplitude differentiation (i.e., N400 amplitudes that were more negative for non-congruently primed pictures than for congruently primed pictures) regardless of the visual field in which the primes appeared. Reference back to Appendix E1 indicated that the amplitude differences at Cz ranged from 3.4 to 5.6 µV and reached 1-tailed statistical significance regardless of the laterality of the prime which preceded the eliciting stimuli. Statistical significance was reached at Pz only for the comparison involving the right priming condition and at Fz for neither priming condition. In contrast to the grand average waveforms for the controls, which showed the predicted pattern of N400 amplitude differentiation most robustly at Pz (see Figure 4), this participant's pattern of differentiation was most robust at Cz.

ERP waveforms have also been presented in Figure 7 for a patient (P109) whose target waveform comparisons also showed the predicted pattern of N400 amplitude differentiation regardless of the visual field in which the primes appeared. Reference back to Appendix E2 revealed that the N400 amplitude differences ranged from 0.7 to 5 µV, which indicated greater variability compared to the values presented above for the control participant. One-tailed statistical significance was reached at all midline sites but only for the comparisons involving left and not right priming conditions. The finding of statistical significance for the left and not right priming condition is intriguing given that it was the left primes that were visually neglected.

As mentioned above, few of the individual patient or control waveform comparisons with the expected pattern of N400 differentiation yielded amplitude differences sufficiently large to attain 1-tailed significance. However, statistical significance was attained for patients and controls in the group-based analysis. Thus, for the present sample of elderly participants, the Semantic Priming Paradigm provided an electrophysiological measure that was adequately sensitive to the manipulation of semantic congruency for group-based analyses but not for the evaluation of performance by individuals with or without unilateral visual neglect.

DISCUSSION

A paradigm consisting of lateralized picture primes and centralised picture targets was developed to permit an investigation of the behavioural and electrophysiological correlates of semantic priming for patients with visual hemineglect and healthy age-matched controls. The primary goal was to determine whether the amplitude of the N400 elicited by the centralised targets could serve as an electrophysiological correlate of the behavioural semantic priming effects that have been elicited when the primes have been presented in the neglected field (Berti & Rizzolatti, 1992) even when they remain subjectively unavailable to patients with visual hemineglect (McGlinchey-Berroth et al., 1993; McGlinchey-Berroth & Milberg, 1996). ERPs for the lateralized primes and centralised targets were examined to gain insight into the neurocognitive processing fate of pictures in the neglected field that remain subjectively unavailable to patients with visual hemineglect yet continue to influence the patients' behaviour. In addition, comparison of the N400 semantic priming effects for the left and right priming conditions was undertaken to address the extent to which the N400 may be modulated by automatic forms of semantic processing in the absence of more controlled forms of processing.

Review of the Experimental Paradigms

The design of the Lateralized Semantic Priming Paradigm developed for this investigation was based on the computerised experimental paradigms used to demonstrate behavioural semantic priming effects for patients with visual hemineglect (e.g., Berti & Rizzolatti, 1992; McGlinchey-Berroth et al., 1993; McGlinchey-Berroth & Milberg, 1996). For the present study, participants used a two-button response pad to categorise target pictures (green line drawings depicting an animal or article of clothing) that appeared at central fixation. Each target picture was preceded (primed) on the left or right by a picture prime (a red line drawing) that was semantically congruent (same category as target) or non-congruent (different category from target). Along with the accuracy and latency of the target categorisations, ERPs were collected for the lateralized picture primes and centralised picture targets.

Overview of Semantic Priming Effects Elicited by Targets

Of the four components identified in the ERPs elicited by the centralised targets, only the N400 provided a reliable electrophysiological correlate of semantic priming. As expected, the N400 semantic priming effects were characterised by greater amplitude negativity for targets in the non-congruent rather than congruent priming conditions. Moreover, within the patient and control data, the magnitude of these effects did not differ significantly when the primes appeared in the left (patients' neglected) or right (patients' non-neglected) visual fields.

Consistent with general findings in the literature, the N400 semantic priming effects were elicited most robustly at the centro-parietal sites for the controls. In contrast, the patients' N400 semantic priming effects were characterised by a more fronto-central distribution. Moreover, analysis of the N400 latencies revealed a general non-lateralized delay in the N400s of the patients relative to those of the controls.

Both the electrophysiological and behavioural data collected during the patients' and controls' categorisation of the centralised picture targets showed semantic priming that did not differ in magnitude as a function of the laterality of the preceding primes. As expected, the behavioural categorisation times of both the patients and controls were significantly faster for the centralised picture targets that were congruently rather than non-congruently primed regardless of the laterality of the primes. The patients' behavioural semantic priming effects, like their electrophysiological responses, were generally delayed relative to those of the controls. Once again, however, the magnitude of these effects did not differ significantly as a function of the laterality of the primes. Moreover, the behavioural and electrophysiological effects for both the patients and controls were elicited reliably at a group but not individual level.

With respect to the components preceding the N400 in the ERPs elicited by the centralized targets (i.e., P200, N200, and P300), there was a non-significant trend suggestive of a semantic priming effect in the controls' P200 amplitude data. However, as expected, no significant semantic priming effects were revealed during analysis of the amplitudes or latencies of these pre-N400 components.

For the experimental paradigm, participants were to categorise the centralised targets and no response was required for the lateralized primes. Therefore, the tendency to neglect the contralesional primes had to be inferred from the patients' performance on a control version of the experimental paradigm (e.g., McGlinchey et al., 1993). For the present experiment, this control or neglect-verification task consisted of a shortened version of the Lateralized Semantic Priming Paradigm that required a verbal report of everything seen for each trial rather than the categorisation of the centralised target picture.

During the pre-experimental verbal-report version of the Lateralized Semantic Priming Paradigm, the patients' subjective awareness of the primes was significantly influenced by the side of the visual field in which the primes were presented. More specifically, the patients' verbal reports demonstrated subjective awareness significantly less frequently for the contralesional primes than for the ipsilesional primes or centralised targets. A similarly lateralized deficit of awareness would therefore have likely been present for the patients during the longer experimental version of the Lateralized Semantic Priming Paradigm when the non-lateralized behavioural and electrophysiological semantic priming effects described above were elicited for both the patients and controls.

Thus, the primary behavioural and electrophysiological predictions of Experiment One were supported. Consistent with their visual hemineglect, the patients were more frequently subjectively unaware of contralesional rather than ipsilesional primes. Nevertheless, the magnitude of the behavioural (categorisation time) and electrophysiological (N400 amplitude) semantic priming effects elicited by the targets did not differ significantly as a factor of the extent to which the preceding primes had been implicitly or explicitly processed.

IMPLICATIONS

Implications of the Semantic Priming Results for an Understanding of Hemineglect

There has been controversy over the extent to which the residual or implicit processing of information in the neglected visual field may be considered 'normal' (Behrmann & Megan, 1998; Farah et al., 1991). The controversy does not seem to entail whether or not the implicit processing of neglected information is possible. Instead, the debates concern 1) the level to which the information may be processed implicitly, 2) whether or not the residual or implicit processing is typical of patients with hemineglect, and 3) the extent to which the level of implicit processing demonstrated may be considered to have followed the normal neurocognitive routes associated with the explicit processing of the same information.

With respect to the first and second points of this controversy, the behavioural results of Experiment One are consistent with reports in which similar implicit behavioural measures were used to demonstrate that information in the neglected visual hemifield may be processed to the level of object identification or semantic categorisation even when the patients' subjective awareness of the eliciting contralesional stimuli is absent (Berti & Rizzolatti, 1992; D'Eposito et al., 1993; Ladavas et al., 1997; McGlinchey-Berroth et al., 1993; McGlinchey-Berroth & Milberg, 1996; Schweinberger & Stief, 2000). The present results extend the previous behavioural-based findings by providing electrophysiological data consistent with the view that the residual processing of information in the contralesional field of patients with visual hemineglect is considerable with much of the processing taking place implicitly (Driver & Mattingley, 1998). Together, these results contrast with the view of D'Erme et al (1993) that covert knowledge of neglected stimuli represents an uncommon event among patients with hemineglect.

With respect to the extent to which the present results may generalise to other patients with hemineglect, it is noteworthy that the ERP-compatible paradigm used for Experiment One differed in several ways from the behavioural paradigms upon which it was based (Berti & Rizzolatti, 1992; McGlinchey-Berroth et al., 1993; McGlinchey-Berroth & Milberg, 1996). For example, in the paradigm of Berti and Rizzolatti (1992), all of the primes occurred on the left of centre in green and all of the targets appeared on the right in red. The present experimental paradigm was similar in that the prime and targets were presented in different colours. However, the colours assigned to the targets and primes were reversed to ensure that the well-established association between green and go (target) or red and stop (prime) would not run counter to well-established response tendencies.

In contrast to the paradigm of Berti and Rizzolatti (1992), the present paradigm was more like the paradigm of McGlinchey-Berroth et al. (1993). For the present paradigm, all of the targets appeared centrally and the primes appeared with equal frequency to the left or right of fixation (see also McGlinchey-Berroth & Milberg, 1996). This format was selected to permit comparison of the implicit processing of primes in the contralesional visual field with the explicit processing of primes in the ipsilesional field. Moreover, it was intended to guard against any formation of expectancies for stimuli in the contralesional visual field that might serve to direct the patients' attention toward the left primes during the course of the experiment. However, the present paradigm differed from the paradigm of McGlinchey-Berroth et al. (1993) or McGlinchey-Berroth & Milberg (1996) in that each prime was not presented simultaneously with a meaningless stimulus in the opposite visual field. This difference was intended to ensure that the ERP elicited by each prime would reflect stimulation of one visual field only. Also, it was intended to permit the investigation of the processing fate of stimuli that were unavailable to subjective awareness due to neglect rather than to extinction.

In summary, the present experimental paradigm was not exactly the same as the paradigms used by previous researchers in their investigations of hemineglect. Therefore, the behavioural and electrophysiological demonstration of similar implicit semantic priming effects suggests a degree of generalisation consistent with the growing evidence that visual stimuli, which have been behaviourally neglected at the level of subjective awareness, may nevertheless continue to influence behaviour. Thus, the present behavioural and electrophysiological results suggest that high-level processing of subjectively neglected information is a general phenomenon of hemineglect rather than a specific characteristic of the patient participants in the previous investigations.

As noted in the Introduction, hemineglect is associated with dissociable behavioural manifestations as well as a number of differing frames of reference involving spatial co-ordinates that may also be dissociated. Consequently, it is possible that the specific nature of the residual or implicit processing for patients with hemineglect may not be entirely uniform. Thus, in the replication study of D'Erme et al (1993) it is possible that the failure to demonstrate the covert processing effects in four of the six patients examined may have been a reflection of the task-specific nature of the patients' neglect rather than the absence of covert processing *per se*. However, it could also be that the power associated with group-based analyses might be required to demonstrate statistically significant implicit processing effects that cannot be seen reliably from the analysis of data from individual patients with hemineglect.

ERP Correlates of Implicit and Explicit Processing by Patients with Visual Hemineglect

As already mentioned, the extent to which the residual implicit processing of information in the neglected visual field follows the normal route has been controversial (Behrmann & Megan, 1998; Farah et al., 1991). Therefore, with respect to the semantic priming effects demonstrated in the present experiment, the question remained about the extent to which the implicit processing of the neglected semantic information may be considered to be comparable to the explicit processing of this information.

As pointed out by Schweinberger and Stief (2001), behavioural reaction times are not well suited to examine the precise time at which the processing of a prime begins to exert an influence on the subsequent processing of a target. In contrast, the temporal resolution of ERPs as on-line correlates of information processing make them very well suited to address these concerns (Schweinberger & Stief, 2001; Verleger et al., 1996). In line with these recommendations, the Lateralized Semantic Priming Paradigm was used to obtain ERPs for picture primes that appeared directly within the patients' neglected or non-neglected visual fields and for the subsequent picture targets that were presented at central fixation. The analysis of the ERP data was intended to assist in the determination of the extent to which the implicit processing of neglected information is comparable to the processing of information that has not been neglected. To be consistent with the order in which the stimuli were presented in the experimental paradigm, the ERPs results for the lateralized primes will be discussed ahead of those for the centralized targets.

ERP Elicited by the Lateralized Primes. As reviewed in the Introduction, previous comparisons of the early sensory or perceptual electrophysiological correlates of processing in the neglected and non-neglected visual fields have used relatively simple visual stimuli, such as changes in illumination or a simple letter-shape (Angelelli et al., 1996; L'hermitte et al., 1985; Pitzalise et al., 1997; Spinelli & DiRusso, 1996; Spinelli et al., 1994; Vallar et al., 1991; Viggiano et al., 1995. During administration of the Lateralized Semantic Priming Paradigm, ERPs for the lateralized picture primes were collected to permit direct investigation of the electrophysiological correlates of relatively more complex stimuli in the patients' neglected and non-neglected visual fields. Although limited to 400 ms of recording time, these early ERP components were expected to permit comparison of the magnitude, timing, and scalp distribution of some early correlates of implicit and explicit processing for relatively complex pictorial stimuli in the patients' contralesional or ipsilesional fields.

As described in the Results section, however, visual inspection of the ERPs elicited by the lateralized picture primes revealed components that could not be scored reliably, particularly in the patients' waveforms. At each recording site, the four components identified in the controls' grand average waveforms for the left and right primes were nearly identical. However, of the four components identified in the controls' waveforms, corresponding peaks could be readily identified in only about half of the individual ERPs upon which the grand average was based. At each site, the morphologies of the patients' grand average waveforms were generally attenuated compared to those of the controls. For the patients', the only component revealed through visual inspection of the grand average waveforms was a possible P200 in only the left congruent condition for which corresponding peaks were evident in the individual waveform of only one of the patients. Consequently, no further analyses of the ERPs elicited by the lateralized primes were undertaken.

The weakness of the early components elicited by the lateralized picture primes may be attributed to several factors. First, the advanced age of the elderly participants and the presence of neurological impairment in the patient group would result in a poorer signal to noise ratio in the ERPs relative to what would be expected in the ERPs from samples of younger and neurologically intact volunteers. These factors would likely elicit relatively degraded ERPs for both the primes and targets presented in the experimental task. However, as reported in the Results section, the waveforms elicited by the targets were found to contain components that could be scored.

When comparing the signal to noise ratios of the primes and targets, it should be remembered that the paradigm was designed to investigate the N400 component elicited by the centralised target-pictures that were preceded by the lateralized picture primes and the direct examination of the ERP waveforms elicited by the lateralized picture primes was more exploratory. In contrast to the centralised picture-targets, the lateralized picture-primes were not presented in the attended location or in the attended colour. Had the primary focus been direct comparison of the ERPs elicited by the lateralized pictures rather than examination of the influence of these lateralized primes on subsequent processing of centralised targets, a different experimental design and more trials of EEG would have been necessary for a better signal to noise ratio.

For example, to directly investigate the processing of pictures presented to the left and right of central fixation, ERPs could be collected for a series of pictures presented singly and randomly at lateralized locations that differ in their distance from central fixation or possibly in different quadrants. The task could be to indicate by means of a button press whenever a picture has been detected. The behavioural responses could be used to provide a concurrent measure of the extent to which the contralesional pictures were omitted due to neglect. In fact, the distance of the pictures from fixation and the duration of picture presentation could be tailored for each patient to maximise the proportion of contralesional pictures that would fall outside the patients' attentional range. The ERP data could be sorted and averaged on the basis of whether or not there was a behavioural response to the stimuli.

The overall morphologic differences observed during visual inspection of the patients' and controls' grand average ERPs for the first 400 ms from onset of lateralized picture primes do not likely address any specific disruption in information processing that may unambiguously be attributable to visual neglect *per se*. Instead, the general attenuation likely reflected the more general disruption of information processing associated with the patients' stroke as a form of neurological trauma and possibly due to the various medications with which the patients were being treated. In future investigations, such as the one proposed in the previous paragraph, the inclusion of a patient control group consisting of individuals who have experienced unilateral stroke that has not resulted in contralesional visual neglect would allow for this speculation to be empirically evaluated.

ERPs Elicited by the Centralised Targets. Analysis of the behavioural and electrophysiological data elicited by the centralised picture targets provided evidence that semantic information contained within the subjectively neglected contralesional picture primes was nevertheless processed implicitly to the extent that it was able to significantly affect subsequent behaviour (i.e., the rate of target picture categorisation).

However, the question still remains as to the extent to which the implicit processing followed the same neurocognitive route as would the same stimuli when explicitly processed (see Behrman & Megan, 1998; Farah, et al., 1991). The ERP components of patients with neurological impairment may differ from those of healthy age-matched controls in several ways, all of which would provide evidence of abnormal information processing. For example, amplitude attenuation, latency delay, increased latency variability (jitter), differing topographical distributions, or a combination of these features can provide evidence of differences in the magnitude, timing, and neurocognitive processing routes used by the patient participants. While discussing these features of the ERP results elicited by the centralised targets, the extent to which they permit neurocognitive conclusions that are consistent with or go beyond what can be surmised on the basis of the behavioural categorisation data will be addressed.

In contrast to the striking similarities noted so far in the patients' and controls' behavioural and electrophysiological semantic priming effects, analysis of these neurocognitive correlates of information processing also revealed evidence of statistically significant abnormalities in the patients' data. For example, analysis of the behavioural data revealed that the patients' picture target categorisations were significantly delayed compared to those of the controls. However, the magnitude of the delay did not differ significantly as a function of the laterality of the primes. The N400s were similarly significantly delayed for the patients relative to the controls, again with no regard to the laterality of the primes. Moreover, the patients' P300 and N200 but not P100 latencies were significantly delayed relative to those of the controls, yet again regardless of prime laterality. Thus, both the behavioural and electrophysiological correlates of semantic categorisation provided evidence of a general slowing in the patients' neurocognitive processing relative to that of the controls. However, the electrophysiological correlates provided a more precise specification of the point in time at which the patients' processing abnormality began. The delay in the patients' ERP latencies relative to those of the controls were not present for the earliest component identified in the waveforms (i.e., the P200). Instead, the delay began with the N200 component and was also seen for the subsequent P300 and N400 components.

Whereas topographical location of N200 is typically linked with stimulus modality, and amplitude with stimulus differentiation, the latency of the component is associated with studies of mental chronometry and is closely linked to behavioral response times. (Fabiani et al., 2000). Thus, the observed N200 delay in this study would be consistent with the patients' picture-target categorization times, which were consistently delayed relative to those of the controls. However, the fact that the delays in the behavioral and ERP data occurred equally irrespective of the laterality of the primes suggests that the abnormality reflect response slowing due to stroke or possibly the medications used as treatment. The inclusion of a control group with unilateral brain damage with no symptoms of contralesional visual hemineglect would be required to be more definitive about this conclusion in future investigations.

Analysis of the amplitude data for the four components revealed no overall attenuation for the patients relative to the controls *per se*. Instead, there were patterns of amplitude attenuation in the various interactions involving the congruency manipulation, the scalp-recording site, or both of these factors. As a specific example, there was a significant Group by Congruency of Prime interaction in the P200 amplitude data. However, the only significant difference revealed by post hoc analyses involved attenuation of the patients' P200 amplitudes relative to those of the controls for one experimental condition (i.e., the congruent condition) regardless of the laterality of the prime. Given that the post hoc analysis also revealed no other significant differences, these results suggest a non-significant trend in the controls' P200 amplitude data of semantic priming effects. Overall, however, analysis of the P200 amplitudes revealed no statistically significant semantic priming effects in response to the experimental manipulation of semantic congruity for either the patient or control groups.

More potentially interesting results for determining if the processing of information by patients was similar to normal control performance comes from the different topographical distributions observed in the patient and control data. As predicted, the N400 amplitude differentiation was elicited most robustly at the centro-parietal sites for the controls. In contrast, the amplitude differentiation was elicited with a more fronto-central scalp distribution for the patients. These significant differences in the topography of the N400 amplitudes may reflect the patients' neurological damage, which typically involved the right parietal lobe. As well, a frontal N400 has been linked to increased task or memory demands. Therefore it may be that the patients had to work harder than the neurologically unimpaired controls to complete the task. The target categorisation data collected during the administration of the experimental paradigm provides support for the interpretation that the task was experienced as more challenging for the patients than for the controls. For example, the patients were significantly less accurate than were the controls in categorising the centralised picture targets. Also, as mentioned already, the picture target categorisations were made significantly more slowly by the patients than they were by the controls. For verification, this difference in topography would need to be replicated in future studies, preferably with a neurological control group as described above.

There were different topographical distributions for patients and controls for the ERP correlates of earlier stages of processing as well. The P300 amplitudes were maximal at the frontal and central sites for controls but did not differ across the three recording sites for the patients. Similarly, the N200 amplitudes were maximal at Pz for controls but did not differ significantly across the three recording sites for the patients. Thus, these earlier ERP components provided evidence that information processing by patients with hemineglect is not entirely normal. However, the abnormalities were probably due to the presence of severe neurological impairment rather than to the presence of hemineglect *per se*. Once again, for verification, these differences in topography would need to be replicated in future studies with a neurological control group as described above.

As mentioned previously, there were few ERP investigations of hemineglect upon which to base hypotheses of what to expect for ERP components, particularly when elicited by a relatively complex picture stimulus preceded by a lateralized picture prime. Consequently, there are few prior findings with which to compare the present results. The closest source of comparison is the data collected using a covert cueing paradigm (Verleger et al., 1996). The stimuli used in the covert cueing paradigm were less complex than were those used in the present experiment. Also, presentation of the targets was lateralized rather than centralised. Moreover, no latencies of the ERP components elicited using the covert cueing paradigm were reported.

A major difference in the results of Verleger et al.'s (1996) covert cueing investigation was the elicitation of N100 components, which differentiated between the cues presented to the contralesional and ipsilesional visual field of the patients with hemineglect. In contrast, the N100 elicited to the lateralized targets did not differentiate between those that were in the contralesional or ipsilesional visual field. However, in the present experiment, no consistent N100-like component was elicited for the centralised targets in either the control or patient data. The absence of the N100 component could be because of differences in the paradigm used or to the absence of the lateralized occipital recording sites that had been used by Verleger et al. (1996). Because of missing data at these sites for several of the participants, these sites were not included in the present analysis. In the study by Verleger et al (1996), the N100s were most prominent at the lateralized occipital recording sites. For the patients in the present experiment who did have data available from the occipital sites, visual inspection of the waveforms indicated that the N100 components were more readily identifiable at the lateralized occipital rather than midline sites. Verleger et al. (1996) also reported that their averaged waveforms typically contained more single trials than were available in the present experiment, which would have facilitated the extraction of the relatively small N100 component. Finally, Verleger et al.'s (1996) use of lateralized rather than centralized presentation of the target stimuli may have been another factor that enabled the elicitation of the N100 at the lateralized occipital sites.

Based on their covert cueing investigation, Verleger et al. (1996) identified the amplitude of the Nd, a component at about 160 to 280 ms that is generally enhanced for processing of same-location targets, as a reliable electrophysiological correlate of the patients' delayed behavioural response times for invalidly cued targets (i.e., preceded by a right cue). The authors went on to describe the attenuation of the Nd as the most direct estimate of the time at which the patients' pathology of information processing occurred in the covert cueing task. According to Verleger et al. (1996), the ERP evidence of an information processing abnormality as early as 200 ms from target onset suggests that neglect occurs during early perceptual processing and is not simply the result of an inability to re-evaluate the intact results of initial perceptual processing.

The Nd component could not be elicited in the paradigm used for the present experiment because the primes and targets were presented at different locations. However, it is interesting to note that the timing of the first signs of latency delay in the present investigation and the timing of the first indication of abnormality in the amplitudes of the components reported by Verleger et al. (1996) are similar. However, whereas the abnormality in the study by Verleger et al. (1996) was reported to be specific to the neglect deficit, the abnormality found in the present experiment appeared to reflect more general disruption due to the stroke.

Implications for the Conceptualisation of N400 in Semantic Priming Paradigms

The results of Experiment One have implications for conceptualising the N400 in relation to semantic priming. As described in the introductory chapters, the N400 has been referred to as an endogenous ERP component because of the sensitivity of its amplitude to manipulations involving controlled forms of semantic processing. The N400 amplitude semantic priming effects for neglected primes in this experiment support the idea that N400 amplitudes can be modulated by automatic forms of semantic processing, such as the automatic spreading of activation (ASA; Neely & Keef, 1989), in the absence of more controlled forms of processing for which subjective awareness are required.

The extent to which the N400 is sensitive to automatic forms of processing has been a long-standing area of controversy within the N400 literature (Okita & Jibu, 2000; Sternberg, 2000). For example, Brown and Hagoort (1993) reported a dissociation in normal subjects between behavioural and ERP priming effects. They used a lexical decision task during which primes were not subjectively perceived because they were presented for a short duration followed by a mask. Under these conditions, their subjects showed the usual behavioural semantic priming effects but no corresponding priming effects were found in the amplitudes of the N400.

In contrast, several paradigms have been used to demonstrate the sensitivity of the N400 to automatic processing. These paradigms have involved the manipulation of stimulus timing and perceptual thresholds (Anderson & Holcomb, 1995; Besson, Fischler et al., 1992; Schnyer et al., 1997), the attentional blink phenomenon (Rolke et al., 2001), variation in task demands (Bentin et al., 1993; Besson, Fischler et al., 1992; Holcomb, 1988; Kutas & Hillyard, 1989), and selective attention manipulations (Otten et al., 1993). The demonstrations have been criticised, however, because it was not possible to ensure that all forms of controlled processing had been eliminated from the automatic processing conditions (Brown & Hagoort, 1993; Chwilla et al., 1995; Kellenbach & Michie, 1996; Okita & Jibu, 1998; Sternberg et al., 2000; Vogel et al., 1998). These demonstrations and the criticism are presented more fully in Chapter Four.

As summarised by Rafal (1998), patients with hemineglect afford an opportunity to investigate whether measures, such as the N400 semantic priming effect, can be modulated in the absence of the controlled forms of processing that depend on subjective awareness of the stimuli. According to this account, if the patient has no explicit awareness of the stimuli in the neglected field, yet produces effects that are also produced by stimuli in the ipsilesional field, evidence for processing without awareness is gleaned. The within-subjects comparison determines whether the processing necessary to produce the effect required attention or subjective awareness. If comparable effects are observed for contralesionally neglected and ipsilesionally perceived stimuli, then the inference is that the perceptual process being measured can proceed without attention and in the absence of subjective awareness.

Admittedly, it could be argued that controlled processing of the contralesional primes was not completely eliminated for every trial for the demonstration of implicit priming in the present investigation. The deficits of patients with hemineglect can be variable and inconsistent over time (Bartolomeo et al., 2001; Bisiach, 1999). Thus, it is possible that the demonstration of N400 semantic priming for the contralesional priming condition might reflect those trials during which the contralesional primes were perceived and not those during which they were neglected. This is a possibility given that the severity of the patients' contralesional neglect on the experimental paradigm was inferred from impaired performance on a similar version of the paradigm for which a verbal report of each trial was required instead of a motor response to categorise the central target. However, if the N400 elicited for the left-primed targets reflected those trials during which the stimuli were perceived and not those during which the stimuli were neglected, then averaging them together would be expected to result in an N400 that was reduced overall, which was not the case. When the magnitude of the peak amplitudes of an ERP component are unaffected by the attentional manipulation within an experiment, the ERP activity is considered to be an automatic response to the stimulation and ERP responses with these properties are often referred to as exogenous components (Fabiani et al., 2000).

Nevertheless, it would be useful to replicate the implicit N400 semantic priming effects with patients for whom consistent and extensive contralesional neglect of the primes has been documented. Within this context, a version of the paradigm requiring concurrent verbal report of what was seen for each trial might be useful. For example, for each trial, participants could be asked to categorise the centralised target and then report on whether or not any other pictures were present during the trial. However, the requirement of a concurrent verbal report for each trial would likely alter the neurocognitive task demands of the semantic priming paradigm.

The present results are, however, consistent with the results of other investigations in which other paradigms were used to demonstrate that the N400 semantic priming effects are not entirely endogenous. For example, Schweinberger and Stief (2001) demonstrated that the ASA can be evoked by missed prime words within the attentional blink. Furthermore, this ASA was sufficient to elicit N400 word repetition priming effects that were of larger magnitude than those elicited when more controlled forms of processing were available (Schweinberger & Stief, 2001). It would, therefore, be of interest in future investigations based on the present paradigm, to determine whether the implicit N400 priming effects would also be of larger magnitude in paradigms in which the repetition of words was examined in addition to manipulation of semantic congruity (e.g., Schweinberger & Stief, 2001). It is also of interest to note that the present demonstration of implicit N400 amplitude semantic priming effects in the visual modality is consistent with previous although controversial demonstrations of implicit N400 amplitude semantic priming effects obtained in the auditory modality for sleeping subjects (Brualla et al., 1998).

Implications for Interpreting the N400 Elicited for Normal Subjects

With respect to the elicitation of the N400 amplitude priming effect, the extent to which the underlying mechanisms represent an automatic or controlled form of processing has been unclear because they are typically confounded in paradigms administered to normal subjects. As discussed earlier, both automatic and controlled processing mechanisms are available to the normal control participants. In contrast, for the patients with visual hemineglect, both controlled and automatic processes are similarly available for ipsilesional primes and only automatic processes are presumed to be available for contralesional stimuli. However, there were no differences found in the behavioural or ERP data based on the laterality of prime presentation in the patients' or controls' data. Therefore, it is possible that the patients with visual hemineglect were not employing the controlled mechanisms available on the ipsilesional side possibly because the primes were not task relevant (i.e., they were in a non-attended location and colour with instructions to attend to the centralised targets and to ignore stimuli that might appear else where).

Taken one step further, the results of Experiment One make interpretation of the control data somewhat ambiguous. As expected for the controls, no differences in the ERP data were found on the basis of the laterality of the prime. Moreover, the only significant differences between the control and patient data involved a general slowing and a more frontal topographical distribution for the patients. However, neither difference was significantly influenced by the laterality of the prime. Therefore, where as controlled processing of the task irrelevant primes was possible for the controls, it was not necessary for completion of the categorisation of the centralised targets. The lack of any sort of lateralized difference between the semantic priming effects for the control and patient groups suggests that the controls may not have employed the controlled processing available for the task irrelevant primes in the task that required responses only for the centralised picture targets. Subjective awareness of the lateralized picture primes was not prevented for the controls as indicated by their near perfect performance on the verbal report version of the experimental paradigm. Controlled processing of the lateralized primes, however, would not have been required to categorise the targets, which appeared centrally and in a different colour with specific instructions to attend to the features of the targets and not those of the primes. So, whereas awareness of the primes would have been necessary for the completion of the pre-experimental version of the experimental paradigm that was used as an awareness check, awareness of the primes was not required for the completion of the experimental semantic priming paradigm itself. Detailed examination of the early and late ERP components elicited by the targets indicate that the role of automatic processing in eliciting the N400 should not be discounted under normal conditions or when designing paradigms for the assessment of various patient groups.

Some support for the idea that the N400 semantic priming effect may reflect relatively early or automatic forms of processing even when controlled forms are available has been reported within the context of sentence verification paradigms (e.g., Fischler et al, 1983; Kounios & Holcomb, 1992). Reading is a task that typically becomes quite automated for educated adults (Benjafield, 1992). Within sentence verification paradigms, both the amplitude of the N400 and the behavioural response times were sensitive to the predictability of a word in the sentence fragments based on mismatch between the subjects and predicates (e.g., Fischler et al, 1983) or categories and exemplars (e.g., Kournios & Holcomb, 1992). However, only the behavioural and not the electrophysiological data were sensitive to the truth-value of the sentence fragment as a whole (see Chapter Four for a fuller description of these experiments). Thus, the electrophysiological semantic priming effects appear to have reflected a semantic mismatch between the terms at a preliminary stage of sentence comprehension rather than the truth or falseness of the sentence fragment taken as a whole.

Implications for the Conceptualisation of the N400 in Clinical Populations

The present demonstration of implicit N400 amplitude semantic priming effects for visually neglected stimuli also has implications for the interpretation of N400 semantic priming effects for other patient populations. The results of Experiment One demonstrate that the N400 can be useful for assessing the processing of information of which the participant may not be subjectively aware. The results are also consistent with the idea that the N400 can be useful for assessing information that the participant may not have subjective access to. For example, the elicitation of N400 priming effects has recently been used to demonstrate the existence of spared knowledge during the assessment of picture naming in patients with anomia due to Alzheimer's Disease (Ford, et al., 2001).

The utility of a number of relatively late response-independent ERP components, including the N400, have been demonstrated to be of use for the neuropsychological assessment of cognitive functioning in patients with various forms of severe motor and verbal impairment (Connolly & D'Arcy, 2000, Connolly et al., 2000). For example, it has previously been demonstrated how N400 semantic priming effects can contribute to the assessment of the level of acquired receptive vocabulary for patients who are unable to provide reliable motor and verbal responses, such as patients with severe cerebral palsy (Byrne et al., 1995a, 1995b). The present results add to this growing body of work in confirming the suitability of ERP components for the assessment of information processing in a wide variety of patients for whom the ability to report on their level of acquired knowledge is of concern. However, the present results suggest that caution be taken when interpreting the results. The present findings suggest that the presence of an N400 semantic priming effect may provide evidence of information that has acquired some degree of semantic association. However, these acquired associations may not be accessible to subjective awareness, therefore making them of little practical use to the patient.

Sensitivity of the Experimental Measure

The primary results of Experiment One demonstrated that it is possible to elicit an N400 amplitude priming effect when primes have been presented to the contralesional visual field of patients with hemineglect. Future replication and extension of these results will contribute to a better understanding of priming and visual selection for individuals with or without hemineglect.

In accordance with views expressed by Rafal (1998), ideal replication of the results of Experiment One would require the testing of patients with hemineglect who show no explicit awareness of the contralesional stimuli being used in the test. Given that it is not common for such severe deficits to persist for long, and given that when it is present, the patient is often quite ill and unable to participate in prolonged testing, single case designs may be necessary. Accordingly, the extent to which the group-based effects of Experiment One were also obtained for individual participants was also examined.

As described earlier, the waveforms for a majority of the controls showed the predicted pattern of N400 amplitude differentiation at Pz for both the right (92.3% of cases) and left (84.6% of cases) priming conditions. Similarly, the waveforms for a majority of the patients showed the predicted pattern of N400 amplitude differentiation at all 3 sites for both the right and left priming conditions. Few of these comparisons, reached statistical significance (i.e., 3 of the controls and only 1 of the patients) even when the data from each site were considered independently. However, as noted above, statistical significance was attained for patients and controls in the group-based analysis. Thus, for the present sample of elderly participants, the experimental paradigm provided an electrophysiological measure that was adequately sensitive to the manipulation of semantic congruency for group-based analyses but not for the evaluation of performance by individuals with or without visual hemineglect. Thus, while ERPs have been shown to be useful for the assessment of a variety of individual patients (e.g., Connolly et al., 2000), the current paradigm or analysis will require refinement before it will be sensitive at the level of the individual with or without hemineglect. Some refinements to increase the sensitivity of the experimental paradigm for case study assessment of the individual will be addressed in the General Discussion (Chapter Eight).

Summary

The results of Experiment One provide both behavioural and electrophysiological evidence that processing of the primes took place to the level of semantic categorisation among patients with visual hemineglect as it did for normal controls. Detailed comparison of the patients' target waveforms elicited for contralesional and ipsilesional primes revealed no differences attributable to the laterality of prime presentation. These results suggest that the semantic processing responsible for the observed priming effects were not dependent on controlled processing of the primes even when controlled forms of processing were available. Extension of these results to the Control data suggested that the impact of automatic processing should not be disregarded in the interpretation of the semantic priming effects obtained when the priming stimuli are not task relevant. Finally, whereas the present experimental paradigm was sensitive for group-based analysis, refinements would be necessary to demonstrate similar effects in case study designs.

CHAPTER SEVEN

EXPERIMENT TWO: P300 AND IMPLICIT STIMULUS DIFFERENTIATION IN VISUAL HEMINEGLECT

INTRODUCTION

As previously described, patients with visual hemineglect may appear unaware of contralesional but not ipsilesional stimuli when tests require overt responses (Heilman et al., 1995). This lateralized deficit has enabled comparison of the implicit and explicit processing of information using a within-subjects design in which patients with hemineglect have served as their own controls. For example, semantic priming paradigms have been used to demonstrate that patients with visual hemineglect may implicitly process contralesional stimuli to remarkably high levels (e.g., object identification and semantic categorisation) even when more explicit behavioural measures indicate that the contralesional stimuli remained outside of the patients' subjective awareness (e.g., Berti & Rizzolatti, 1992; D'Esposito et al., 1993; Ladavas et al., 1997; McGlinchey-Berroth et al., 1993, 1996; Schweinberger & Stief, 2001). Moreover, results from the ERP-compatible Lateralized Semantic Priming Paradigm of Experiment One provided behavioural and electrophysiological data consistent with these demonstrations. The electrophysiological support involved N400 amplitude semantic priming effects for centralised picture targets that were preceded by lateralized picture primes even when these primes were in the contralesional field of patients with visual hemineglect (see Experiment One for details).

The P300 is another relatively late ERP component that has been examined in studies of contralesional hemineglect. The P300s elicited by contralesional stimuli have typically been reported to be abnormal regardless of whether or not the components preceding the P300 were within normal limits. The P300 abnormalities have been variable, involving peak amplitude attenuation, peak latency delay, or even increased peak amplitudes (L'hermitte et al., 1985; Verleger et al., 1996; Watson et al., 1977). Nevertheless, for patients with visual hemineglect, the amplitude of the P3a (a component of the P300) revealed evidence of a stimulus differentiation effect based on the relative novelty of the eliciting stimuli even when these stimuli were presented contralesionally (Verleger et al., 1996).

When behavioural data were collected in these ERP investigations of hemineglect, the lateralized deficits took the form of delayed responses for contralesional relative to ipsilesional stimuli. These delayed responses (rather than non-responses) indicate that the P300s were elicited by stimuli of which the patients were subjectively aware even though the stimuli were in the contralesional (neglected) visual field.

The present investigation was designed to examine implicit stimulus differentiation in the ERPs elicited by contralesional stimuli that remain subjectively unavailable to patients with visual hemineglect. For this purpose, two versions of a Lateralized Oddball Paradigm were developed. One version had an equal number of target and non-target trials (50% target version). The other version had a lower ratio of target to non-target trials (25% target version). For both versions, each trial consisted of the simultaneous presentation of two stimuli with one to the left and the other to the right of central fixation. Target trials consisted of a target (letter O) and a non-target (letter X) with the target to the left or right equally. Non-target trials consisted of a non-target (letter X) in each position.

For both versions of the paradigm, participants were instructed to press a button as quickly as possible for each target (letter O) regardless of where it might appear on the screen. No response was required for trials when a target was not present (non-target trials) or when a target was not detected (missed target trials).

For both versions of the paradigm, patients with visual hemineglect were expected to miss more contralesional than ipsilesional targets. Is similar to a deficit referred to as contralesional extinction upon double simultaneous presentation (extinction) except that there were no single trials to verify extinction. As described in the introductory chapters, extinction is a component of the hemineglect syndrome that may be seen in the presence or absence of other forms of hemineglect (Critchley, 1949; Driver & Mattingley, 1998; Kohler & Moscovitch, 1997; Mesulam, 1999; Rafal, 1998).

As with the first experiment, an age-matched group of healthy volunteers was used as a comparison group to control for potential laterality effects in the analysis of the behavioural and electrophysiological data. For these neurologically unimpaired individuals, neither the incidence nor the rates of correct target detection were expected to differ as a function of the visual field in which the stimuli appeared (L'hermitte et al., 1985).

The electrophysiological correlate of primary interest was the amplitude of the P300. As described in the introductory chapters, P300 amplitudes are generally more positive for target than non-target stimuli in variants of the standard oddball paradigm. Moreover, a robust inverse relationship between the amplitude of the P300 and the relative probability of the target stimulus within the randomised stream of non-target stimuli has generally been reported. Thus, for both versions of the Lateralized Oddball Paradigm, the P300 amplitudes of the neurologically intact controls were expected to show stimulus differentiation effects (more positive amplitudes for target than for non-target trials) regardless of the visual field in which the eliciting stimuli appeared. Moreover, these P300 amplitude stimulus differentiation effects were expected to be of greater magnitude for the 25% rather than 50% target version of the paradigm in accordance with the relatively lower ratio of target to non-target trials and regardless of the laterality of the eliciting stimuli. Finally, the P300 amplitude effects were expected for both the group- and individual-based analysis of the data so that the sensitivity of the P300-based experimental measure could be evaluated at the level of the individual participant (e.g. Connolly & D'Arcy, 2000; Connolly et al., 2000; Connolly, Major et al., 1999).

With respect to patients with visual hemineglect, the main focus of the investigation involved determining, at a group and individual level, the extent to which the P300 amplitudes elicited during the administration of the Lateralized Oddball Paradigms would yield results similar to the patterns anticipated for the age-matched healthy controls. Prior to creating the ERP averages, the EEG trials were sorted on the basis of experimental condition and behavioural responses. Sorting on the basis of the behavioural responses involved the exclusion of contralesional trials for which a target was detected and ipsilesional trials for which a target was missed. This sorting strategy was intended to ensure that any P300 amplitude stimulus differentiation or relative stimulus probability effects elicited by the contralesional and ipsilesional stimuli would be attributed to implicit and explicit processing respectively. If there are a sufficient number of contralesional trials during which a target was detected to permit the creation of reliable waveforms, then separate ERPs could be created to permit direct comparison of the implicit and explicit processing of the eliciting stimuli within the patients' contralesional visual field.

The successful elicitation of implicit P300 stimulus differentiation effects for contralesional stimuli of which patients with visual hemineglect demonstrate no subjective awareness would provide further electrophysiological evidence that information can be processed to a relatively high level even when it remains unavailable to subjective awareness. If on the other hand, the P300 amplitude stimulus-probability effect is obtained for ipsilesional but not contralesional stimuli, this result would indicate that there is an upper limit to the extent of implicit information processing that can occur in the neglected visual field.

As described in the introductory chapters, modulation of the amplitude of the P300 has commonly been thought to require (or be a marker of) subjective awareness of the eliciting stimuli (Andreassi, 2000; Kutas & Dale, 1997; Pritchard, 1981). However, there have been reports of the successful elicitation of mostly auditory P300 amplitude modulations for subjects who were in non-conscious states, such as various stages of sleep (Colrain et al., 2000; Doran, 2000; Pratt et al., 1999; Wesensten & Badia, 1988) or coma (Gott et al., 1991; Kane et al., 1996, Signorino et al., 1997). Thus, successful demonstration in the visual modality of P300 amplitude stimulus-probability effects for contralesional stimuli that remain outside of the subjective awareness of patients with visual hemineglect would have implications for the way in which the P300 has commonly been modelled or conceptualised. More specifically, such a demonstration would provide support for the idea that the amplitude of the P300 is sensitive to implicit as well as explicit forms of information processing. Such a demonstration would thus have implications for the way in which the elicitation of P300 amplitude effects may be interpreted in different experimental and clinical contexts.

As already stated, the amplitude of the P300 is the electrophysiological correlate of primary interest in this investigation of patients with visual hemineglect. However, as described in the introductory chapters, earlier components in the ERPs from standard versions of the oddball paradigm may also show similar but typically less robust stimulus differentiation and relative stimulus probability effects (Goodin et al., 1978; Kutas & Dale, 1997; Ritter et al., 1982; Squires et al., 1977). With respect to patients with visual hemineglect, however, the literature reviewed in the introductory chapters contained few consistent findings upon which to evaluate the extent to which the stages of information processing indexed by these early components are preserved. This is particularly true for contralesional stimuli that escape the subjective awareness of patients with visual hemineglect. Thus, additional exploratory analysis of the amplitude and latency of the pre-P300 ERP components elicited by the Lateralized Oddball Paradigms is expected to be informative about the processing fate of stimuli in the neglected field as it relates to awareness for patients with visual hemineglect.

METHODS

PARTICIPANTS

Patients and Controls

The patients and controls recruited for Experiment One were also recruited for Experiment Two. All 11 of the patients in Table 1 and all 14 of the controls in Table 5 participated in Experiment Two. Data from one patient (P106) and one control (C214) could not be included in the analysis due to technical difficulties during acquisition of the EEG data. Thus, this experiment was based on data from 10 patients (5 females, 5 males) and 13 controls (8 females, 5 males) who have been described in the Participant Section of Experiment One.

PROCEDURES

The Lateralized Oddball Paradigm

Stimuli. Two versions of a 200-trial Lateralized Oddball Paradigm were developed. Each trial of both paradigms consisted of the simultaneous presentation of two stimuli with one to the left and the other to the right of central fixation, which was indicated by a small, continuously present plus sign. Target trials consisted of a target (letter O) and a non-target (letter X) with the target to the left or right equally. Non-target trials consisted of a non-target (letter X) in each position. The two versions of the Lateralized Oddball Paradigm differed in the relative probability of the target and non-target trials. The 25% target version consisted of 12.5% left target trials, 12.5% right target trials, and 75% non-target trials. The 50% target version consisted of 25% left target trials, 25% right target trials, and 50% non-target trials. Thus, for each version of the paradigm there were 3 experimental conditions: Left Target (O + X), Right Target

(X + O), and Non-Target (X + X). For both versions of the Lateralized Oddball Paradigm, the relative proportion of trials for each of the three experimental conditions has been presented in Table 31.

Stimulus Presentation. Each participant was tested individually in a quiet hospital research laboratory. Each version of the Lateralized Oddball Paradigm consisted of 200 randomised trials, divided into 5 blocks of 40 trials each. The two versions were administered in counterbalanced order across subjects. In the darkened room, stimuli were rear-projected onto a large screen using a high-resolution computer data pad and overhead projector while the participants were seated comfortably in a padded chair (some patients preferred to remain in their wheel chairs). Each letter and the central fixation point (a plus sign) appeared in yellow on a black background. The letters subtended a visual angle of approximately 10 degrees (width) and 8 degrees (height). The internal edge of each laterally presented letter appeared 5 degrees from the central fixation point. The rate of stimulus presentation was computer-controlled and varied from 1 to 2.5 s/trial with a mean of 1.5 s/trial. This traditional method of varying the rate of stimulus presentation was used to avoid establishment of expectancy based on time of stimulus presentation, which could otherwise become confound the data. Participants were required to press a button whenever the target letter O was detected so that the frequency of correct detection, incorrect false-positives, and the corresponding response latencies could be recorded on the computer.

Prior to the collection of EEG data, practice trials were provided to familiarise participants with the protocol and with the response pad. For controls, a single administration of 25 computerised practice trials was generally sufficient. For patients, it was sometimes necessary to start the practice trials with flash cards at the bedside as a test of their stamina before introducing the computerised paradigm in the ERP laboratory. Then, these practice trials were repeated as necessary to ensure mastery of the task.

During the experimental run, participants were watched carefully to ensure that they maintained attention to the task. Every effort was taken to minimise any discomfort associated with post-stroke fatigue or postural impairments (e.g., additional breaks were provided to adjust sitting postures that had become uncomfortable or to rest tired eyes, cushions were provided for back and neck support, footstools and cushions were provided for leg elevation, sessions were terminated with the remainder of testing scheduled for a subsequent session to accommodate fatigue). Data collection was generally completed within a single session for controls and within a pair of sessions for four of the patients who became too fatigued to complete the testing within a single session (see Table 4). For the patients who were unable to complete testing within a single session, testing was typically resumed the following day with a maximum time interval of 3 days.

Task Instructions. Participants were informed that a series of Xs and Os would be presented briefly in different locations on the screen. They were instructed to press a button as quickly as possible whenever they saw an O and to refrain from pressing the button if only Xs appeared on the screen. To assist in the collection of ERP data, participants were requested to maintain their gaze on the central fixation point and to avoid blinking or moving except for during brief breaks which would be provided after every 5 to 10 trials. Participants were also informed that longer breaks would be given after every 40 trials and that additional breaks would be available as needed. The computer was programmed to pause until restarted by the experimenter at the end of each block of 40 trials. The experimenter was able to tailor the provision of the additional breaks to the requirements of each participant using a hand-held button that paused and resumed the computerised sequence of trials.

Electrophysiological Data

EEG Recordings. While participants completed the Lateralized Oddball Paradigms, their EEG and EOG activity were acquired. The recording methods were identical to those used for Experiment One with the exception that the data were not acquired continuously. Instead, the recordings were made with a half-amplitude bandpass of 0.01 to 100 Hz (with 60 Hz notch filter active) and a digital sampling rate of 500 Hz for 100 ms before and 1000 ms after the onset of the eliciting stimuli (letter pairs with or without a specified target).

ERP Averaging. In contrast to the averaging procedures used for Experiment One, no epoching of the EEG data was necessary because it was not acquired continuously. The methods of filtering and dealing with artefact were identical to those used for Experiment One. In contrast to Experiment One, the incorporation of behavioural accuracy into the sorting of the EEG epochs by experimental condition was more complicated in this experiment. The epochs were first sorted on the basis of the 3 experimental conditions (Left Targets, Right Targets, and Non-Targets). Within the 2 target conditions, the epochs were sorted on the basis of behavioural accuracy into target hits and target misses. Within the Non-Target condition, any epoch associated with an incorrect false positive response was tagged for rejection from the ERP averaging procedures. Averaging of each participant's epochs by stimulus condition therefore resulted in 5 potential ERP waveform conditions once behavioural accuracy was taken into account (Left Target Hits, Left Target Misses, Right Target Hits, Right Target Misses, and Non-Targets that were not associated with false-positive responses). For the controls, it was anticipated that the incidence of target misses would be too low for ERP averaging regardless of the laterality of the targets. For the patients, it was anticipated that the number of epochs per category would be more variable, particularly with respect to the Left Target Hits and Misses. Therefore, it was left to be determined if there would be a sufficient number of epochs in each of the five categories for averaging into stable ERPs. The manner in which ERP averaging was dealt with has been presented in detail in the results section. The averaging procedures used for the construction of the individual and grand average ERP waveforms were identical to those of Experiment One.

ERP Scoring. For the manipulations of stimulus targetness and relative stimulus probability, the ERP component of primary theoretical interest was the P300, which was anticipated to occur between 300 and 600 ms from onset of the target and non-target trials. Scoring of earlier components (e.g., N100, P200, N200) elicited by the stimulus pairs was undertaken to investigate electrophysiological correlates of earlier stages of visual processing by the participants with and without neglect. As in Experiment One, visual inspection of the grand average waveforms was used to identify the presence and latency ranges of the P300 and other potentially scoreable components. The peak amplitude and latency values of each component were derived using the same peak identification procedures described for Experiment One.

Statistical Procedures.

The statistical procedures used for analysis of the behavioural response data included: Independent Samples t-Tests and mixed-factorial ANOVAs. The between-subjects factors included Group (Patient, Control) or Subgroup (up to 3 levels for analyses in which the data of the two patient subgroups and the controls were compared). The within-subjects factors included Paradigm Version (50% and 25% Target Versions) and Target Laterality (Left, Right) as appropriate.

The statistical procedures used for the analysis of the electrophysiological data included 1-Tailed Independent Subjects t-Tests, Repeated Measures ANOVAs, and Mixed-Factorial ANOVAs. For the Repeated Measures ANOVAs, the within-subjects factors included Paradigm Version (50% and 25% Target Versions), Stimulus Condition (Left Targets, Right Targets, and Non-Targets), and Recording Site (Fz. Cz. Pz) as appropriate. For the Mixed-factorial ANOVAs, the between-subjects factors included Group or Subgroup as described above and the within-subjects factors included Paradigm Version, Stimulus Condition, and Recording Site (Fz. Cz. Pz) also as described above.

As was the case for analysis of Experiment One, the results of all ANOVAs have been presented with conservative Greenhouse and Geisser (1959) degrees of freedom and degrees of freedom whenever statistical significance was met on tests of Sphericity. All significant main effects involving 3 or more levels and significant interactions were submitted to post hoc analysis using the Tukey HSD Test when the pool of potential differences being examined could be limited to all possible differences between pairs of means. These main effects and interactions were instead submitted to the Scheffé when the pool of potential differences being examined could not be limited to all possible differences between pairs of means.

Throughout the Results, the statistical procedures have been presented within a context in which the specific goals of each analysis have been outlined. All analyses required an alpha level of $p \leq .05$ before statistical significance was met. Unless otherwise indicated, significance has been used to denote statistical significance.

RESULTS

BEHAVIOURAL RESULTS

Accuracy: Between Group Comparisons

For the 50% and 25% target versions of the Lateralized Oddball Paradigm, response accuracy was evaluated in two ways. First, the incidence of correct detection of the left and right targets (i.e. target hits) were compared to establish the extent to which the tasks were sensitive to the patients' neglect. Second, the incidence of incorrect responses to the non-targets (i.e., non-target false positives) was examined as an index of positive response bias. The participants' mean percentage of target hits and non-target false positives for each version of the paradigm have been summarised in Table 32.

Target Hits. The mean percentage of target hits was analysed using a 2 x 2 x 2 mixed-factorial ANOVA with Group (Patient, Control) as a between-subjects factor and Paradigm Version (50% and 25% target versions) and Target Laterality (Left, Right) as within-subjects factors (see Table 33). There was a significant main effect of Group, F (1, 21) = 13.27, $p = .002$, $\eta^2 = .39$. On average, target detection was more accurate for controls ($M = 99.1\%$, $SD = 4.52$) than for patients ($M = 74.2\%$, $SD = 5.15$). There was also a significant main effect of Target Laterality, F (1, 21) = 6.78, $p = .017$, $\eta^2 = .24$. Overall, right targets were more often detected ($M = 94.5\%$, $SD = 1.85$) than left targets ($M = 78.8\%$, $SD = 6.17$).

These main effects were qualified, however, by a significant Group by Target Laterality interaction, F (1, 21) = 7.38, $p = .013$, $\eta^2 = .26$ (see Table 34 for the data and Appendix F1 for a graph of the interaction). Post hoc analysis revealed that the controls did not differ significantly in their near-perfect detection of left ($M = 99.5\%$, $SD = 8.14$) and right ($M = 98.8\%$, $SD = 2.44$) targets. The patients' showed no significant impairment in their detection of right targets ($M = 90.14\%$, $SD = 2.78$) compared to control performance. However, the patients' detection of left targets ($M = 58.2\%$, $SD = 9.23$) was significantly impaired compared to control performance and compared to the patients' own detection of right targets. As indicated in Table 33, no other main effects or interactions reached statistical significance. Thus, as a group, the patients showed behavioural evidence of left visual hemineglect on both the 50% and 25% target versions of the Lateralized Oddball Paradigm.

False Positives. The mean percentage of incorrect false positive responses to non-targets was analysed using a 2 x 2 mixed-factorial ANOVA with Group (Patient, Control) as a between-subjects factor and Paradigm Version (50% and 25% target versions) as a within-subjects factor (see Table 35). This analysis yielded a significant main effect of Group, F (1, 21) = 15.86, $p = .034$, $\eta^2 = .20$. On average, more false positives were committed by patients (M = 2.02%, SD = .49) than by controls (M = 0.55%, SD = .43). Neither group's percentage of false positives was high enough to warrant concern regarding indiscriminate responding, inability to comprehend task instructions, or inattention to task. As indicated in Table 35, neither the main effect of Paradigm Version nor the interaction between Paradigm Version and Group reached statistical significance.

Accuracy: Individual Within Group Variability

Inspection of each controls' accuracy data (see Table 36) revealed little inter-subject variability for either the 50% or 25% target versions of the Lateralized Oddball Paradigm. In contrast, there was far greater inter-subject variability in the patients' accuracy data (see Table 37). Inspection of the patients' data revealed a subgroup for whom left target detection was impaired (Non-Detectors, $n = 5$) and a subgroup for whom left target detection was intact (Detectors, $n = 5$).

The mean percentage of target hits and non-target false positives for each of these patient subgroups and for the controls have been summarised in Table 38. Visual inspection of these data suggested that the patients who were unimpaired in left target detection (Detectors) were more similar in performance to the controls than to the patients who were impaired in left target detection (Non-Detectors). For statistical evaluation of this observation, a 3 x 2 x 2 mixed-factorial ANOVA was run on the mean percentage of target hits with Group (Non-Detector, Detector, Control) as a between-subjects factor and Paradigm Version (50% and 25% target versions) and Target Laterality (Left, Right) as within-subjects factors (see Table 39).

There was a significant main effect of Group, F (2, 20) = 287.09, $p < .001$, $\eta^2 = .97$. Post-hoc analysis revealed that Non-Detectors detected an average of only 51.2% of the targets (SD = 1.75), which was significantly poorer than the near-perfect detection of Detectors (M = 97.1%, SD = 1.75) or Controls (M = 99.1%, SD = 1.08). There was also a significant main effect of Target Laterality, F (1, 20) = 27.89, $p < .001$, $\eta^2 = .58$.

Overall, significantly more right ($M = 93.02\%$, $SD = 1.80$) than left ($M = 71.95\%$, $SD = 2.52$) targets were detected.

These main effects were qualified, however, by a significant Group by Target Laterality interaction, $F(2, 20) = 28.51$, $p < .001$, $\eta^2 = .74$ (see Table 40 for the data and Appendix F2 for a graph of the interaction). Post hoc comparisons revealed no significant differences in the accuracy of detection for the controls and Detectors. Both of these groups showed high rates of detection that did not differ significantly for targets in the left or right visual field. Compared to the controls and Detectors, the Non-Detectors were significantly impaired in the detection of both left and right targets with significantly greater impairment for targets on the left ($M = 18.6\%$, $SD = 4.89$) rather than right ($M = 83.9\%$, $SD = 3.5$). Thus, compared to the incidence of left and right target hits by controls on the 50% and 25% target versions of the Lateralized Oddball Paradigms, half of the patients (Non-Detectors, $n = 5$) showed behavioural evidence of left visual hemineglect and half of the patients (Detectors, $n = 5$) did not.

The rate of non-target false-positives for the 3 groups was compared to determine whether the subgroup of patients who responded to left targets (Detectors) also showed a significantly elevated positive response bias. A 3 x 2 mixed-factorial ANOVA with Group (Non-Detector, Detector, Control) as a between-groups factor and Paradigm Version (50% and 25% target versions) as a within-subjects factor was used to explore the percentage of false positive responses to non-targets (see Table 31).

The analysis yielded a significant main effect of Group, $F(1, 20) = 7.88$, $p = .003$, $\eta^2 = .44$. Post hoc analysis revealed significantly higher rates of non-target false positives for Detectors ($M = 3.25\%$, $SD = .59$) than for Non-Detectors ($M = .79\%$, $SD = .59$) or Controls ($M = .55\%$, $SD = .364$). The rates of non-target false positives for Non-Detectors and Controls did not differ significantly. Thus, the Detectors rather than the Non-Detectors showed evidence of a positive response bias. As indicated in Table 31, neither the main effect of Paradigm Version nor the Group by Paradigm Version interaction were statistically significant.

With respect to the main effect of Group, it is possible that patients in the Detector subgroup displayed an increased tendency to indicate 'yes' in their responses when unsure about what they saw as a form of compensation for their visual hemineglect. The Detectors' false positive rate was significantly elevated compared to those of the Non-Detector patient group and the control group. However, at the low rate of 3.25%, it was not high enough to warrant concern that the patients in this subgroup were responding indiscriminately or not attending to the task.

Target Response Latencies

Mean target response latencies were examined to determine whether Detectors showed behavioural evidence of left visual hemineglect on the experimental paradigms in the form of significantly slower detection of left than right targets (see Table 42). A $\log_{10}$ transformation was used to normalise the distribution of the reaction time data[12]. Then the mean response latencies for target hits were analysed using a 2 x 2 x 2 mixed-factorial ANOVA with Group (Detector, Control) as a between-subjects factor and Paradigm Version (50% and 25% target versions) and Target Laterality (Left, Right) as within-subjects factors (see Table 43). Non-Detectors could not be included in this analysis due to an insufficient number of detected left targets.

The analysis yielded a significant main effect of Target Laterality, $F\,(1,16) = 25.44, p < .001, \eta^2 = .61$. On average, detection was slower for left targets ($M_{log} = -.30$, $SD = .02$, $M_{inv\,log} = 501$ ms) than for right targets ($M_{log} = -.32$, $SD = .01$, $M_{inv\,log} = 474$ ms). This effect was qualified, however, by a significant Group by Target Laterality interaction, $F\,(1, 16) = 29.47, p < .001, \eta^2 = .65$ (see Table 44 for the data and Appendix F3 for a graph of the interaction). Post hoc analysis revealed that the controls' mean reaction times did not differ significantly for left ($M_{log} = -0.327$, $SD = .02$, $M_{inv\,log} = 471$ ms) and right ($M_{log} = -0.326$, $SD = .02$, $M_{inv\,log} = 472$ ms) targets. The reaction times for Detectors were comparable to those of the controls for right targets ($M_{log} = -0.323$, $SD = .03$, $M_{inv\,log} = 475$ ms) but were significantly delayed for left targets ($M_{log} = -0.272$, $SD = .03$, $M_{inv\,log} = 535$ ms). Thus, in terms of the behavioural manifestation of visual hemineglect on the Lateralized Oddball Paradigms, Non-Detectors *omitted* more left

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[12] Prior to $\log_{10}$ transformation of the data the mean within each condition was elevated above the median for each participant. The transformation brought the mean closer to the median in every case, thus reducing skew in the distribution. At a group level, comparison of the pre- and post-transformation skew values demonstrated an average reduction of 71.25% (range = 62.68 to 82.12%) for the controls and 48.98% (range = 42.67 to 54.67%) for the patients.

than right targets. In contrast, Detectors (hence forth to be called Delayed-Detectors) responded to left targets significantly more slowly than to right targets.

Direct comparison of the target response latencies of the two patient subgroups was also undertaken. Non-Detectors generally did not respond to left targets so no analysis could be done but their lack of responses for left targets indicate that they were impaired on that side. There were, however, a sufficient number of responses to right targets for all groups to allow for comparison of response times. Therefore, mean response latencies for right targets were analysed using a 3 x 2 mixed-factorial ANOVA with Group (Non-Detector, Delayed Detector, Control) as a between-subjects factor and Paradigm Version (50% and 25% target versions) as a within-subjects factor (see Table 45).

The analysis yielded a main effect of Group F (2, 20) = 6.30, p = .008, η^2 = .39. Post hoc analysis revealed that the right targets were detected more slowly by the Non-Detectors (M_{log} = - .198, SD = .03, $M_{inv\ log}$ = 634 ms) than by the Delayed Detectors (M_{log} = - .323, SD = .03, $M_{inv\ log}$ = 475 ms) or the controls (M_{log} = - .326, SD = .02, $M_{inv\ log}$ = 472 ms). Thus, the Non-Detectors, who generally failed to detect left (contralesional) targets, were also impaired relative to the controls in the time required for the detection of right (ipsilesional) targets. In contrast, the Delayed-Detectors' impairment in the time required for target detection was specific to stimuli in the contralesional rather than ipsilesional visual field.

The main effect of Paradigm Version was also significant, F (1, 20) = 10.39, p = .004, η^2 = .34. Post hoc analysis revealed that right targets were on average responded to more slowly in the 25% target version (M_{log} = -0.268, SD = .02, $M_{inv\ log}$ = .540 s) compared to in the 50% target version (M_{log} = -0.296, SD = .02, $M_{inv\ log}$ = .506 s). The Group by Paradigm Version interaction, however, was not significant. Together, the results of this significant main effect and non-significant interaction indicate that for all three groups, the version in which the proportion of targets was relatively low was more attentionally demanding than the version in which the proportion of targets and non-targets was equal. Thus, decreasing the relative proportion of targets in the Lateralized Oddball Paradigm from 50% to 25% had the desired effect of increasing the attentional demands of the task for all participants.

Overall, the different behavioural manifestations of neglect on the experimental measure may have involved different degrees of severity, with Non-Detectors more severely impaired than Delayed-Detectors. Whereas the patients who tended not to detect contralesional targets (Non-Detectors) also showed some evidence of impaired ipsilesional target detection, the patients who were generally delayed in the detection of contralesional targets (Delayed-Detectors) showed impaired reaction times that were specific to the left targets.

Patient Subgroup Performance on Other Measures of Hemineglect

Each patient's total score on the Sunnybrook Neglect Battery has been presented in Table 46. On average, higher neglect scores were obtained by Non-Detectors (M = 45.6, SD = 32.0) than by Delayed Detectors (M = 36.4, SD = 21.6) but this difference did not even approach statistical significance, t (8) = .532, p = .609. Inspection of individual performance revealed that the Non-Detector subgroup contained patients whose severity of neglect scores ranged from mild to severe and the Delayed-Detector subgroup contained patients whose severity of neglect scores ranged from mild to moderate.

Two-tailed Pearson-Product Moment Correlations revealed no statistically significant correlation between the Sunnybrook Battery Total Neglect Score and the logged response times for right targets for the 50% [r (N = 10) = -0.369, p = .294] or 25% [r (N = 10) = -284, p = .427] target versions of the paradigm. For the Delayed-Detectors, correlational analysis similarly revealed no statistically significant evidence of a linear relationship between the transformed left target detection times and the neglect battery total score for the 50% [r (N = 5) = -6.02, p = .153] or 25% [r (N = 5) = -7.24, p = .104] target versions of the paradigm.

One-tailed Pearson Product Moment correlations revealed no statistically significant evidence of a relationship between Subgroup (Non-Detector = 1, Delayed Detector = 2) and the Sunnybrook Battery Total Neglect Score [r (N = 10) = - .183, p = .304]. However, there was a significant relationship between Subgroup and the Pre-Experimental Chi-Square Index of Neglect from Experiment One, r (N = 10) = - .690, p = .014. Thus, whereas the Sunnybrook Bedside Battery Total Neglect Score was not sensitive to the differences in the patients' manifestations of visual hemineglect observed in the behavioural response data of Experiment Two, the pre-experimental chi-square-based neglect verification task developed for Experiment One was sensitive. With respect to visual hemineglect, the computerised pre-experimental neglect verification task of Experiment One and the computerised Lateralized Oddball Detection Paradigm of Experiment Two were both designed to assess the ability to detect contralesional stimuli. In contrast, the Total Neglect Score from the paper-and-pencil-based Sunnybrook Bedside Battery is a composite of several subtest scores that are likely sensitive to features of the hemineglect syndrome above and beyond mere stimulus detection.

ELECTROPHYSIOLOGICAL RESULTS

Unless otherwise specified, all analyses used ERP data obtained from the midline sites (Fz, Cz, and Pz). Grand averaged ERP waveforms obtained from each of these sites and for each version of the Lateralized Oddball Paradigm have been presented in Figures 8 and 9 for the controls and in Figures 10 and 11 for the patients. Similar waveforms have been presented for the two patient subgroups identified during the analysis of the behavioural data. Those for Non-Detectors have been presented in Figures 12 and 13. Those for Delayed Detectors have been presented in Figures 14 and 15.

For the control and patient groups, the mean number of trials of EEG averaged per condition (with the corresponding standard deviations and ranges) have been presented in Table 47. To ensure adequate sampling of data per condition, the number of trials of EEG averaged per condition were analysed using a mixed-factorial ANOVA with Group (Patient, Control) as a between-subjects factor and Stimulus Condition (Left Target, Right Target, Non-Target) and Paradigm Version (50% and 25% Target Versions) as within-subjects factors. There was a statistically significant main effect of Group, $F(1, 21) = 10.68, p = .004$. On average, there were more trials per condition for controls ($M = 55.7$, $SD = 2.00$) than for patients ($M = 45.82$, $SD = 2.28$).

The significant main effect of Stimulus Condition, $F(2, 42) = 784.18, p <. 001$, was qualified by a significant Stimulus Condition by Paradigm Version interaction, $F(2, 42) = 186.58, p < .001$. As expected, post hoc analysis revealed that there were more EEG trials in the target ERPs (and correspondingly fewer EEG trials in the non-target

ERPs) for the 50% rather than 25% target version of the Lateralized Oddball Paradigms. Nevertheless, as indicated in Table 47, no average contained fewer than 12 trials for the controls and 9 trials for the patients even for the 25% target version of the paradigm.

The percentage of EEG trials rejected per condition due to artefact has also been presented in Table 47. These data were similarly analysed using a mixed-factorial ANOVA with Group (Patient, Control) as a between-subjects factor and Stimulus Condition (Left Target, Right Target, Non-Target) and Paradigm Version (50% and 25% target versions) as within-subjects factors. The analysis yielded a significant main effect of Group $F(1, 21) = 12.57, p = .002$. On average, the percentage of trials rejected per condition due to artefact was greater for the patients ($M = 32.6\%$, $SD = 3.5$) than for the controls ($M = 15.9\%$, $SD = 3.1$). No other main effects or interactions reached statistical significance.

Taken together, the results of the two analyses indicate that the number of trials per condition for each version of the paradigm differed significantly as an expected function of the experimental design but more importantly, the proportion of trials rejected per condition due to artefact did not differ significantly. Also, whereas significantly more of the patient than the control data was lost due to artefact, the loss of data did not differ significantly across experimental conditions for either group of participants.

Visual inspection of the waveforms presented in Figures 8 to 15 revealed 3 scoreable components. Following onset of the eliciting stimuli, a P200 was the most positive peak between 90 and 250 ms, an N200 was the most negative peak between 150 and 350 ms, and a P300, was the most positive peak between 300 and 700 ms. A consistent N100-type component was not evident.

Analysis of the electrophysiological data proceeded through four stages. Preliminary analysis of the controls' data was for validation of the Lateralized Oddball Paradigm. The goal was to determine whether the ERPs would show evidence of the predicted stimulus differentiation and relative stimulus probability effects in a neurologically intact sample of elderly adults who were similar in age to the patients with visual hemineglect. Full analysis of the patient and control ERPs was then performed to determine whether the stimulus differentiation and stimulus probability effects of participants with or with out visual hemineglect were similar. As described in the behavioural result section, however, the patient group consisted of equal numbers of patients who generally omitted left but not right targets (Non-Detectors, $n = 5$) and patients whose target detection times were impaired for left but not right targets (Delayed-Detectors, $n = 5$). Consequently, inclusion of the patients as a single group in the full analysis of the patient and control data would not address whether or not the predicted stimulus differentiation and relative stimulus probability effects could be elicited by contralesional stimuli of which patients with visual hemineglect remain subjectively unaware. To address this question, a follow up analysis involving the ERP data collected from the two patient subgroups (Non-Detectors and Delayed Detectors) was performed.

As described previously, the P300 was the ERP component of primary theoretical interest. Therefore at each of the 3 stages of the analysis outlined so far, the peak amplitude and corresponding peak latency of the P300 were analysed ahead of those for the two earlier components identified in the ERP waveforms. Subsequent analysis of the peak amplitudes and latencies of the two earlier components was then performed to investigate earlier levels of visual processing within the context of experimental task validation and in relation to the deficits associated with visual hemineglect.

Finally, as a follow up to the group-based analyses of the P300 amplitude data, each participant's P300 peak amplitudes were examined separately. This follow up analysis was intended to permit evaluation of the sensitivity of the P300 for the Lateralized Oddball Paradigms at an individual rather than group level. It also offered another way of determining whether or not the patterns of the predicted stimulus differentiation or relative stimulus probability effects would be evident in the amplitudes of the P300s elicited by stimuli in the contralesional visual field of which individuals with visual hemineglect remain subjectively unaware.

Preliminary Task Validation Using Control ERP Data

The controls' grand averaged ERP waveforms for the 50% and 25% target versions of the Lateralized Oddball Paradigm have been presented in Figures 8 and 9. As mentioned, preliminary analysis of the controls' ERP data was for task validation.

More specifically, the peak amplitude and latency of the P300 were analysed to determine whether the topographical distribution and timing of this component were consistent with those observed in other neurologically intact elderly samples. For both versions of the Lateralized Oddball Paradigm, P300 amplitudes were expected to be more positive for the target rather than non-target trials regardless of the visual field in which the eliciting stimuli were presented. These P300 amplitude stimulus differentiation effects were expected to be of greater magnitude for the 25% rather than 50% target version of the Lateralized Oddball Paradigm due to the manipulation of relative stimulus probability between the paradigm versions. Data from the preceding P200 and N200 components were analysed to determine whether either of these early components would also show evidence of the stimulus differentiation and relative stimulus probability effects. The controls' peak amplitudes and latencies for each of the 3 ERP components were therefore analysed using 2 x 3 x 3 repeated measures ANOVAs with Stimulus Condition (Left Target, Right Target, Non-Target), Paradigm Version (50% and 25% target versions) and Recording Site (Fz, Cz, Pz) as within-subjects factors (see Tables 48 to 57).

P300 Amplitudes. Analysis of the controls' P300 amplitudes (see Table 48) yielded a significant main effect of Stimulus Condition, F (2, 24) = 22.73, $p < .001$, $\eta^2 = .65$. Post hoc analysis revealed that the mean P300 amplitudes for left (*M* = 12.23 μV, *SD* = 1.52) and right (*M* = 12.78 μV, *SD* = 1.82) targets were both significantly more positive than those for non-targets (*M* = 8.16 μV, *SD* = 1.42). These results support the prediction that the amplitudes of the P300 could be used to differentiate between the target and non-target stimuli regardless of the visual field in which the eliciting stimuli were presented.

The main effect of Stimulus Condition was, however, qualified by a significant Paradigm Version by Stimulus Condition interaction, F (2, 24) = 8.2, $p = .002$, $\eta^2 = .41$. Post hoc analysis revealed that the 25% target version of the paradigm elicited statistically significant P300 amplitude stimulus differentiation effects (i.e., greater P300 amplitudes for targets than for non-targets) regardless of the laterality of the eliciting stimuli. In contrast, the 50% target version of the paradigm elicited similar patterns of stimulus differentiation regardless of the laterality of the eliciting stimuli but the magnitude of these effects were not statistically significant (see Table 49 for the data and Appendix F4 for a graph of the interaction). Thus, in support of the predictions based on the between paradigm version manipulation of relative stimulus probability, the magnitude of the stimulus differentiation effect was greater for the 25% rather than 50% target version of the Lateralized Oddball Paradigm.

The main effect of Recording Site was also significant, $F(2, 24) = 8.09$, $p = .002$, $\eta^2 = .40$. Consistent with expectations, post hoc analysis revealed that the P300 amplitudes generally showed a centro-posterior distribution with those at Cz ($M = 12.87$ µV, $SD = 1.70$) and Pz ($M = 12.31$ µV, $SD = 1.69$) more positive than those at Fz ($M = 7.98$ µV, $SD = 1.76$). The main effect of Recording Site was, however, qualified by a significant Stimulus Condition by Recording Site interaction, $F(4, 48) = 10.27$, $p < .001$, $\eta^2 = .46$. Post hoc analysis revealed that amplitude positivity for the left and right targets did not differ significantly at any of the three recording sites. However, the amplitude positivities for both the left and right targets were significantly greater than were those for the non-targets at each of the recording sites, with the greatest magnitude of difference at Pz (see Table 50 for the data and Appendix F5 for a graph of the interaction). Put more simply, the pattern of results for this interaction indicated that the P300 amplitude stimulus differentiation effects were present at all three recording sites with the most robust effects at the posterior site.

As indicated in Table 48, none of the remaining main effects or interactions reached statistical significance. In terms of the stimulus differentiation and relative stimulus probability effects, all of the results described here were consistent with the predicted patterns. Thus, satisfactory task validity was achieved for this sample of neurologically healthy elderly controls.

P300 Latencies. Analysis of the controls' P300 latencies (see Table 49) yielded no significant main effects. There was a significant Stimulus Condition by Paradigm Version interaction, $F(1.3, 24) = 6.32$, $p = .017$, $\eta^2 = .35$ (see Table 52 for the data and Appendix F6 for a graph of the interaction). Post hoc analysis revealed that for the 50% target version of the paradigm, the P300 latencies for the non-target trials were significantly earlier than were those for the left or right target trials. In contrast, post hoc analysis revealed no significant differences in the P300 latencies for the 25% target version of the paradigm as a function of stimulus condition. This pattern of results suggests that the P300 latencies were sensitive to the manipulation of stimulus targetness but not relative stimulus probability. However, given the difficulty of scoring latencies for non-target trials, these conclusions concerning the latencies of the P300 are likely to be less robust compared to conclusions concerning amplitude differentiation.

There was also a significant Paradigm Version by Recording Site interaction, F (2, 24) = 4.12, p = .029, η^2 = 0.26. Post hoc analysis revealed no significant difference in the P300 latencies across the 3 recording sites for the 25% target version of the paradigm. For the 50% target version, however, the P300 latencies at Fz (M = 440 ms, SD = 11.73) were significantly earlier than were those at Cz (M = 463.90 ms, SD = 10.34) or Pz (M = 461.49 ms, SD = 10.25). See Table 53 for the data and Appendix F7 for a graph of the interaction. As indicated in Table 51, no other main effects or interactions reached statistical significance.

P200 Amplitudes. Analysis of the controls' P200 amplitudes (see Table 54) yielded a significant main effect of Recording Site, F (1.3, 24) = 6.84, p = .012, η^2 = .36. Post hoc analysis revealed that the mean P200 amplitudes at Cz (M = 3.14 μV, SD = 0.47) were greater than those at Pz (M = 2.00 μV, SD = 0.78) or Fz (M = 1.07 μV, SD = 0.65). As indicated in Table 54, none of the other main effects or interactions reached statistical significance. Thus, the controls' P200 amplitudes were maximal at Cz, and showed no significant evidence of the stimulus differentiation effect within each version of the Lateralized Oddball Paradigm or the relative stimulus probability effect between versions of the paradigm.

P200 Latencies. Analysis of the controls' P200 latencies (see Table 55) yielded a significant main effect of Recording Site F (1.3, 24) = 6.25, p = .019, η^2 = .34. Post hoc analysis revealed that the P200 peak latencies at Pz (M = 128.1 ms, SD = 3.05) were significantly earlier compared to those at Fz (M = 133.2 ms, SD = 3.78) or Cz (M = 131.9 ms, SD = 3.05). As indicated in Table 55, no other main effects or interactions reached statistical significance. Thus, the controls' P200 latencies were earliest at Pz and were not significantly influenced by the manipulation of targetness within each version of the Lateralized Oddball Paradigm or of relative stimulus probability between the two versions of the paradigm.

N200 Amplitudes. Analysis of the controls' N200 amplitudes (see Table 56) yielded a significant main effect of Recording Site, F (1.3, 24) = 21.9, $p < .001$, $\eta^2 = 0.65$. Post hoc analysis revealed that the N200 peak amplitudes at Pz ($M = -7.54$ μV, $SD = 0.80$) were significantly more negative than were those at Cz ($M = -4.46$ μV, $SD = 0.91$) or Fz ($M = -3.75$ μV, $SD = 1.08$). As indicated in Table 56, no other main effects or interactions reached statistical significance. Thus, the controls' N200 amplitudes were maximal at Pz and were not significantly influenced by the manipulation of targetness within each version of the Lateralized Oddball Paradigm or of relative stimulus probability between the two versions of the paradigm.

N200 Latencies. As indicated in Table 57, analysis of the controls' N200 latencies yielded no significant main effects or interactions. Thus, the controls' N200 peak latencies were not significantly influenced by the manipulation of targetness within each version of the Lateralized Oddball Paradigm or of relative stimulus probability between the two versions of the paradigm.

Full Analysis of Patient and Control ERP Data

The patient's grand averaged ERP waveforms for the 25% and 50% target versions of the Lateralized Oddball Paradigm have been presented in Figures 10 and 11 for comparison with the controls' waveforms in Figures 8 and 9. As mentioned, full analysis of the patient and control data was to determine whether the stimulus differentiation and stimulus probability effects of participants with and without visual hemineglect are similar. Of particular interest was whether the anticipated ERP effects would be evident for stimulus presented in the neglected field of the patients with visual hemineglect. However, as already described, the patient group contained a subgroup whose behavioural manifestation of hemineglect on the Lateralized Oddball Paradigms involved the delayed rather than non-detection of the contralesional targets. Thus, it is important to bear in mind that the question of whether or not the ERP effects could be elicited by stimuli in the contralesional visual field of which the patients remained subjectively unaware could not be addressed at this stage of the analysis.

For the full analysis of the ERP data, the patients' and controls' mean peak amplitude and latency values for each of the 3 ERP components identified in the waveforms were analysed using 2 x 2 x 3 x 3 mixed-factorial ANOVAs. In these

ANOVAs Group (Patient, Control) was a between-groups factor and Stimulus Condition (Left Target, Right Target, and Non-Target trials), Paradigm Version (50% and 25% target versions), and Recording Site (Fz, Cz, Pz) were within-subjects factors (see Table 58 to 69). As the electrophysiological component of primary interest, the P300 data were analysed ahead of the data for the two preceding ERP components identified in the waveforms.

P300 Amplitudes. Full analysis of the patients' and controls' P300 amplitudes (see Table 58) yielded a significant main effect of Group, $F\,(1, 21) = 10.82, p = .003, \eta^2 = 0.34$. P300 amplitudes for the patients ($M = 3.76$ μV, $SD = 1.67$) were on average attenuated compared to those for the controls ($M = 11.06$ μV, $SD = 1.46$). There was also a significant main effect of Stimulus Condition, $F\,(1.3, 42) = 23.88, p < .001, \eta^2 = .53$. Post hoc analysis revealed that the amplitudes for each condition differed significantly from one another. Arranged in order of increasing amplitude the conditions were: Non-Targets ($M = 4.19$ μV, $SD = 1.07$), Left Targets ($M = 7.39$ μV, $SD = 1.16$), and Right Targets ($M = 10.64$ μV, $SD = 1.44$). The Site main effect was also significant, $F\,(1.3, 42) = 10.12, p = .002, \eta^2 = 0.33$. Post hoc analysis revealed that the amplitudes at Fz ($M = 4.77$ μV, $SD = 1.44$) were less positive than those at Cz ($M = 8.72$ μV, $SD = 1.13$) or Pz ($M = 8.73$ μV, $SD = 1.17$).

These main effects were, however, qualified by a pair of significant two-way interactions. First, there was a significant Stimulus Condition by Recording Site interaction, $F\,(2.35, 84) = 6.11, p = .003, \eta^2 = 0.23$. Post hoc comparisons of the P300 amplitudes at each site revealed that those for the right targets were of significantly greater magnitude than those for left targets, which in turn were of significantly greater magnitude than were those for non-targets. Moreover, the differences between conditions were of greatest magnitude at the Pz site (see Table 47 for the data and Appendix F9 for a graph of the interaction). During the preliminary analysis of the controls' P300 amplitudes, post hoc analysis of the same Stimulus Condition by Recording Site interaction had yielded a slightly different pattern of results. In the preliminary analysis of the control's data, P300 amplitudes for left and right targets did not differ significantly although, as in the subsequent full analysis of the patient and control data, the P300s for left and right targets were significantly more positive than those for non-targets. An explanation for the difference becomes apparent from examination of the statistically significant and conceptually more central Group by Stimulus Condition interaction, $F(2, 42) = 4.37, p = .019, \eta^2 = .17$.

Post hoc analysis of this second statistically significant two-way interaction revealed that the controls showed the anticipated pattern of stimulus differentiation with greater P300 amplitude positivity for targets than for non-targets regardless of the visual field in which the eliciting stimuli were presented. Inspection of the patients' data revealed that that their waveforms also showed the anticipated pattern of stimulus differentiation regardless of the laterality of the eliciting stimuli. However, the post-hoc comparisons revealed that these effects reached statistical significance only when the eliciting stimuli were in the patients' right (intact) rather than left (neglected) visual field (see Table 59 for the data and Appendix F8 for a graph of the interaction). Thus, the major difference between the patient and control P300 amplitudes involved attenuation primarily for targets in the patients' neglected visual field. Consequently, there were statistically significant stimulus differentiation effects for target and non-target stimuli when the eliciting stimuli were in the patients' ipsilesional but not contralesional visual field.

As indicated in Table 45, neither the main effect of Paradigm Version nor any of the remaining interactions reached statistical significance. Of note, the Paradigm Version by Stimulus Condition interaction was not statistically significant even though it had been during the preliminary analysis of the controls' P300 amplitudes. Thus, the P300 amplitudes no longer showed statistically significant evidence of sensitivity to the manipulation of relative stimulus probability between versions of the paradigm once the preliminary analysis was altered to permit comparison of the patient and control data.

P300 Latencies. Full analysis of the patients' and controls' P300 latencies (see Table 61) yielded a significant main effect of Stimulus Condition, $F(2, 42) = 6.33, p = .004, \eta^2 = .23$. Post hoc analysis revealed longer P300 latencies for left targets ($M = 480.71$ ms, $SD = 16.70$) than for non-targets ($M = 456.48, SD = 12.14$). The mid-range latencies for right targets ($M = 467.71$ ms, $SD = 13.89$) did not differ significantly from those in the two other stimulus conditions. This main effect was qualified, however, by a significant Stimulus Condition by Paradigm Version interaction, $F(2, 42) = 4.00, p =$

.026, $\eta^2 = 160$ (see Table 62 for the data and Appendix F13 for a graph of the interaction). Post hoc analysis revealed that the pattern described above for the main effect of condition was accurate for the 25% target version of the Lateralized Oddball Paradigm. For the 50% target version of the paradigm, there were no significant differences in the P300 latencies across the three conditions. These results indicate that the P300 latencies showed statistically significant evidence of stimulus differentiation only when the eliciting stimuli were presented in the left visual field within the context of the 25% rather than 50% target version of the experimental paradigm. The presence of the stimulus differentiation effect for the 25% and not 50% target version of the paradigm indicates that the left-lateralized stimulus differentiation effect was also influenced by the manipulation of relative stimulus probability between the versions of the paradigm. These unexpected effects, which were lateralized to the left, had been non-lateralized and more robust during the preliminary analysis of the controls' P300 latency data. As indicated in Table 51, no other main effects or interactions reached statistical significance. Apart from the lack of a main effect of Group or any interaction involving this variable, comparison of the patient and control P300 latencies yielded little of theoretical interest.

P200 Amplitudes. Full analysis of the patients' and controls' P200 amplitudes (see Table 63) yielded no statistically significant main effect of Group. Thus, there was no indication of significant attenuation in the amplitude of this component for the patients relative to the controls. There was a significant main effect of Stimulus Condition, $F\,(2, 42) = 6.91$, $p = .003$, $\eta^2 = .25$. Post hoc analysis revealed that the P200 amplitudes for left ($M = 2.5$ μV, $SD = 0.56$) or right ($M = 2.95$ μV, $SD = 0.56$) targets were significantly more positive than those for non-targets ($M = 1.59$ μV, $SD = 0.5$). This main effect was qualified, however, by a significant Group by Stimulus Condition interaction, $F\,(2, 42) = 4.77$, $p = .014$, $\eta^2 = .18$. Post hoc analysis revealed that the main effect of Stimulus Condition just described provided an accurate description of the patients' data. In contrast, consistent with the preliminary analysis of the controls' P200 amplitudes, no significant differences across the three conditions were evident in the controls' P200 amplitudes (see Table 64 for the data and Appendix F10 for a graph of the interaction). Thus, as expected, the controls' P200 amplitudes were not significantly influenced by the manipulation of targetness within the versions of the experimental paradigm. In contrast, the patients' P200 amplitudes were influenced by the manipulation of targetness in the manner predicted for the P300 amplitudes regardless of whether the eliciting stimuli were in the patients' right (intact) or left (neglected) visual field.

There was also a significant main effect of Recording Site, *F* (1.3, 42) = 6.89, *p* = .009, η^2 = .25. Consistent with the preliminary analysis of the controls' P200 amplitudes, post hoc analysis revealed that the P200 amplitudes at Cz (*M* = 3.3 µV, *SD* = 0.50) were more positive than those at Pz (*M* = 2.0 µV, *SD* = 0.62) or Fz (*M* = 1.7 µV, *SD* = 0.57). As indicated in Table 62, no other main effects or interactions reached statistical significance.

In summary, the patients' P200 peak amplitudes showed no significant overall attenuation compared to control performance. In contrast to control performance, the patients' P200 amplitudes showed evidence of stimulus differentiation effects for targets and non-targets within the experimental paradigms regardless of the laterality of the eliciting stimuli in the manner predicted for the amplitude of the P300. There was no indication that the P200 amplitude stimulus differentiation effects in the patients' data were influenced by the manipulation of relative stimulus probability between versions of the experimental paradigm.

P200 Latencies. Full analysis of the patients' and controls' P200 latencies (see Table 65) yielded a significant main effect of Group, *F* (1, 21) = 49.4, *p* < .001, η^2 = 0.70. The mean latencies for the patients (*M* = 172.2 ms, *SD* = 4.40) were significantly delayed relative to those for the controls (*M* = 131.1 ms, *SD* = 3.86). There was also a significant main effect of Recording Site, *F* (1.3, 42) = 8.8, *p* = .003, η^2 = .30. Consistent with the preliminary analysis of the controls' data, post hoc analysis revealed that the peak latencies were earlier at Pz (M = 147.4 ms, SD = 3.5) than they were at Fz (*M* = 153.6 ms, *SD* = 2.8) or Cz (*M* = 153.9 ms, *SD* = 2.9. As indicated in Table 65, no other main effects or interactions reached statistical significance. Thus, the P200 latencies of the patients were significantly delayed relative to those of the controls. However, the P200 latencies of both groups showed no significant evidence of a stimulus differentiation effect within the two versions of the Lateralized Oddball

Paradigm or of relative stimulus probability effects between the two versions of the paradigm.

N200 Amplitudes. Full analysis of the patients' and controls' N200 amplitudes (see Table 66) yielded a significant main effect of Recording Site, $F\,(1.5, 42) = .4.92$, $p = .020$, $\eta^2 = 0.192$. Consistent with the preliminary analysis of the controls' N200 amplitudes, post hoc analysis revealed that the mean N200 amplitudes were significantly more negative at Pz ($M =$ -5.53 µV, $SD = 0.59$) compared to those at Fz ($M = -4.2$ µV, $SD = 0.85$) or Cz ($M = -4.03$ µV, $SD = 0.70$). This effect was qualified by a significant Group by Recording Site interaction, $F\,(2, 42) = 11.2$, $p < .001$, $\eta^2 = 0.35$ (see Table 67 for the data and Appendix F11 for a graph of the interaction). Post hoc analysis revealed that the main effect of Recording Site accurately described the controls' data. In contrast, the patients' N200 amplitudes did not differ significantly across the 3 recording sites. As indicated in Table 66, no other main effects or interactions reached statistical significance.

In summary, the patients' N200 amplitudes showed no significant overall attenuation compared to those of the controls. In contrast to the controls' N200s, which were maximal at the posterior site, the patients' N200s showed no significant difference in amplitude across the three recording sites. The N200 amplitudes of neither group showed evidence of stimulus differentiation effects within the paradigm versions or relative stimulus probability effects between the paradigm versions.

N200 Latencies. Full analysis of the patients' and controls' N200 latencies (see Table 68) yielded a significant main effect of Group $F\,(1, 21) = 49.32$, $p < .001$, $\eta^2 = 0.70$. N200 latencies for the patients ($M = 264.9$ ms, $SD = 8.62$) were delayed relative to those for the controls ($M = 184.4$ ms, $SD = 7.56$). There was also a significant main effect of Recording Site, $F\,(1.5, 42) = 3.96$, $p = .039$, $\eta^2 = 0.16$. Post hoc analysis revealed that the N200 latencies were earlier at Pz ($M = 220.8$ ms, $SD = 5.79$) than at Cz ($M = 226.1$ ms, $SD = 5.70$) or Fz ($M = 227.0$ ms, $SD = 6.20$). These main effects were qualified, however, by a significant Group by Recording Site interaction, $F\,(2, 24) = 4.62$, $p = .015$, $\eta^2 = .18$ (see Table 69 for the data and Appendix F12 for a graph of the interaction). Post hoc analysis revealed that the Recording Site main effect described only the patients' data. In contrast, the controls' N200 latencies did not differ significantly across the 3 recording sites (consistent with the preliminary analysis of the controls' N200 latencies). As indicated in Table 68, no other main effects or interactions reached statistical significance. In summary, the patients' N200 latencies were generally delayed relative to control performance most notably at the posterior recording site. The N200 latencies of neither group showed evidence of stimulus differentiation effects within the paradigm versions or relative stimulus probability effects between the paradigm versions of the Lateralized Oddball Paradigm.

Follow up Analysis of the Non-Detectors' and Delayed Detectors' ERP Data

The grand averaged ERP waveforms for the 25% and 50% target versions of the Lateralized Oddball Paradigm have been presented for the two patient subgroups in Figures 12 to 15. Those for the patients who generally omitted left targets more than right targets (Non-Detectors, *n* = 5) have been presented in Figures 12 to 13. Those for the patients whose impairment involved the rate of left but not right target detection (Delayed-Detectors, *n* = 5) have been presented in Figures 14 to 15.

As outlined previously, analyses of the ERP data collected from the Non-Detector and Delayed Detector subgroups was performed to follow up on the full analysis of the patient and control data in which the patients' data was included as a single group. The purpose of the follow up analyses was to address whether or not the predicted ERP stimulus differentiation and relative stimulus probability effects could be elicited by contralesional stimuli of which patients with visual hemineglect remain subjectively unaware. The subgroups' mean peak amplitude and latency data for each of the three identified ERP components were therefore analysed using 2 x 2 x 3 x 3 mixed-factorial ANOVAs with Patient Subgroup (Non-Detectors, Delayed Detectors) as a between-groups factor and Paradigm Version (50% and 25% Target Versions), Stimulus Condition (Left Target, Right Target, Non-Target), and Recording Site (Fz, Cz, Pz) as within-subjects factors (see Tables 70 to 78).

P300 Amplitudes. Analysis of the patient subgroups' P300 amplitudes (see Table 70) yielded a significant main effect of Stimulus Condition, $F(1.27, 16) = 9.15$, $p = .009$, $\eta^2 = .53$. Consistent with the pattern of results for the patients revealed during the full analysis of the P300 amplitudes, post hoc analysis revealed that the P300 amplitudes for the right targets ($M = 8.51$ µV, $SD = 2.37$) were more positive than those for the left targets (*M* = 2.55 µV, *SD* = 1.85) or non-targets (*M* = 0.22 µV, *SD* = 1.64). The P300 amplitudes for the left targets and non-targets did not differ significantly. As indicated in Table 70, no other main effects or interactions reached statistical significance. Thus, despite their differing behavioural manifestations of hemineglect on the experimental measure, both Non-Detectors and Delayed Detectors revealed the predicted pattern of P300 amplitude stimulus differentiation for target and non-target stimuli in the right (intact) but not left (neglected) visual field. The P300 amplitudes of both subgroups showed no evidence of relative stimulus probability effects.

P300 Latencies. Analysis of the patient subgroups' P300 latencies (see Table 71) yielded a significant main effect of Stimulus Condition, $F\,(2, 16) = 5.26, p = .018, \eta^2 = .397$. Consistent with the results of the full analysis of the patient and control P300 latencies, post hoc analysis revealed longer P300 latencies for left targets (*M* = 497.37 ms, *SD* = 33.69) than for non-targets (*M* = 458.37 ms, *SD* = 27.09). Once again, the mid-range P300 latencies for right targets (*M* = 472.47 ms, *SD* = 27.21) did not differ significantly from those in the two other conditions. In contrast to the full analysis of the patient and control P300 latencies, the significant main effect of Stimulus Condition was not qualified by a significant Stimulus Condition by Paradigm Version interaction. As indicated in Table 71, no other main effects or interactions reached statistical significance.

These results indicate that the P300 latencies of both patient subgroups showed evidence of stimulus differentiation effects regardless of the laterality of the eliciting stimuli but the effects reached statistical significance only when the eliciting stimuli were in the left (contralesional) rather than right (ipsilesional) visual field. In contrast to the patient results from the full analysis of the P300 latencies, there was no statistically significant evidence of a relative stimulus probability effect in the P300 latencies of either subgroup of patients. In contrast to the preliminary analysis of the control P300 latencies, there was no significant Stimulus Condition by Paradigm Version interaction by which different patterns of stimulus differentiation effects for the 50% and 25% target versions of the experimental paradigm could be derived.

Preliminary analysis of the P300 latencies of the controls yielded results that suggested that this aspect of the P300 might be useful for the elicitation of stimulus differentiation and relative stimulus probability effects. However subsequent analyses in which the patient and control data were compared and in which the patient subgroup data were compared demonstrated that these effects involving the latency of the P300 were highly unstable.

P200 Amplitudes. Analysis of the patient subgroups' P200 amplitudes (see Table 72) yielded a significant main effect of Stimulus Condition, F (2, 16) = 6.16, p = .010, η^2 = 0.44. Post hoc analysis revealed that the P200 amplitudes were attenuated in the non-target condition (M = 1.24 µV, SD = 0.89) compared to those in the left (M = 2.93 µV, SD = 1.04) or right (M = 3.74 µV, SD = 1.11) target conditions. The P200 amplitudes for the left and right targets did not differ significantly. As indicated in Table 72, no other main effect or interaction reached statistical significance.

Despite their differing behavioural manifestations of hemineglect on the experimental measure, these results indicate that the P200 amplitudes of both subgroups of patients with hemineglect showed significant stimulus differentiation effects when the eliciting stimuli were in the left (neglected) or right (intact) visual field. These findings stand in contrast to the lack of similar stimulus differentiation effects revealed during the preliminary analysis of the control P200 amplitudes.

P200 Latencies. Analysis of the patient subgroups' P200 latencies (see Table 73) yielded a significant main effect of Recording Site, *F* (2, 16) = 5.49, *p* = .015, η^2 = .595. Consistent with both the preliminary analysis of the control P200 latencies and the full analysis of the patient and control P200 latencies, post hoc analysis revealed that the latencies of the P200 were earliest at Pz and did not differ significantly at Fz and Cz. In contrast to the preceding analyses, the main effect of Recording Site was qualified, however, by a significant Group by Recording Site interaction, *F* (2, 16) = 4.77, *p* = .024, η^2 = 0.373 (see Table 74 for the data and Appendix F14 for a graph of the interaction). Post hoc analysis revealed that the P200 latencies for Non-Detectors were earliest at Pz and did not differ significantly at Cz or Fz (same pattern as the main effect obtained in the present analysis and in the two preceding analyses of the P200 latencies). In contrast, the P200 latencies for Delayed-Detectors did not differ significantly across the 3 recording sites. Thus, on the basis of the topographical distribution of the P200, the Non-Detectors but not the Delayed-Detectors were similar to the controls.

More importantly, there was also a significant Group by Stimulus Condition interaction, $F(2, 16) = 4.13, p = .036, \eta^2 = 0.34$ (see Table 75 for the data and Appendix F15 for a graph of the interaction). Post hoc analysis revealed that the latencies for Non-Detectors did not differ significantly across the 3 stimulus conditions (same as Control performance). In contrast, the latencies for Delayed Detectors were significantly later for targets than for non-targets but only when the eliciting stimuli were in the right (intact) rather than left (neglected) visual field. Thus, for Delayed Detectors only, the latency of the P200 could be used to elicit stimulus differentiation effects but only when the eliciting stimuli were presented in the ipsilesional rather than contralesional visual field.

As indicated in Table 60, none of the other main effects or interactions reached statistical significance. Thus, there was no evidence of a significant relative stimulus probability effect in the P200 latencies of either subgroup of patients.

N200 Amplitudes. Analysis of the patient subgroups' N200 amplitudes (see Table 76) yielded a significant Group by Recording Site interaction $F(2, 16) = 4.18, p = .035, \eta^2 = 0.34$ (see Table 77 for the data and Appendix F16 for a graph of the interaction). Post hoc analysis revealed that the N200 amplitudes for Non-Detectors were most negative at Fz with no significant difference at Cz or Pz. For Delayed Detectors, the N200 amplitudes did not differ significantly across the three recording sites. Thus, the topographical distribution of the amplitude of the N200 differ for the two patient subgroups with neither subgroup showing the same posterior distribution revealed during the preliminary analysis of the controls' N200 amplitudes.

As indicated in Table 76, no other main effect or interaction reached statistical significance. Thus, consistent with the results of the preliminary analysis of the controls' ERPs, the N200 amplitudes of both patient subgroups showed no significant stimulus differentiation or relative stimulus probability effects.

N200 Latencies. Analysis of the patient subgroups' N200 latencies (see Table 78) yielded a significant main effect of Recording Site, $F(1.2, 16) = 5.81, p = .034, \eta^2 = 0.42$. Consistent with the topographical distribution revealed for the patient group during the full analysis of the patient and control data, post hoc analysis revealed that the N200 latencies for both subgroups were earliest at Pz ($M = 256.9$ ms, $SD = 11.53$)

and did not differ significantly at Fz (*M* = 286.7 ms, *SD* = 11.89) or Cz (*M* = 269.1 ms, *SD* = 11.21). Whereas the frontal distribution of the two patient subgroups' N200 latencies did not differ from one another, it contrasted with the controls' scalp distribution, for which the N200 latencies did not differ significantly across the three recording sites.

As indicated in, no other main effect or interaction reached statistical significance. Thus, consistent with the results of the preliminary analysis of the controls' ERPs, the N200 latencies of both subgroups showed no evidence of a stimulus differentiation or relative stimulus probability effect.

P300 Amplitudes and Experimental Task Sensitivity at the Level of the Individual

As follow up to the group-based analyses, each participant's P300 amplitudes were analysed separately to determine whether a case-study approach might reveal evidence of implicit stimulus differentiation effects within the versions of the Lateralized Oddball Paradigms and relative stimulus probability effects between the versions of the paradigms. The mean P300 amplitudes and standard deviations recorded at the midline sites for the target and non-target trials of the 25% and 50% target versions of the Lateralized Oddball Paradigms have been presented in Appendix G1 for each control and in Appendix G2 for each patient. Mean P300 amplitude difference scores for each side of target presentation have also been presented for each participant in Appendices G1 and G2. The P300 amplitude difference scores were calculated by subtracting the mean P300 amplitude for the non-target condition from those of the right or left target condition. Positive difference scores indicated that the pattern of the predicted stimulus differentiation effect was present in the waveform comparison. As indicated in Appendices G1 and G2, 1-tailed independent *t*-tests were used to determine when the pattern of the stimulus differentiation effect was of great enough magnitude to be considered statistically significant.

The data presented in Appendices G1 and G2 have been summarised in Table 79. This table contains the percentage of participants within each group or subgroup whose P300s showed the pattern of the predicted stimulus differentiation effect (i.e., a positive P300 amplitude difference score). As indicated in Table 79, the P300 amplitudes elicited for individual controls during the Lateralized Oddball Paradigms (particularly the 25% target version) provided a robust correlate of stimulus differentiation at Pz regardless of the visual field of the eliciting stimuli. At Pz, over 92.3% of the controls' P300 amplitude difference scores were positive (i.e., yielded the pattern of the predicted stimulus differentiation effect) regardless of the laterality of the eliciting stimuli or version of the experimental paradigm used. These P300 amplitude difference scores reached statistical significance for 61.5 to 69.2% of the controls for the 50% Target Version of the paradigm and for 76.9 to 84.6% of the controls for the 25% Target Version of the paradigm. Therefore, the percentage of controls who showed the predicted stimulus differentiation effect was consistently higher for the version of the paradigm with the lower (25% Target Version) than equal (50% target Version) proportion of target to non-target trials regardless of the laterality of the eliciting stimuli. Thus, these data provide additional support for the idea that the amplitude of the P300 was sensitive to the between paradigm version manipulation of relative stimulus probability for the controls. ERPs (recorded at Pz using the 25% Target Version of the Paradigm) from a control (C217) for whom the positive mean P300 amplitude difference scores reached statistical significance regardless of the laterality of the eliciting stimuli, has been presented in Figure 16.

For the Delayed Detectors, inspection of Table 79 indicated that the amplitude of the P300s elicited by the experimental paradigms provided an electrophysiological correlate of stimulus differentiation comparable to that of the controls when the eliciting stimuli were in the right or left visual field. At the Pz site, the pattern of the predicted stimulus differentiation effect was observed for a majority of the Delayed Detectors (100% of cases for the right visual field and 80% of cases for the left visual field). These patterns reached statistical significance for 60 percent of the Delayed Detectors regardless of the visual field in which the stimuli were presented and regardless of the version of the paradigm used.

For the Non-Detectors, results comparable to those of the controls and Delayed Detectors were also obtained for the ipsilesional but not contralesional stimuli. The P300s for the ipsilesional stimuli showed the expected pattern of stimulus differentiation for 80% of the Non-Detectors with statistical significance reached for 60% of the cases. The contralesional stimuli showed the expected pattern of stimulus differentiation for 60 to 80% of the Non-Detectors (depending on the version of the paradigm used) with the pattern reaching statistical significance for only two (40%) of the Non-Detectors. The P300s of one of these Non-Detectors (P113) showed a significant stimulus differentiation effect at Pz for the 50% Target Version of the paradigm. The P300s of the other Non-Detector (P114) showed a significant stimulus differentiation effect at Cz for the 25% Target Version of the Paradigm. The ERPs (recorded at Pz using the 25% Target Version of the paradigm) for the first of these Non-Detectors (P113) whose mean P300 amplitudes showed statistically significant stimulus differentiation effects for both left and right stimuli have been presented in Figure 16.

While admittedly atypical, these two cases are of particular interest because their P300 amplitudes showed evidence of a significant stimulus differentiation effect even though the eliciting target stimuli had been behaviourally omitted (remained subjectively unavailable) due to visual hemineglect. Case-study results such as these suggest that P300 amplitudes elicited during the Lateralized Oddball Paradigms *may* show implicit stimulus differentiation effects for contralesional stimuli that have been omitted due to visual hemineglect. However, these implicit effects were not elicited with the same reliability or consistency with which the effects were elicited for stimuli on the non-neglected side. The case study approach revealed no evidence that the P300s of either patient group were sensitive to the between version manipulation of relative stimulus probability even for stimuli presented to the ipsilesional (non-neglected) visual field.

DISCUSSION

Review of the Experimental Goals

A Lateralized Oddball Paradigm was developed to investigate the P300 as an ERP correlate of information processing for patients with visual hemineglect. More specifically, the degree to which the amplitude of the patients' P300s can be used to reliably differentiate between targets and non-targets when these stimuli are presented to the intact or neglected visual field was examined. Of particular interest was the extent to which P300 amplitudes would be sensitive to the manipulation of relative stimulus probability in the neglected visual field when concurrently obtained behavioral data indicates that these contralesional stimuli were not available to the patients' subjective awareness. In addition, a somewhat exploratory analysis of the amplitudes and latencies of the earlier ERP components elicited using this P300-based paradigm was intended to address controversy concerning whether the abnormalities associated with hemineglect primarily involve early or late stages of information processing.

Review of the Experimental Measure

A Lateralized Oddball Paradigm was developed with the amplitude of the P300 as the primary electrophysiological correlate of interest. One version of this computerized paradigm contained an equal number of target and non-target trials (the 50% Target Version). The other version contained a lower ratio of target to non-target trials (the 25% Target Version). For both versions of the paradigm, the trials involved simultaneous presentation of two stimuli with one to the left and the other to the right of central fixation (a continuously present small plus sign). Target trials consisted of a target (the letter O) and non-target (the letter X) with the target to the left or right equally often. Non-target trials consisted of a non-target (letter X) in each position. Participants pressed a button for every target (letter O) detected within a randomized sequence of target and non-target trials. Target detection by age-matched healthy controls was not expected to differ as a function of target laterality. In contrast, the behavioral manifestation of the patients' hemineglect on this extinction-based paradigm was expected to involve greater impairment for contralesional relative to ipsilesional target detection. In addition to the accuracy and latency of target detection, ERPs time-locked to the onset of each target and non-target trial were obtained.

How the Experimental Paradigm Differs from Previous Paradigms

As reviewed in the introductory chapters, previous reports of the P300 for patients with hemineglect were based on data from stimuli that were detected more slowly in the contralesional than ipsilesional visual field (L'hermitte et al., 1985; Verleger et al, 1996). The delayed contralesional response times in these investigations indicated that the patients were subjectively aware of the contralesional stimuli. Thus, these previous investigations permitted comparison of the electrophysiological correlates of information processing in the contralesional and ipsilesional visual fields of patients with visual hemineglect. However, their results do not address the electrophysiological correlates of implicit processing that may occur in the patients' contralesional visual field (i.e., when patients appear to be unaware of the contralesional information). Moreover, with respect to the P300s elicited in the contralesional visual field of patients with visual hemineglect, the sensitivity of the amplitude of this component to the manipulation of relative stimulus probability has not previously been assessed directly. For example, in the investigation by L'hermitte et al. (1985), P300s were elicited in the contralesional visual field of patients with visual hemineglect using lateralized green diodes flashed on a background of a reversing illuminated checkerboard. Consequently, relative stimulus probability was only one of the ways in which the lateralized green diodes differed from the background stimuli. For example, compared to the lateralized green diodes, the background stimuli were non-lateralized, larger in overall size, different in stimulus form, and different in color. Thus, the extent to which these P300 amplitude stimulus differentiation effects may be attributed to the experimental manipulation of relative stimulus probability was not addressed. In the investigation by Verleger et al. (1996), the ERP components were elicited within the context of a covert cueing paradigm that provided insight into information processing in the neglected visual hemifield but not with respect to the manipulation of relative stimulus probability.

In this experiment, the Lateralized Oddball Paradigm was developed to elicit ERPs for contralesional stimuli even when they were not detected due to hemineglect. The concurrent behavioral target-detection data was intended to permit sorting of the ERPs according to whether or not subjective awareness was demonstrated for the eliciting target stimuli. Thus, the electrophysiological correlates of implicit processing of the contralesional information could be compared to the explicit processing of the same information in the ipsilesional visual field. Moreover, to permit direct assessment of whether or not the P300 effects elicited in the patients' ipsilesional and contralesional visual field were sensitive to the manipulation of relative stimulus probability, two version of the Lateralized Oddball Paradigm were developed. As already described, the two versions differed in their relative proportions of target and non-target trials. Within each visual field, elicitation of significantly larger P300 amplitude stimulus differentiation for the version with the lower (25% Target Version) rather than equal

(50% Target Version) proportion of target and non-target trials would indicate that the P300 amplitudes were sensitive to the manipulation of relative stimulus probability.

Thus, for the present investigation, a computerized paradigm was developed to examine the P300 as a possible correlate of implicit processing for contralesional stimuli that remain subjectively unavailable to patients with visual hemineglect. Moreover, the paradigm was designed to determine whether or not the amplitude of the P300 is sensitive to the manipulation of relative stimulus probability, particularly for contralesional stimuli that elicit no concurrent behavioral evidence of subjective awareness.

Task Validation of the Lateralized Oddball Paradigm

Behavioral Results. Overall, analysis of the age-matched healthy controls' behavioral responses revealed good experimental task validity. Regardless of the visual field in which the stimuli were presented, the detection of oddballs was nearly perfect, the rate of false positive responses to non-targets was low, and the rate of target detection did not differ significantly. The controls' rate of target detection was significantly slower, however, for the 25% rather than 50% target version of the paradigm. This difference in reaction time was consistent with the expectation that the version of the paradigm in which the targets were the rarest would be a more challenging test of vigilance compared to the version in which the targets were relatively more common (Parasuraman, Warm, & See, 1998). As a final comparison, little inter-subject variability from the group-based results was evident when each control's behavioral response data were examined separately. As expected, there were no significant differences in the controls' behavioral responses that could be attributed to the laterality of the stimuli. Thus, good experimental task validity was demonstrated for the behavioral component of the Lateralized Oddball Paradigms during analysis of the age-matched healthy participants' data.

P300 Amplitudes. Analysis of the controls' P300 amplitudes also revealed good experimental task validity. Overall, the amplitude of this component showed the expected centro-parietal scalp distribution within a time range (i.e., 300 to 700 ms) consistent with other samples of healthy older adults (Friedman, 1995; Picton et al., 1995). More importantly, the anticipated stimulus differentiation effects were successfully elicited in the controls' P300 amplitudes regardless of the laterality of the eliciting stimuli. As expected, the amplitudes of the P300s were more positive for targets than for non-targets whether these stimuli were in the left or right visual field.

For both the 25 and 50% target versions of the paradigm, the P300 amplitude stimulus differentiation effects were largest at Pz, the posterior recording site. However, these effects were statistically significant for the 25% but not 50% target version of the paradigm. In other words, regardless of the laterality of the eliciting stimuli, the P300 stimulus differentiation effects were more robust for the version of the paradigm in which the relative proportion of targets was the most rare.

Analysis of the P300 amplitude data at an individual rather than group level revealed the pattern of the expected stimulus differentiation effects for almost every control (over 92.3% of cases at the Pz site regardless of the laterality of the eliciting stimuli or version of the paradigm used). These patterns were statistically significant for a majority of the controls (61.5 to 69.2% of cases for the 50% Target Version of the paradigm and 76.9 to 84.6% of cases for the 25% Target Version) regardless of the laterality of the eliciting stimuli. The percentage of controls whose P300s showed the predicted stimulus differentiation effect was consistently higher for the version of the paradigm with the lower rather than equal ratio of target to non-target trials. Thus, for the individuals within this sample of healthy elderly adults, the P300s elicited by the experimental paradigms provided a robust measure of stimulus differentiation within each version of the paradigm and were also sensitive to differences in relative stimulus probability between the versions of the paradigms regardless of the laterality of the eliciting stimuli.

P300 Latencies. Across the three recording sites, both versions of the paradigm yielded similar patterns of P300 peak latency results (i.e. earlier peaks at Fz than at Cz or Pz) but statistical significance of this site effect was reached for the 50% but not 25% target version of the paradigm. The preliminary analysis of the controls' P300 latencies unexpectedly revealed possible stimulus differentiation but not relative stimulus probability effects for both left and right stimuli. This evidence took the form of a statistically significant stimulus condition by paradigm version interaction. This interaction was characterized by P300 latencies that were significantly longer for target than for non-target trials for the 50% target version of the paradigm and P300 latencies that did not differ significantly between target and non-target trials for the 25% target version of the paradigm. These results suggest that the P300 latencies were more sensitive to the manipulation of stimulus targetness within the 50% target version of the paradigm than they were when the target trials were more rare. It may be of note that the behavioural responses were generally slower in the 25% target version condition. However, it could also be that the latencies of the non-targets were earlier than those of the targets due to a possible scoring artefact that arises because the amplitudes elicited by non-targets are generally of smaller magnitude compared to those elicited by targets. Given the potential scoring bias, the conclusions concerning stimulus differentiation effects based on ERP amplitudes are generally more reliable than are conclusions based on the corresponding latencies. Moreover, subsequent analyses in which the patient and control data were compared and in which the patient subgroups' data were compared confirmed that the stimulus differentiation effects involving the P300 latencies were generally less stable than were those effects when based on amplitude data.

With respect to task validation, the most important result from analysis of the P300 latencies was that there were no significant differences on the basis of the laterality of the target stimuli. The stimulus differentiation effects elicited when the P300 latencies of the targets and non-targets were compared are noteworthy because they were unexpected. However, because the Lateralized Oddball Paradigm was designed with the amplitude rather than latency of the P300 as the ERP correlate of interest, differences in latency but not in amplitude between target and non-target stimuli may reflect a scoring artefact. Thus, the unexpected P300 latency stimulus differentiation effects have been noted but will not be discussed further.

Earlier ERP Components. Little of theoretical interest emerged when the peak amplitudes and latencies of the controls' earlier P200 or N200 components were analysed. The P200 peak amplitudes were of greatest magnitude at Cz and earliest at Pz. The N200 peak amplitudes were of greatest magnitude at Pz with corresponding latencies that did not differ across the three recording sites. These topographical distributions did not differ as a function of the laterality of the eliciting stimuli. More importantly, analysis of the amplitudes and latencies of these components revealed no statistically significant stimulus differentiation effects for stimuli in the left or right visual field of the age-matched healthy controls. These results stand in contrast to the results of other investigations using more standard versions of the oddball task in which some components prior to the P300 have been associated with stimulus differentiation and even relative stimulus probability effects (Gooden et al., 1978; Kutas & Dale, 1997; Näätänen, 1992; Ritter et al., 1982; Squires et al., 1977). However, the stimulus differentiation and relative stimulus probability effects elicited in these previous investigations have generally been more robust for the amplitude of the P300 compared to the amplitudes of the earlier components. Thus, as expected, the P300 was the only component associated with significant stimulus differentiation and relative stimulus probability effects when the Lateralized Oddball Paradigms were administered to the present sample of healthy elderly controls.

Patient Performance on the Lateralized Oddball Paradigm.

Behavioral Responses. Overall, the patients detected fewer targets compared to the near-perfect performance of the controls. They also committed significantly more false positive responses than did the controls, but these rates were nevertheless not high enough to warrant concern about indiscriminant responding, failure to comprehend instructions, or inattention to task. These results simply indicate that the experimental paradigm was generally more challenging for the patients than it was for the controls.

Consistent with their left visual hemineglect, the patients reliably showed lateralized deficits that involved greater impairment for left rather than right target detection. At an individual level, however, the patients' behavioral manifestation of the left-lateralized impairments took two forms. For half of the patients (Non-Detectors), the left-lateralized impairment relative to control performance on the experimental measure involved greater left than right target omissions although the detection of right targets was also delayed for these individuals. For the other half of the patients (Delayed-Detectors), behavioral impairment on the experimental measure was specific to the left targets and involved a delay in detection. Thus, contralesional impairment on the behavioral component of the experimental measure involved the incidence of detection for some patients (Non-Detectors) and the rate of detection for others (Delayed Detectors).

Further Comparison of the Patient Subgroups. Reducing the relative proportion of the targets from 50% to 25% had the desired effect of increasing the attentional demands of the Lateralized Oddball Paradigm for both patient subgroups. As previously noted, the controls' detection times were significantly faster for the paradigm version with the equal (i.e., 50% target version) rather than lower (i.e., 25% target version) ratio of targets to non-targets whether the targets were presented in the left or right visual field. Similarly, the patients' response time data showed the same between-paradigm difference, although the analysis could be conducted using data collected for ipsilesional targets only since the Non-Detectors' tended to omit the contralesional targets altogether. Nevertheless, these results indicate that the between paradigm reduction of the relative proportion of targets to non-targets successfully increased the attentional demands of the experimental task for all participants.

A tendency to selectively omit contralesional targets (Non-Detectors) could be conceptualised as a more severe manifestation of hemineglect compared to a tendency to be selectively delayed in the detection of contralesional targets (Delayed Detectors). To address this question, total scores on the standardised Sunnybrook Neglect Battery (Black et al., 1990; 1994) were used to compare the severity of neglect for the two patient subgroups. Whereas the Delayed Detector subgroup was composed of patients whose severity rating on the battery ranged from mild to moderate, the Non-Detector subgroup was composed of patients whose severity of neglect ranged from mild to severe. As predicted, Non-Detectors were on average more impaired on the clinical screening measure than were Delayed Detectors but the difference did not approach statistical significance, perhaps due to the small sample size (i.e., $n = 5$ per cell).

Despite the small sample size, however, a computerised chi-square-based pre-experimental neglect verification task from Experiment One was sensitive to the group differences in the behavioural manifestations of hemineglect on the Lateralized Oddball Paradigms. However, the pre-experimental measure from Experiment One and the experimental measure of Experiment Two were similar in that they were developed as computerised measures of basic target detection. In contrast, the Sunnybrook Battery provides a composite score based on several paper and pencil subtests that are sensitive to features of hemineglect that likely extend beyond an impairment in the basic detection of contralesional stimuli (Black et al, 1990, 1994). The differing sensitivities of the different measures to the patients' hemineglect are consistent with the task specificity typically reported for manifestation of the hemineglect deficits (Bisiach, 1999).

There was additional behavioural evidence from the Lateralized Oddball Paradigm consistent with the idea that the Non-Detectors were more generally impaired than were the Delayed Detectors. In contrast to left-target detection impairments, which provide indices of neglect-specific deficits, right-target detection impairments provide potential indices of more generalised impairment for the patient participants. With respect to target response latencies, direct comparison of the control group's and patient subgroups' data was possible only for right targets because data for left targets was not available for the Non-Detectors. Compared to control performance, right target detection was impaired for Non-Detectors but not for Delayed Detectors. Thus, the two patient subgroups differed on a potential index of general impairment (i.e., ipsilesional response times) such that the Non-Detectors appeared to be more generally impaired than the Delayed-Detectors. These results are consistent with some of the non-lateralized attentional deficits (described in the introductory chapters), which have been reported to be strong predictors of the severity or persistence of hemineglect (Lavie & Robertson, 2001; Robertson, 1997, 2001).

Statistically, the Delayed Detectors committed significantly more false positive responses to non-targets than did the Non-Detectors or the Controls. While not sufficient in number to invalidate results, the higher rate of false positives in the Delayed Detector group suggests a possible bias to respond on the basis of a relatively small amount of information or the failure to inhibit a response when uncertain.

Overall, the unexpected behavioural manifestation of two distinct subgroups, which appeared to differ in severity of hemineglect and more general impairment, was important because it meant that the analysis of the ERP data had to be altered to address the primary experimental goal. Fortunately, the number of patients who demonstrated subjective awareness of the contralesional targets and who demonstrated no subjective awareness of the contralesional targets was equal and so data from these two patient subgroups were considered separately in the course of subsequent analyses. These comparisons permit the direct examination of questions pertaining to the presence and absence of subjective awareness of the eliciting stimuli. However, the smaller sample sizes associated with the subgroups would be associated with reduced statistical power.

Although not predicted, these differing manifestations of hemineglect in the behavioral responses of the patients are consistent with the heterogeneity that has frequently been reported in the behavioral manifestation of the hemineglect syndrome on other clinical and experimental measures (Banich, 1997; Bisiach, 1999; Rafal, 1998; Vallar, 1998). These results also emphasize the importance of case study or small sample investigations for a syndrome as heterogeneous as hemineglect (Code, 1996).

ELECTROPHYSIOLOGICAL RESULTS

P300 Amplitude Stimulus Differentiation and Relative Stimulus Probability Effects

Full Analysis of Patient and Control Group P300 Amplitudes. In contrast to the P300 amplitude stimulus differentiation effects of the controls, which were significant regardless of the laterality of the eliciting stimuli, those of the patients' were reliable for the stimuli in the intact but not neglected visual field. Also in contrast to the P300 amplitudes of the controls, those of the patients were not sensitive to the manipulation of relative stimulus probability between the two versions of the experimental paradigm, even when the eliciting stimuli were in the patients' intact visual field. Thus, full analysis of the patients' and controls' P300 amplitudes revealed no significant evidence of processing of the stimuli in the patients' neglected visual field.

Follow up Analysis of Patient Subgroup P300 Amplitudes. Although it did not reach statistic significance, the pattern of the expected stimulus differentiation effect was seen in the P300s elicited by stimuli in the patients' neglected visual field. Therefore, analysis of the patient subgroups' P300 amplitudes was undertaken. The purpose was to determine whether stimulus differentiation effects might be elicited for the Delayed Detectors. The analysis revealed no significant subgroup differences. Consistent with the full analysis of the patient and control group data, reliable stimulus differentiation effects were elicited for the stimuli in the intact but not neglected visual field regardless of whether the targets in the neglected field were detected (Delayed Detectors) or not (Non-Detectors). Also consistent with the overall patient group results, no significant relative stimulus probability effects were elicited in the P300 amplitudes of either patient subgroup. Thus, analysis of the P300 amplitudes at the level of the patient subgroups revealed no significant evidence that stimuli in the neglected visual field were being processed sufficiently to elicit a P300 stimulus differentiation effect even for the patients who behaviourally detected the stimuli in the neglected field (Delayed Detectors).

Further Follow up Analysis of Individual Participant P300 Amplitudes. Although not statistically significant, some evidence of the pattern of the expected stimulus differentiation effect was however seen in the P300s for stimuli in the neglected field of the Delayed Detectors (i.e., at the Pz when the 25% target version of the paradigm was used). In contrast, the pattern of the expected stimulus differentiation effect was not seen for stimuli in the neglected field of the Non-Detectors regardless of the recording site or paradigm version used. Therefore, the P300s of each patient were analysed separately to determine whether a case study approach would reveal evidence of statistically significant stimulus differentiation effects for the patients who detected or failed to detect the contralesional stimuli.

For stimuli in the intact visual field, the P300 amplitudes of every patient showed the pattern of the expected stimulus differentiation effect with these differences reaching statistical significance for 60% of the cases ($n = 6$). Evidence of the stimulus differentiation effect was less robust in the P300s for stimuli in the neglected visual field. Among the patients who detected the targets in the neglected visual field (Delayed Detectors, $n = 5$), P300 stimulus differentiation effects for stimuli in the neglected visual field were evident for a majority (80%) of the cases with statistical significance met in about half (60%) of the cases. Among the patients who did not detect targets in the neglected field (Non-Detectors, $n = 5$), the P300 amplitude stimulus differentiation effects for stimuli in the neglected field were also evident for a majority of the cases (60 to 80% depending on the paradigm version used) but with significance met for only two cases (40%). Thus, when the patients' data were analysed at an individual rather than group level, reliable stimulus differentiation effects for stimuli in the neglected field were revealed for some patients ($n = 5$) including some who showed no subjective awareness of the eliciting stimuli (i.e., Non-Detectors, $n = 2$). Although atypical, the two Non-Detectors for whom reliable P300 amplitude stimulus differentiation effects were elicited for stimuli in the neglected field indicate that the effect can be elicited implicitly by stimuli that have escaped subjective awareness due to severe contralesional hemineglect.

When analysed at an individual level, the number of patients within either the Non-Detector or Delayed Detector subgroups was too small to permit meaningful evaluation of the sensitivity of the P300 amplitudes to the between paradigm manipulation of relative stimulus probability. This limitation was particularly evident when the number of stimulus differentiation effects that reached significance were considered.

Implications of the P300 Amplitude Stimulus Differentiation Results

The main question concerned whether the P300 amplitude might serve as a correlate of stimulus processing presumed to take place implicitly in the neglected visual field of patients with visual hemineglect. As summarised above, group level analyses of the P300 amplitudes would indicate that they could not. At a group and subgroup level, the P300 amplitudes were shown to be sensitive to the targetness of stimuli in the intact visual field. However, P300 amplitudes were not sensitive, at the group level, to stimulus differentiation in the neglected visual field even for the subgroup of patient who actually detected the contralesional targets. In contrast, when analysed at an individual level, there was evidence of stimulus differentiation in the amplitudes of the P300 for five cases, including two cases that showed no subjective awareness of the eliciting stimuli. Thus, these case study data provide at least some evidence that P300 amplitudes can be sensitive to the experimental manipulation of stimuli in the neglected visual field of some patients who showed no subjective awareness of the eliciting stimuli. These case-study results are intriguing because they bring into question the widely held assumption that P300 amplitude effects represent unequivocal evidence of attention being allocated to the eliciting stimuli (Andreassi, 2001; Kutas & Dale, 1997; Pritchard, 1981). However, these case study effects need to be replicated before this standard interpretation of the P300 amplitude effect can be dismissed.

Implications for an Understanding of Hemineglect. At the group and subgroup level, the presence of stimulus differentiation effects in the intact but not neglected visual field is consistent with the lateralized disruptions of attentional processing associated with a diagnosis of hemineglect. Also, at the group and subgroup level, the lack of significant relative stimulus probability effects even for stimuli in the intact visual field suggests a more general disruption of attentional processing that goes beyond the more lateralized disruptions that have typically been the focus of investigations of the hemineglect syndrome. Once again, these non-lateralized attentional deficits are consistent with the more generalised reduction in perceptual load or attentional capacity that have recently been reported as a modulating factor for the strong ipsilesional bias typically associated with patients with hemineglect (Lavie & Robertson; Robertson, 1997, 2001). However, individual case study results are consistent with the view that information presented to the neglected field can be processed implicitly (Driver & Mattingley, 1998). Moreover, the case study results indicate that this implicit processing can be reflected in the P300 amplitude stimulus differentiation effect for some individuals.

The individual case study results suggest that not all patients with hemineglect process contralesional information or, more conservatively, that not all patients with hemineglect process contralesional information in the same way. Consequently these results emphasise the importance of a case study approach for the investigation of attentional factors in the hemineglect syndrome. Whereas it is important to stress once again the need for replication of these case-study results, nevertheless, these results are consistent with other evidence that high-level implicit processing of information can occur in the contralesional visual field of some patients with hemineglect (Driver & Mattingley, 1998).

Thus, whereas the elicitation of a P300 in the contralesional visual field of patients with hemineglect has been demonstrated in patients with delayed but not absent responses (L'hermitte et al., 1985; Verleger et al, 1996), the results of Experiment Two indicate that this effect can be seen even when there is no behavioural evidence that the patients were aware of the stimuli. However, these P300 effects appear not to be typical of the information processing of patients with visual hemineglect. Moreover, in contrast to the P300 amplitudes of the controls, those of the patients were not sensitive to the between version manipulation of relative stimulus probability even for the ipsilesional stimuli that elicited statistically significant stimulus differentiation effects. This lack of sensitivity was evident when the patients' data were sub-grouped in accordance with those who detected the left-sided targets (Delayed Detectors) and those who did not (Non-Detectors). This lack of sensitivity could not be assessed reliably when the patients' data were analysed at an individual rather than group level.

Implications for an Understanding of the P300. The statistically reliable P300 stimulus differentiation effects for the two Non-Detectors who demonstrated no subjective awareness of the eliciting stimuli bring into question the widely held assumption that P300 amplitude modulation effects represent unequivocal evidence of subjective awareness of the eliciting stimuli (Andreassi, 2000; Kutas & Dale, 1997). Once again, replication of these results and further investigation will be necessary before it can be stated with confidence that the P300 amplitude stimulus differentiate effect can occur in the absence of subjective awareness of the eliciting stimuli. Nonetheless, the P300 amplitude stimulus differentiation effect can be elicited more robustly when controlled processing of the eliciting stimuli is unrestricted (i.e., in the intact visual field) than when the more controlled forms of attentional processing are relatively unavailable (i.e, in the neglected visual field). Moreover, the failure to elicit statistically significant stimulus differentiation effects for the contralesional stimuli for which patients with visual hemineglect demonstrated subject awareness (i.e., the delayed detector subgroup) demonstrate a potential dissociation between the behavioural response and P300 amplitude data. (i.e., some of the patients who showed reliable behavioural responses to the left targets did not consistently demonstrate reliable target differentiation in the amplitude of their P300s).

When trying to account for why the P300 stimulus differentiation effect was more difficult to elicit for contralesional rather than ipsilesional stimuli even when reliable behavioural responses are made, several alternative explanations may be proposed. For example, failure to elicit statistically significant stimulus differentiation effects in the group or subgroup analysis of the P300 amplitudes elicited contralesionally might be due to the smaller sample size of the patient group ($N = 10$) or subgroups ($n = 5$ each) relative to that of the controls ($N = 13$). It might be that statistically significant stimulus differentiation effects, particularly in the Delayed Detector subgroup might be reached with a larger sample size. However, despite the small sample sizes, the group and subgroups' stimulus differentiation effects for stimuli in the ipsilesional visual field did reach statistical significance. These within-subject comparisons demonstrate that any evidence of stimulus differentiation in the neglected visual field of the patients who detected (i.e., Delayed Detectors) or failed to detect (Non-Detectors) the contralesional stimuli was significantly less robust compared to the stimulus differentiation effects elicited when the same stimuli were presented ipsilesionally.

With respect to the lack of stimulus probability effects in the patient group, it should be noted that this too could not be accounted for by the smaller sample size. In the patients' ipsilesional visual field, the mean difference between targets and non-targets in the ipsilesional field is virtually the same for both versions of the paradigm (equally large at about 8 μV each). In the controls' data, the amplitude difference was very small for the 50% target version (i.e., about 2 μV) and it was about three times larger in the 25% version (about 6.5 μV). Thus, failure to find relative stimulus probability effects in the patient group did not arise simply do to a smaller sample size but because the mean differences between targets and non-targets for both versions of the paradigm were almost identical.

Increased variability in the responses of patients with hemineglect to contralesional stimuli has been proposed as the basis of the deficits seen in behavioural data (Bartolomeo et al., 2001). In the present data, the patients' behavioural responses were characterised by a bimodal distribution. Whereas one subgroup rarely responded to contralesional targets, the other subgroup responded most of the time. For those who responded, there was evidence of latency delay but not greater variability in the response times for contralesional relative to ipsilesional stimuli. For the electrophysiological data, the only measure of variability available was the between subject variability which does not address the hypothesis of Bartolomeo et al., 2001. To properly address the question, one would have to specifically examine the influence of variability on amplitudes using for example, woody filters, which would allow one to realign peaks prior to analysis. Examination of this issue has been undertaken with respect to the flattened P300 associated with schizophrenia (Ford, White, Lim, & Pfefferbaum, 1994) and traumatic brain injury (Unsal & Segalowitz, 1995). In both of these investigations, variability of the P300 latencies was greater in the patient relative to the control groups. However, in neither investigation did this difference in variability account for the observed differences in the amplitude of the P300. Thus, it is unlikely that increased variability in the latencies of the P300 would account for the lack of statistically significant P300 differentiation effects for stimuli in the patients' neglected visual field. Nonetheless, to properly address this question empirically would require more focused analyses that go beyond the scope of this thesis.

The amplitude of the P300 can be influenced by the confidence of target detection (Andreassi; 2000; Donchin, 1981; Kerkhof & Uhlenbroek, 1981; Parasuraman & Beatty, 1980; Sutton, Ruchkin, Munson, Kietzman, & Hammer, 1982). Therefore, for the Delayed-Detectors, it could be that P300 amplitude differentiation effects were not elicited for stimuli in the neglected field because the patients were less confident of whether they detected targets on the contralesional rather than ipsilesional side. This explanation may have some validity in that the Delayed-Detectors, were more likely to produce false positive responses than were the Non-Detectors or Controls, suggestive of a lower response threshold (i.e., they were more likely to respond at lower levels of confidence). The significant delay in the patients' detection of the targets in the neglected rather than intact visual field could also be interpreted as potential evidence of a relatively lower level of confidence. This hypothesis could be addressed in follow up studies by obtaining confidence ratings for each target as long as this dual task did not prove too difficult for this type of patient.

Pre-P300 Amplitudes and Stimulus Differentiation

Altogether, three ERP components were identified in the waveforms of the participants (i.e., the P200, N200, and P300). The amplitude of the P300 was the primary component of interest because it has consistently been elicited by the experimental manipulation of relative stimulus probability in standard Oddball paradigms (Adreassi, 2000; Coles & Rugg, 1995; Kutas & Dale, 1997). However, as described in the introductory chapters, the amplitude of preceding ERP components have also been reported to be sensitive to the experimental manipulation of stimulus targetness and relative stimulus probability (Kutas & Dale, 1997). Therefore, working backward from the P300, the amplitudes of the N200 (2nd component) and P200 (1st component) were analyzed to determine whether they might reflect a sensitivity to stimulus targetness or relative target probability for the participants with or without visual hemineglect.

Consistent with the N200 amplitudes of the controls, those of the patients revealed no statistically significant stimulus differentiation or relative stimulus probability effects regardless of the laterality of the eliciting stimuli. Moreover, no statistically significant evidence of these effects was evident in the N200 amplitudes of the patients in the Non-Detector or Delayed Detector subgroups.

In contrast, the P200 amplitudes of the patients differed from those of the controls. Specifically, the P200 amplitudes in the control data showed no statistically significant stimulus differentiation effects whereas the patients' P200 amplitudes were significantly more positive for the targets than for the non-targets regardless of the laterality of the eliciting stimuli. Moreover, these statistically significant effects were evident in the P200 amplitudes of the Non-Detectors and Delayed Detectors, again regardless of whether the eliciting stimuli were in the ipsilesional or contralesional visual field. Thus, the P200 amplitudes provided evidence that information pertaining to the identity of the stimuli was processed in the patients' neglected visual field despite the absence of a statistically significant P300 stimulus differentiation effect. Moreover, these results indicate that the processing occurred implicitly in the neglected field for some of the patients (i.e., for Non-Detectors).

These unexpected findings, which require replication, indicate that prior to the elicitation of the P300 component, the information processing of the patients differed from normal control performance regardless of whether the eliciting stimuli were presented in the left (neglected) or right (non-neglected) visual fields. Because the difference in processing revealed by analysis of the P200 amplitude data was not lateralized for stimuli presented to the contralesional visual field of the patients with left hemineglect, it likely reflects the impact of the stroke in general or possibly the medications that were being used to treat it rather than the visual hemineglect *per se*. In future investigations, inclusion of a control group consisting of patients with right hemisphere damage and no visual hemineglect would be necessary to empirically evaluate between these alternatives. The P200 amplitudes of the patient group or patient subgroups revealed no statistically significant evidence of relative stimulus probability effects regardless of the laterality of the eliciting stimuli.

The P200 stimulus differentiation effects are consistent with growing evidence that considerable information processing may be revealed in remarkably early components of the ERP. For example, Haline, Schendan, Ganis, & Kutas (1998) have recently provided ERP evidence that the visual perceptual categorization of words and faces occurs within the first 150 ms from stimulus onset. Although speculative, it may be that the evidence of early processing of stimulus identity was evident in the patient and not control data due to some form of general release from inhibition associated with the stroke. This speculative interpretation may be supported by the observation that components preceding the P300, such as the P200 and N200, have been associated with amplitude increases during the reduction of subjective awareness or lowered state of arousal associated with the onset of sleep (Segalowitz, Ogilvie, & Simons, 1990). Similarly, the amplitudes of some of these earlier components of the ERP have been observed to be enhanced in patients with brain dysfunction or injury when higher-order controlled processes were inadequate (Robaey, Breton, Dogus, & Renault, 1992). This type of release from cortical inhibition (or cortical disinhibition) has most typically been reported for damage to the frontal rather than parietal lobes for very early components within auditory (Alain & Woods, 1999; Knight, Scabini, & Woods, 1989) and somatosensory (Yamaguchi & Knight, 1990) ERPs. ERP evidence of similar disinhibition in the visual modality for patients with hemineglect would be in keeping with either hemispheric asymmetry (Mesulam, 1999) or cortical network (Heilman et al, 1985; Kinsbourn, 1993) accounts of the syndrome.

For patients with hemineglect, the ERP results from Experiment Two demonstrate that the P300 may not be the most sensitive electrophysiological correlate of the implicit processing of stimulus differentiation in the Lateralized Oddball Paradigm. Although it requires replication, an earlier component, the P200 may be more sensitive to implicit processing especially once effects of more controlled processing have been disrupted (Delayed Detectors) or removed (Non-Detectors). Alternatively, the electrophysiological evidence may indicate that the processing of visual stimuli is qualitatively different in both the ipsilesional and contralesional visual fields following stroke. The information may follow different processing routes even when the contralesional stimuli are detected and the subsequent processing results in a behavioural response. This interpretation would be consistent with parallel route conceptualisations of information processing (Driver & Mattingley, 1998) Further study with additional patients would need to be conducted to determine the validity of these data-based speculations.

Abnormalities in the ERPs of Patients with Visual Hemineglect

When the ERPs of patients with neurological impairment show abnormalities compared to those of age-matched healthy controls, the abnormalities may involve the amplitude, latency, topographical distribution, or a combination of these features for one or more components. Previous electrophysiological investigations of information processing in the neglected visual field have yielded mixed results. Some researchers reported that the early sensory processing of information in the neglected visual field remains intact but the later stages of visual processing become impaired, as measured by a lengthening in latency and decrease in amplitude of the P300 (e.g., L'hermitte et al., 1985). Others have reported that different early and late components are sensitive to different aspects of the patients' disorder (e.g., Verleger et al., 1996).

Amplitudes and Latencies of the ERP Components. Three components (the P200, N200, and P300) were identified in the ERPs elicited during the Lateralized Oddball Paradigm. As mentioned earlier the amplitude of the P300 was the primary electrophysiological correlate of interest. The main abnormalities in the patients' P300 amplitudes compared to those of the age-matched controls have already been described. The first of these abnormalities involved the sensitivity of the patients' P300 amplitudes to the manipulation of stimulus targetness in the ipsilesional but not contralesional visual field. As described previously, the lateralized nature of this abnormality compared to the non-lateralized P300 amplitude stimulus differentiation effects of the age-matched healthy controls indicates that this abnormality may be attributed to the patients' hemineglect.

The second major abnormality noted in the P300 amplitudes of the patient group and of both patient subgroups compared to those of the age-matched controls has also already been described. It involved an overall insensitivity to the between paradigm version manipulation of relative stimulus probability even for the stimuli within the patients' ipsilesional visual field that elicited a statistically significant stimulus differentiation effect based on the target status of the eliciting stimuli. In contrast, relative stimulus probability effects were observed for the controls regardless of the laterality of the eliciting stimuli. These results are consistent with recent reports of a more general loss of sensitivity in the patients' attentional processing that goes beyond their lateralized deficits that have typically been the focus of investigations of patients with hemineglect (Lavie & Robertson, 2001; Robertson, 1997, 2001). In future research, controls with right hemisphere damage and no visual hemineglect would be required to determine whether the decreased sensitivity of the P300 amplitudes to the manipulation of relative stimulus probability may be attributed to the neurocognitive changes associated with the patients' stoke and the medications used as treatment rather that to their hemineglect *per se*.

With respect to the latencies of the P300, those of the patients were not significantly delayed overall relative to those of the controls. These results indicate that at this stage of the ERP (300 to 700 ms), the patients' deficits were better characterized in terms of problems with attention allocation rather than speed of processing. However, processing speed differences were observed for the two earlier components. The patients' P200s (1st component) and N200s (second component) were significantly delayed overall relative to those of the controls regardless of whether the patients were in the Non-Detector or Delayed-Detector subgroup. The magnitude of these delays did not differ significantly as a function of the laterality of the eliciting stimuli. Therefore, these early processing speed delays likely reflect abnormalities attributable to the patients' stroke and the medications used as treatment rather than to their hemineglect *per se*. In future investigations, addition of controls with right hemisphere damage and no hemineglect as previously described would also permit the latency delays resulting from the patients' stroke and those resulting from their hemineglect to be differentiated.

The amplitudes of the N200 did not differ significantly between the patients and controls. In contrast, the amplitudes of the patients' P200s were atypical but in an interesting way. Whereas the P200 amplitudes of the controls were not sensitive to the stimulus differentiation effect, those of the patients were sensitive to stimulus differentiation effect whether the eliciting stimuli were in the contralesional or ipsilesional visual field. As with the previously described non-lateralized abnormalities, the increased sensitivity of the patients' P200s to the stimulus differentiation effect is likely attributable to the patients' stroke and possibly to the medications with which they were being treated rather than to their hemineglect *per se*. Once again, the bilateral enhancement of the patients' P200 amplitudes may correspond to relatively automatic stages of processing that may be released when more controlled stages of processing associated with the subsequent P300 amplitude effects have been disrupted (e.g., Alain & Woods, 1999; Knight et al., 1989; Robaey et al., 1992; Segalowitz et al., 1990; Yamaguchi & Knight, 1990).

The P200 latencies did not differ across conditions for the controls and Non-Detectors. For the Delayed Detectors, however, the P200 latencies for the right (ipsilesional) but not left (contralesional) target trials were significantly longer compared to those for the non-target trials. However, as mentioned before, differences in the latencies between target and non-target conditions may reflect artifactual delays associated with the general attenuation of the amplitudes elicited by non-target stimuli. .

Topographical Effects. Abnormal topographic distributions were found for the patients' P200 and N200 but not P300 components. The P300 amplitudes of all the groups and subgroups showed the same scalp distribution, with significantly greater magnitudes at the central (Cz) and posterior (Pz) sites than at the frontal (Fz) site. With respect to the P300 amplitude stimulus differentiation effects, those of the controls (in either visual field) and patients (in the ipsilesional visual field) were of the greatest magnitude at the Pz rather than Cz or Fz sites. Thus, compared to the scalp topography of the P300 amplitudes of the age-matched healthy controls, those of the patients with visual hemineglect showed no significant evidence of abnormality regardless of whether the patients were members of the Non-Detector or Delayed Detector subgroups.

During the full analysis of the patient and control data and follow up analysis of the patient subgroup data, the P300 latencies did not differ significantly across the three scalp sites. There was a non-significant trend, however, during the full analysis of the patient and control data for the P300 latencies to be earlier at the frontal (Fz) rather than central (Cz) or posterior (Pz) sites. This topographical distribution of latencies reached statistical significance for only the 50% but not 25% target version of the paradigm during the preliminary analysis of the controls' P300 latencies. A similar but non-significant distribution was noted in the P300 latencies for the 25% target version (there would be more trials in the 50% version than in the 25% version, thus the effect may be more stable in the 50% target version). Examination of the P300 latencies of the patient group and subgroups showed similar but statistically non-significant frontal distributions in the P300 latencies for both versions of the paradigm. The lack of statistical significance for the effect in the patient grouped ($N = 10$) or subgrouped ($n = 5$ per subgroup) data may be a consequence of small sample size relative to the control group ($N = 13$). Thus, compared to the topographic distribution of the latencies of the P300s for the age-matched controls, those of the patients with visual hemineglect showed no significant abnormality regardless of whether the patients were members of the Non-Detector or Delayed Detector subgroups.

With respect to the controls' N200s, the amplitudes showed a significant posterior distribution (Pz > Fz or Cz) and the latencies did not differ significantly across the three recording sites. In contrast, N200 amplitudes of the Non-Detectors showed a significant frontal distribution (Fz > Cz or Pz). In contrast to the N200 amplitudes of the Non-Detectors, those of the Delayed Detectors did not differ significantly across the three recording sites. Instead, the topography of the Delayed Detectors' N200 amplitudes showed a posterior distribution similar to that of the controls, although this difference between sites did not approach statistical significance. Nevertheless, with respect to the topography of the N200 amplitudes, normal performance involved a posterior distribution and there was a shift to a more frontal distribution associated with an increase in the severity of the patients' contralesional detection deficits (i.e., the N200 amplitudes were equal across sites for the Delayed Detectors and were frontally distributed for the Non-Detectors).

In contrast to the N200 latencies of the controls, those of the Non-Detectors and Delayed Detectors were significantly earlier at Pz than they were at Cz or Fz. Although the difference did not even approach statistical significance, the N200 latencies of the controls were also earlier at Pz than they were at Cz or Fz. Thus, the pattern was similar for the three groups but the discrepancy between sites was greater in the patient subgroups rather than in the control group. These results are intriguing given that the patients' neurological damage typically involved the parietal lobe and a delay rather than facilitation in the speed of processing at the posterior recording site would generally be expected. However, as described in the introductory chapters, the recordings made from an electrode site represents the summation of neurocognitive activity from a number of brain regions and the ability to localize the neurogenerators of a specific component is limited, particularly when only three recording sites are available. Therefore, replication of the results would be required before attempting to derive serious theoretical implications from these topographical differences noted in the latency of the N200. More importantly, for the topographical differences noted in the N200 amplitudes and latencies between the control group and patient subgroups, it is important to note that none of these differences were significantly influenced by the laterality of the eliciting stimuli. Consequently, the abnormalities may be attributed to changes in neurocognitive processing attributed to the patients having experienced a severe stroke and the medications with which they were being treated rather than to the presence of hemineglect *per se*. Again, as mentioned earlier, the addition of a comparison group consisting of patients with right hemisphere stroke and no symptoms of visual hemineglect would be necessary to address this concern.

Analysis of the P200 latencies but not amplitudes revealed significant between-group topographical differences. The P200 amplitudes of all of the groups and subgroups were of greater magnitude at Cz than they were at Pz or Fz. The P200 latencies of the controls were earlier at Pz than at Cz or Fz. Whereas the P200 latencies of the Non-Detectors were also earlier at Pz than at Cz or Fz, those of the Delayed-Detectors did not differ significantly across the three sites. In contrast to the abnormality noted in the N200 amplitudes (2nd component), which appeared to be more pronounced for the Non-Detectors than for the Delayed Detectors, the abnormality noted in the P200 latencies (1st component) appeared to be more pronounced for the Delayed Detectors than for the Non-Detectors. As with the topographical differences noted in the N200 amplitudes and latencies between the control group and patient subgroups, those noted for the P200 latencies were not significantly influenced by the laterality of the eliciting stimuli. Consequently, these abnormalities may also be attributed to changes in neurocognitive processing attributed to the patients having experienced a severe stroke and the medications used as treatment rather than to the presence of hemineglect *per se*. Once again, in future investigations, the addition of a comparison group consisting of patients with right hemisphere stroke and no symptoms of visual hemineglect would be necessary to address this concern.

Overall, none of the topographical differences described for the amplitudes or latencies of the ERP components of the patients and controls differed as a function of the laterality of the eliciting stimuli. Consequently, the effects likely address differences due to the patients' stroke or possibly to the medications with which they were being treated rather than differences that may be attributed to the patients' hemineglect *per se*. As mentioned throughout this section, the incorporation of a neurological control group with right hemisphere damage and no visual hemineglect would be required in future investigations to empirically evaluate these alternatives.

Summary.

Using the present paradigm, the ERP examinations of early components of visual information processing reveal more evidence of differences attributable to the patients' stroke and the medications used as treatment rather than to their hemineglect *per se*. When developing models to account for the full deficit of hemineglect syndrome consideration of the interaction of top down and bottom up processing deficits may be necessary (e.g., Hopfinger, Buonocore, & Mangun, 2000). For example, to account for the growing evidence of residual processing of information in the neglected visual field that can take place implicitly, it may be that the general disruption of more controlled forms of processing may facilitate the release from inhibition of relatively automatic forms of processing of which the effects might normally be masked or held in check by the more controlled forms of processing (e.g., Alain & Woods, 1999; Knight et al., 1989; Robaey et al., 1992; Segalowitz et al., 1990; Yamaguchi & Knight, 1990).

In contrast to the conclusions based on previous ERP investigations of hemineglect (e.g., L'hermitte et al., 1985; Verleger et al., 1996) the present results do not indicate that the patients' abnormalities may be confined to the early or later stages of information processing. Based on the present results, there appear to be abnormalities at all of the identified stages of processing. Whereas some of these abnormalities appear to be attributable to hemineglect (e.g., the insensitivity of the amplitude of the P300 to stimulus targetness in the neglected but not intact visual field), the majority of the abnormalities appear to be attributable to the severe stroke for which the patients were being medically treated. As previously noted, one of the major advantages of the present paradigm over previous paradigms in which the visual ERPs of patients with hemineglect were examined was the availability of a concurrent behavioral measure of subjective awareness for the stimuli in the neglected visual field. When examining the ERPs elicited by the lateralized targets and non-targets presented in the current paradigm, it is important however to remember that each lateralized stimulus was presented with another stimulus in the contralateral visual field. The simultaneous presentation of a stimulus in each visual field for each trial may account for why many of the abnormalities observed in the patients' ERPs showed evidence of generalized rather than lateralized changes in the correlates of information processing. In other words, each time that the ERP data were recorded, there was a stimulus in each visual field. Thus, whenever the critical event occurred in the neglected visual field, there was the potential for the patients to process aspects of the non-critical stimulus in the intact visual field in addition to or instead of the critical stimuli in the neglected visual field.

CHAPTER EIGHT

GENERAL DISCUSSION

Patients with visual hemineglect allowed for powerful within-subject comparisons of information processing for stimuli in the intact and neglected visual fields. For this dissertation, a pair of ERP paradigms was developed to assess the on-line processing of information in the patients' neglected and non-neglected visual fields. The extent to which specific ERP components can be used to investigate the implicit processing for information in the neglected visual field was of particular interest. This General Discussion will begin with a review of the goals and major findings for each experimental paradigm. Then, the major results of the two experiments will be compared with respect to their contribution to an understanding of the hemineglect syndrome and to an understanding of ERPs as correlates of neurocognitive information processing. The relative strengths and limitations of each investigation will also be addressed with recommendations for further studies.

Experimental Purpose

For Experiment One, a Lateralized Semantic Priming Paradigm was developed with the N400 as an electrophysiological correlate of semantic processing. The primary goal was to determine whether N400 amplitudes for centralized picture-targets that are preceded by lateralized picture-primes could serve as ERP correlates of the implicit semantic priming effects that have been reported for stimuli in the neglected visual field using behavioral response time data (Berti & Rizzolatti, 1992; D'Eposito et al., 1993; Kanne, 2000; Ladavas et al., 1997; McGlinchey-Berroth et al., 1993; McGlinchey-Berroth & Milberg, 1996; Schweinberger & Stief, 2000). For Experiment Two, a Lateralized Oddball Paradigm was developed with the P300 as an ERP correlate of stimulus differentiation. The primary goal was to determine whether the P300 amplitudes would be sensitive to the manipulations of stimulus targetness and relative stimulus probability for stimuli (target and non-target letters) in the neglected field when concurrent behavioral responses indicate that the eliciting stimuli were subjectively unavailable to the patients.

As already stated, the primary ERP correlate was the amplitude of the N400 for Experiment One and the amplitude of the P300 for Experiment Two. However, both experimental paradigms provided the opportunity to conduct exploratory analyses on the amplitudes and latencies of earlier ERP components to address controversy concerning whether the information processing abnormalities associated with hemineglect involve primarily early or late stages (L'hermitte et al., 1985; Verleger et al., 1996).

Strengths of the Experimental Paradigms

The ERP paradigms of Experiments One and Two both were developed with behavioral components so that the extent to which the stimuli remained subjectively inaccessible when in the neglected visual field could be assessed. In some previous visual ERP studies, the patients' hemineglect was defined as the delay in response time for stimuli in the neglected rather than intact visual field (e.g., L'hermitte et al., 1985). In others, the patients' hemineglect on the experimental measure was never actually assessed (e.g., Verleger et al., 1996). Therefore, in contrast to previous investigations, the present paradigms were designed to examine ERPs elicited by information in the neglected visual field of which patients remained subjectively unaware.

Another advantage was that the stimuli used for Experiment One (line drawings of animals and clothing) and Experiment Two (target and non-target letters) were more complex than the changes in luminance or presence of a stimuli used in previous investigations of hemineglect in which visual EPs or ERPs were obtained (L'hermitte et al., 1995; Verleger et al., 1996). Thus, for the present investigations, ERPs were used to assess the presence of implicit processing within a context in which higher order processing would be required for successful task completion. Admittedly, the letter stimuli used for the second experiment could be conceptualized as two shapes rather than two letters. However, the nature of the task was nevertheless more complex than were those used in previous investigations because it involved implicit and explicit differentiation between stimuli (targets and non-targets) rather than the processing associated with the mere onset or presence of a stimulus.

Another distinct advantage was that for Experiments One and Two, the data were collected from the same samples of patients with visual hemineglect and age-matched healthy controls. Thus, when comparing the results of the two experiments, inferences can be made with respect to different stages of information processing that would be more difficult to make if the data had been collected from different groups of participants.

Main Experimental Findings

Experiment One. For Experiment One, the patients' verbal responses on a pre-experimental version of the semantic priming task indicated a general lack of subjective awareness for the picture primes in the neglected visual field. The behavioral data from the experimental measure (picture target categorizations) confirmed that semantic priming occurred and that this semantic priming was of comparable magnitude regardless of whether the picture primes were in the neglected or intact visual field. These behavioral results were consistent with previous behavioral evidence of implicit semantic priming for patients with visual hemineglect (Berti & Rizzolatti, 1992; D'Esposito et al., 1993; Kanne, 2000; Ladavas et al., 1997; McGlinchey-Berroth et al., 1993, McGlinchey-Berroth & Milberg, 1996; Schweinberger & Stief, 2001).

Electrophysiologically, the N400s elicited by the centralized picture targets were also sensitive to the manipulation of semantic congruity regardless of whether the preceding picture prime was in the neglected or intact visual field. Moreover, consistent with the magnitude of the behavioral semantic priming effects, the N400 amplitude semantic priming effects did not differ significantly in magnitude as a function of the laterality of the picture primes for either the patients with visual neglect or age-matched healthy controls.

With respect to hemineglect, the results of Experiment One are consistent with the view that considerable information processing takes place implicitly within the neglected visual field (Driver & Mattingley, 1998). Moreover, the neurocognitive processes required to elicit the N400 semantic priming effect do not appear to differ significantly for stimuli that are presented in the presence (intact visual field) or absence (neglected visual field) of subjective awareness of the priming stimuli. With respect to an understanding of ERPs, these results indicate that N400 amplitude semantic priming effects are not dependent on the availability of the more controlled forms of processing that have generally been associated with subjective awareness.

The N400 semantic priming effects were much more robust in the patients' data as a group rather than at the individual level of analysis although the general pattern of results was evident for a majority of cases and reached statistical significance for a few cases. Thus, as is typical for semantic priming paradigms, the amplitude of the N400 was the only feature of the ERP data that was sensitive to either the implicit or explicit semantic processing associated with the experimental manipulation (i.e., no semantic priming effects were found for the P200, N200, or P300 components).

As described in Chapter Four, the extent to which the N400 is sensitive to automatic forms of processing in the absence of more controlled forms of processing has been a long-standing topic of controversy (Okita & Jibu, 2000; Sternberg, 2000). With respect to this controversy the results of Experiment One are consistent with the results of paradigms that have been used to demonstrate the sensitivity of the N400 to automatic processing. These paradigms, which have involved the manipulation of stimulus timing and perceptual thresholds (Anderson & Holcomb, 1995; Besson, Fischler et al., 1992; Schnyer et al., 1997), the attentional blink phenomenon (Rolke et al., 2001), variation in task demands (Bentin et al., 1993; Besson, Fischler et al., 1992; Holcomb, 1988; Kutas & Hillyard, 1989), and the manipulation of selective attention (Otten et al., 1993), have been reviewed in Chapter Four. As indicated in Chapter Six, these demonstrations have been criticised because it was not possible to ensure that all forms of controlled processing had been eliminated from the automatic processing conditions (Brown & Hagoort, 1993; Chwilla et al., 1995; Kellenbach & Michie, 1996; Okita & Jibu, 1998; Sternberg et al., 2000; Vogel et al., 1998).

The patients with hemineglect who participated in Experiment One provided an opportunity to investigate whether the N400 semantic priming effect can be elicited in the absence of the more controlled forms of processing that depend on subjective awareness of the priming stimuli. As described by Rafal (1998), when patients have no explicit awareness of the stimuli in the neglected field and yet produce effects that are also produced by stimuli in the ipsilesional field, they are showing evidence for processing without awareness. In other words, the within-subjects comparison determines whether the processing necessary to produce the effect required attention or subjective awareness. If comparable effects are observed for contralesionally neglected and ipsilesionally perceived stimuli, then the perceptual process being measured can proceed without attention and in the absence of subjective awareness.

As already described in Chapter Six, it could be argued that controlled processing of the contralesional primes was not completely eliminated for every trial for the demonstration of implicit priming in Experiment One. The deficits of patients with hemineglect can be variable and inconsistent over time (Bartolomeo et al., 2001; Bisiach, 1999). Thus, it is possible that the demonstration of N400 semantic priming for the contralesional priming condition might reflect those trials during which the contralesional primes were perceived and not those during which they were neglected. This is a possibility given that the severity of the patients' contralesional neglect on the experimental paradigm was inferred from impaired performance on a similar version of the paradigm for which a verbal report of each trial was required instead of a motor response to categorise the central target. However, if the N400 elicited for the left-primed targets reflected those trials during which the stimuli were perceived and not those during which the stimuli were neglected, then averaging them together would be expected to result in an N400 that was reduced overall, which was not the case. When the magnitude of the peak amplitudes of an ERP component are unaffected by the attentional manipulation within an experiment, the ERP activity is considered to be an automatic response to the stimulation and ERP responses with these properties are often referred to as exogenous components (Fabiani et al., 2000).

Nevertheless, it would be useful to replicate the implicit N400 semantic priming effects with patients for whom consistent and extensive contralesional neglect of the primes has been documented. Within this context, a version of the paradigm requiring concurrent verbal report of what was seen for each trial might be useful. For example, for each trial, participants could be asked to categorise the centralised target and then report on whether or not any other pictures were present during the trial. However, the requirement of a concurrent verbal report for each trial would likely alter the neurocognitive task demands of the semantic priming paradigm.

The present results are, however, consistent with the results of other investigations in which other paradigms were used to demonstrate that the N400 semantic priming effects are not entirely endogenous. For example, Schweinberger and Stief (2001) demonstrated that the ASA can be evoked by missed prime words within the attentional blink. Furthermore, this ASA was sufficient to elicit N400 word repetition priming effects that were of larger magnitude than those elicited when more controlled forms of processing were available (Schweinberger & Stief, 2001). It would, therefore, be of interest in future investigations based on the present paradigm, to determine whether the implicit N400 priming effects would also be of larger magnitude in paradigms in which the repetition of words was examined in addition to the manipulation of semantic congruity (e.g., Schweinberger & Stief, 2001). It is also of interest to note that the present demonstration of implicit N400 amplitude semantic priming effects in the visual modality is consistent with previous although controversial demonstrations of implicit N400 amplitude semantic priming effects obtained in the auditory modality for sleeping subjects (Brualla et al., 1998).

Experiment Two. In the Lateralized Oddball Paradigms, analysis of the age-matched controls' data demonstrated excellent task validity for both the behavioral and ERP components of the task. However, analysis of the patients' target detection data unexpectedly revealed two distinct behavioral manifestations of hemineglect. For half of the patients, who formed the Non-Detector subgroup, hemineglect was manifested as the consistent omission of targets in the neglected but not intact visual field. For the other half of the patients, who formed the Delayed Detector subgroup, hemineglect was appeared in the form of detection times that were significantly delayed for targets in the neglected but not intact visual field. Although not anticipated, the differing manifestations of hemineglect on the experimental measure are consistent with reports of heterogeneity and task specificity of the deficits of patients with hemineglect on a range of clinical and experimental measures (Banich, 1997; Bisiach, 1999; Rafal, 1998; Vallar, 1998).

Fortunately, the number of patients within each subgroup was equal, which permitted the ERP data to be analyzed at a group and subgroup level. The group-based analysis of the ERP data indicated that the amplitude of the P300 provided a reliable correlate of stimulus differentiation for stimuli presented in the patients' intact but not neglected visual field. Furthermore, the P300 amplitude stimulus differentiation effects elicited in the patients' intact visual field could be attributed to stimulus targetness but not relative stimulus probability. Moreover, analysis of the P300 amplitude data at the patient subgroup level revealed no significant between subgroup differences. Therefore, there were no reliable P300 amplitude stimulus differentiation effect for stimuli in the neglected visual field even for the patients in the Delayed Detector subgroup whose behavioral manifestation of hemineglect on the experimental measure consisted only of a delay rather than omission of the targets in the neglected visual field. The lack of significance for the effect in the neglected field was not due solely to small sample size given that the result was elicited easily in the intact visual field with the same sample of subjects.

In contrast, the P300 amplitudes of the age-matched controls were sensitive to the manipulation of stimulus targetness and relative stimulus probability regardless of the laterality of the eliciting stimuli. The patients' lack of reliable P300 amplitude stimulus differentiation effects for stimuli in the neglected but not intact visual field was consistent with the lateralized disruption of attentional processing that is typically associated with the hemineglect syndrome. The lack of sensitivity of the patients' P300 amplitudes to the manipulation of relative stimulus probability even for stimuli within the intact visual field suggests a general disruption of attention processing that goes beyond the more lateralized attentional deficits that have typically been the focus of investigations of hemineglect. These results are consistent with the generalized reduction in perceptual load or attentional capacity that has recently been reported as modulating factors for the strong ipsilesional bias typically associated with hemineglect (Robertson, 1997, 2001). The presence of similar disruptions of generalized attention has also been associated with the severity and chronicity of the more lateralized symptoms of hemineglect (Lavie & Robertson, 2001).

When analyzed at the level of the individual rather than group or subgroup, there was evidence of stimulus differentiation in the amplitudes of the P300 for five cases, including two cases that showed no subjective awareness of the eliciting stimuli. Thus, these case study data provide at least some evidence that the P300 amplitudes can be sensitive to the experimental manipulation of stimulus targetness in the neglected visual field of some patients who showed no subjective awareness of the eliciting stimuli. These case-study results are intriguing because they bring into question the widely held assumption that P300 amplitude effects represent unequivocal evidence of controlled attention being allocated to the eliciting stimuli (Andreassi, 2001; Kutas and Dale, 1997; Pritchard, 1981). The results of the second experiment indicate that the P300 stimulus differentiation effect *can* be elicited by stimuli of which the participant is subjectively unaware but the implicit effect is not nearly as robust as its explicit counterpart. These results are consistent with previous reports of the successful elicitation of the P300 during coma (Gott et al., 1991; Kane et al., 1996; Signorino et al., 1997) and of the successful elicitation of the P300 or N400 during various stages of sleep (Brualla et al., 1998; Colrain et al., 2000; Doran, 2000; Pratt et al., 1999; Wesensten & Badia, 1988). However, with respect to the results of the present experiment, the somewhat atypical case study effects need to be replicated before the standard interpretation of the P300 amplitude effect can be dismissed.

It was of interest to note, however, that the amplitude of a much earlier component, the P200, was sensitive at the group level to the implicit and explicit processing of stimulus targetness but only for the participants who had sustained a stroke and not for controls. Of particular interest, the unexpected stimulus differentiation effect revealed through the analysis of the earlier P200 amplitude data serves as a reminder that the P300 is not the only component of the ERP that has been reported to be sensitive to the manipulation of stimulus targetness (Kutas & Dale 1997). It also indicates that some of the processing generally associated with relatively late components of the ERP may actually be completed much earlier in time (e.g., Haline et al, 1998). The hemineglect syndrome might present a situation in which some of the normal inhibitory processes of pre-attentive early processing have been removed, which would be consistent with a model of brain function which suggests that earlier, more automatic processes can be enhanced when top down cortical processing decline (Alain & Woods, 1990; Knight et al., 1989; Robaey et al., 1992; Segalowitz et al., 1990; Yamaguchi & Knight, 1990).

Requirements of Subjective Awareness for the Experimental Tasks

It has generally been accepted that the amplitude of the P300 reflects processes such as stimulus categorization, stimulus evaluation, and memory updating, that are normally associated with subjective awareness (Coles & Rugg, 1995; Luck & Girelli, 1998; Fabiani et al., 2000). Moreover, standard ERP nomenclature implies that the P300 precedes the N400 in temporal sequence (Luck & Girelli, 1998). Given these generalizations, it is not difficult to form the impression that the elicitation of an implicit

N400 semantic priming effect might be more difficult than the elicitation of an implicit P300 stimulus differentiation or stimulus probability effect. However, the results of the two studies described here indicate that this general impression is inaccurate.

The main differences between the paradigms used for Experiments One and Two have been summarized in Table 80. As indicated in the table, Experiment One was designed to assess the N400 semantic priming effect within the context of contralesional neglect. The task involved the influence of implicit and explicit processing of information contained in the primes on the subsequent explicit processing of the target. However, it is ambiguous as to whether the instructions to selectively attend to the target location and color were associated with inhibition of responses for the non-target primes or whether these stimuli were simply subjectively unattended by the participants. For successful behavioral performance on the semantic priming task, no subjective awareness of the primes was required.

In contrast, Experiment Two was designed to assess the P300 stimulus differentiation and relative stimulus probability effects within the context of contralesional extinction. The implicit and explicit processing of information contained in the targets was assessed directly in the ability to discriminate between the target and non-target letters. Participants were instructed to attend to the experimentally relevant stimuli. In contrast to the semantic priming paradigm of Experiment One, for which subjective awareness of the primes is not actually required, successful behavioral performance on the oddball detection task did require subjective awareness of the target and non-target stimuli. Thus, in both experiments, the line between the implicit automatic processing of information that can occur without subjective awareness and the controlled processing of information that occurs in full awareness is not as distinct as might have been expected.

Early Information Processing Abnormalities in the ERPs

Some authors (e.g., Berhmann & Meegan, 1998; Farah et al., 1991) have raised concerns regarding the extent to which the early stages of information processing in patients with hemineglect may be considered to be normal. Analysis of the morphologic, temporal, and topographic features of the ERP waveforms elicited in Experiments One and Two provide information relevant to these concerns.

First, with respect to Experiment One, the early components elicited by the centralized targets were slowed irrespective of the laterality of the prime. Thus, these delays (which were also evident in the later components) reflect generalized slowing due to stroke or possibly to the medications used to treat the stroke rather than alteration of information processing attributable to the patients' visual hemineglect.

Similarly, in Experiment Two, most of the earlier components elicited by the lateralized stimuli demonstrated the same general latency delays that reflected slowed processing bilaterally. Overall, none of the topographical differences described for the amplitudes or latencies of the ERP components elicited for the patients and controls in Experiment Two differed as a function of the laterality of the eliciting stimuli. More significant was the increased sensitivity of amplitude of the P200 to the manipulation of stimulus targetness, as already described in the General Discussion. Once again, however, this early processing abnormality was not dependent on the laterality of the eliciting stimuli. In the second experiment, it was at the level of the P300 that the major neglect-related processing deficits was evident. At this stage of the ERP (300 to 700 ms), the patients' deficits were better characterized in terms of problems with attention allocation rather than speed of processing (i.e., the sensitivity of the patients' P300 amplitudes to the manipulation of stimulus targetness was selectively impaired for stimuli in the neglected visual field but the latencies of their P300s showed no significant delay regardless of the laterality of the eliciting stimuli). However, again as already described, there was evidence of more generalized attentional disruption in the patients' P300 amplitudes. They were not sensitive to the manipulation of relative stimulus probability even for stimuli in the intact visual field or when the stimuli in the neglected visual field were actually detected. Thus, in addition to evidence of lateralized processing abnormalities in the amplitude of the P300, there was considerable evidence of more generalized processing deficits for this component and for the earlier components. The generalized processing deficits are interesting to note given reports that the severity of the strong ipsilesional bias associated with hemineglect can be modulated by the presence of more general attentional disruptions (Robertson, 1997, 2001).

The ERP results of both Experiment One and Two indicate that the higher level processing of information by patients with hemineglect, whether implicit or explicit, does not follow from earlier sensory or perceptual processing that is entirely normal. These early processes are not equivalent for patients with cortical damage compared to age-matched controls regardless of the laterality of stimulus presentation. Therefore, the present results do not support models that imply either the complete disruption of early stages of sensory processes (e.g., Battersby et al., 1956; Denny-Brown et al., 1952) nor those that propose the complete preservation of early sensory perceptual processing (e.g., L'hermitte et al, 1985; Valler et al, 1991; Watson et al., 1977). Rather, the results are consistent with models that propose some sort of disruption in the parallel processing routes available for information, such as the more recent network (e.g., Mesulam, 1999) or parallel processing (e.g., Driver & Mattingly, 1998) models.

As described in Chapter One, the parallel processing model by Driver and Mattingly (1998) was based on data obtained from investigations of the visual systems of primates and humans. The model posits that for patients with visual hemineglect due to parietal lobe damage, the non-retinotopic attentional deficits arise in a context of considerable low level visual processing within the occipital lobe (e.g., figure-ground segregation and perceptual grouping). Two streams of visual processing that originate in the primary visual or striate cortex and pass through extra-striate regions are identified in the model to account for the more extensive levels of implicit information processing observed for patients with hemineglect due to parietal lobe lesions. A dorsal stream projects to the upper regions of the parietal lobe superior to the site of the lesions that are typically involved in the onset of hemineglect and is thought to be involved in the spatial control of action. The more ventral stream, which projects to the temporal lobe inferior to the site of the lesions that are typically involved in the onset of hemineglect, is though to be involved in object recognition.

According to the model, damage to the primary visual cortex disrupts the ventral object-recognition stream from its onset and the more dorsal projections from striate cortex. The behavioral manifestation is hemianopia and possibly blindsight. In contrast, hemineglect due to parietal lobe damage would be expected to leave much of the ventral object recognition stream intact. As a result, significantly more processing of information concerning object recognition would be expected to occur along the intact ventral pathway for patients with hemineglect consistent with the extensively preserved implicit processing observed in these patients. According to Driver and Mattingley (1998), the challenge for current neuropsychological theory is not in accounting for the preserved processing in hemineglect. Instead, it is in explaining the dramatic loss of awareness itself, which arises for neglected stimuli that escape subjective awareness despite the considerable processing that these stimuli evidently receive as indicated by the implicit priming effects.

A conceptual framework similar to that of Driver and Mattingley (1998) was recently used to account for why stimuli with strong emotional connotations (i.e., threat significance) may be privileged in summoning attention within the neglected visual field (Vuilleumier & Schwartz, 2001). In this investigation, the effects of the emotional content of a stimulus on visual detection were examined in two individuals with right parietal lobe damage and chronic left visual hemineglect. The patients were selected because they both demonstrated intact visual fields on both sides when each side was assessed separately but showed reliable left-sided visual extinction on bilateral simultaneous stimulation. During the experimental extinction-based paradigm, pictures were briefly presented in the neglected, intact, or both visual fields. The pictures depicted spiders (emotionally threatening condition) or flowers (emotionally neutral condition) with similar overall features. The patients detected the emotionally threatening stimuli on the left side significantly more often than the emotionally neutral stimuli. To account for these findings, it was proposed that distinct attentional mechanisms pertaining to the emotional content of the stimuli, possibly involving intact processing pathways to the ventral temporal lobe and amygdala, were available despite disruption of other mechanisms of spatial attention by the parietal lobe damage (Vuilleumier & Schwartz, 2001).

For parallel processing or network models, such as these (i.e, Driver and Mattingly, 1998; Vuilleumier & Schwartz, 2001), the ERP results, particularly of Experiment One, suggest that the disruptions in the parallel processing routes likely involve both bottom up and top down processing mechanisms. Relative to the P200 amplitudes of the controls, those of the patients showed evidence of enhanced sensitivity to stimulus differentiation possibly due to some form of general release of automatic forms of attentional processing when the more controlled forms of attentional processing associated with the amplitude of the P300 were disrupted. Although speculative, this interpretation involving top-down cortical disruptions resulting in bottom-up cortical disinhibition has been demonstrated in other contexts, as described in Chapter Six. For example, components preceding the P300, such as the P200 and N200, have been associated with amplitude increases during the reduction of subjective awareness or lower state of arousal associated with the onset of sleep (e.g., Segalowitz et al., 1990). Similarly, the amplitudes of some of these earlier components have been observed to be enhanced in patients with brain dysfunction or injury when higher-order controlled processes were inadequate (e.g., Robaey et al., 1992). However, this type of release from cortical inhibition has most typically been reported for frontal rather than parietal lobe damage for very early components within ERPs elicited in the auditory (e.g., Alain & Woods, 1999, Knight, Scabini, & Woods, 1989) and somatosensory (Yamaguchi & Knight, 1990) rather than visual modalities.

Group and Individual Case Study Approaches

The results of Experiments One and Two demonstrate the value of analyzing data at both the group and individual level when charting new experimental territory. Analysis of the group data can reveal effects that may be too weak to detect in the data of an individual. In contrast, a case study approach may enable an effect to be observed when it characterizes the performance of a minority of individuals within a clinical population (Code, 1996). Despite their lower statistical power, single case designs are often considered adequate and necessary when investigating the syndrome of hemineglect because the manifestation of the unilateral impairments can be heterogeneous, of short-lived duration, or present only when the patient is quite ill (Rafal, 1998). As stated by Rafal (1996), replication of the results of a given case study in additional patients is desirable to confirm the generality of the conclusions.

Increasing Power

In future investigations, the sensitivity of the experimental measures at an individual or group level could be increased by means of any revision to the paradigm that results in greater statistical power. For example, increasing the number of trials per condition might be helpful to ensure a larger number of artifact-free trials in the ERP data after the removal of movement artifact and behavioral error correction. In the current version of the semantic priming paradigm used for Experiment One, repetition of the line-drawing exemplars of clothing and animals was used to increase the number of trials and to ensure adequate counter-balancing. However, given that there is a negative association between the number of stimulus repetitions within an experimental paradigm and the amplitude of the N400 (Bentin & McCarthy, 1994; Okita & Jibu, 2000), the use of a larger sample of unique stimuli might facilitate the elicitation of the effect.

The use of word rather than picture stimuli may be of assistance for the formation of larger sets of related exemplars of a category membership from which to select. The use of a categorization task rather than a lexical decision task was selected for Experiment One so that every trial could contribute to the experimental conditions that would be meaningful in the analysis. In a lexical decision version of the paradigm, the trials with non-words as targets typically cannot be included in the semantic priming analyses because they are meaningless (e.g., McGlinchey-Berroth et al., 1993).

Importance of Behavioral Criteria

Subject selection is among the most crucial factors to consider when conducting a within-subjects comparison of the extent of explicit and implicit processing for information in the ipsilesional and contralesional visual fields of patients with hemineglect (Rafal, 1998). According to Rafal, patients for this kind of within-subjects design must be selected based on behavioral rather than anatomical criteria. This is not a moot point given that of the ten patients who were selected on the basis of CT- or MRI- verified parietal lobe lesion in the ERP investigation by Verleger et al. (1996), two of the patients obtained a total neglect score of zero on a battery of eleven tests of hemineglect. In contrast, in the present experiments, two patients (P113 and P114) with moderate impairment due to hemineglect were found to show no evidence of a lesion in their CT scans. The extent to which the patients show evidence of contralesional visual extinction or neglect is the important variable and the anatomy of the responsible lesion is not directly relevant to the question being addressed nor is the presence of absence of other signs of hemineglect (i.e., hemineglect in other modalities, hemineglect on tasks that differ considerably from the experimental measure).

For the present experiments, the Sunnybrook Bedside Neglect Battery (Black et al., 1990, 1994) was used as the basic screening measure for neglect. The primary advantages of this measure was that it provided a reasonably sensitive index of the severity of hemineglect that could be easily re-administered for patients whose testing extended over several sessions so that the continued presence of the deficit could be verified. This measure correlated well with the verbal-report version of the neglect verification task used to assess the presence of hemineglect in Experiment One. It correlated less well with the extent of extinction demonstrated by the patients in Experiment Two, possibly because of limited sample size after sub-grouping the data or because the battery does not contain a specific measure of contralesional extinction.

The primary strength of both investigations was the inclusion of a behavioral measure of contralesional deficit on the experimental task above and beyond the more generic screening battery. In this regard, the behavioral assessment of extinction for each contralesional target in Experiment Two was superior to the assessment of contralesional neglect of the primes in Experiment One. In Experiment Two, a concurrent behavioral measure was used. In contrast, in Experiment One, performance on the verbal-report version of the semantic priming task was used to infer the extent of contralesional neglect in the motor response version of the experimental paradigm. As noted earlier, the task demands may have differed on this awareness check task. Thus, only for Experiment Two was it possible to ensure that only trials for which no evidence of subjective awareness had been demonstrated were included in the average waveforms. In future investigations of P300 stimulus differentiation for stimuli in the neglected visual field (Experiment Two), it would be beneficial to select patients on the basis of contralesional extinction rather than other forms of hemineglect. As described by Rafal (1998), this screening could be accomplished using the method of visual confrontation testing which permits the integrity of the visual fields to be evaluated at the patient's bedside or in the clinic.

In Experiment Two, the behavioral index of extinction enabled the identification of two subgroups of patients who manifest hemineglect in different ways. Non-Detectors generally did not respond to contralesional targets. Delayed Detectors generally responded to contralesional targets more slowly than ipsilesional targets. The presence of two separate subgroups of patients based on their manifestation of neglect was not anticipated but was not surprising given the numerous dissociations reported for the manifestation of hemineglect and extinction on different commonly used measures (Bisiach et al., 1999). Moreover, the advantage of having the concurrent behavioral response measure in Experiment Two was that it helped to identify the two subgroups so that the data for each subgroup could be examined separately. However, the sub-grouping of patients resulted in considerably smaller sample sizes, which negatively affected the power of the group-based analyses.

In future investigations of the N400 semantic priming effect (Experiment One), it would be useful to incorporate a concurrent measure of subjective awareness of the primes for each trial so that any trials for which awareness was demonstrated could be excluded from the analysis or looked at separately as they were in Experiment Two. Unfortunately, this sort of concurrent measure would likely alter the very nature of the task by drawing attention to the primes, which would induce a controlled processing strategy. One way around this might be to include a condition for which no prime is presented along with the concurrent measure of subjective awareness. This control might minimize establishment of a bias to detect a prime each time. Alternatively, the stimulus presentation times of the primes might be adjusted for each patient to better ensure that every contralesional prime has been neglected.

In future investigations, the selection of deficit screening measures that are maximally comparable to the experimental measure being used and the inclusion of concurrent behavioral measures of the deficit if possible would help to ensure that neglect or extinction of the contralesional stimuli are indeed taking place. As a result, one potential source of ambiguity in the interpretation of the results will have been eliminated.

Control Group

According to Rafal (1998), when a critical manipulation is done within subjects, the performance of the patients with hemineglect need not be compared to normal performance or to the performance of any group of individuals because each patient serves as his or her own control. However, in the present experimental design, the inclusion of an age-matched comparison group was intended to ensure that the lateralized versions of the experimental tasks would not normally elicit an asymmetric performance in healthy older adults. The age-matched participants in the neurologically intact control group were generally better educated and of higher social-economic status than were the patients. This subject selection bias is to be expected when controls are selected from healthy community volunteers and patients are selected from consecutive admissions. However, the ERP data would not likely be affected by differences in these factors. Another age-matched control group consisting of patients with right hemisphere damage and no symptoms of visual hemineglect would help determine whether the non-lateralized abnormalities noted in the patients' data could be attributed to hemineglect rather than to the neurocognitive disruptions associated with stroke or the medications used as treatment.

Although subsequently corrected, the controls and patients were initially given different amounts of practice with the Semantic Priming Paradigm of Experiment One. All participants were encouraged to practice the task until they felt comfortable with it. The patients generally required extensive practice to master the task. In contrast, the controls typically appeared to have mastered the task within the first block of practice trials. Analysis of the pattern of errors made by controls, however, indicated that they generally did not take adequate practice. There were a disproportionate number of errors and missed trials within the first block of trials for controls but not patients. To correct for this inadvertent practice effect, the first block of experimental trials was considered practice trials for the controls and was excluded from the analysis for the controls only.

Earlier ERP Components

With respect to the early correlates of information processing in the ERP waveforms, it is important to keep in mind that the experimental paradigms were not specifically designed to assess the components that occur prior to the N400 in the first experiment or prior to the P300 in the second experiment. Moreover, given the lack of consistency in previous reports (L'hermitte et al., 1985; Verleger, 1996), the analyses of the amplitudes and latencies of these early components were more exploratory than were those of the components of primary interest. Further investigation of earlier ERP components could be undertaken using paradigms more compatible with their elicitation with a fuller montage of recording sites to facilitate better localization of the associated neurocognitive activity.

Conclusions

The implicit behavioral semantic priming results of Experiment One are compatible with the accumulating evidence that considerable processing occurs for information in the neglected field even when it remains subjectively unavailable to the patients (Driver & Mattingley, 1998). Moreover, the results of Experiment One demonstrate that the amplitude of the N400 elicited by centralized targets can provide a robust electrophysiological correlate of the differential stimulus processing associated with this implicit behavioral semantic priming effect. These results also demonstrate that the N400 amplitude modulations elicited for targets in semantic priming paradigms are not dependent on the participants' subjective awareness of the primes.

In Experiment Two, the P200 was unexpectedly found to be a better index of information processing in the patient group than was the P300. The amplitude of the P300 was generally sensitive to the targetness of the lateralized stimuli but only when they were in the intact visual field. In contrast, the amplitude of the P200 was sensitive to targetness of the lateralized stimuli when they were in the intact or neglected visual field of the patients even when the patients' concurrently obtained behavioral responses indicated no subjective awareness of the contralesional stimuli. Similar P200 stimulus differentiation effects were not seen in the data of the age-matched controls. These results suggest that for the patients with hemineglect, as for other brain damaged groups (Alain & Woods, 1999; Knight et al., 1989; Robaey et al., 1992; Yamaguchi & Knight, 1990) the disruption of cortical control over top-down information processing can result in the release of earlier and more automatic information processing of which the amplitude of the P200 is a correlate.

When the P300 amplitudes elicited during Experiment Two were analyzed at an individual rather than group level, reliable stimulus differentiation effects were elicited for stimuli in the neglected visual field of half of the patients (n = 5), including two patients who demonstrated no subjective awareness of the eliciting stimuli. Although not a typical effect at the individual level, or a robust effect at the group level, the elicitation of P300 amplitude stimulus differentiation effects for stimuli of which the participants remained unaware highlight ambiguities in the interpretation of this component of the ERP. The degree to which automatic versus controlled processing are associated with the ERP components examined in the present experiments presents a challenging focus for future research.

Table 1. Demographics for Patients with Left Visual Hemineglect ($N = 11$) in Experiments One and Two.

ID	Age (years)	Sex	Education (years)	Employment (highest level)	Retired
101	66	M	12	blue collar	Y
103	83	M	10	blue collar	Y
105	67	F	12	home maker	NA
106	83	M	12	clerical	Y
107	65	M	9	blue collar	Y
109	65	F	11	home maker	NA
110	83	M	8	civil service	Y
112	67	F	8	clerical	Y
113	86	F	14	education/healthcare	Y
114	76	F	10	home maker	NA
116	51	M	12	civil service	N
M (SD)	72 (11)		10.7 (1.9)		

Note. Retirement status (Y = yes, retired, N = no, not retired, NA = never worked outside home). Behavioural response latency and electrophysiological data collected from P105 were excluded from the analyses for Experiment One because of the severity of the patient's left-sided neglect, which resulted in empty and unreliable RT data cells. Due to technical difficulties during acquisition of the electrophysiological data, all data from P116 were excluded from the analyses for Experiment One and all data from P106 were excluded from the analyses for Experiment Two.

Table 2. Chart Reviews for Patients with Right Hemisphere Stroke and Left Visual Hemineglect (*N* = 11) in Experiments One and Two.

ID	Feature	Chart Data
101	a) CVA	Ischemic.
	b) CT	Frontal, Temporal.
	c) Neglect	Left visual neglect gradually cleared with return of motor strength.
	d) Visual	None.
	e) S/M	Mild left hemiparesis and hemisensory loss, left hemiparesthesia arm (total) and leg (partial).
	f) Other	None.
103	a) CVA	Ischemic.
	b) CT	Occipital, (Frontal, Parietal from previous CVA).
	c) Neglect	Left visual neglect from previous stroke. Continued to omit all left numbers on clock drawing. No visual extinction.
	d) Visual	None.
	e) S/M	Left arm weak and clumsy, unsteady gait (residual from past stroke).
	f) Other	Mild cognitive deficits (attention, memory, following commands, confusion).
105	a) CVA	Ischemic with hemorrhagic transformation and hydrocephalus.
	b) CT	Temporal, Frontal, Parietal, Occipital.
	c) Neglect	Initially severe left visual neglect with no gaze past mid-line. Neglect and inattention contributed to poor wheel chair posture at discharge.
	d) Visual	Left homonymous hemianopia.
	e) S/M	Severe left hemiplegia, severe oral motor apraxia (eventually regained some swallowing).
	f) Other	Poor executive functions, poor judgement, anosagnosia, depressed mood, fatigue, chronic headache.

106	a) CVA	Hemorrhagic.
	b) CT	Thalamus.
	c) Neglect	Gross left visual neglect with poor tracking. Marked improvement but continued difficulty with drawing (clock, figure) and scanning at discharge. Left sensory extinction (fingers).
	d) Visual	None. Full visual fields and eye movement.
	e) S/M	Mild left arm and leg weakness, marked clumsiness and decreased fine motor control.
	f) Other	Slurring, fatigue.
107	a) CVA	Ischemic.
	b) CT	Basal Ganglia (Lentiform Nucleus, Corona Radiata).
	c) Neglect	Mild left visual neglect (line bisection, figure cancellation, scanning). Marked left inattention. Ambulate well at discharge but still inattentive to left hemispace (not to drive). Left visual and tactile extinction.
	d) Visual	None.
	e) S/M	Severely decreased left sensory-motor function, increased left reflexes, left facial palsy, tongue weakness, and drooling (unaware). Ambulating well at discharge able to walk by self.
	f) Other	Dysarthria, poor concentration, variable attention, visual memory, sequential learning, response disinhibition, perseveration (drawing), drowsy, disturbing auditory and visual hallucinations, paranoid delusions.
109	a) CVA	Ischemic.
	b) CT	White matter.
	c) Neglect	Left visual neglect. Conjugate deviation of eyes. Unable to cross mid-line.
	d) Visual	Left homonymous hemianopia.
	e) S/M	Severe left hemiplegia (arm, leg, face).
	f) Other	Mild dysarthria, confusion, fatigue.

110	a) CVA	Ischemic.
	b) CT	Parietal, Occipital.
	c) Neglect	Left visual neglect observed in behaviour and sensory disturbance.
	d) Visual	Left visual field loss, decreased vision.
	e) S/M	Left weakness, left hemiparesis.
	f) Other	Sustained attention, mild short-term memory.
112	a) CVA	Ischemic (1st) and Ischemic with hemorrhagic transformation (2nd).
	b) CT	Parietal, Temporal (1st) and Parietal, Frontal, Temporal (2nd)
	c) Neglect	Severe left visual neglect (line bisection, figure cancellation, copy designs, behavioural observation). Milder at discharge but remained unable to compensate despite awareness of problems. Left auditory extinction.
	d) Visual	Initial left homonymous hemianopia not replicated because no central fixation.
	e) S/M	Left hemiplegia, left arm and leg weakness, Impaired fine motor ability left hand, left facial palsy.
	f) Other	Slurring (from past stroke), dysarthria, attention, memory, visuo-spatial functions, Right-Left disorientation, motor impersistance, poor self-initiation/regulation, severe frontal disinhibition, perseveration, paranoid ideation, anosagnosia.
113	a) CVA	Ischemic.
	b) CT	Negative.
	c) Neglect	Left visual inattention on visual-motor test but not on confrontation testing or with simple object cancellation. Aware of it. Left sensory inattention in self-care "I'm trying to attend to left side". Left tactile extinction.
	d) Visual	None.
	e) S/M	Left hemiparesis (arm and leg weakness) eventually improved to only affecting left hand, reduced gag reflex.

	f) Other	Poor co-operation.
114	a) CVA	Ischemic.
	b) CT	Negative.
	c) Neglect	Marked left visual neglect. Read "fish stew" for "Irish stew." Inattention to left side. Eyes will come to mid-line with insistent prompting otherwise completely ignores left visual field.
	d) Visual	Left homonymous hemianopia, eyes deviated to right.
	e) S/M	Marked left hemipariesis (eventually able to walk briefly with braces and canes), left facial weakness.
	f) Other	Mild dysarthria, slurring, articulators imprecision, dysphonia.
116	a) CVA	Ischemic.
	b) CT	Temporal, Parietal, Frontal.
	c) Neglect	Mild left visual neglect and left homonymous hemianopia contribute to visual-spatial problems. Left inattention. Left sensory extinction.
	d) Visual	Left homonymous hemianopia.
	e) S/M	Left hemiplegia, left weakness, left-sided drooling, left facial droop.
	f) Other	Severe slurring, severe disorientation.

Note. CVA = Type of Cerebral Vascular Accident; CT = Brain Regions Identified in Interpretation of Computerised Axial Tomography Scan (when reports were negative, side of brain damage was from neurological examination); Neglect = Neglect Syndrome (e.g., hemineglect, hemi-inattention, and contralesional extinction in any modality). Visual = Visual Symptoms; S/M = Sensory Motor Symptoms; Other = Other Symptoms.

Table 3. Sunnybrook Neglect Battery Results for Patients with Left Visual Hemineglect ($N = 11$) in Experiments One and Two.

ID	Draw and Copy max 30	Line-Bisection max 10	Line Cancellation max 30	Figure Cancellation max 30	Total Score max 100	Neglect Severity[a]
101	20	2	0	0[b]	22	Mild
103	0	8	0	0[b]	8	Mild
105	30	10	30	30	100	Severe
106	30	6	3	25	64	Moderate
107	0	2	0	13	15	Mild
109	20	6	9	15	50	Moderate
110	30	10	0	0	40	Moderate
112	30	4	0	5	39	Moderate
113	0	4	0	30	34	Moderate
114	30	4	3	3	40	Moderate
116	30	2	0	30	62	Moderate

Note. [a] For the classification of neglect severity, total battery scores of 6 to 30 = Mild, 31 to 74 = Moderate, and 75 to 100 = Severe. [b] For these two patients, conservative Figure Cancellation Subtest scores of zero were assigned rather than the score of 2 for patient 101 or 4 for patient 103 because the actual scores did not reflect the non-lateralized impairments observed. To take normal performance (i.e., a single omission) into account, the subtest score is one less than the number of contralesional omissions. For patient 101, there were 6 omissions evenly distributed across the page (3 left, 3 right). The subtest score of 2 does not reflect the non-lateralized distribution of target omissions. For patient 103, there were 10 omissions evenly distributed across the page (5 left, 5 right) plus 23 false-positive non-target cancellations that were also evenly distributed (10 left, 13 right). The subtest score of 4 does not reflect the non-lateralized nature of impairment. Given that the impairments noted on these subtests could not unambiguously be attributed to hemineglect, the more conservative score of 0 was assigned in both cases. Note that the overall neglect classification (Mild) remains unchanged for both patients regardless of whether the more or less conservative subtest scores were used.

Table 4. Time Post-CVA When Patients with Left Hemineglect ($N = 11$) in Experiments One and Two were First Contacted, When Each Component of Testing was Completed, and the Number of Sessions Required for ERP Acquisition.

ID	First Contact	When Screen Neglect	When Semantic Priming Completed Experiment One		When Lateralized Oddballs Completed Experiment Two		When All Tests Done
		D	D	Sessions	D	Sessions	
101	1 wk	7	8	1	8	1	< 2 wk
103	1.4 yr	507	510	1	510	1	> 1 yr
105	7.5 wk	55	73	5	78	2	7-10 wk
106	2.1 wk	32	38	1	41	2	5-6 wk
107	4 d	5	12	1	12	1	< 2 wk
109	2 wk	14	19	2	20	2	2-3 wk
110	6.7 wk	47	48	1	55	1	7-10 wk
112	7.7 wk	71	54	1	61	1	7-10 wk
113	6 d	6	6	4	15	2	2-3 wk
114	2.3 yr	831	834	1	834	1	> 1 yr
116	1.3 wk	9	15	1	15	1	< 2 wk

Note. D or d = days post CVA, wk = weeks post CVA, yr = years post CVA. The Sunnybrook Bedside Neglect Battery was the screening measure. Behavioural response latency and electrophysiological data collected from P105 were excluded from the analyses for Experiment One because of the severity of the patient's left-sided neglect, which resulted in empty and unreliable RT data cells. Due to technical difficulties during acquisition of the electrophysiological data, all data from P116 were excluded from the analyses for Experiment One and all data from P106 were excluded from the analyses for Experiment Two.

Table 5. Demographics for the Age-Matched Controls (*N* = 14) in Experiments One and Two.

ID	Age (years)	Sex	Education (years)	Employment (highest level)	Retired
201	79	M	15	civil service	Y
202	60	F	10	Clerical	Y
207	58	F	18	home maker	NA
208	64	F	13	education/healthcare	Y
209	53	F	17	education/healthcare	N
211	62	F	14	education/healthcare	N
213	65	M	13	civil service	Y
214	66	M	20	education/healthcare	Y
215	75	F	25	education/healthcare	Y
216	73	M	22	education/healthcare	Y
217	64	M	21	education/healthcare	N
218	67	M	12	civil service	Y
219	67	F	10	Clerical	Y
224	71	F	9	home maker	NA
M (SD)	66 (6.9)		15.6 (5.0)		

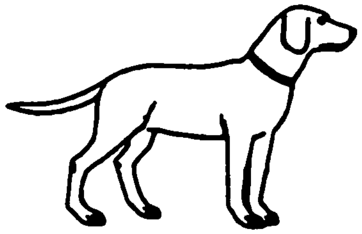
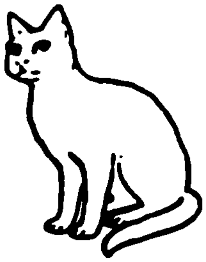
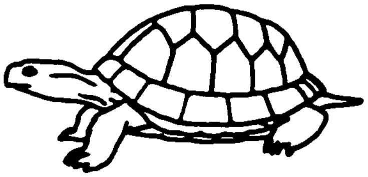
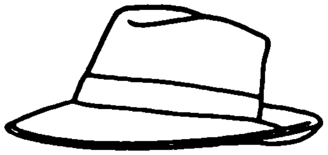
Note. Retirement status (Y = yes, retired, N = no, not retired, NA = never worked outside home). Due to technical difficulties during acquisition of the EEGs, data collected from C214 was excluded from the analysis of Experiment One and data collected from C211 was excluded from the analysis of Experiment Two.

Table 6. Comparison of the Demographic Data of the Patients with Left Hemineglect and the Age-Matched Controls in Experiments One and Two.

Comparison	Patients (*N* = 11)	Controls (*N* = 14)
1. Mean age in years (*SD*)	72 (11)	66 (6.9)
2. Gender	6 men, 5 women	6 men, 8 women
3. Mean years of Education (*SD*)*	10.7 (1.9)	15.6 (4.97)
4. Highest Level Employment		
a) Education or Health Professionals*	9.10 %	50.0 %
b) Civil Service Workers	18.2 %	21.4 %
c) Clerical Workers	18.2 %	14.3 %
d) Blue Collar Workers*	27.3 %	0.00 %
e) Homemakers	27.3 %	14.3 %
5. Retired	90.9 %	71.4 %

Note. The groups did not differ significantly on the basis of age, $t\ (16.02) = 1.59$, $p = 0.13$, or gender, $X^2 = .032$, $p > .05$. On average, controls were better educated than were patients, $t\ (17.51) = 3.4$, $p = .003$. The level of employment data for the controls contains a disproportionate representation among Education and Health Care Professionals and a disproportionate absence of Blue Collar Workers for the controls relative to the representation within these categories for the patients. These differences were confirmed by a 2 (groups) by 5 (4a to 4e) Test of Independence, $X^2 = 9.87$, $p < .05$. For retirement status, homemakers over the age of 65 years were considered to have retired. The two groups did not differ significantly in terms of the proportion of members who had retired, $X^2 = 1.45$, $p > .05$.

Table 7. Example Picture Stimuli From the Lateralized Semantic Priming Paradigm of Experiment One.

Condition	Lateralized Prime	Centralised Target
Congruent		
Non-Congruent		

Note. The pictures ($N = 30$) were exemplars of common animals ($n = 15$) or clothing ($n = 15$) selected mostly from the line drawings of Snodgrass and Vanderwort (1980). The lateralized primes preceded the centralised targets and appeared with equal frequency in the left and right visual fields. Using a two-button response pad, participants were to categorise each centralised target picture (clothing or animal) which had been preceded by a semantically congruent or non-congruent lateralized picture prime. Semantic priming in the behavioural data was expected to involve response times that were faster for targets that were non-congruently rather than congruently primed. In the ERP data, the amplitude of the N400 was expected to be more positive for targets that were non-congruently rather than congruently primed targets. The central hypothesis involved the determination of whether or not these priming effects could be elicited reliably when the lateralized primes were presented in the neglected field of patients with left visual hemineglect.

Table 8. Mean Percentage Accuracy Scores for Patients with Left Visual Hemineglect ($N = 11$) on the Neglect Verification Task of Experiment One.

ID	Central Targets ($N = 24$ trials)			Left Primes ($N = 12$ trials)			Right Primes ($N = 12$ trials)			X^2
	Cor	Miss	Inc	Cor	Miss	Inc	Cor	Miss	Inc	
101	95.8	0	4.2	100	0	0	91.7	8.3	0	-1.04
103	91.7	8.3	0	66.7	33.3	0	83.3	16.7	0	+0.89
106	75	25	0	41.7	58.3	0	100	0	0	+9.88*
107	95.7	4.4	0	36.4	63.6	0	58.3	25	16.7	+2.37
109	100	0	0	91.7	8.3	0	91.7	8.3	0	0
110	58.3	41.7	0	25	66.7	8.3	83.3	8.3	8.3	+9.21*
112	95.8	4.2	0	0	100	0	83.3	16.7	0	+17.14*
113	100	0	0	8.3	91.7	0	66.7	33.3	0	+8.71*
114	100	0	0	0	100	0	91.7	8.3	0	+20.31*
105	54.2	0	45.8	0	100	0	91.7	8.3	0	+20.31*
116	75	25	0	66.7	33.3	0	100	0	0	+4.8*

Note. Percentage accuracy scores are for correct categorisation (Cor), incorrect categorisation (Inc), and no response (Miss). Chi Square values (X^2) are positive (+) when more left than right primes were missed and negative (-) when the pattern was reversed. The asterisks (*) denote statistical significance at $p \leq .05$ ($X^2_{crit} = 3.84$).

Table 9. Comparison of Performance for Patients with Left Visual Hemineglect (N = 11) on the Neglect Verification Task of Experiment One and the Sunnybrook Bedside Neglect Battery.

ID	A Verification Task	B Draw/Copy max 30	C Line Bi max 10	D Line Can max 30	E Fig Can max 30	F Total max 100	G Class
101	- 1.04	20	2	0	0	22	Mild
103	0.89	0	8	0	0	8	Mild
105	20.31	30	10	30	30	100	Severe
106	9.88	30	6	3	25	64	Moderate
107	2.37	0	2	0	13	15	Mild
109	0	20	6	9	15	50	Moderate
110	9.21	30	10	0	0	40	Moderate
112	17.14	30	4	0	5	39	Moderate
113	8.71	0	4	0	30	34	Moderate
114	20.31	30	4	3	3	40	Moderate
116	4.8	30	2	0	30	62	Moderate

1-Tailed Pearson Product-Moment Correlations Between the Verification Task (A) and Scores From the Sunnybrook Battery (B to G) for the Patients (N = 11).

	A	B	C	D	E	F	G
r	--	.56	.28	.45	.14	.55	.65
p	--	.037*	.207	.083	.341	.040*	.015*

Note. The 24-trial neglect verification task (A) involved verbal classification of picture primes in the left (n = 12) or right (n = 12) visual field and of centralized picture targets (n = 24). The measure of field asymmetry for the primes was derived through Chi Square analyses. Positive values indicate a greater incidence of missed left than right primes. The Sunnybrook Neglect Battery subtests are: Drawing and Copying (B), Line Bisection (C), Line Cancellation (D), and Figure Cancellation (E). The Total Neglect Score (F) is derived by summing the 4 subtest scores. Severity classifications (G) are Mild (5 to 30 points), Moderate (31 to 74 points) and Severe (75 to 100 points). An asterisk (*) denotes 1-tailed significance at $p \leq .05$.

Table 10. The Mean Number of Target Categorisation Times Identified as Outliers and the Mean Percentage of Total Target Categorisation Times Excluded as Outliers per Condition of the Lateralized Semantic Priming Paradigm of Experiment One for the Patients with Left Visual Hemineglect and the Age-Matched Controls.

Group/Condition	# of Target Categorisation Times Identified as Outliers			% of Total Target Categorisation Times Excluded as Outliers	
	M	*SD*	Range	*M*	*SD*
Patients (N = 9)					
Right Congruent	1.00	0.87	0-2	3.51	2.94
Right Non-Congruent	0.33	0.50	0-1	1.19	1.80
Left Congruent	0.56	0.73	0-2	1.72	2.09
Left Non-Congruent	0.67	0.71	0-2	2.40	2.42
Total	2.56	2.07	0-6	2.21	0.69
Controls (N = 13)					
Right Congruent	1.23	1.01	0-3	5.40	4.49
Right Non-Congruent	1.31	0.63	0-2	5.15	2.49
Left Congruent	1.23	0.83	0-3	5.23	3.47
Left Non-Congruent	1.08	1.04	0-4	4.83	4.72
Total	4.85	2.12	2-9	5.15	0.58

Note. Outliers within each condition were identified as target categorisation times that were 2 *SD* or more from the mean of the condition. To correct for a practice effect in the controls' data, the first block of 26 trials was excluded for each control.

Table 11. The Target Picture Categorisation Times (in s) from the Semantic Priming Paradigm of Experiment One for the Patients with Left Visual Hemineglect and the Age-Matched Controls: The ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
Time	Group (G)	8.70	1, 20	.008	*
	Congruency (C)	8.67	1, 20	.008	*
	Laterality of Prime (L)	0.02	1, 20	.876	
	C x L	4.05	1, 20	.058	
	G x C	1.02	1, 20	.324	
	G x L	0.04	1, 20	.846	
	G x C x L	4.25	1, 20	.052	

Note. G = Group ($N_{\text{patient}} = 9$, $N_{\text{control}} = 13$), C = Congruency of Prime (Congruent, Non-Congruent), and L = Laterality of Prime (Left, Right). An asterisk (*) denotes statistical significance at $p \leq .05$.

Table 12. Mean Target Picture Categorisation Times (in *ms*) and Percentage Correct Categorisations from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect and Age-Matched Controls.

Group	Left Primed Targets				Right Primed Targets			
	C		NC		C		NC	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Patients (*N* = 9)								
RT	992	1385	1111	1394	1044	1493	1057	1495
% Correct	86.8	10.3	82.6	17.9	85.8	14.7	76.7	17.6
Controls (*N* = 13)								
RT	727	1239	749	1239	720	1262	743	1249
% Correct	99	1.9	100	0	99.3	1.6	100	0

Note. RT = response time. Each target picture was preceded by a semantically congruent (C) or non-congruent (NC) picture prime lateralized to the left or right visual field. The mean percentage accuracy data have been provided so that the participants' criteria for speed versus accuracy could be evaluated.

Table 13. Mean Number of Trials Averaged and Percentage of Total Trials Rejected per Condition Prior to Averaging the Patient and Control EEG Data for the Lateralized Picture Primes from the Semantic Priming Paradigm of Experiment One.

Group/Condition	# of Trials Averaged			% of Total Trials Rejected	
	M	*SD*	Range	*M*	*SD*
Patients (*N* = 9)					
Left Prime	42.0	11.64	25-58	30.0	22.33
Right Prime	43.9	11.16	30-59	27.8	21.22
Controls (*N* = 13)					
Left Prime	50.5	7.94	38-62	15.7	12.64
Right Prime	49.5	6.41	40-60	17.7	10.51

Table 14. Sensitivity of the Behavioural Data from the Lateralized Semantic Priming Paradigm of Experiment One for Individual Patients with Visual Hemineglect and Age-Matched Controls: The percentage of cases who showed the predicted pattern of semantic priming, whose pattern reached statistical significance, and whose pattern showed evidence of at least a trend.

Group/Criteria	Right Primed Condition	Left Primed Condition
Controls (*N* = 13)		
Pattern Present	69.2	69.2
Pattern Significant	23.1	30.8
Total if Trends Included	30.8	38.5
Patients (*N* = 9)		
Pattern Present	44.4	100
Pattern Significant	22.2	33.3
Total if Trends Included	44.4	44.4

Note. The predicted pattern of semantic priming involved faster categorisation times for picture targets that were congruently rather than non-congruently primed. Statistical significance or the 1-tailed *t*-test comparisons was met when $p \leq .05$. A trend was met when $p < .1$.

Table 15. Mean Number of Trials Averaged and Percentage of Total Trials Rejected per Condition Prior to Averaging the Patient and Control EEG Data for the Centralised Picture Targets from the Semantic Priming Paradigm of Experiment One.

Group/Condition	# of Trials Averaged			% of Total Trials Rejected	
	M	*SD*	Range	*M*	*SD*
Patients (*N* = 9)					
Right Congruent	23.9	3.14	19-28	21.8	8.67
Right Non-Congruent	23.0	3.57	15-27	26.0	12.8
Left Congruent	23.8	5.39	15-31	21.5	16.3
Left Non-Congruent	22.3	4.09	14-27	27.2	13.8
Controls (*N* = 13)					
Right Congruent	21.8	2.60	15-24	6.4	10.29
Right Non-Congruent	23.3	2.86	18-27	8.5	10.96
Left Congruent	21.2	2.07	18-24	10.4	8.48
Left Non-Congruent	19.7	2.66	14-22	12.0	11.70

Note. To correct for a practice effect in the control's data, the first block of 26 trials was excluded for each control.

Table 16. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect and Age-Matched Controls: The N400 Amplitude (in μV) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
N400 Amplitude	Group (G)	6.70	1, 20	.018	*
	Congruency (C)	11.82	1, 20	.003	*
	Laterality of Prime (L)	1.81	1, 20	.194	
	Site (S)	10.01	1.4, 40	.001	*
	C x L	1.11	1, 20	.305	
	C x S	0.76	1.5, 40	.440	
	L x S	2.53	2, 40	.092	
	C x L x S	1.94	2, 40	.157	
	G x C	0.26	1, 20	.619	
	G x L	0.03	1, 20	.854	
	G x S	13.36	2, 40	< .001	*
	G x C x L	0.01	1, 20	.915	
	G x C x S	3.83	2, 40	.030	*
	G x L x S	0.17	2, 40	.848	
	G x C x L x S	0.42	2, 40	.659	

Note. G = Group ($N_{\text{patient}} = 9$, $N_{\text{control}} = 13$); C = Congruency of Prime (Congruent, Non-Congruent); L = Laterality of Prime (Left, Right); and S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p \leq .05$.

Table 17. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect and Age-Matched Controls: The N400 Amplitude (in μV) Group by Recording Site Interaction.

Group	*(N)*	Site	*M*	*SD*
Patient	(9)	Fz	-2.05	.97
		Cz	-2.16	.86
		Pz	-1.84	.71
Control	(13)	Fz	1.90	.80
		Cz	1.59	.71
		Pz	-1.67	.59

Table 18. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect and Age-Matched Controls: The N400 Amplitude (in *μV*) Group by Congruency of Prime by Recording Site Interaction.

Group	(*N*)	Congruency	Site	*M*	*SD*
Patient	(9)	Congruent	Fz	-1.37	1.06
			Cz	-1.31	.93
			Pz	-1.47	.67
		Non-Congruent	Fz	-2.74	1.05
			Cz	-3.02	.94
			Pz	-2.21	.88
Control	(13)	Congruent	Fz	2.41	.89
			Cz	2.37	.77
			Pz	-0.60	.56
		Non-Congruent	Fz	1.40	.88
			Cz	.769	.78
			Pz	-3.13	.73

Note. The amplitude differences reached statistical significance for the controls at Pz and Cz and for the patients at Fz and Cz.

Table 19. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect and Age-Matched Controls: The N400 Latency (in *ms*) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
N400 Latency	Group (G)	11.03	1. 20	.003	*
	Congruency (C)	0.18	1, 20	.674	
	Laterality of Prime (L)	0.73	1, 20	.404	
	Site (S)	0.62	1.4, 40	.490	
	C x L	0.19	1, 20	.667	
	C x S	0.03	2, 40	.970	
	L x S	1.28	2, 40	.280	
	C x L x S	4.53	2, 40	.017	*
	G x C	0.69	1, 20	.415	
	G x L	0.35	1, 20	.560	
	G x S	0.64	2, 40	.530	
	G x C x L	0.37	1, 20	.549	
	G x C x S	0.81	2, 40	.974	
	G x L x S	1.17	2, 40	.321	
	G x C x L x S	4.00	2, 40	.026	*

Note. G = Group ($N_{\text{patient}} = 9$, $N_{\text{control}} = 13$); C = Congruency of Prime (Congruent, Non-Congruent); L = Laterality of Prime (Left, Right); and S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p \leq .05$.

Table 20. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect and Age-Matched Controls: The P200 Amplitude (in μV) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
P200 Amplitude	Group (G)	1.53	1, 20	.23	
	Congruency (C)	0.46	1, 20	.50	
	Laterality of Prime (L)	2.79	1, 20	.11	
	Site (S)	2.92	2, 40	.07	
	C x L	0.76	1, 20	.39	
	C x S	0.82	2, 40	.45	
	L x S	0.28	1.5, 40	.69	
	C x L x S	0.04	2, 40	.96	
	G x C	4.86	1, 20	.04	*
	G x L	0.10	1, 20	.76	
	G x S	0.40	2, 40	.67	
	G x C x L	0.27	1, 20	.61	
	G x C x S	1.55	2, 40	.23	
	G x L x S	1.75	2, 40	.19	
	G x C x L x S	0.60	2, 40	.55	

Note. G = Group ($N_{\text{patient}} = 9$, $N_{\text{control}} = 13$); C = Congruency of Prime (Congruent, Non-Congruent); L = Laterality of Prime (Left, Right); and S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p \leq .05$.

Table 21. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect and Age-Matched Controls: The P200 Amplitude (in μV) Group by Congruency of Prime Interaction.

Group	*(N)*	Congruency	M	SD
Patient	(9)	Congruent	2.18	.91
		Non-Congruent	2.85	.63
Control	(13)	Congruent	4.29	.76
		Non-Congruent	3.03	.52

Table 22. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect and Age-Matched Controls: The P200 Latency (in *ms*) ANOVA .

Dependent Variable	Factor	*F*	*df*	*P*	
P200 Latency	Group (G)	2.56	1, 20	.12	
	Congruency (C)	0.03	1, 20	.87	
	Laterality of Prime (L)	0.05	1, 20	.83	
	Site (S)	6.22	2, 40	.01	*
	C x L	0.36	1, 20	.55	
	C x S	0.06	1.3, 40	.87	
	L x S	1.86	1.3, 40	.18	
	C x L x S	0.76	2, 40	.47	
	G x C	3.01	1, 20	.10	
	G x L	0.07	1, 20	.80	
	G x S	0.56	2, 40	.57	
	G x C x L	0.05	1, 20	.83	
	G x C x S	1.45	2, 40	.25	
	G x L x S	1.89	2, 40	.18	
	G x C x L x S	0.96	2, 40	.39	

Note. G = Group ($N_{\text{patient}} = 9$, $N_{\text{control}} = 13$); C = Congruency of Prime (Congruent, Non-Congruent); L = Laterality of Prime (Left, Right); and S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p \leq .05$.

Table 23. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect and Age-Matched Controls: The N200 Amplitude (in μV) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
N200 Amplitude	Group (G)	3.83	1, 20	.06	
	Congruency (C)	0.24	1, 20	.63	
	Laterality of Prime (L)	1.41	1, 20	.25	
	Site (S)	12.19	1.6, 40	<.001	*
	C x L	1.53	1, 20	.23	
	C x S	0.33	1.2, 40	.72	
	L x S	2.50	1.5, 40	.12	
	C x L x S	1.27	2, 40	.29	
	G x C	1.50	1, 20	.23	
	G x L	1.39	1, 20	.25	
	G x S	7.48	2, 40	.002	*
	G x C x L	1.65	1, 20	.21	
	G x C x S	0.72	2, 40	.49	
	G x L x S	1.59	2, 40	.22	
	G x C x L x S	1.71	2, 40	.19	

Note. G = Group ($N_{\text{patient}} = 9$, $N_{\text{control}} = 13$); C = Congruency of Prime (Congruent, Non-Congruent); L = Laterality of Prime (Left, Right); and S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p \leq .05$.

Table 24. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect and Age-Matched Controls: The N200 Amplitude (in μV) Group by Recording Site Interaction.

Group	*(N)*	Site	M	SD
Patient	(9)	Fz	-.69	.79
		Cz	-1.00	.90
		Pz	-1.23	.83
Control	(13)	Fz	2.36	.66
		Cz	1.75	.75
		Pz	-1.40	.69

Table 25. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect and Age-Matched Controls: The N200 Latency (in *ms*) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
N200 Latency	Group (G)	7.32	1, 20	.01	*
	Congruency (C)	.001	1, 20	.98	
	Laterality of Prime (L)	0.35	1, 20	.56	
	Site (S)	0.74	1.5, 40	.45	
	C x L	0.19	1, 20	.67	
	C x S	1.91	2, 40	.16	
	L x S	3.36	2, 40	.045	*
	C x L x S	0.61	1.5, 40	.51	
	G x C	.001	1, 20	.97	
	G x L	1.89	1, 20	.18	
	G x S	0.61	2, 40	.55	
	G x C x L	1.54	1, 20	.23	
	G x C x S	2.95	2, 40	.06	
	G x L x S	1.49	2, 40	.24	
	G x C x L x S	1.01	2, 40	.37	

Note. G = Group ($N_{\text{patient}} = 9$, $N_{\text{control}} = 13$); C = Congruency of Prime (Congruent, Non-Congruent); L = Laterality of Prime (Left, Right); and S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p \leq .05$.

Table 26. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect and Age-Matched Controls: The N200 Latency (in *ms*) Laterality of Prime by Recording Site Interaction.

Prime Laterality	Site	M	SD
Left	Fz	187.1	5.59
	Cz	186.2	6.07
	Pz	184.9	5.75
Right	Fz	184.2	5.82
	Cz	188.9	6.29
	Pz	194.4	6.30

Table 27. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect and Age-Matched Controls: The P300 Amplitude (in μV) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
P300 Amplitude	Group (G)	76.97	1, 20	.02	*
	Congruency (C)	0.28	1, 20	.60	
	Laterality of Prime (L)	0.02	1, 20	.88	
	Site (S)	4.32	1.5, 40	.03	*
	C x L	0.71	1, 20	.11	
	C x S	0	2, 40	1.0	
	L x S	0.88	1.5, 40	.40	
	C x L x S	0.57	2, 40	.57	
	G x C	0.10	1, 20	.75	
	G x L	0.05	1, 20	.83	
	G x S	5.13	2, 40	.01	*
	G x C x L	2.01	1, 20	.17	
	G x C x S	0.05	2, 40	.95	
	G x L x S	0.50	2, 40	.61	
	G x C x L x S	0.15	2, 40	.86	

Note. G = Group ($N_{\text{patient}} = 9$, $N_{\text{control}} = 13$); C = Congruency of Prime (Congruent, Non-Congruent); L = Laterality of Prime (Left, Right); and S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p \leq .05$.

Table 28. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect and Age-Matched Controls: The P300 Amplitude (in μV) Group by Recording Site Interaction.

Group	*(N)*	Site	M	SD
Patient	(9)	Fz	3.24	1.03
		Cz	3.68	.95
		Pz	3.72	.86
Control	(13)	Fz	6.60	.86
		Cz	7.57	.79
		Pz	5.02	.71

Table 29. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect and Age-Matched Controls: The P300 Latency (in *ms*) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
P300 Latency	Group (G)	13.48	1, 20	.002	*
	Congruency (C)	2.14	1, 20	.16	
	Laterality of Prime (L)	0.41	1, 20	.53	
	Site (S)	1.11	2, 40	.34	
	C x L	0.29	1, 20	.60	
	C x S	0.37	2, 40	70	
	L x S	0.29	1.3, 40	.65	
	C x L x S	0.86	1.5, 40	.41	
	G x C	2.96	1, 20	.10	
	G x L	.004	1, 20	.95	
	G x S	2.01	2, 40	.15	
	G x C x L	0.03	1, 20	.88	
	G x C x S	1.33	2, 40	.28	
	G x L x S	0.27	2, 40	.77	
	G x C x L x S	1.47	2, 40	.24	

Note. G = Group ($N_{\text{patient}} = 9$, $N_{\text{control}} = 13$); C = Congruency of Prime (Congruent, Non-Congruent); L = Laterality of Prime (Left, Right); and S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p \leq .05$.

Table 30. Sensitivity of the Lateralized Semantic Priming Paradigm of Experiment One: The Percentage of Patients with Left Visual Hemineglect and Age-Matched Controls Whose N400 Amplitudes (in μV) for Centralised Picture Targets Showed the Predicted Pattern of Differentiation and for Whom Statistical Significance was Reached.

Site	Group	(n)	Right Prime Condition		Left Prime Condition	
			Pattern	%sig	Pattern	%sig
Fz	Patient	(9)	66.6	11.1	88.9	11.1
	Control	(13)	38.5	7.7	61.5	7.7
Cz	Patient	(9)	55.6	22.2	88.9	11.1
	Control	(13)	84.6	7.7	53.8	23.1
Pz	Patient	(9)	77.8	0	66.7	11.1
	Control	(13)	92.3	7.7	84.6	7.7

Note. The predicted pattern of differentiation entailed greater amplitude negativity for non-congruently than for congruently primed targets. Statistical significance (1-tailed) was met when $p \leq .05$.

Table 31. The Relative Stimulus Probabilities For the Two Versions of the Lateralized Oddball Paradigm of Experiment Two.

Condition	Stimuli	50% Target Version	25% Target Version
Left Targets	O + X	25	12.5
Right Targets	X + O	25	12.5
Non-Targets	X + X	50	75

Note. The plus sign (+) represents the central fixation point. The two versions of the paradigm were developed to assess the extent to which patients with visual hemineglect could implicitly differentiate target from non-target stimuli presented in the contralesional visual field. Moreover, if the magnitude of the P300 amplitude effects for targets relative to non-targets were found to be significantly greater for the 25% than 50% target version of the paradigm, this result would provide evidence that information about relative stimulus probability was being processed.

Table 32. The Mean Percentage Accuracy and False Positive Scores on the Lateralized Oddball Paradigms of Experiment Two for Patients with Left Visual Hemineglect and Age-Matched Controls.

Paradigm/ Group	*(N)*	Left Target Hits		Right Target Hits		Non-Target False Positives	
		M	*SD*	*M*	*SD*	*M*	*SD*
50% Target Version							
Controls	(13)	98.9	1.55	99.4	1.26	0.85	0.99
Patients	(10)	61.2	43.9	90.3	11.7	1.99	1.57
25% Target Version							
Controls	(13)	100	0	98.2	2.06	0.26	0.34
Patients	(10)	55.2	47.7	90.2	15.5	2.05	3.71

Note. 50% Target Version = 25% Left Targets, 25% Right Targets, and 50% Non-Targets. 25% Target Version = 12.5% Left Targets, 12.5% Right Targets, and 75% Non-Targets.

Table 33. The Percentage of Target Hits on the Lateralized Oddball Paradigms of Experiment Two for the Patients with Left Visual Hemineglect and Age-Matched Controls: The ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
Mean %Target Hits	Group (G)	13.27	1, 21	.002	*
	Paradigm (P)	1.47	1, 21	.240	
	Target Laterality (L)	6.78	1, 21	.017	*
	G x P	1.34	1, 21	.260	
	G x L	7.38	1. 21	.013	*
	P x L	0.32	1, 21	.577	
	G x P x L	1.75	1, 21	.200	

Note. G = Group ($N_{patient}$ = 10, $N_{control}$ = 13), P = Paradigm (50% and 25% Target Versions), and L = Target Laterality (Left, Right). An asterisk (*) denotes statistical significance at $p \leq .05$.

Table 34. The Percentage of Target Hits on the Lateralized Oddball Paradigms of Experiment Two for the Patients with Left Visual Hemineglect and Age-Matched Controls: The Group by Target Laterality Interaction.

Group	(*N*)	Target Laterality	*M*	*SD*
Patient	(10)	Left	58.19	9.28
		Right	90.14	2.78
Control	(13)	Left	99.46	8.14
		Right	99.78	2.44

Table 35. The Percentage of Non-Target False Positives on the Lateralized Oddball Paradigms of Experiment Two for the Patients with Left Visual Hemineglect and Age-Matched Controls: The ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
Mean % False Positives	Group (G)	15.86	1, 21	.034	*
	Paradigm (P)	0.29	1, 21	.594	
	G x P	0.42	1, 21	.526	

Note. G = Group ($N_{patient}$ = 10, $N_{control}$ = 13) and P = Paradigm (50% and 25% Target Versions). An asterisk (*) denotes statistical significance at $p \leq .05$.

Table 36. The Mean Percentage Accuracy and False Positive Scores on the Lateralized Oddball Paradigms of Experiment Two for Each Age-Matched Control ($N = 13$).

Paradigm/ Participant	Left Target Hits	Right Target Hits	Non-Target False Positives
50% Target Version			
201	100	100	0
202	100	100	1
207	98	100	2
208	96	100	0
209	100	100	1
211	100	96	0
213	100	100	0
215	98	100	2
216	100	98	1
217	100	100	0
218	100	100	3
219	96	98	1
224	98	100	0
M (SD)	*98.92 (1.55)*	*99.38 (1.26)*	*0.85 (.99)*
25% Target Version			
201	100	100	0
202	100	100	0
207	100	100	0
208	100	100	.67
209	100	96	0
211	100	96	.67
213	100	96	.65
215	100	100	0
216	100	96	.67
217	100	96	0
218	100	100	0
219	100	100	0
224	100	96	.67
M (SD)	*100 (0)*	*98.17 (2.06)*	*0.26 (.34)*

Note. 50% Target Version = 25% Left Targets, 25% Right Targets, and 50% Non-Targets. 25% Target Version = 12.5% Left Targets, 12.5% Right Targets, and 75% Non-Targets.

Table 37. The Mean Percentage Accuracy and False Positive Scores on the Lateralized Oddball Paradigms of Experiment Two for Individuals Within the Two Subgroups of Patients with Left Visual Hemineglect (*N* = 10).

Paradigm/ Group	Left Target Hits	Right Target Hits	Non-Target False Positives
50% Target Version			
Non-Detectors (*n*=5)			
105	2.00	80.0	2.00
107	56.0	62.0	2.00
112	60.0	96.0	0
113	1.82	88.7	0.93
114	2.00	92.0	1.00
Detectors (*n*=5)			
101	96.0	100	0
103	100	100	4.00
109	98.0	92.0	2.00
110	96.0	100	4.00
116	100	92.0	4.00
25% Target Version			
Non-Detectors (*n*=5)			
105	0	88.0	1.33
107	56.0	48.0	0
112	0	100	0
113	8.00	88.0	0.67
114	0	96.0	0
Detectors (*n*=5)			
101	100	100	0
103	100	92.0	0.67
109	100	92.0	7.33
110	88.0	100	0
116	100	96.2	10.46

Note. 50% Target Version = 25% Left Targets, 25% Right Targets, and 50% Non-Targets. 25% Target Version = 12.5% Left Targets, 12.5% Right Targets, and 75% Non-Targets. Non-Detectors = patients who *omitted* more left than right targets. Detectors = patients who *detected* left and right targets.

Table 38. The Mean Percentage Accuracy and False Positive Scores on the Lateralized Oddball Paradigms of Experiment Two for the Two Subgroups of Patients with Left Visual Hemineglect and the Age-Matched Controls.

Paradigm/ Group	*(N)*	Left Target Hits		Right Target Hits		Non-Target False Positives	
		M	*SD*	*M*	*SD*	*M*	*SD*
50% Target Version							
Non-Detector	(5)	24.4	30.4	83.7	13.5	1.19	0.84
Detector	(5)	98.0	2.00	96.8	4.38	2.80	1.79
Control	(13)	98.9	1.55	99.4	1.26	0.85	0.99
25% Target Version							
Non-Detector	(5)	12.8	24.4	84.0	20.8	0.40	0.60
Detector	(5)	97.6	5.37	96.0	4.00	3.69	4.88
Control	(13)	100	0	98.2	2.06	0.26	0.34

Note. 50% Target Version = 25% Left Targets, 25% Right Targets, and 50% Non-Targets. 25% Target Version = 12.5% Left Targets, 12.5% Right Targets, and 75% Non-Targets. Non-Detector = patient who *omitted* more left than right targets. Detector = patient who *detected* left and right targets.

Table 39. The Percentage of Target Hits on the Lateralized Oddball Paradigms of Experiment Two for the Two Subgroups of Patients with Left Visual Hemineglect and the Age-Matched Controls: The ANOVA.

Dependent Variable	Factor	*F*	*df*	*P*	
Mean %Target Hits	Group (G)	287.09	2, 20	<.001	*
	Paradigm (P)	2.20	1, 20	.154	
	Target Laterality (L)	27.89	1, 20	<.001	*
	G x P	1.54	2, 20	.240	
	G x L	28.51	2, 20	<.001	*
	P x L	0.88	1, 20	.359	
	G x P x L	1.85	2, 20	.184	

Note. G = Group ($N_{non\text{-}detector} = 5$, $N_{detector} = 5$, $N_{control} = 13$), P = Paradigm (50% and 25% Target Versions), and L = Target Laterality (Left, Right). Non-Detector = patient who *omitted* more left than right targets. Detector = patient who *detected* left and right targets. An asterisk (*) denotes statistical significance at $p \leq .05$.

Table 40. The Percentage of Target Hits on the Lateralized Oddball Paradigms of Experiment Two for the Two Subgroups of Patients with Left Visual Hemineglect and the Age-Matched Controls: The Group by Target Laterality Interaction.

Group	*(N)*	Target Laterality	*M*	*SD*
Non-Detector	(5)	Left	18.58	4.89
		Right	83.87	3.50
Detector	(5)	Left	97.80	4.89
		Right	96.42	3.50
Control	(13)	Left	99.46	3.03
		Right	98.78	2.17

Note. Non-Detector = patient who *omitted* more left than right targets. Detector = patient who *detected* left and right targets.

Table 41. The Percentage of Non-Target False Positives from the Lateralized Oddball Paradigms of Experiment Two for the Two Subgroups of Patients with Left Visual Hemineglect and the Age-Matched Controls: The ANOVA.

Dependent Variable	Factor	*F*	*df*	*P*	
Mean % False Positives	Group (G)	25.63	1, 20	.003	*
	Paradigm (P)	0.09	1, 20	.768	
	G x P	0.83	2, 20	.449	

Note. G = Group ($N_{non\text{-}detector} = 5$, $N_{detector} = 5$, $N_{control} = 13$) and P = Paradigm (50% and 25% Target Versions). Non-Detector = patient who *omitted* more left than right targets. Detector = patient who *detected* left and right targets. An asterisk (*) denotes statistical significance at $p \leq .05$.

Table 42. Mean Log_{10} Transformed Correct Target Categorisation Times (and the Inverse Log_{10} Transformed Mean Times (in s) From the Lateralized Oddball Paradigms of Experiment Two for the Two Subgroups of Patients with Left Visual Hemineglect and the Age-Matched Controls.

Paradigm/Group	Left Targets (LT)				Right Targets (RT)			
	(N)	*M*	*SD*	*RT*	*(N)*	*M*	*SD*	*RT*
50% Target Version								
Controls	(13)	-.343	.014	.457	(13)	-.341	.015	.457
Non-Detector	(2)	NA	NA	NA	(5)	-.216	.029	.603
Detector	(5)	-.269	.022	.537	(5)	-.331	.025	.468
25% Target Version								
Control	(13)	-.312	.021	.490	(13)	-.310	.021	.490
Non-Detector	(1)	NA	NA	NA	(5)	-.179	.036	.794
Detector	(5)	-.275	.034	.525	(5)	-.314	.034	.490

Note. 50% Target Version = 25% LT, 25% RT, and 50% Non-Targets. 25% Target Version = 12.5% LT, 12.5% RT, and 75% Non-Targets. Non-Detector = patient who *omitted* more left than right targets. Detector = patient who *detected* left and right targets. NA = not available due to insufficient data per cell.

Table 43. The Mean Log_{10} Transformed Target Response Latencies from the Lateralized Semantic Priming Paradigm of Experiment Two for the Patients with Left Visual Hemineglect who Detected Left Targets (Detectors) and the Age-Matched Controls: The ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
Mean % RT (in s)	Group (G)	0.84	1, 16	.373	
	Paradigm (P)	2.70	1, 16	.120	
	Target Laterality (L)	25.44	1, 16	<.001	*
	G x P	1.25	1, 16	.277	
	G x L	29.47	1, 16	<.001	*
	P x L	2.39	1, 16	.142	
	G x P x L	2.46	1, 16	.137	

Note. G = Group ($N_{detector} = 5$, $N_{control} = 13$), P = Paradigm (50% and 25% Target Versions), and L = Target Laterality (Left, Right). Detector = patient who responded to left and right targets. An asterisk (*) denotes statistical significance at $p \leq .05$.

Table 44. The Mean Log_{10} Transformed Target Response Latencies from the Lateralized Semantic Priming Paradigm of Experiment Two for the Patients with Left Visual Hemineglect who Detected Left Targets (Detectors) and the Age-Matched Controls: The Group by Target Laterality Interaction.

Group	(*N*)	Target Laterality	*M*	*SD*	RT
Detector	(5)	Left	-.272	.026	.534
		Right	-.323	.028	.475
Control	(13)	Left	-.327	.016	.471
		Right	-.326	.018	.472

Note. Detector = patient who responded to left and right targets. RT = the inverse Log_{10} transformed target response latencies in *ms*.

Table 45. The Mean Log_{10} Transformed Right Target Response Latencies from the Lateralized Semantic Priming Paradigms of Experiment Two for the two Subgroups of Patients with Left Visual Hemineglect and Age-Matched Controls: The ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
Mean % RT (in s)	Group (G)	6.30	2, 20	.008	*
	Paradigm (P)	10.39	1, 20	.004	*
	G x P	0.37	2, 20	.695	

Note. G = Group (Non-Detector s who *omitted* more left than right targets ($n = 5$), Delayed Detectors who detected left targets *more slowly* than right targets ($n = 5$), and Controls who were age-matched ($N = 13$). P = Paradigm Version (50% and 25% Targets). An asterisk (*) denotes statistical significance at $p \leq .05$.

Table 46. Performance on the Sunnybrook Neglect Battery by the two Subgroups of Patients with Left Visual Hemineglect in Experiment Two.

Patient Subgroup	Neglect Score	Classification
Non-Detector (*n*=5)		
105	100	Severe
107	15	Mild
112	39	Moderate
113	34	Moderate
114	40	Moderate
M (SD)	*45.6 (32.0)*	
Delayed Detector (*n*=5)		
101	22	Mild
103	8	Mild
109	50	Moderate
110	40	Moderate
116	62	Moderate
M (SD)	*36.4 (21.6)*	

Note. Non-Detector = patient who *omitted* more left than right targets. Delayed Detector = patient who detected left targets *more slowly* than right targets. Neglect scores (maximum 100 points) positively relate to deficit severity.

Table 47. The Number of EEG Trials Averaged and The Percentage of Total EEG Trials Rejected per Condition of the Lateralized Oddball Paradigms of Experiment Two for the Patients with Left Visual Hemineglect and the Age-Matched Controls.

Group/Version/ Condition	# of Trials Averaged			% of Total Trials Rejected	
	M	*SD*	Range	*M*	*SD*
Patients (*N* = 10)					
50% Target Version					
LT (25%)	28.7	11.85	13-47	42.6	23.70
RT (25%)	32.4	10.24	20-46	35.2	20.49
NT (50%)	65.7	22.09	27-87	34.3	22.09
25% Target Version					
LT (12.5%)	17.5	5.19	9-24	30.0	20.76
RT (12.5%)	17.9	5.04	10-24	28.4	20.17
NT (75%)	112.7	20.64	88-135	24.9	13.76
Controls (*N* = 13)					
50% Target Version					
LT (25%)	43.2	3.61	36-48	13.5	7.22
RT (25%)	42.3	3.86	36-47	15.4	7.72
NT (50%)	82.4	6.80	72-94	17.6	6.80
25% Target Version					
LT (12.5%)	21.1	3.78	12-25	15.4	15.13
RT (12.5%)	20.9	1.82	18-23	16.6	7.27
NT (75%)	124.3	19.09	85-142	17.1	12.73

Note. Each version of the Lateralized Oddball Paradigm had a total of 200 trials. LT = Left Target, RT = Right Target, and NT = Non-Target.

Table 48. Preliminary Validation of the Lateralized Oddball Paradigms of Experiment Two Using ERPs from the Age-Matched Controls ($N = 13$): The P300 Amplitude (in μV) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
P300 Amplitude	Paradigm (P)	0.10	1, 12	.753	
	Condition (C)	22.73	1.2, 24	<.001	*
	Site (S)	8.09	2, 24	.002	*
	P x C	8.20	2, 24	.002	*
	P x S	0.59	2, 24	.563	
	S x C	10.27	4, 48	<.001	*
	P x C x S	1.80	4, 48	.144	

Note. P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 49. Preliminary Validation of the Lateralized Oddball Paradigms of Experiment Two Using ERPs from the Age-Matched Controls ($N = 13$): The P300 Amplitude (in μV) Paradigm Version by Stimulus Condition Interaction.

Paradigm Version	Condition	*M*	*SD*
50% Targets	Left Target (25%)	11.34	1.96
	Right Target (25%)	11.80	1.88
	Non-Target (50%)	9.38	1.76
25% Targets	Left Target (12.5%)	13.12	1.36
	Right Target (12.5%)	13.76	2.14
	Non-Target (75%)	6.95	1.38

Table 50. Preliminary Validation of the Lateralized Oddball Paradigms of Experiment Two Using ERPs from the Age-Matched Controls (*N* = 13): The P300 Amplitude (in μV) Stimulus Condition by Recording Site Interaction.

Condition	Site	*M*	*SD*
Left Target	Fz	8.71	1.81
	Cz	13.78	1.72
	Pz	14.20	1.75
Right Target	Fz	8.72	2.01
	Cz	14.31	2.14
	Pz	13.30	1.96
Non-Target	Fz	6.51	1.67
	Cz	10.53	1.56
	Pz	7.45	1.47

Table 51. Preliminary Validation of the Lateralized Oddball Paradigms of Experiment Two Using ERPs from the Age-Matched Controls (*N* = 13): The P300 Latency (in *ms*) ANOVA.

Dependent Variable	Factor	*F*	*df*	*P*	
P300 Latency	Paradigm (P)	1.40	1, 12	.260	
	Condition (C)	0.85	2, 24	.439	
	Site (S)	3.10	1.1, 24	.098	
	P x C	6.32	1.3, 24	.017	*
	P x S	4.14	2, 24	.029	*
	S x C	1.76	4, 48	.153	
	P x C x S	0.53	4, 48	.710	

Note. P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 52. Preliminary Validation of the Lateralized Oddball Paradigms of Experiment Two Using ERPs from the Age-Matched Controls ($N = 13$): The P300 Latency (in *ms*) Paradigm Version by Stimulus Condition Interaction.

Paradigm Version	Condition	*M*	*SD*
50% Targets	Left Target (25%)	452.10	14.22
	Right Target (25%)	450.26	12.55
	Non-Target (50%)	463.13	6.53
25% Targets	Left Target (12.5%)	476.00	19.98
	Right Target (12.5%)	475.64	16.11
	Non-Target (75%)	446.05	11.29

Table 53. Preliminary Validation of the Lateralized Oddball Paradigms of Experiment Two Using ERPs from the Age-Matched Controls (*N* = 13): The P300 Latency (in ms) Paradigm Version by Recording Site Interaction.

Paradigm Version	Site	*M*	*SD*
50% Targets	Fz	440.10	11.73
	Cz	463.90	10.34
	Pz	461.49	10.25
25% Targets	Fz	459.49	17.02
	Cz	470.87	15.82
	Pz	467.33	14.49

Note. 50% Target Version = 25% Left Targets, 25% Right Targets, and 50% Non-Targets. 25% Target Version = 12.5% Left Targets, 12.5% Right Targets, and 75% Non-Targets.

Table 54. Preliminary Validation of the Lateralized Oddball Paradigms of Experiment Two Using ERPs from the Age-Matched Controls (*N* = 13): The P200 Amplitude (in μV) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
P200 Amplitude	Paradigm (P)	0.83	1, 12	.380	
	Condition (C)	0.18	1.2, 24	.712	
	Site (S)	6.84	1.3, 24	.012	*
	P x C	0.41	1.2, 24	.576	
	P x S	2.19	2, 24	.130	
	S x C	0.63	4, 48	.646	
	P x C x S	1.84	4, 48	.136	

Note. P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 55. Preliminary Validation of the Lateralized Oddball Paradigms of Experiment Two Using ERPs from the Age-Matched Controls ($N = 13$): The P200 Latency (in *ms*) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
P200 Latency	Paradigm (P)	0.01	1, 12	.930	
	Condition (C)	1.88	1.3, 24	.189	
	Site (S)	6.25	1.3, 24	.019	*
	P x C	0.34	2, 24	.713	
	P x S	0.25	2, 24	.781	
	S x C	1.26	4, 48	.298	
	P x C x S	0.72	4, 48	.583	

Note. P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 56. Preliminary Validation of the Lateralized Oddball Paradigms of Experiment Two Using ERPs from the Age-Matched Controls ($N = 13$): The N200 Amplitude (in μV) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
N200 Amplitude	Paradigm (P)	0.53	1, 12	.482	
	Condition (C)	0.01	2, 24	.990	
	Site (S)	21.87	1.3, 24	.000	*
	P x C	0.45	2, 24	.644	
	P x S	0.02	2, 24	.979	
	S x C	1.38	4, 48	.255	
	P x C x S	0.94	4, 48	.449	

Note. P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 57. Preliminary Validation of the Lateralized Oddball Paradigms of Experiment Two Using ERPs from the Age-Matched Controls (*N* = 13): The N200 Latency (in *ms*) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*
N200 Latency	Paradigm (P)	1.90	1, 12	.193
	Condition (C)	1.88	2, 24	.830
	Site (S)	0.37	1.2, 24	.595
	P x C	1.84	2, 24	.181
	P x S	2.12	2, 24	.142
	S x C	0.93	4, 48	.453
	P x C x S	1.06	1.5, 48	.348

Note. P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 58. Full Analysis of ERPs from Patients with Left Visual Hemineglect and Age-Matched Controls on the Lateralized Oddball Paradigms of Experiment Two: The P300 (in μV) Amplitude ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
P300 Amplitude	Group (G)	10.82	1, 21	.003	*
	Paradigm (P)	3.20	1, 21	.088	
	Condition (C)	23.88	1.3, 42	<.001	*
	Site (S)	10.12	1.3, 42	.002	*
	P x C	1.04	1.3, 42	.339	
	P x S	0.73	2, 42	.487	
	C x S	6.12	2.4, 84	.003	*
	P x C x S	0.86	2.2, 84	.438	
	G x P	1.86	1, 21	.187	
	G x C	4.37	2, 42	.019	*
	G x S	0.43	2, 42	.651	
	G x P x C	0.88	2, 42	.421	
	G x P x S	1.49	2, 42	.237	
	G x C x S	0.62	4, 84	.647	
	G x P x C x S	0.83	4, 84	.513	

Note. G = Group ($N_{patient}$ = 10, $N_{control}$ = 13); P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 59. Full Analysis of ERPs from Patients with Left Visual Hemineglect and Age-Matched Controls on the Lateralized Oddball Paradigms of Experiment Two: The P300 Amplitude (in μV) Group by Stimulus Condition Interaction

Group	(*N*)	Condition	*M*	*SD*
Patient	(10)	Left Target	2.55	1.74
		Right Target	8.50	2.17
		Non-Target	0.22	1.61
Control	(13)	Left Target	12.23	1.52
		Right Target	12.77	1.90
		Non-Target	8.16	1.41

Table 60. Full Analysis of ERPs from Patients with Left Visual Hemineglect and Age-Matched Controls on the Lateralized Oddball Paradigms of Experiment Two: The P300 Amplitude (in μV) Stimulus Condition by Recording Site Interaction.

Condition	Site	*M*	*SD*
Left Target	Fz	4.86	1.47
	Cz	8.24	1.24
	Pz	9.07	1.50
Right Target	Fz	6.85	1.79
	Cz	11.82	1.60
	Pz	13.26	1.46
Non-Target	Fz	2.60	1.39
	Cz	6.12	1.06
	Pz	3.86	1.07

Table 61. Full Analysis of ERPs from Patients with Left Visual Hemineglect and Age-Matched Controls on the Lateralized Oddball Paradigms of Experiment Two: The P300 Latency (in *ms*) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
P300 Latency	Group (G)	0.32	1, 21	.580	
	Paradigm (P)	1.60	1, 21	.220	
	Condition (C)	6.33	2, 42	.004	*
	Site (S)	3.82	1.2, 42	.057	
	P x C	4.00	2, 42	.026	*
	P x S	1.54	2, 42	.226	
	C x S	1.67	4, 84	.164	
	P x C x S	0.23	4, 84	.921	
	G x P	0.25	1, 21	.623	
	G x C	2.64	2, 42	.083	
	G x S	0.77	2, 42	.471	
	G x P x C	2.34	2, 42	.108	
	G x P x S	1.34	2, 42	.272	
	G x C x S	1.34	4, 84	.263	
	G x P x C x S	1.32	4, 84	.270	

Note. G = Group ($N_{patient} = 10$, $N_{control} = 13$); P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 62. Full Analysis of ERPs from Patients with Left Visual Hemineglect and Age-Matched Controls on the Lateralized Oddball Paradigms of Experiment Two: The P300 Latency (in *ms*) Paradigm Version by Stimulus Condition Interaction.

Paradigm Version	Condition	*M*	*SD*
50% Targets	Left Target (25%)	468.02	17.16
	Right Target (25%)	464.06	13.11
	Non-Target (50%)	461.26	12.74
25% Targets	Left Target (12.5%)	493.40	18.35
	Right Target (12.5%)	471.35	15.52
	Non-Target (75%)	451.69	12.81

Table 63. Full Analysis of ERPs from Patients with Left Visual Hemineglect and Age-Matched Controls on the Lateralized Oddball Paradigms of Experiment Two: The P200 (in μV) Amplitude ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
P200 Amplitude	Group (G)	0.31	1, 21	.584	
	Paradigm (P)	0.09	1, 21	.768	
	Condition (C)	6.91	2, 42	.003	*
	Site (S)	6.88	1.3, 42	.009	*
	P x C	1.29	2, 42	.286	
	P x S	1.46	1.6, 42	.245	
	C x S	1.64	2.3, 84	.201	
	P x C x S	1.38	2.4, 84	.261	
	G x P	1.74	1, 21	.202	
	G x C	4.78	2, 42	.014	*
	G x S	1.06	2, 42	.356	
	G x P x C	2.21	2, 42	.123	
	G x P x S	0.88	2, 42	.421	
	G x C x S	1.18	4, 48	.323	
	G x P x C x S	0.72	4, 48	.582	

Note. G = Group ($N_{patient}$ = 10, $N_{control}$ = 13); P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 64. Full Analysis of ERPs from Patients with Left Visual Hemineglect and Age-Matched Controls on the Lateralized Oddball Paradigms of Experiment Two: The P200 Amplitude (in μV) Group by Stimulus Condition Interaction.

Group	(*N*)	Condition	*M*	*SD*
Patient	(10)	Left Target	2.93	.85
		Right Target	3.74	.88
		Non-Target	1.24	.76
Control	(13)	Left Target	2.12	.74
		Right Target	2.15	.73
		Non-Target	1.93	.66

Table 65. Full Analysis of ERPs from Patients with Left Visual Hemineglect and Age-Matched Controls on the Lateralized Oddball Paradigms of Experiment Two: The P200 Latency (in *ms*) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
P200 Latency	Group (G)	49.46	1, 21	.000	*
	Paradigm (P)	0.04	1, 21	.842	
	Condition (C)	0.62	2, 42	.544	
	Site (S)	8.85	1.3, 42	.003	*
	P x C	0.02	2, 42	.985	
	P x S	0.54	1.3, 42	.517	
	C x S	0.47	2.6, 84	.679	
	P x C x S	1.35	2.3, 84	.269	
	G x P	0.07	1, 21	.790	
	G x C	0.59	2, 42	.557	
	G x S	1.19	2, 42	.315	
	G x P x C	0.10	2, 42	.903	
	G x P x S	0.36	2, 42	.702	
	G x C x S	1.20	4, 48	.316	
	G x P x C x S	1.12	4, 48	.354	

Note. G = Group ($N_{patient}$ = 10, $N_{control}$ = 13); P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 66. Full Analysis of ERPs from Patients with Left Visual Hemineglect and Age-Matched Controls on the Lateralized Oddball Paradigms of Experiment Two: The N200 Amplitude (in μV) ANOVA.

Dependent Variable	Factor	*F*	*df*	*P*	
N200 Amplitude	Group (G)	1.02	1, 21	.324	
	Paradigm (P)	0.65	1, 21	.429	
	Condition (C)	1.0	1.6, 42	.359	
	Site (S)	4.92	1.5, 42	.020	*
	P x C	0.07	1.5, 42	.894	
	P x S	1.40	1.6, 42	.258	
	C x S	1.15	2.5, 84	.333	
	P x C x S	0.74	1.7, 84	.461	
	G x P	2.19	1, 21	.154	
	G x C	1.04	2, 42	.361	
	G x S	11.2	2, 42	<.001	*
	G x P x C	0.47	2, 42	.630	
	G x P x S	1.60	2, 42	.214	
	G x C x S	0.35	4, 84	.843	
	G x P x C x S	0.59	4, 84	.671	

Note. G = Group ($N_{patient}$ = 10, $N_{control}$ = 13); P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 67. Full Analysis of ERPs from Patients with Left Visual Hemineglect and Age-Matched Controls on the Lateralized Oddball Paradigms of Experiment Two: The N200 Amplitude (in μV) Group by Recording Site Interaction.

Group	(*N*)	Site	*M*	*SD*
Patient	(10)	Fz	-4.65	1.28
		Cz	-3.60	1.05
		Pz	-3.53	0.88
Control	(13)	Fz	-3.75	1.12
		Cz	-4.46	0.92
		Pz	-7.54	0.78

Table 68. Full Analysis of ERPs from Patients with Left Visual Hemineglect and Age-Matched Controls on the Lateralized Oddball Paradigms of Experiment Two: The N200 Latency (in *ms*) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
N200 Latency	Group (G)	49.32	1, 21	<.001	*
	Paradigm (P)	1.13	1, 21	.299	
	Condition (C)	0.97	2, 42	.386	
	Site (S)	3.96	1.5, 42	.039	*
	P x C	1.12	2, 42	.336	
	P x S	0.14	1.5, 42	.801	
	C x S	0.43	2.1, 84	.666	
	P x C x S	0.92	1.9, 84	.404	
	G x P	0.52	1, 21	.480	
	G x C	0.78	2, 42	.464	
	G x S	4.62	2, 42	.015	*
	G x P x C	1.31	2, 42	.282	
	G x P x S	2.36	2, 42	.107	
	G x C x S	0.31	4, 84	.871	
	G x P x C x S	0.35	4, 84	.840	

Note. G = Group ($N_{patient}$ = 10, $N_{control}$ = 13); P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 69. Full Analysis of ERPs from Patients with Left Visual Hemineglect and Age-Matched Controls on the Lateralized Oddball Paradigms of Experiment Two: The N200 Latency (in *ms*) Group by Recording Site Interaction.

Group	(*N*)	Site	*M*	*SD*
Patient	(10)	Fz	268.7	9.3
		Cz	269.1	8.6
		Pz	256.9	8.7
Control	(13)	Fz	185.4	8.2
		Cz	183.1	7.5
		Pz	184.7	7.6

Table 70. Follow-up Analysis of ERPs from the two Subgroups of Patients with Left Visual Hemineglect on the Lateralized Oddball Paradigms of Experiment Two: The P300 Amplitude (in μV) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
P300 Amplitude	Group (G)	5.48	1, 8	.548	
	Paradigm (P)	3.98	1, 8	.081	
	Condition (C)	9.15	1.3, 16	.009	*
	Site (S)	3.21	2, 16	.067	
	P x C	0.07	1.2, 16	.846	
	P x S	1.05	2, 16	.374	
	C x S	1.58	4, 32	.204	
	P x C x S	0.54	4, 32	.708	
	G x P	0.03	1, 8	.867	
	G x C	0.18	2, 16	.840	
	G x S	1.21	2, 16	.324	
	G x P x C	2.24	2, 16	.139	
	G x P x S	0.84	2, 16	.452	
	G x C x S	1.83	4, 32	.148	
	G x P x C x S	0.61	4, 32	.658	

Note. For subgroups, Non-Detectors omitted more left then right targets and Delayed Detectors detected left targets more slowly than right targets. G = Subgroup ($N_{\text{non-detector}} = 5$, $N_{\text{delayed-detector}} = 5$); P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 71. Follow-up Analysis of ERPs from the two Subgroups of Patients with Left Visual Hemineglect on the Lateralized Oddball Paradigms of Experiment Two: The P300 Latency (in *ms*) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
P300 Latency	Group (G)	0.36	1, 8	.565	
	Paradigm (P)	0.38	1, 8	.557	
	Condition (C)	5.26	2, 16	.018	*
	Site (S)	1.44	2, 16	.267	
	P x C	1.44	2, 16	.265	
	P x S	0.04	2, 16	.959	
	C x S	1.51	4, 32	.224	
	P x C x S	1.24	4, 32	.312	
	G x P	0.22	1, 8	.649	
	G x C	0.27	2, 16	.765	
	G x S	0.63	2, 16	.544	
	G x P x C	0.15	2, 16	.860	
	G x P x S	0.75	2, 16	.487	
	G x C x S	1.59	4, 32	.202	
	G x P x C x S	2.10	4, 32	.104	

Note. For subgroups, Non-Detectors omitted more left then right targets and Delayed Detectors detected left targets more slowly than right targets. G = Subgroup ($N_{\text{non-detector}} = 5$, $N_{\text{delayed-detector}} = 5$); P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 72. Follow-up Analysis of ERPs from the two Subgroups of Patients with Left Visual Hemineglect on the Lateralized Oddball Paradigms of Experiment Two: The P200 Amplitude (in μV) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
P200 Amplitude	Group (G)	0.58	1, 8	.468	
	Paradigm (P)	0.76	1, 8	.408	
	Condition (C)	6.16	2, 16	.010	*
	Site (S)	2.45	2, 16	.118	
	P x C	1.73	2, 16	.210	
	P x S	0.67	2, 16	.078	
	C x S	1.34	4, 32	.278	
	P x C x S	0.74	4, 32	.572	
	G x P	0.15	1, 8	.709	
	G x C	0.05	2, 16	.948	
	G x S	3.18	2, 16	.669	
	G x P x C	0.41	2, 16	.668	
	G x P x S	0.82	2, 16	.460	
	G x C x S	2.08	4, 32	.107	
	G x P x C x S	1.09	4, 32	.377	

Note. For subgroups, Non-Detectors omitted more left then right targets and Delayed Detectors detected left targets more slowly than right targets. G = Subgroup ($N_{\text{non-detector}} = 5$, $N_{\text{delayed-detector}} = 5$); P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 73. Follow-up Analysis of ERPs from the two Subgroups of Patients with Left Visual Hemineglect on the Lateralized Oddball Paradigms of Experiment Two: The P200 Latency (in *ms*) ANOVA.

Dependent Variable	Factor	*F*	*df*	*P*	
P200 Latency	Group (G)	0.21	1, 8	.662	
	Paradigm (P)	0.07	1, 8	.797	
	Condition (C)	0.54	2, 16	.592	
	Site (S)	5.49	2, 16	.015	*
	P x C	0.01	2, 16	.989	
	P x S	0.39	1.2, 16	.582	
	C x S	0.56	2.2, 32	.600	
	P x C x S	1.00	4, 32	.421	
	G x P	4.19	1, 8	.075	
	G x C	4.13	2, 16	.036	*
	G x S	4.77	2, 16	.024	*
	G x P x C	0.17	2, 16	.848	
	G x P x S	0.46	2, 16	.640	
	G x C x S	0.56	4, 32	.691	
	G x P x C x S	0.20	4, 32	.937	

Note. For subgroups, Non-Detectors omitted more left then right targets and Delayed Detectors detected left targets more slowly than right targets. G = Subgroup ($N_{\text{non-detector}} = 5$, $N_{\text{delayed-detector}} = 5$); P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 74. Follow-up Analysis of ERPs from the two Subgroups of Patients with Left Visual Hemineglect on the Lateralized Oddball Paradigms of Experiment Two: The P200 Latency (in *ms*) Subgroup by Stimulus Condition Interaction.

Group	(*N*)	Condition	*M*	*SD*
Non-Detector	(5)	Left Target	169.9	10.1
		Right Target	162.9	5.5
		Non-Target	176.4	12.2
Delayed Detector	(5)	Left Target	170.5	10.1
		Right Target	190.0	5.5
		Non-Target	163.6	12.2

Note. Non-Detector = patient who *omitted* more left than right targets. Delayed Detector = patient who detected left targets *more slowly* than right targets.

Table 75. Follow-up Analysis of ERPs from the two Subgroups of Patients with Left Visual Hemineglect on the Lateralized Oddball Paradigms of Experiment Two: The P200 Latency (in *ms*) Subgroup by Recording Site Interaction.

Group	(*N*)	Site	*M*	*SD*
Non-Detector	(5)	Fz	173.3	6.3
		Cz	176.5	7.9
		Pz	174.4	9.8
Delayed Detector	(5)	Fz	174.7	6.3
		Cz	175.4	7.9
		Pz	159.1	9.8

Note. Non-Detector = patient who *omitted* more left than right targets. Delayed Detector = patient who detected left targets *more slowly* than right targets.

Table 76. Follow-up Analysis of ERPs from the two Subgroups of Patients with Left Visual Hemineglect on the Lateralized Oddball Paradigms of Experiment Two: The N200 Amplitude (in μV) ANOVA.

Dependent Variable	Factor	F	df	p	
N200 Amplitude	Group (G)	2.53	1, 8	.150	
	Paradigm (P)	1.23	1, 8	.299	
	Condition (C)	0.95	2, 16	.406	
	Site (S)	1.30	2, 16	.299	
	P x C	0.19	2, 16	.831	
	P x S	1.39	2, 16	.278	
	C x S	0.54	4, 32	.705	
	P x C x S	0.54	1.6, 32	.555	
	G x P	0.01	1, 8	.927	
	G x C	0.70	2, 16	.511	
	G x S	4.18	2, 16	.035	*
	G x P x C	1.14	2, 16	.344	
	G x P x S	0.67	2, 16	.526	
	G x C x S	1.12	4, 32	.367	
	G x P x C x S	1.62	4, 32	.193	

Note. For subgroups, Non-Detectors omitted more left then right targets and Delayed Detectors detected left targets more slowly than right targets. G = Subgroup ($N_{\text{non-detector}} = 5$, $N_{\text{delayed-detector}} = 5$); P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 77. Follow-up Analysis of ERPs from the two Subgroups of Patients with Left Visual Hemineglect on the Lateralized Oddball Paradigms of Experiment Two: The N200 Amplitude (in μV) Subgroup by Recording Site Interaction.

Group	(*N*)	Site	*M*	*SD*
Non-Detector	(5)	Fz	-7.35	1.50
		Cz	-4.58	1.51
		Pz	-4.13	1.23
Delayed Detector	(5)	Fz	-1.95	1.50
		Cz	-2.62	1.51
		Pz	-2.93	1.23

Note. Non-Detector = patient who *omitted* more left than right targets. Delayed Detector = patient who detected left targets *more slowly* than right targets.

Table 78. Follow-up Analysis of ERPs from the two Subgroups of Patients with Left Visual Hemineglect on the Lateralized Oddball Paradigms of Experiment Two: The N200 Latency (in *ms*) ANOVA.

Dependent Variable	Factor	*F*	*df*	*p*	
N200 Latency	Group (G)	0.27	1, 8	.617	
	Paradigm (P)	0.04	1, 8	.838	
	Condition (C)	0.74	2, 16	.491	
	Site (S)	5.81	1.2, 16	.034	*
	P x C	0.82	2, 16	.460	
	P x S	0.78	1.1, 16	.411	
	C x S	0.26	2.0, 32	.768	
	P x C x S	0.33	4, 32	.856	
	G x P	0.06	1, 8	.813	
	G x C	0.47	2, 16	.632	
	G x S	1.79	2, 16	.199	
	G x P x C	0.38	2, 16	.690	
	G x P x S	0.13	2, 16	.882	
	G x C x S	2.54	4, 32	.059	
	G x P x C x S	0.64	4, 32	.639	

Note. For subgroups, Non-Detectors omitted more left then right targets and Delayed Detectors detected left targets more slowly than right targets. G = Subgroup ($N_{\text{non-detector}} = 5$, $N_{\text{delayed-detector}} = 5$); P = Paradigm Version (50% or 25% Targets); C = Stimulus Condition (Left Target, Right Target, Non-Target); S = Recording Site (Fz, Cz, Pz). An asterisk (*) denotes statistical significance at $p < .05$.

Table 79. Individual Sensitivity of the Lateralized Oddball Paradigms of Experiment One: The Percentage of Patients with Left Visual Hemineglect and Age-Matched Controls Whose P300 Amplitudes (in μV) Showed the Predicted Patterns of Differentiation in the Right or Left Visual Field and for Whom Statistical Significance was Reached.

Site	Paradigm	Group	(n)	R Visual Field		L Visual Field	
				Pattern	% sig	Pattern	% sig
Fz	50% Targets	ND	(5)	100	0	60	0
		DD	(5)	80	40	80	0
		C	(13)	53.8	0.08	53.8	0.08
	25% Targets	ND	(5)	100	40	60	0
		DD	(5)	60	40	40	20
		C	(13)	76.9	53.8	92.3	61.5
Cz	50% Targets	ND	(5)	60	20	80	20
		DD	(5)	80	40	80	0
		C	(13)	69.2	38.5	61.5	38.4
	25% Targets	ND	(5)	100	40	60	0
		DD	(5)	60	40	40	20
		C	(13)	92.3	61.5	92.3	53.8
Pz	50% Targets	ND	(5)	100	60	80	0
		DD	(5)	100	60	80	60
		C	(13)	100	69.2	92.3	61.5
	25% Targets	ND	(5)	100	60	60	20
		DD	(5)	100	60	80	60
		C	(13)	100	84.6	100	76.9

Note. The P300 amplitudes were expected to be more positive for target than for non-target stimuli regardless of the laterality of the visual field (L = left, R = Right). Target Versions were 50% Targets (25% LT, 25% RT, and 50% NT) and 25% Targets (12.5% LT, 12.5% RT, and 75% NT). For the two subgroups of patients with left visual hemineglect, ND = Non-Detectors who *omitted* more left than right targets and DD = Delayed-Detectors who detected left targets *more slowly* than right targets. C = Age-Matched Controls. 1-tailed significance was met when $p \leq .05$.

Table 80. Comparison of the Experimental Paradigms.

Contrast	Experiment One	Experiment Two
Component	N400	P300
Contra-lesional Impairment	Contralesional *neglect* of lateralized picture primes that preceded centralised target pictures that were categorised using a two-button response pad.	Contralesional *extinction* of stimuli in a lateralized oddball task. Each trial consisted of a pair of stimuli: a letter to the left and another to the right of central fixation. Participants pressed a button for every target detected.
Information Processing Construct	Semantic Priming: To determine whether the amplitude of the N400 elicited by the centralised picture targets would be influenced by the presence or absence of semantic congruity in the preceding picture primes even for primes in the neglected rather than non-neglected field.	Relative Stimulus Probability. To determine whether the amplitude of the P300 elicited by lateralized letter stimuli would be sensitive to the relative probability of the eliciting stimuli regardless of whether they were extinguished or not. A version of the paradigm with 50% oddballs was used to control for the effect of stimulus targetness in the 25% oddball version.

Task Require-ments	Press one of two buttons to classify centralised green pictures of animals and clothing according to their category membership. Do not respond to non-target pictures of animals or clothing that were presented in a different colour (red) and spatial location (left or right of centre). There is ambiguity as to whether the instructions to selectively attend to the target location and colour were associated with inhibition of the responses for non-target primes or whether the non-target primes were simply ignored.	Press a button every time the target letter (O) is detected within a random series of presentations of a non-target letter (X) regardless of where the letters appear (left or right of centre). For patients with hemineglect, the paradigm was intended to allow for the comparison of explicit discrimination between the target and non target letters in the ipsilesional visual field and implicit discrimination between target and non-target letters in the neglected or non-neglected visual field.
Task Relevance of Critical Stimuli	Subjective awareness of the primes or their semantic relationship with the target is not required for the successful completion of the behavioural task. In this experiment, the effects of implicit and explicit processing of information contained in the primes on the subsequent explicit processing of a target was assessed	Subjective awareness of the letter targets (but not necessarily their relative stimulus probability) is essential for successful completion of the behavioural task. In this experiment, the implicit and explicit processing of information contained in the targets was assessed directly.

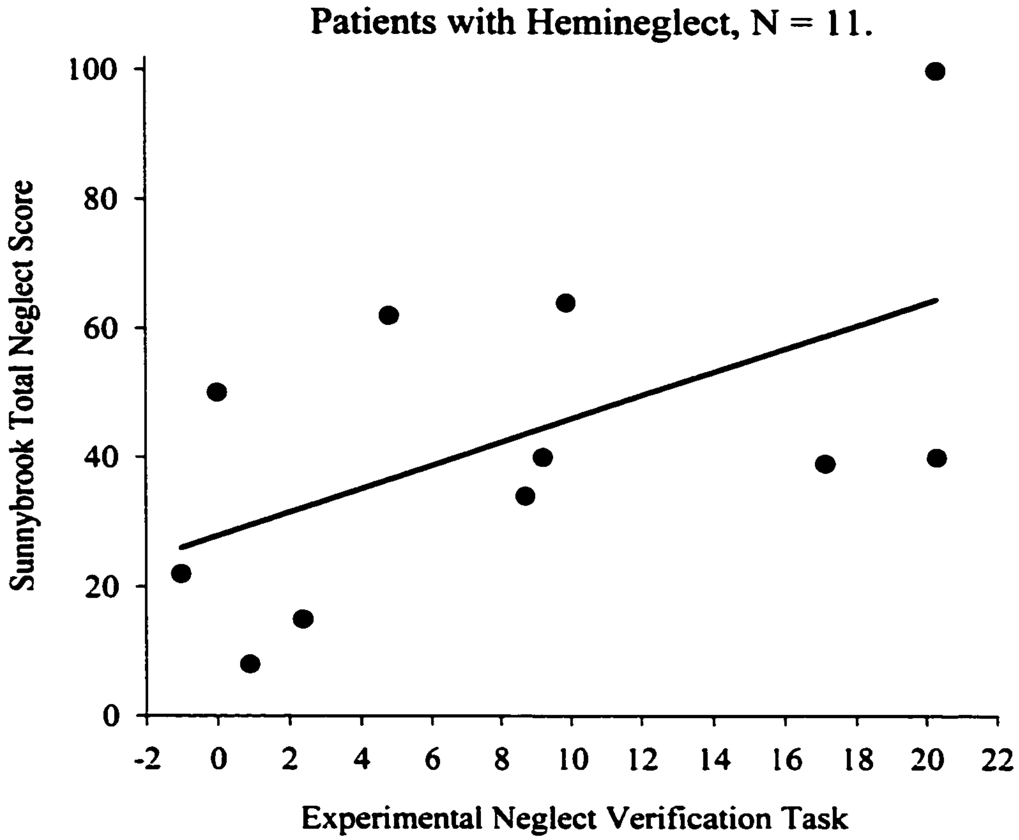
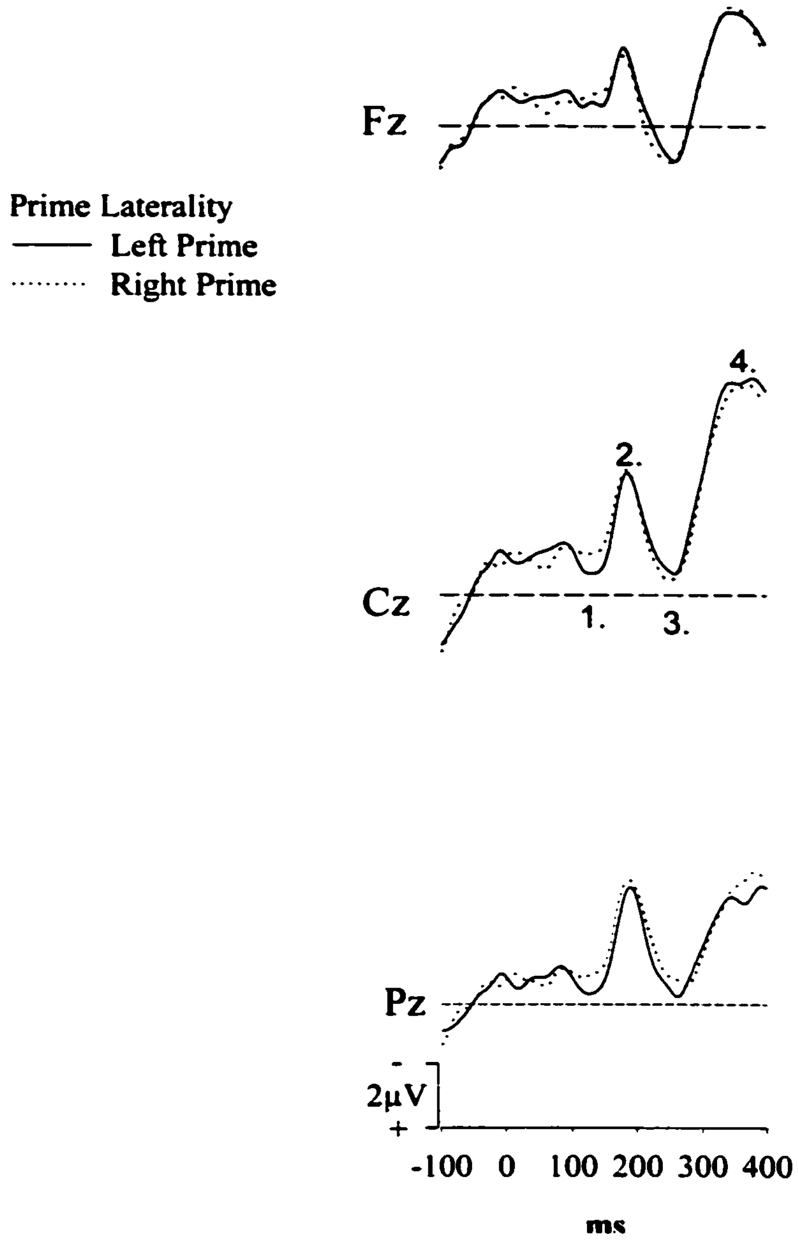


Figure 1. Comparison of performance for patients with left visual hemineglect ($N = 11$) on the Neglect Verification Task of Experiment One and the Sunnybrook Bedside Neglect Battery. The 24-trial Neglect Verification Task involved verbal classification of picture primes presented to the left ($n = 12$) or right ($n = 12$) visual field and of centralized picture targets ($n = 24$). The measure of visual field asymmetry for lateralized primes was derived through chi-square analyses with positive values indicating a greater incidence of missed primes in the left than right visual field. The Sunnybrook Neglect Battery subtests are Drawing and Copying (max 30 points), Line Bisection (max 10 points), Line Cancellation (max 30 points), and Figure Cancellation (max 30 points). The Total Neglect Score (max 100 points) is derived by summing the 4 subtest scores. The linear relationship between the two scores was moderately positive, $r(N = 11) = .55, p = .04$.



Controls, N = 13

Figure 2. Grand Average ERPs from 3 midline sites for the lateralized picture primes from the Lateralized Semantic Priming Paradigm of Experiment One for the age-matched controls (*N* = 13). The primes required no behavioral response. Time (*ms*) is on the *x*-axis with zero indicating stimulus onsets. Amplitude (*μV*) is on the *y*-axis with a horizontal line indicating the average of each site's 100 *ms* pre-stimulus baseline. The four numbered peaks may correspond to the P1, N1, P2, and N4 respectively.

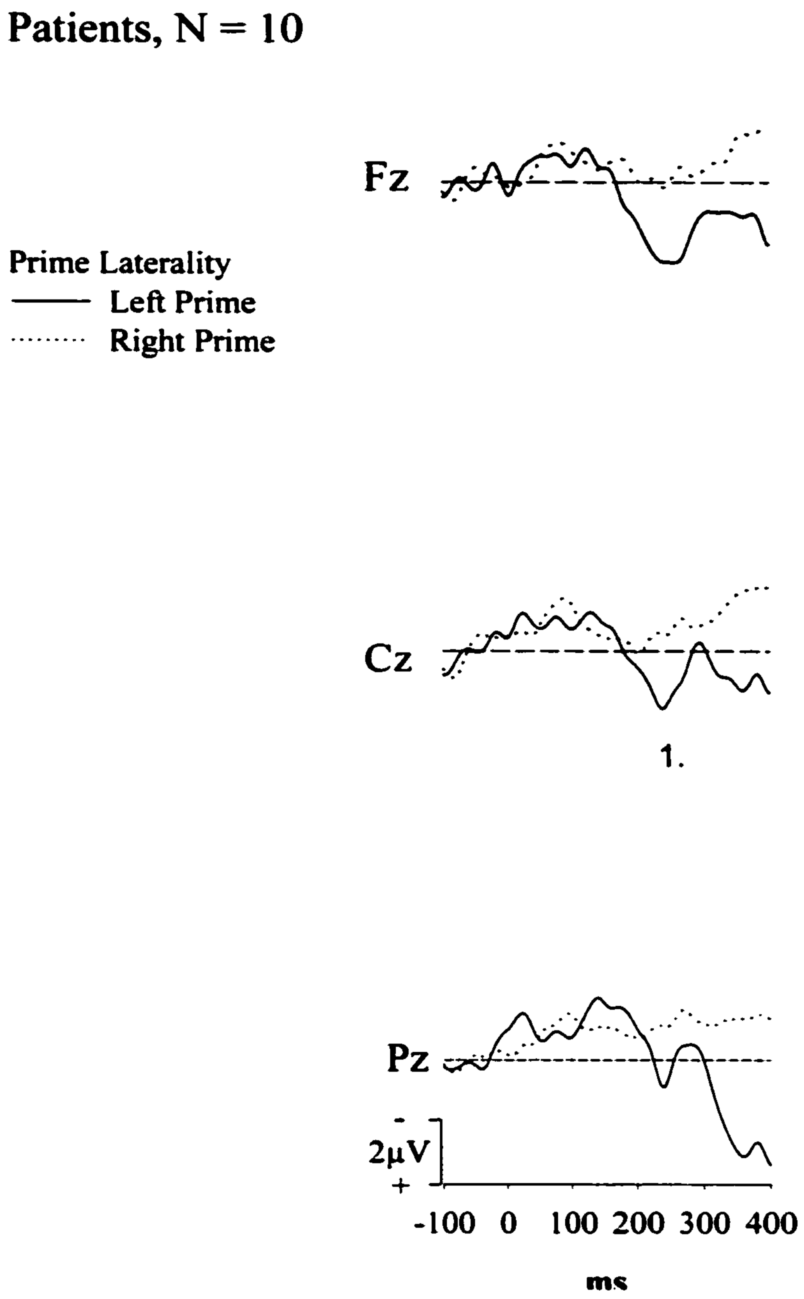


Figure 3. Grand Average ERPs from 3 midline sites for the lateralized picture primes from the Lateralized Semantic Priming Paradigm of Experiment One for the patients with left visual hemineglect ($N = 9$). The primes required no behavioral response. Time (*ms*) is on the x-axis with zero indicating stimulus onsets. Amplitude (μV) is on the y-axis with a horizontal line indicating the average of each site's 100 *ms* pre-stimulus baseline. The numbered peak may correspond to a P2 elicited for left primes.

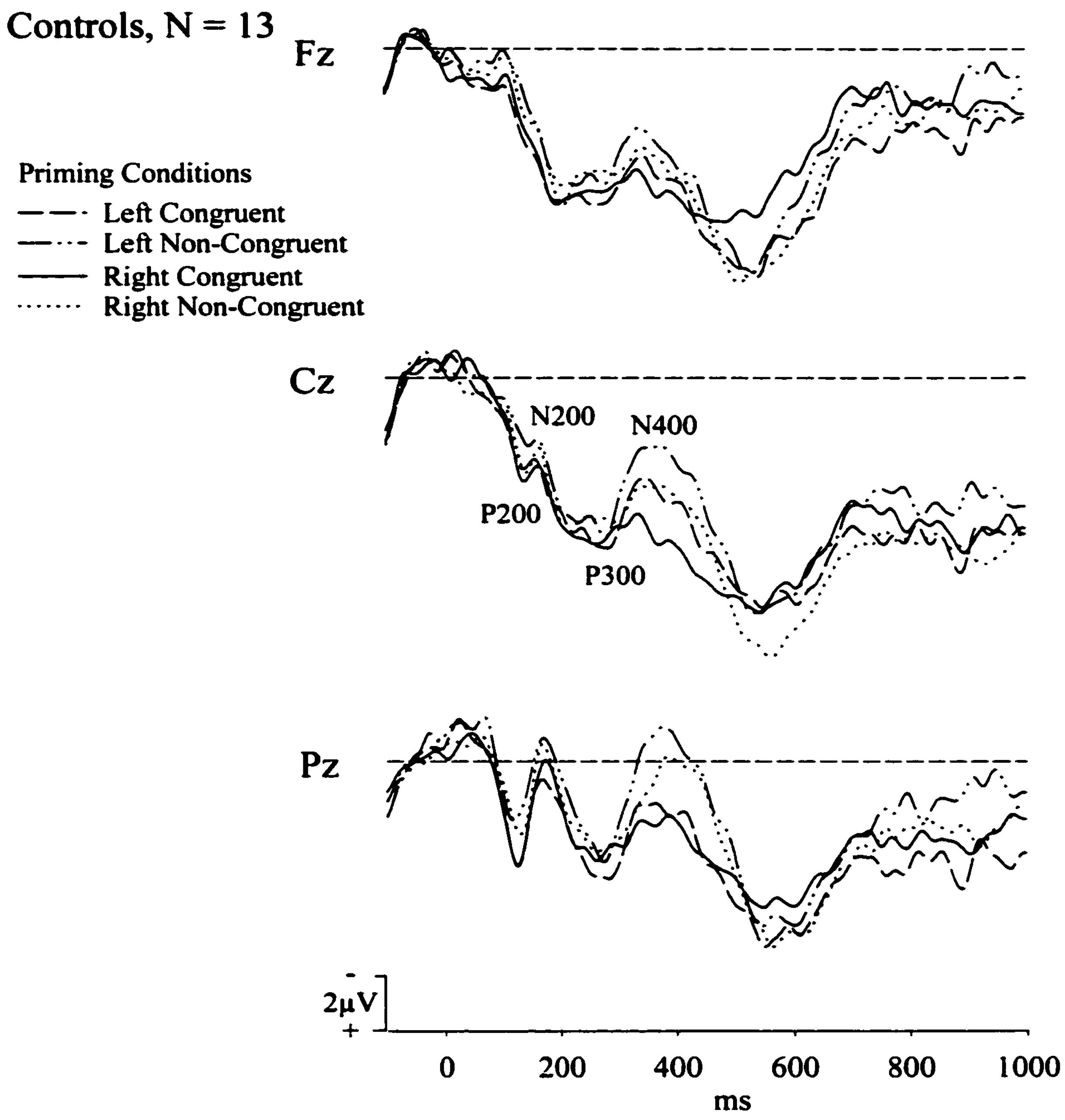


Figure 4. Grand average ERPs from 3 midline sites for the centralized picture targets from the Lateralized Semantic Priming Paradigm of Experiment One for the age-matched controls (*N* = 13). Participants were to categorize each target (clothing or animal) which had been preceded by a lateralized picture prime that was either semantically congruent or non-congruent. Time (*ms*) is on the *x*-axis with zero indicating stimulus onsets. Amplitude (*μV*) is on the *y*-axis with a horizontal line indicating the average of each site's 100 *ms* pre-stimulus baseline.

Patients, N = 9.

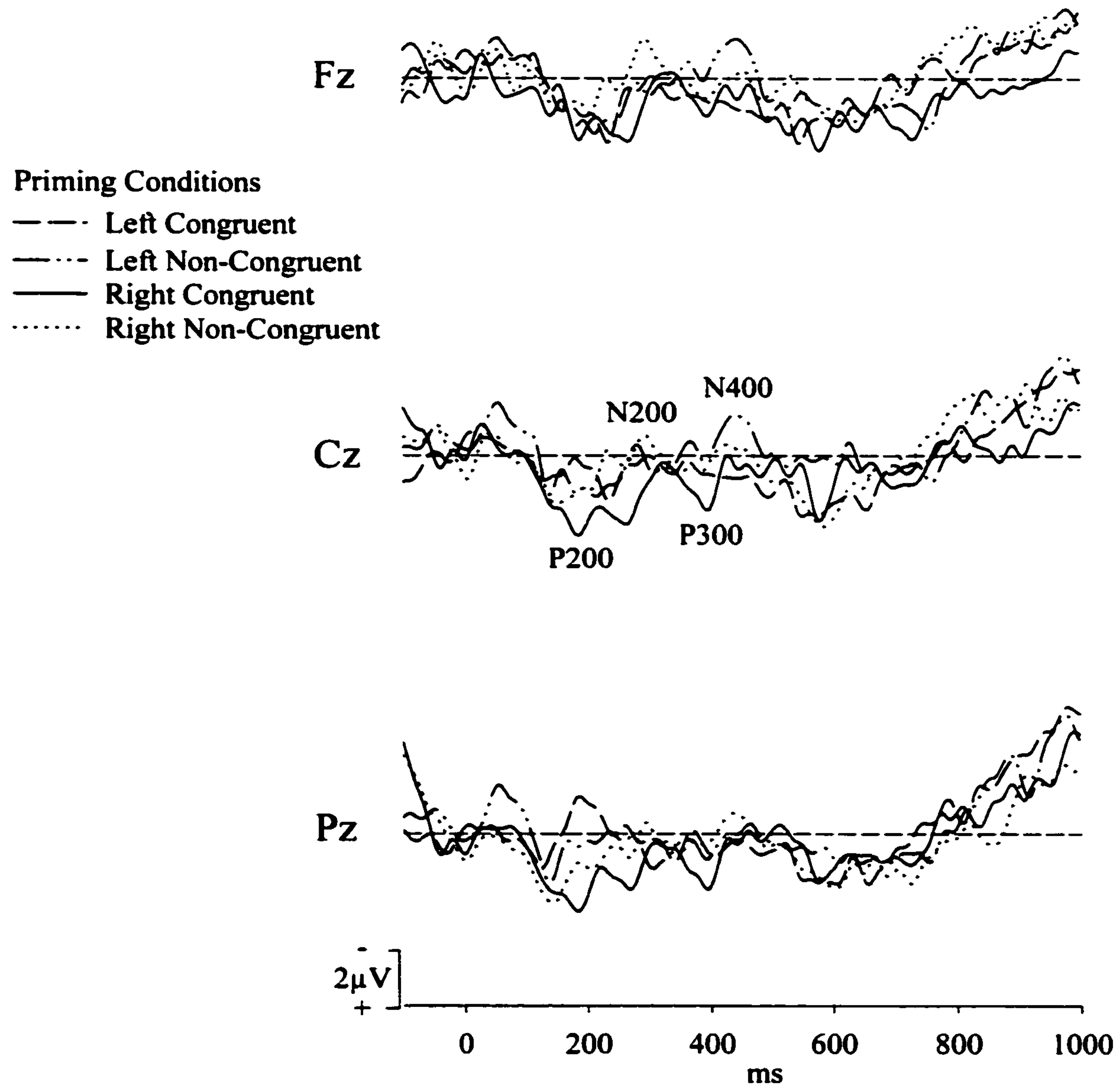


Figure 5. Grand average ERPs from 3 midline sites for the centralized picture targets from the Lateralized Semantic Priming Paradigm of Experiment One for the patients with left visual hemineglect ($N = 9$). Participants were to categorize each target (clothing or animal) which had been preceded by a lateralized picture prime that was either semantically congruent or non-congruent. Time (*ms*) is on the x-axis with zero indicating stimulus onsets. Amplitude (μV) is on the y-axis with a horizontal line indicating the average of each site's 100 *ms* pre-stimulus baseline.

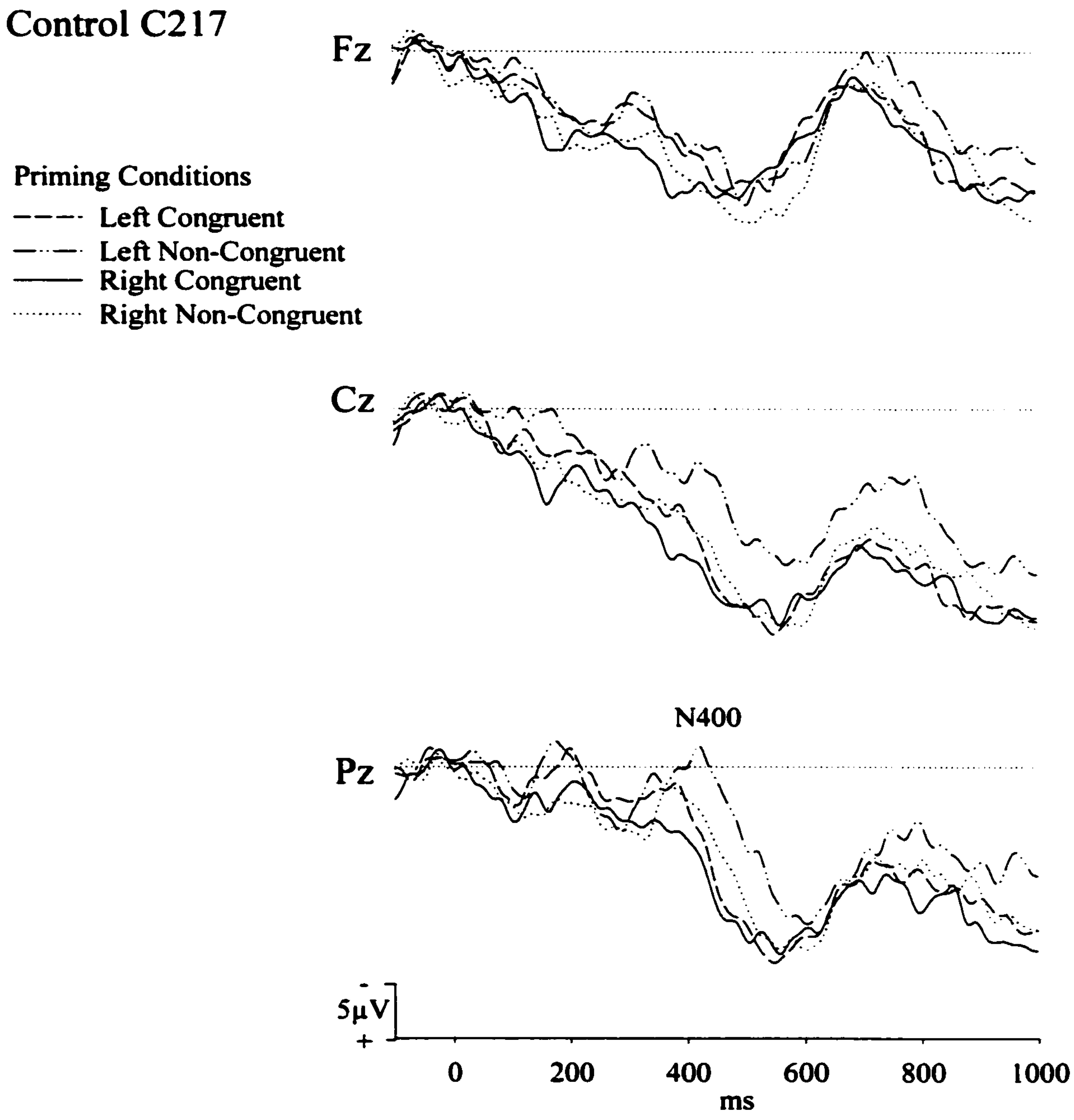


Figure 6. ERPs from 3 midline sites for the centralized picture targets from the Lateralized Semantic Priming Paradigm of Experiment One for an age-matched control (C217). The participant was to categorize each target (clothing or animal) which had been preceded by a lateralized picture prime that was either semantically congruent or non-congruent. Time (*ms*) is on the *x*-axis with zero indicating stimulus onsets. Amplitude (*µV*) is on the *y*-axis with a horizontal line indicating the average of each site's 100 *ms* pre-stimulus baseline.

Patient 109

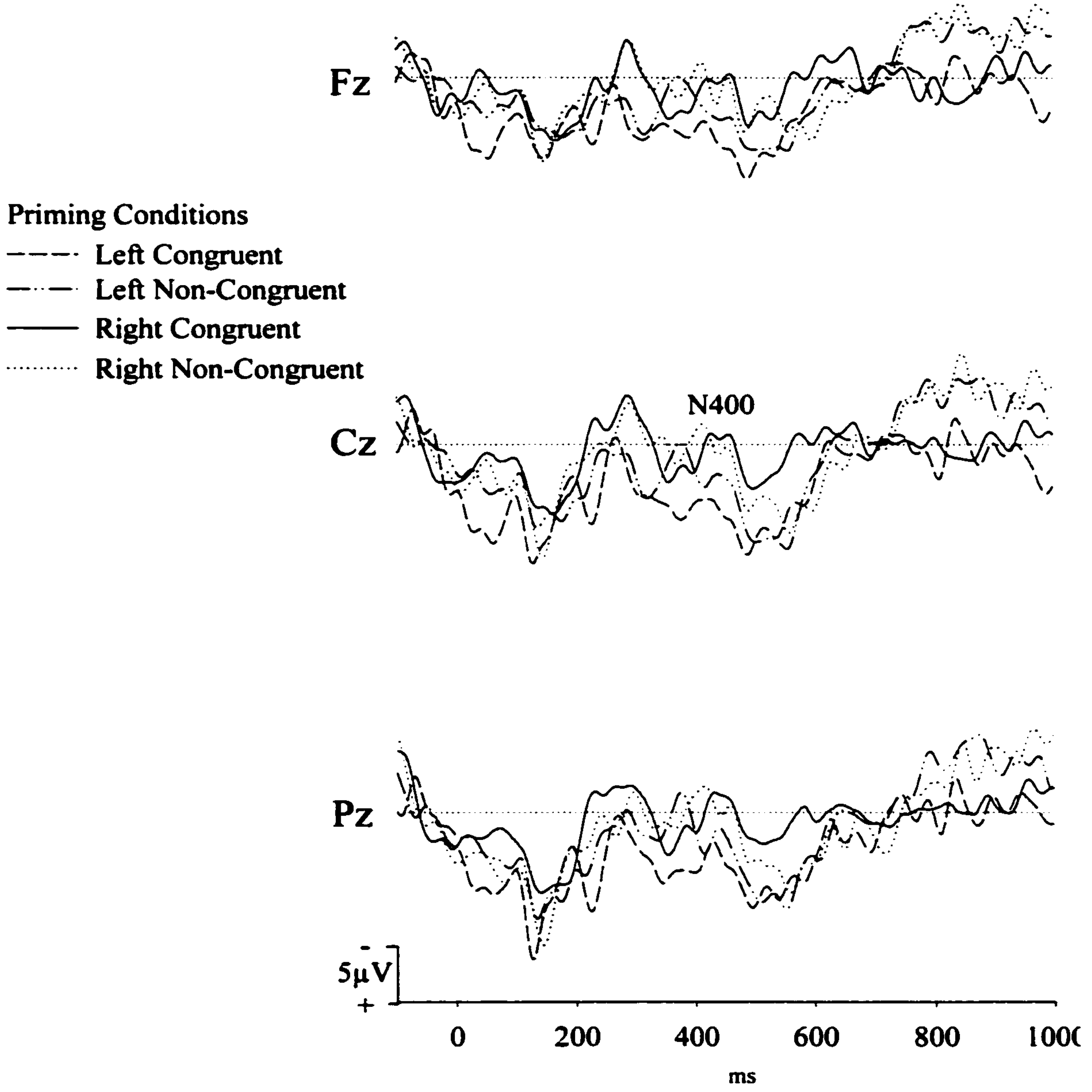


Figure 7. ERPs from 3 midline sites for the centralized picture targets from the Lateralized Semantic Priming Paradigm of Experiment One for a patient with left visual hemineglect (P109). The participant was to categorize each target (clothing or animal) which had been preceded by a lateralized picture prime that was either semantically congruent or non-congruent. Time (*ms*) is on the x-axis with zero indicating stimulus onsets. Amplitude (μV) is on the y-axis with a horizontal line indicating the average of each site's 100 *ms* pre-stimulus baseline.

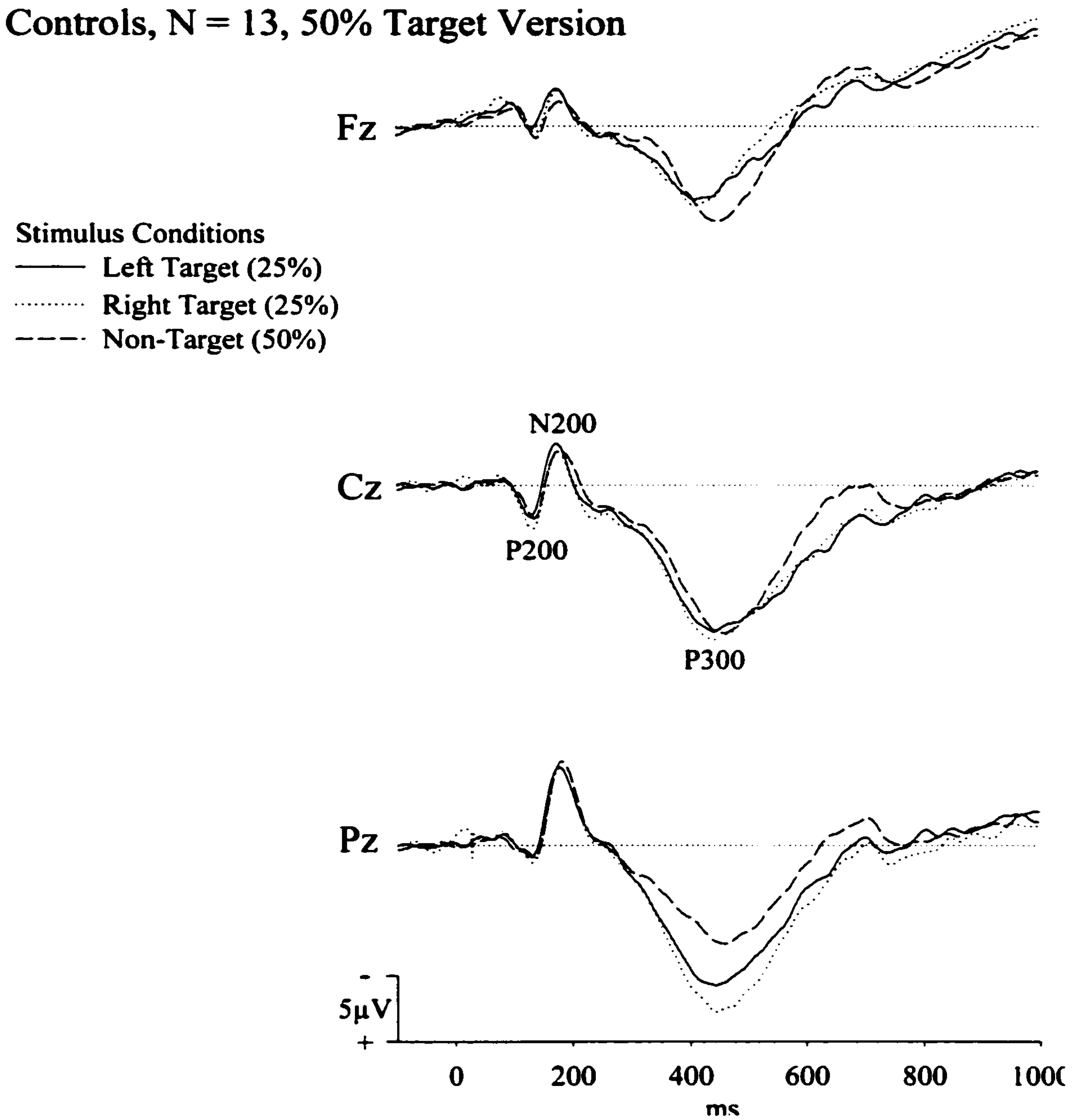


Figure 8. Grand average ERPs from 3 midline sites for the 50% Target Version of the Lateralized Oddball Paradigm of Experiment Two for the age-matched controls (N = 13). Participants were to press a button for every lateralized target letter O that appeared within a randomized series of non-target trials. Time (*ms*) is on the x-axis with zero indicating stimulus onsets. Amplitude (μV) is on the y-axis with a horizontal line indicating the average of each site's 100 *ms* pre-stimulus baseline.

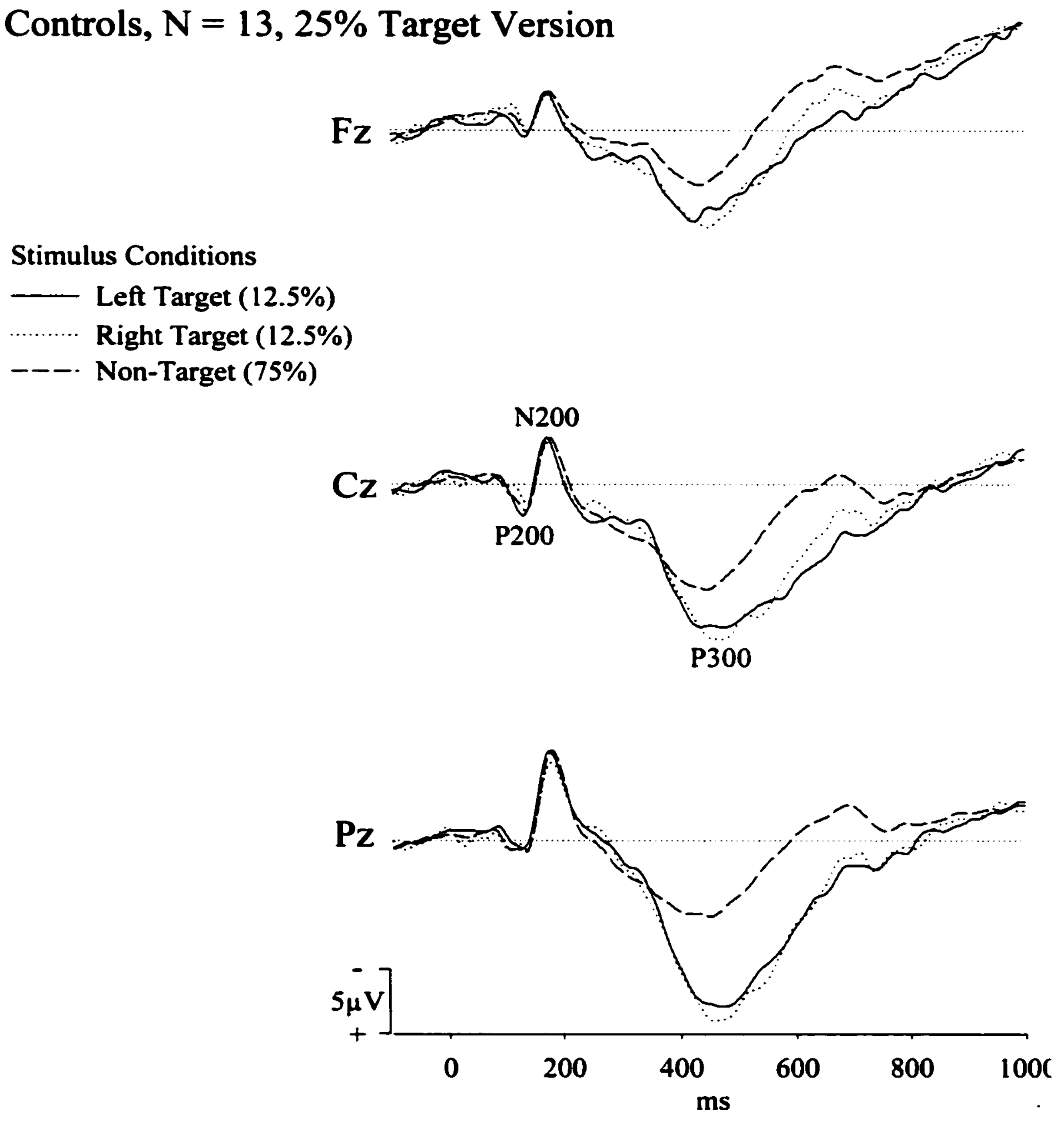


Figure 9. Grand average ERPs from 3 midline sites for the 25% Target Version of the Lateralized Oddball Paradigm of Experiment Two for the age-matched controls (N = 13). Participants were to press a button for every lateralized target letter O that appeared within a randomized series of non-target trials. Time (*ms*) is on the x-axis with zero indicating stimulus onsets. Amplitude (μV) is on the y-axis with a horizontal line indicating the average of each site's 100 *ms* pre-stimulus baseline.

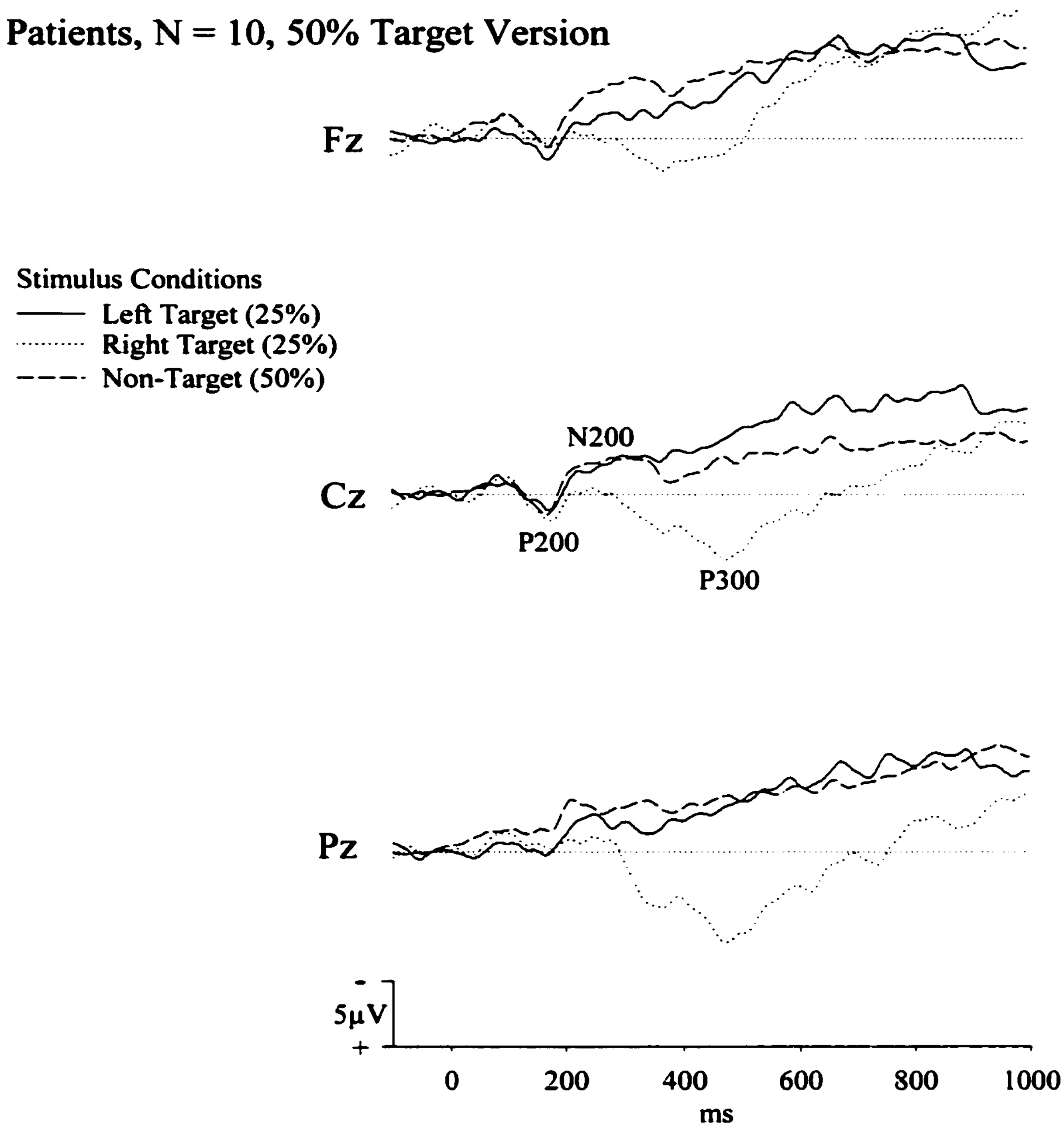


Figure 10. Grand average ERPs from 3 midline sites for the 50% Target Version of the Lateralized Oddball Paradigm of Experiment Two for the patients with left visual hemineglect (*N* = 10). Participants were to press a button for every lateralized target letter O that appeared within a randomized series of non-target trials. Time (*ms*) is on the *x*-axis with zero indicating stimulus onsets. Amplitude (*µV*) is on the *y*-axis with a horizontal line indicating the average of each site's 100 *ms* pre-stimulus baseline.

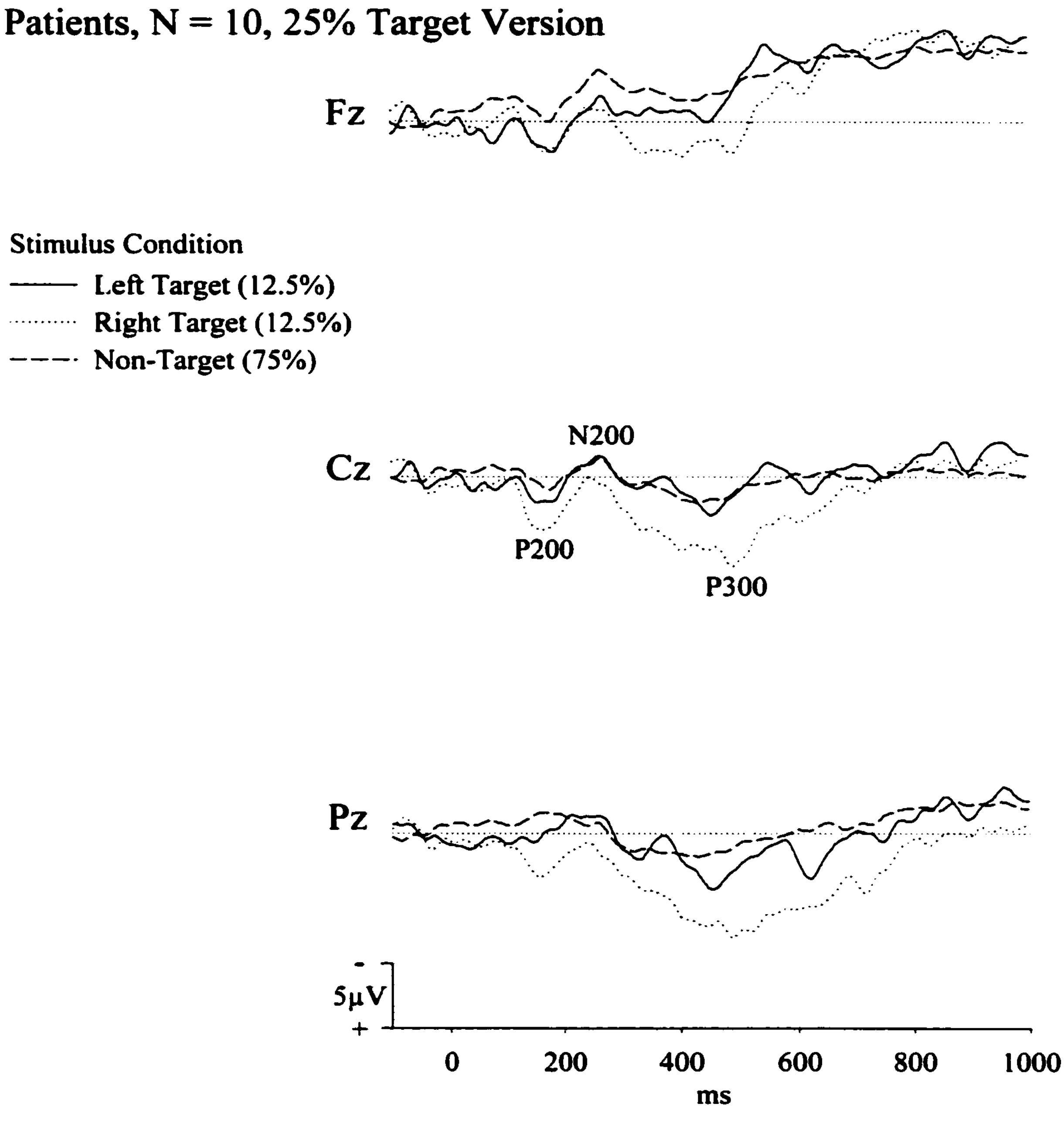


Figure 11. Grand average ERPs from 3 midline sites for the 25% Target Version of the Lateralized Oddball Paradigm of Experiment Two for the patients with left visual hemineglect ($N = 10$). Participants were to press a button for every lateralized target letter O that appeared within a randomized series of non-target trials. Time (*ms*) is on the x-axis with zero indicating stimulus onsets. Amplitude (μV) is on the y-axis with a horizontal line indicating the average of each site's 100 *ms* pre-stimulus baseline.

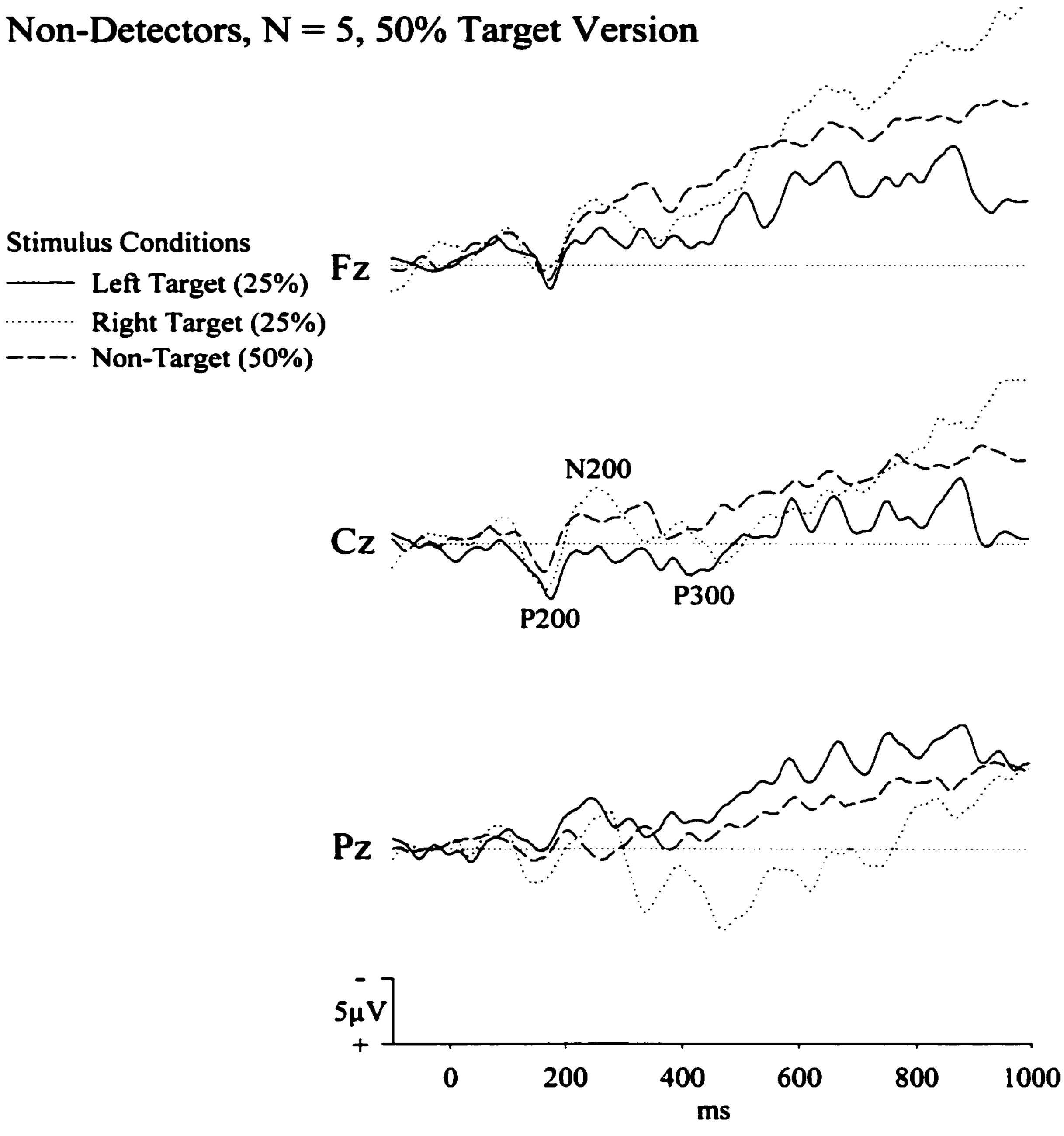


Figure 12. Grand average ERPs from 3 midline sites for the 50% Target Version of the Lateralized Oddball Paradigm of Experiment Two for the patients with left visual hemineglect who omitted more left than right targets (Non-Detectors, *n* = 5). Participants were to press a button for every lateralized target letter O that appeared within a randomized series of non-target trials. Time (*ms*) is on the *x*-axis with zero indicating stimulus onsets. Amplitude (*μV*) is on the *y*-axis with a horizontal line indicating the average of each site's 100 *ms* pre-stimulus baseline.

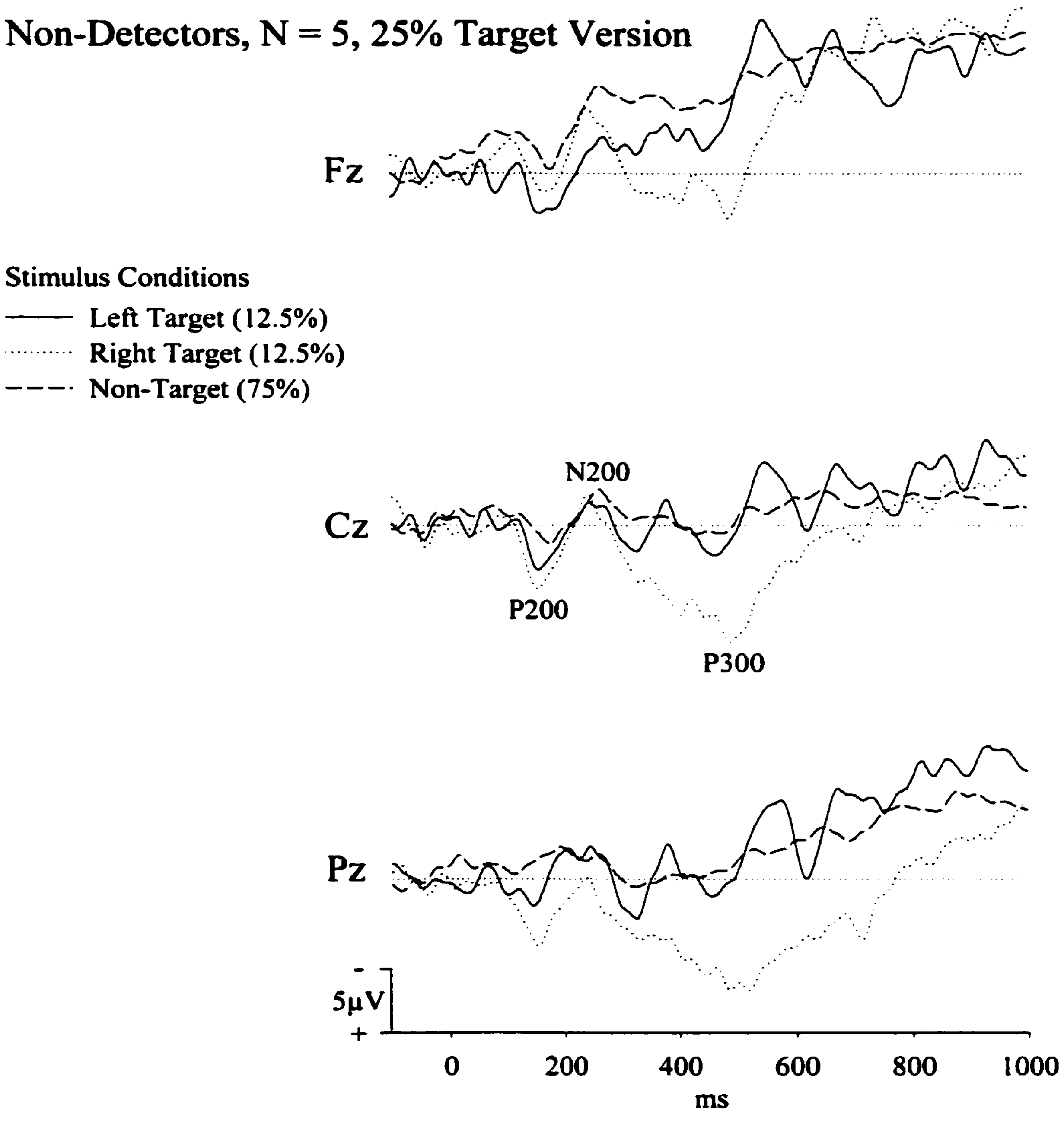


Figure 13. Grand average ERPs from 3 midline sites for the 25% Target Version of the Lateralized Oddball Paradigm of Experiment Two for the patients with left visual hemineglect who omitted more left than right targets (Non-Detectors, $n = 5$). Participants were to press a button for every lateralized target letter O that appeared within a randomized series of non-target trials. Time (*ms*) is on the x-axis with zero indicating stimulus onsets. Amplitude (μV) is on the y-axis with a horizontal line indicating the average of each site's 100 *ms* pre-stimulus baseline.

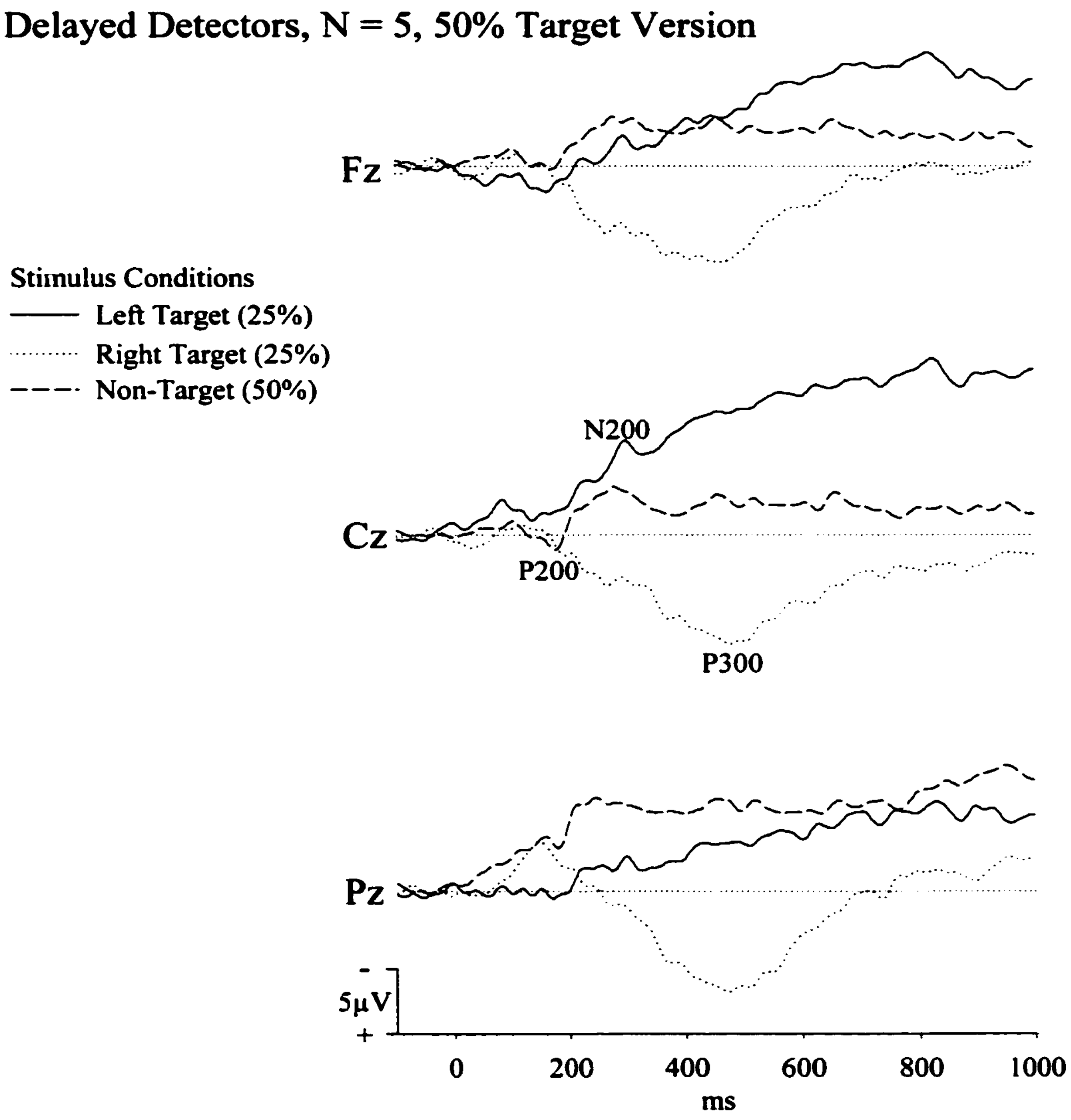


Figure 14. Grand average ERPs from 3 midline sites for the 50% Target Version of the Lateralized Oddball Paradigm of Experiment Two for the patients with left visual hemineglect who detected left targets more slowly than right targets (Delayed-Detectors, *n* = 5). Participants were to press a button for every lateralized target letter O that appeared within a randomized series of non-target trials. Time (*ms*) is on the *x*-axis with zero indicating stimulus onsets. Amplitude (*μV*) is on the *y*-axis with a horizontal line indicating the average of each site's 100 *ms* pre-stimulus baseline.

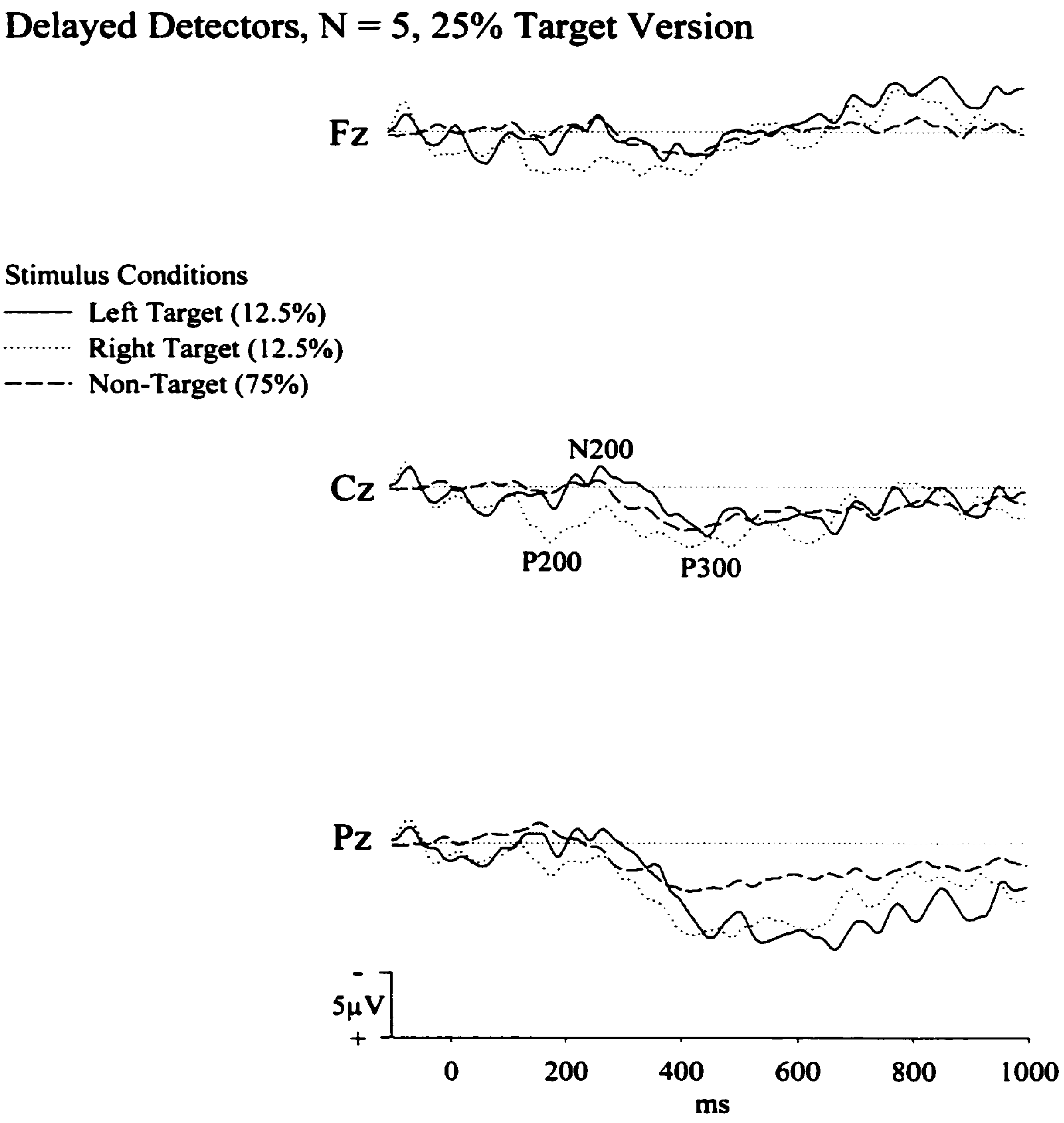


Figure 15. Grand average ERPs from 3 midline sites for the 25% Target Version of the Lateralized Oddball Paradigm of Experiment Two for the patients with left visual hemineglect who detected left targets more slowly than right targets (Delayed-Detectors, $n = 5$). Participants were to press a button for every lateralized target letter O that appeared within a randomized series of non-target trials. Time (*ms*) is on the x-axis with zero indicating stimulus onsets. Amplitude (μV) is on the y-axis with a horizontal line indicating the average of each site's 100 *ms* pre-stimulus baseline.

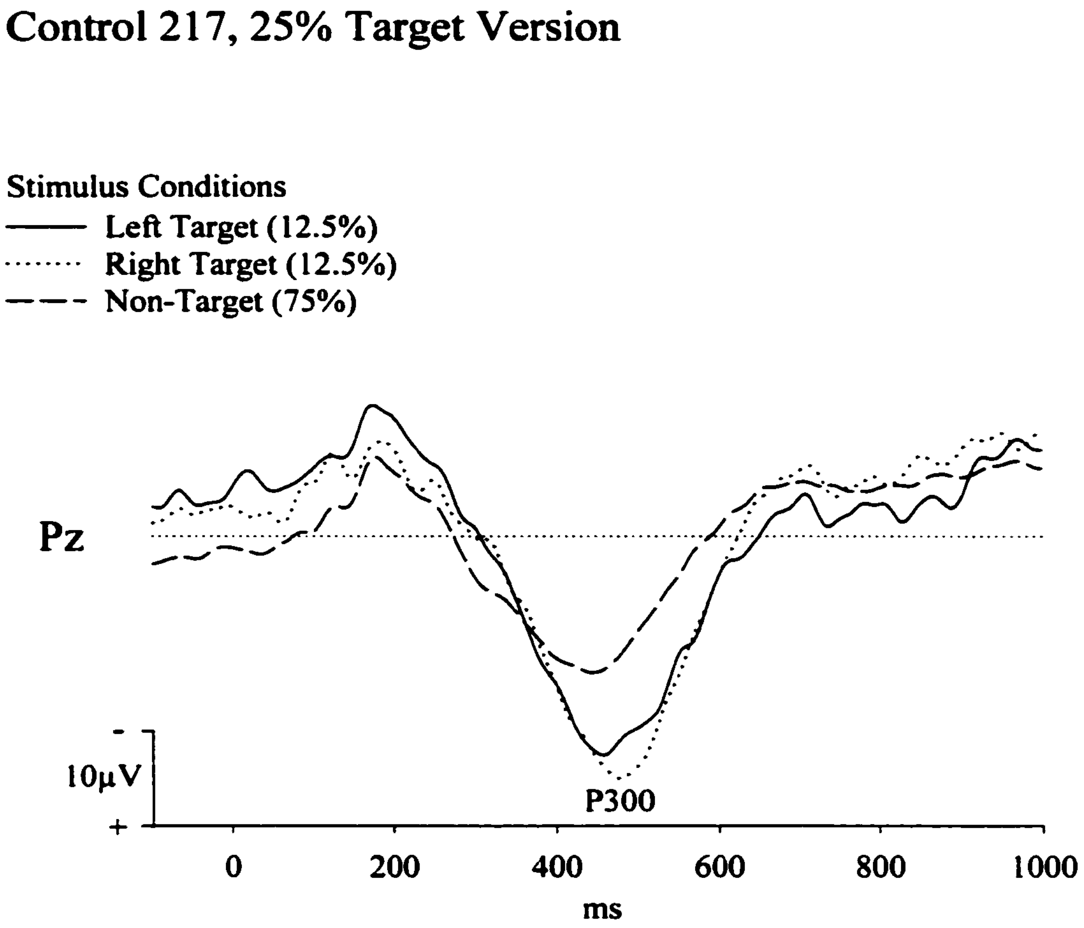


Figure 16. ERPs from 3 midline sites for the 25% Target Version of the Lateralized Oddball Paradigm of Experiment Two for an age-matched control (C217). The participant was to press a button for every lateralized target letter O that appeared within a randomized series of non-target trials. For this case, the amplitudes of the P300 were significantly influenced by the manipulation of stimulus targetness regardless of the laterality of the eliciting stimuli. Time (*ms*) is on the *x*-axis with zero indicating stimulus onsets. Amplitude (*µV*) is on the *y*-axis with a horizontal line indicating the average of each site's 100 *ms* pre-stimulus baseline.

Patient 113, 25% Target Version

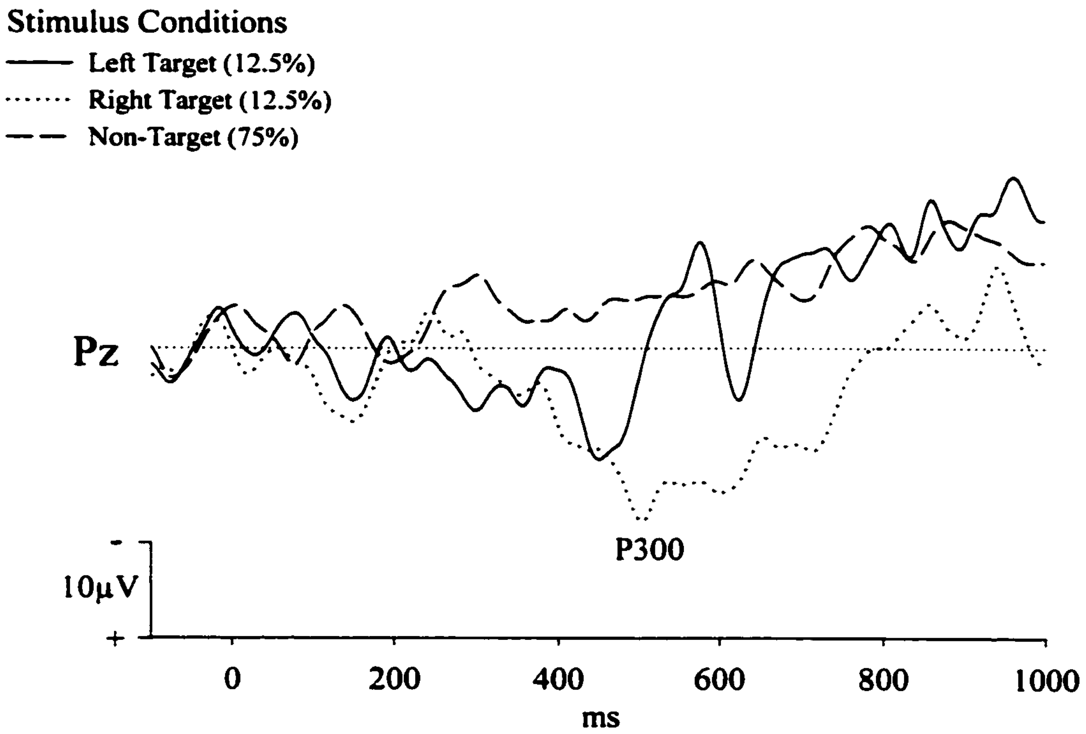


Figure 17. ERPs from 3 midline sites for the 25% Target Version of the Lateralized Oddball Paradigm of Experiment Two for a patient with left visual hemineglect (P113). The participant was to press a button for every lateralized target letter O that appeared within a randomized series of non-target trials. For this case, the left but not right targets were generally omitted (Non-Detector Subgroup). This case is somewhat atypical from the performance of the patient group as a whole in that the amplitudes of this patient's P300 were significantly influenced by the manipulation of stimulus targetness regardless of the laterality of the eliciting stimuli instead of for the right stimuli only. Time (*ms*) is on the *x*-axis with zero indicating stimulus onsets. Amplitude (*μV*) is on the *y*-axis with a horizontal line indicating the average of each site's 100 *ms* pre-stimulus baseline.

Appendix A. Summary of CT Scan Interpretations for the Patients with Left Visual Hemineglect ($N = 11$) in Experiments One and Two.

ID	Date	Interpretation
101	10/01/96	Mild cerebral atrophy. No infarcts, hemorrhage, or mass effect.
	12/01/96	Acute right fronto-temporal infarct with slight narrowing of nearby sulci.
103	19/02/96	Compared to 05/03/95. A new small right occipital infarct. Old right parietal infarct evident. No other abnormality.
	01/03/ 96	Compared to 19/02/96. Old right fronto-parietal infarct. No new infarct or hemorrhage.
105	(CTs follow evolution of hemorrhagic transformations.)	
	12/01/96	Two new right parietal-temporal infarcts in white and grey matter. Also a parietal-occipital infarct. No mass effect or hemorrhage.
	16/01/96	Large right hypo-density in most of temporal and some fronto-parietal regions with sparing of the caudate head of the thalamus and most of the middle cerebral artery distribution. Mass effect with subcalcrine and impending uncal herniation.
	05/02/96	Compared to 16/01/96. Resolution of mid-line shift from right to left. Marked improvement in mass effect from right MCA infarct. Several hemorrhages within infarct. Left occipital infarct smaller and better defined. Hydrocephalus.
	20/02/96	Large right MCA infarct more hypo-dense. A significant amount of hemorrhage remains.

Appendix A (Continued).

ID	Date	Interpretation
	11/03/96	Old right parietal and occipital infarcts. New large right infarct (probably cardiac embolism) with bleeding in the inferior frontal operculum and posterior superior para-sylvian region. It extends to the frontal horn and involves the basal ganglia. The thalamus, anterior and posterior cerebral territories are spared. Sulcal flattening. No shift but crowding of the right cerebral peduncle in the midbrain. Resolution of mass (hemorrhage) but no gliatic scaring.
106	19/02/96	Prominent hematoma centred in right thalamus and extending to the right lateral ventricle. Minor mid-line shift (right to left) with compression of adjacent frontal horns and tilting of septum and peridentrical
107	/2003/96	Incomplete deep infarct involving right lentiform and corona radiata. Some involvement of nearby lateral ventricle but no mid-line shift.
	18/03/96	Age appropriate widening of ventricles and subarachnoid spaces. No bleeding, mass effect or obvious subacute infarct evident. Marked carotid calcifications. Sinuses normally aerated.
109	02//04/96	Movement artefact. Large right hyper-density in MCA but infarct not yet visible.
	16/04/96	Large right MCA infarct primarily involving deep white matter tracts. Relative sparing of cortical surface. Mild mass effect. No hemorrhage.

Appendix A (Continued).

ID	Date	Interpretation
110	12/04/96	Right parietal-occipital ischemic infarct. Second ischemic infarct high in the right parietal area. No herniation or mass lesions.
	18/03/96	Age appropriate widening of ventricles and subarachnoid spaces. No bleeding, mass effect or obvious subacute infarct evident. Marked carotid calcifications. Sinuses normally aerated.
112	a) 19/04/96	Acute right MCA infarct affecting the parietal and temporal lobes.
	b) 04/06/96	Old right MCA infarct. New fronto-parietal infarct involving white and grey matter. No hematoma, other masses, midline shift, or hydrocephalus.
	b) 12/04/96	Comp to Jun 4 96. Hemorrhage transformations slightly less pronounced within subcortical grey matter of right fronto-temporal infarct.
113	admitted	CT within normal limits with some atrophy but a right ischemic stroke probably from cardiac embolism resulting in left weakness, inattention and neglect was assessed.
114	10/04/94 admitted	No significant abnormality although neurological deficits suggest a massive stroke. Age-appropriate cerebral and cerebellar atrophy. Tiny focal left parietal calcification (subcortical) with no mass effect (probably not clinically significant).

Appendix A (Continued).

ID	Date	Interpretation
116	admitted	CTs performed in another country were initially normal. Repeats showed right tempo-parietal infarct in MCA distribution. Bilateral carotid occlusion evident (collaterally)
	12/07/96.	Interpretation of above CT. Dense right MCA ischemic infarct in the fronto-temporal region (thrombo-embolic material). Mild impressions on right lateral ventricle but no midline shift or hydrocephalus. Complete occlusion of left ICA at the origin.

Note. CT scans were used as part of routine patient care in the hospital and were interpreted by the staff radiologists involved in the care of the patients. MCA = middle cerebral artery. ICA = internal carotid artery.

Appendix B. The Administration and Scoring Procedures for the Sunnybrook Neglect Bedside Battery with Example Subtests Completed by the Patients in Experiments One and Two.

1. Administration.

a) Draw a Clock: Place a blank sheet of 8 x 11" sheet of paper in the portrait position at the patient's mid-line. *"Draw the face of a clock and be sure to include all of the numbers".* If reasonably well done: *"Show me how the clock would look if it were 10 minutes past 11".*

b) Draw a Daisy: With a fresh piece of 8 x 11" paper: *"Now draw a daisy".*

c) Line Cancellation: Centre the 8 x 11" test sheet in the landscape position at patient's mid-line. *"Cross out all of the lines on this page just like this"* (demonstrate with the bottom centre line). *"Let me know when you are finished".*

d) Line Bisections: Centre the 8 x 11" sheet with the two horizontal lines of 15 cm at the patient's mid-line. Point to the top line. *"Make a mark that divides this line segment exactly into two equal parts. In other words, draw a line that cuts this line exactly in half".* If the bottom line is distracting, cover it with a blank page. Point to the bottom line of 15 cm and repeat the instructions. Then, repeat this testing procedure using the sheet with the two horizontal lines of 20 cm.

e) Copy a Clock: Place the 8 x 11" sheet of paper with the picture of clock at the patient's mid-line. *"Copy this picture as best you can".* The copy is made on the same sheet upon which the model of the clock appears. If reasonably well done: *"Show me how the clock would look if it were 25 minutes past 8".*

f) Copy a Daisy: Place the 8 x 11" sheet of paper with the picture of a daisy at patient's mid-line. *"Copy this picture as best you can".* The copy is made on the same sheet upon which the model of the daisy appears.

g) Figure Cancellation: Centre the 8 x 11" test sheet in the landscape position at the patient's mid-line. Draw a target on a separate piece of paper and show it to the patient. *'I have just drawn a target. Your task is to circle all the targets that you can find on this piece of paper. Do not circle anything except for the targets. While you are doing this task, I am going to give different coloured pencils to* *you. However, you are to continue circling the targets. When you are satisfied that you have found all of the targets, put down your pencil".* Begin to time when the patient circles the first target. Provide the patient with a different colour pencil after every 10 targets circled. Noting the sequence of the colours used. Stop timing when the patient puts the pencil down.

2. *Scoring:*

   a) The Drawing and Copying Subtest Score: The drawings and copies are scored together. Count the number of contralateral omissions. Omissions on no drawings or copies (0 points, normal performance), on 1 drawing or copy (20 points), on more than one drawing or copy (30 points, maximum score).

   b) The Line Cancellation Subtest Score: Three points per contralateral line omission to a maximum of 30 points. Normal performance is no omissions.

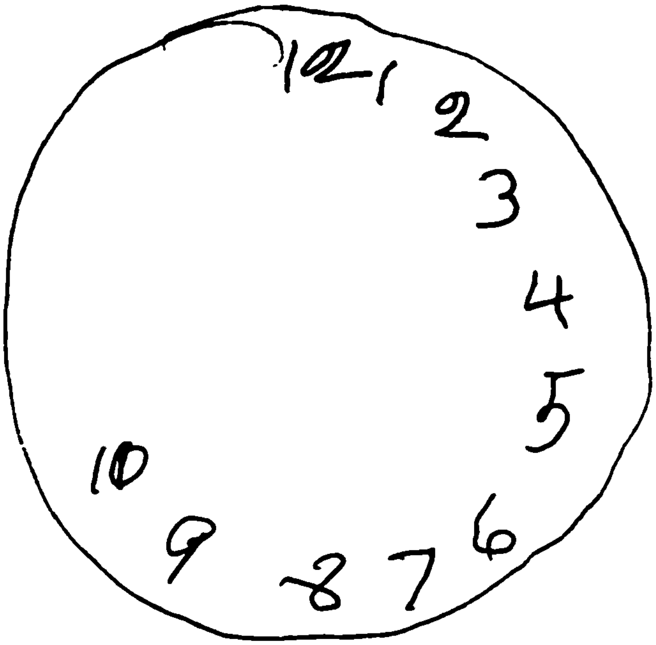
   c) The Line Bisection Subtest Score: Scoring is proportional to the magnitude of the mean percentage of ipsilesional deviation from the mid-point for the 4 lines. Normal performance is -3.6 to 2.8% (*M* = -0.8, *SD* = 3.1). If greater than 1 *SD*, 2 points, 2 *SD* = 3 points, 3 *SD* = 4 points, 4 *SD* = 8 points, 5 *SD* = 10 points, maximum score.

   d) The Figure Cancellation Subtest Score: One point per omission on the contralesional side of the page greater than 1 to a maximum of 30 points. Normal performance is one omission.

   e) The Total Neglect Score: Sum the Subtest scores to a maximum of 100 points.

   f) The Severity of Neglect Classifications: Total Neglect of 6 or greater is classified as neglect with high scores denoting increasing severity: scores over 75 indicate severe neglect, scores below 30 indicate mild neglect and those in between indicate moderate neglect.

Appendix B (Continued). Drawing of a Clock by Patient P101.

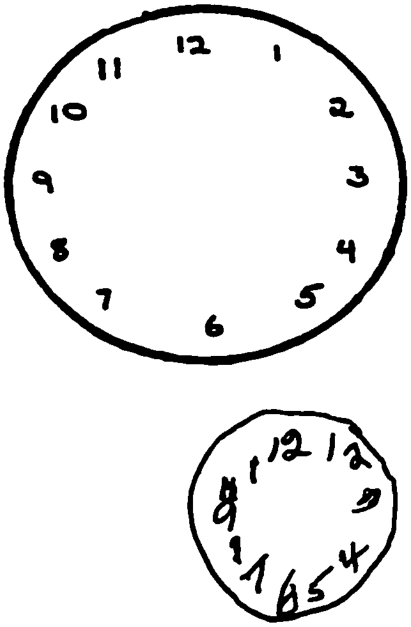


Note. The number '11' was omitted and there was ipsilateral clustering of the remaining numbers.

Appendix B (Continued). Drawing of a Daisy by Patient P116.

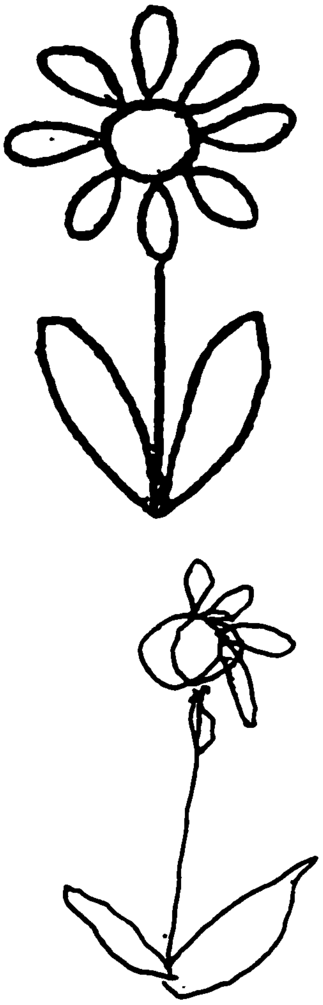
Note. The flower is incomplete on the left side.

Appendix B (Continued). Copy of a Clock by Patient P105.



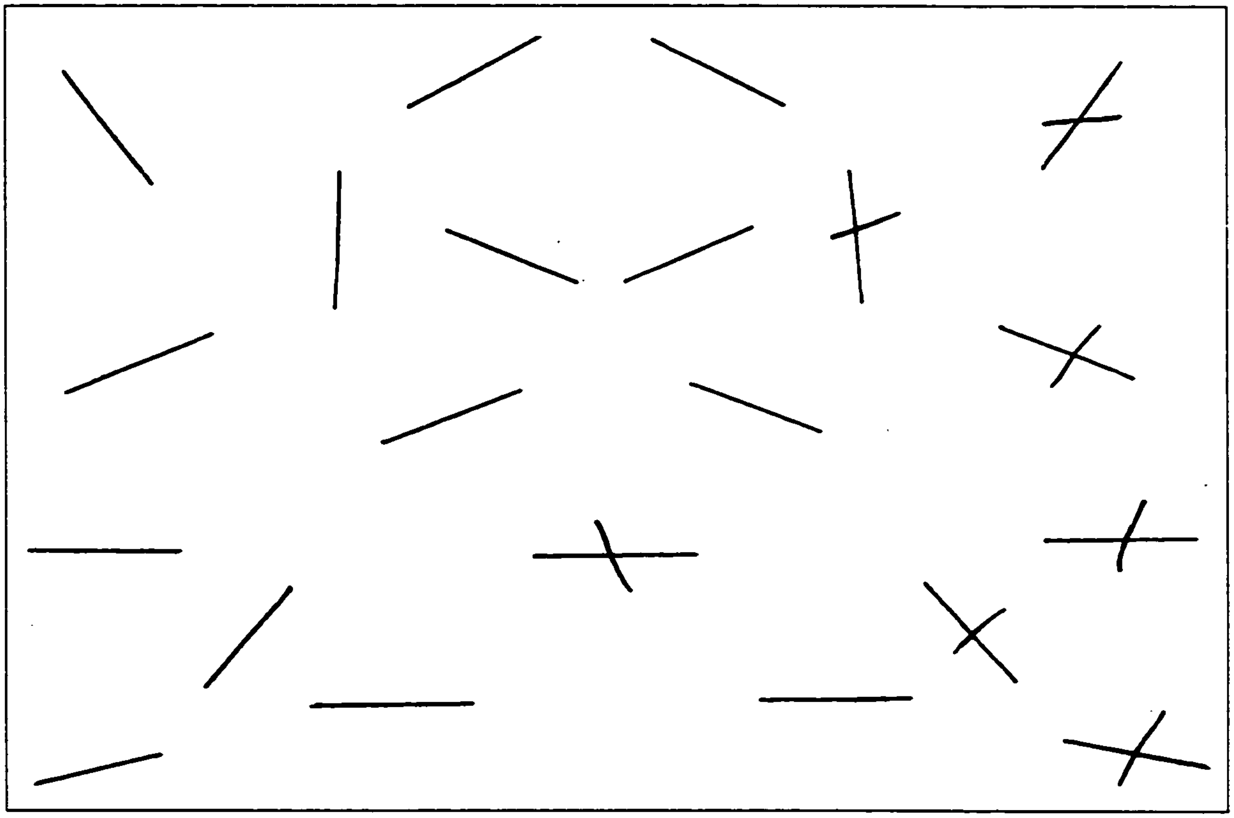
Note. One of the digits in the number 11 was omitted.

Appendix B (Continued). Copy a Daisy by Patient P105.



Note. The flower is incomplete on the left side.

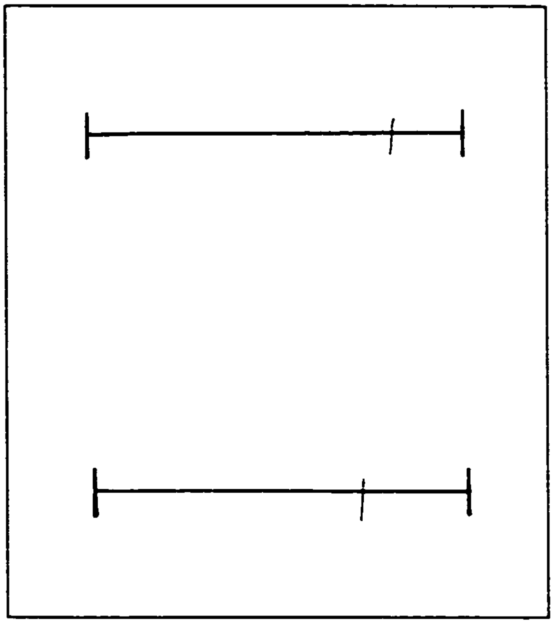
Appendix B (Continued). Line Cancellations by Patient P105.



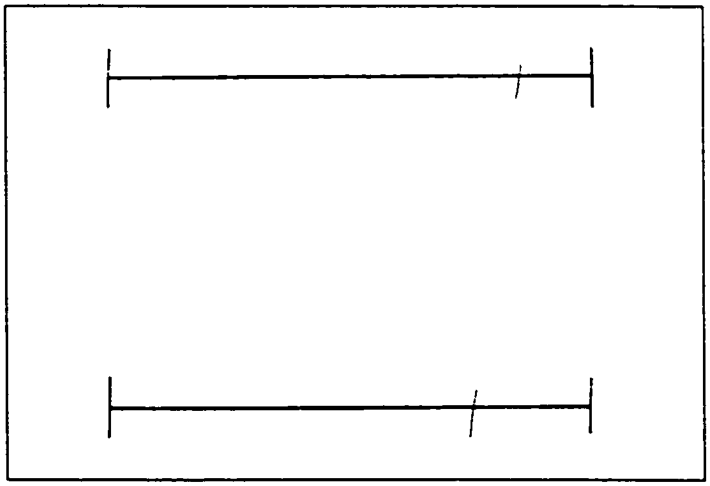
Note. All 10 contralesional lines were omitted as well as the 4 most leftward ipsilesional lines. The subtest score, however, consists of 3 points for every omission of a contralesional line to a maximum of 30 points. The horizontal line that crosses the midline of the page was cancelled by the test administrator as an example of how to cancel the lines. The rectangular border approximates the edges of an 8 by 11" sheet of paper.

Appendix B (Continued). Line Bisections by Patient P110.

a) 15 cm Lines.

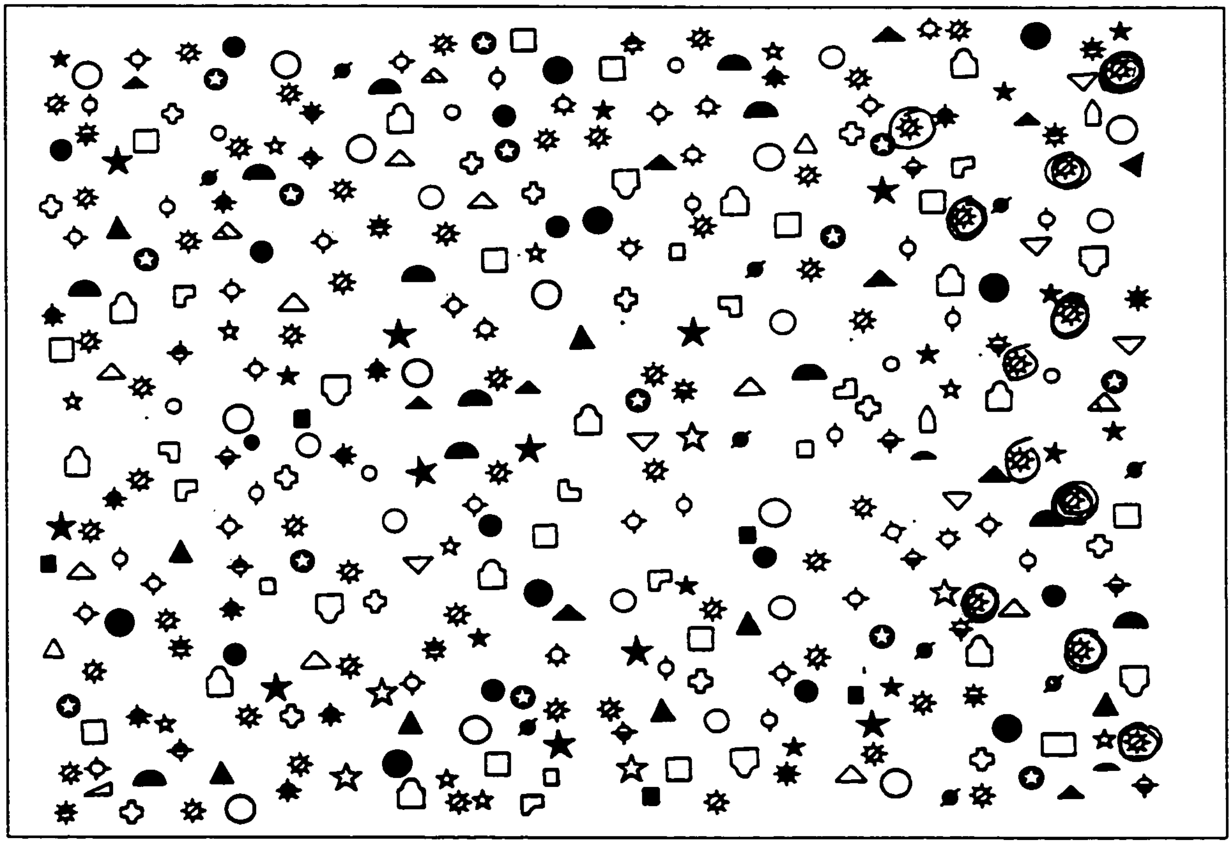


b) 20 cm Lines.



Note. The magnitude of the mean percentage of ipsilesional deviation from the midpoint for the 4 lines exceeded normal performance by 5 *SD*. The rectangular borders approximate the edges of 8 by 11" sheets of paper.

Appendix B (Continued). Figure Cancellations by Patient P105.



Note. During administration of the task instructions, an example of the target is drawn by hand and shown to the patient. Only targets near the extreme right edge of the page were circled. Normal performance is one omission. Scoring consists of one point per omission on the contralesional side of the page greater than 1 to a maximum of 30 points. The rectangular border approximates the edges of an 8 by 11" sheet of paper.

Appendix C1. Health Screening Data for the Patients with Left Visual Hemineglect (N = 11) in Experiments One and Two.

ID	Medical	Surgical	LOC Seizures	Psych	Substance Abuse
101	Ischemic heart disease, hypertension, acute polyneuritis, diabetes.	Coronary bypass, ankle tumour.	no	no	no
103	CVA (3), ischemic heart disease, myincardial infarction, hypertension, angina, lung cancer, asthma, bronchitis, arthritis.	Thumb, appendix, gall bladder, cholestectomy, lung lobectomy.	no	no	no
105	Atrial fibrillation.	Tonsil, appendix, cholecystectomy, gall bladder, hysterectomy, varicose veins.	no	yes[1]	no
106	Obesity.	None.	no	no	no
107	Heart disease (multiple attacks), diverticulitis, back pain.	Gall bladder, hernia.	no	no	no
109	Heart murmur, atrial fibrillation, hypertension, thyroid, obesity, back pain.	Hysterectomy.	no	no	no
110	Coronary artery disease, hypertension.	Coronary bypass.	no	no	no

	(bowel, endometrial), peripheral vascular disease, legionella pneumonia	cholecystectomy.			
113	Heart disease (congenital, ischemic, atrial fibrillation), hypertension, thyroid, pulmonary embolism, diverticulitis, diabetes, left cataract.	Laparotomy, pace maker.	no	no	no
114	Atrial fibrillation, hypertension, hypercholesterolemia.	None.	no	no	no
116	Chronic labyrinitis, ulcers, arthritis.	None.	no	no	no

Note. LOC = Loss of Consciousness, Psych = Psychiatric Condition, CVA = cerebral vascular accident. [1]An episode of depression which had been successfully treated many years prior to stroke onset. All had been experiencing good mental health for many years prior to stroke onset.

Appendix C2: Health Screening Data for the Age-Matched Controls (*N* = 14) in Experiments One and Two.

ID	Medical	Surgical	LOC Seizures	Psych	Substance Abuse
201	Acute labyrinitis, hepatitis-B, colour blind.	Gall bladder.	10 yrs ago[3]	no	no
202	None.	Hysterectomy.	no	no	no
207	None.	None.	no	no	no
208	Hypercholesterolemia, arthritis.	Varicose veins, tonsil.	no	no	no
209	None.	Appendix.	no	no	no
211	Hypertension, hypercholesterolemia.	None.	no	no	no
213	None.	None.	no	no	no
214	Hearing impaired as teen.	Tonsil.	no	no	no
215	Cataracts, episode profound weakness last year.	Yes, no complications.	40 yrs ago[3]	yes[1]	no
216	None.	Tonsil, varicose veins.	20 yrs ago[3]	no	no
217	None.	As child, no complications.	no	no	no
218	Hypertension, hiatus hernia.	Hernia.	no	no	no

219	Thyroid.	Cosmetic.	no	no	possible[2]
224	None.	None.	56 yrs ago[4]	no	no

Note. LOC = loss of consciousness, Psych = History of a Psychiatric Condition. [1]A single episode of conversion disorder at age 11 that was successfully treated at that time. [2]A short period of heavy drinking that was self-terminated 12 years prior to participation in this study. [3] Mild Concussion. [4] Brief LOC.

Appendix C3. The Mean Logged-10 Target Picture Categorization Times (in *s*) from the Semantic Priming Paradigm of Experiment One for the Patients with Left Visual Hemineglect: Individual *t*-test Comparisons.

ID	Congruently Primed		Non-Congruently Primed		M_{dif}	*t*	*df*	*p*	
	M	*SD*	*M*	*SD*					
Right Primed Condition									
101	.1240	.090	.0782	.457	-.0458	.46	44.00	.324	
103	-.0661	.178	-.1242	.430	-.0581	.63	45.00	.267	
106	-.3320	.544	-.2847	.382	.0473	.27	29.00	.393	
107	.0159	.460	.0058	.540	-.0101	.06	36.00	.476	
109	-.1104	.158	-.0538	.099	.0566	1.54	39.90	.066	t
110	.0674	.129	-.0243	.069	-.0917	3.27	42.33	.001	*
112	.2826	.096	.2695	.125	-.0131	.43	46.60	.334	
113	.1143	.144	.2430	.215	.1287	.28	52.33	.004	*
114	.0744	.092	.1091	.074	.0347	1.56	54.00	.062	t
Left Primed Condition									
101	.1780	.157	.1833	.139	.0053	.12	46.00	.452	
103	-.1237	.124	-.0946	.058	.0291	.92	44.00	.182	
106	-.2395	.374	-.2377	.580	.0018	.01	32.00	.496	
107	.0764	.472	.1606	.177	.0842	.80	43.00	.215	
109	-.1432	.135	-.0177	.128	.1255	3.35	48.00	.001	*
110	-.0453	.087	.0150	.126	.0603	1.98	42.44	.028	*
112	.1303	.091	.1826	.112	.0523	1.95	56.00	.029	*
113	.0904	.123	.1398	.123	.0494	.16	66.00	.053	t
114	.0480	.148	.0796	.069	.0316	1.04	56.00	.151	

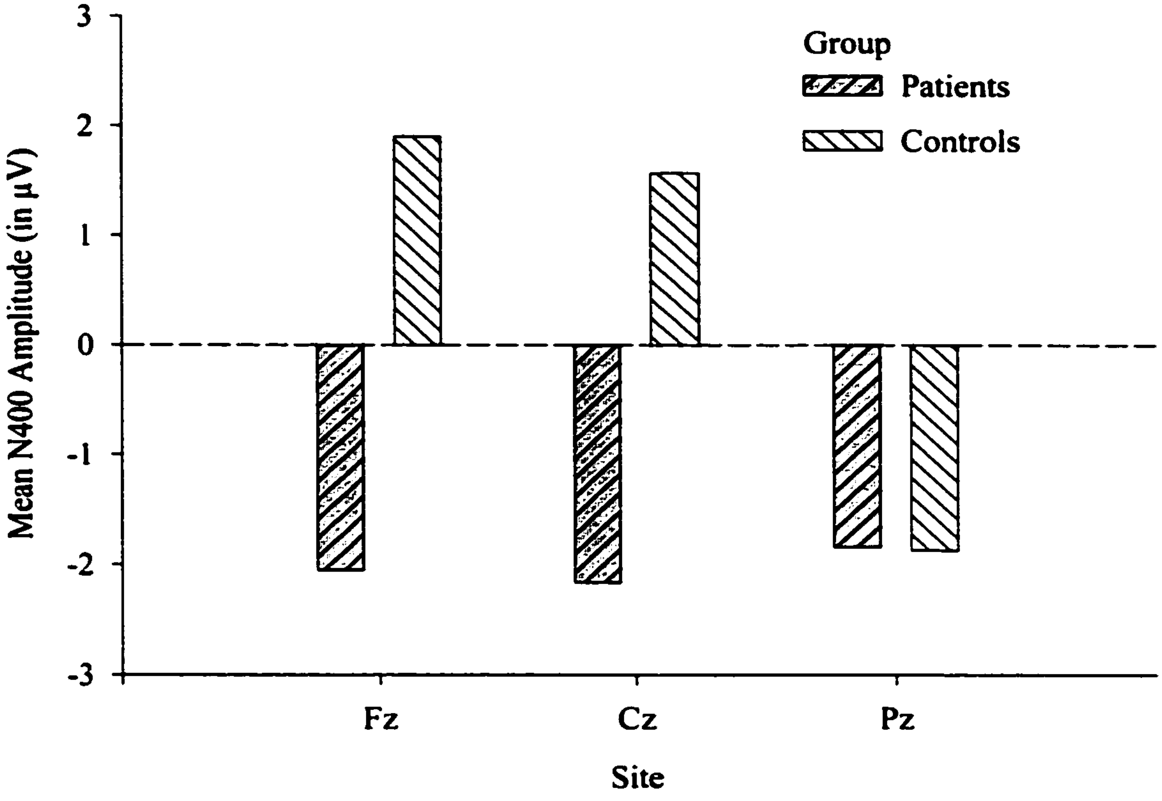
Note. $M_{dif} = M_{non\text{-}congruent} - M_{congruent}$. * = *p (1-tailed)* < .05, t = trend.

Appendix C4. The Mean Logged-10 Target Picture Categorization Times (in *s*) from the Semantic Priming Paradigm of Experiment One for the Age-Matched Controls: Individual *t*-test Comparisons.

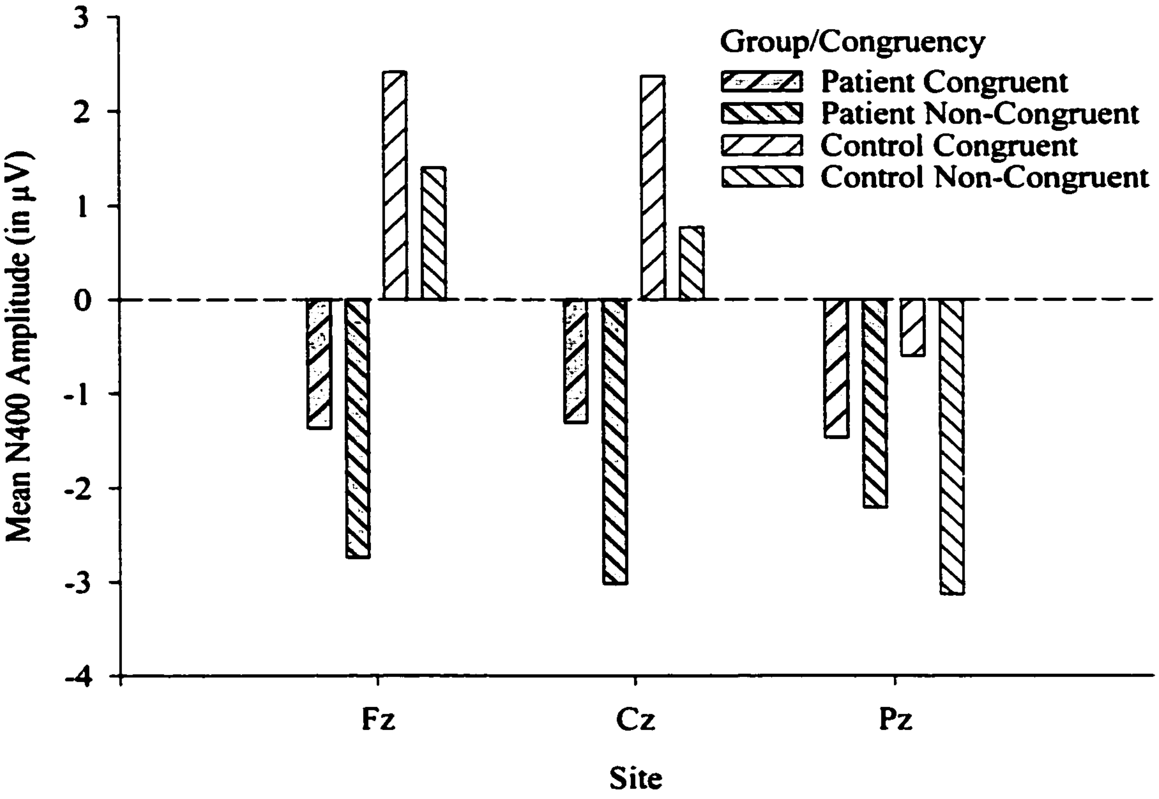
ID	Congruently Primed		Non-Congruently Primed		M_{dif}	*t*	*df*	*p*	
	M	*SD*	*M*	*SD*					
Right Primed Condition									
201	-.1866	.059	-.1933	.066	-.0067	.36	43.00	.361	
202	-.2619	.075	-.2775	.048	-.0156	.81	34.03	.212	
207	-.1248	.082	-.1453	.068	-.0205	.91	43.00	.184	
208	-.2045	.098	-.1762	.039	.0283	1.26	27.68	.110	
209	-.0992	.056	-.0684	.074	.0308	1.56	42.00	.064	t
211	-.0994	.076	-.0819	.076	.0175	.76	42.00	.226	
213	-.0701	.043	-.0429	.032	.0272	2.36	42.00	.012	*
215	-.0104	.052	-.0042	.036	.0062	.42	37.00	.337	
216	.0453	.071	.0339	.050	-.0114	.61	37.92	.272	
217	-.2042	.062	-.1585	.028	.0457	3.21	30.55	.002	*
218	-.1140	.047	-.0964	.059	.0176	1.08	41.00	.142	
219	-.1593	.087	-.1203	.045	.0390	1.90	33.60	.033	*
224	-.2818	.070	-.2703	.024	.0115	.74	27.63	.234	
Left Primed Condition									
201	-.1950	.069	-.1879	.044	.0071	.42	36.62	.339	
202	-.2702	.075	-.2602	.056	.0100	.52	44.00	.305	
207	-.1166	.087	-.1559	.052	-.0393	1.83	33.52	.038	*
208	-.2266	.047	-.1818	.060	.0448	2.83	43.74	.004	*
209	-.0961	.062	-.0899	.070	.0062	.32	44.00	.375	
211	-.0802	.065	-.0737	.046	.0065	.38	35.70	.352	
213	-.0743	.043	-.0679	.030	.0064	.58	42.00	.282	
215	.0057	.042	-.0109	.034	-.0166	1.48	43.00	.074	t
216	.0486	.069	.0730	.061	.0244	1.29	45.00	.102	
217	-.2171	.052	-.1703	.028	.0468	3.83	33.49	.001	*
218	-.0896	.055	-.0978	.051	-.0082	.52	43.00	.303	
219	-.1938	.102	-.1322	.060	.0616	2.51	35.51	.009	*
224	-.2837	.049	-.2853	.039	-.0016	.11	40.00	.456	

Note. $M_{dif} = M_{non\text{-}congruent} - M_{congruent}$. * = *p (1-tailed)* < .05, t = trend.

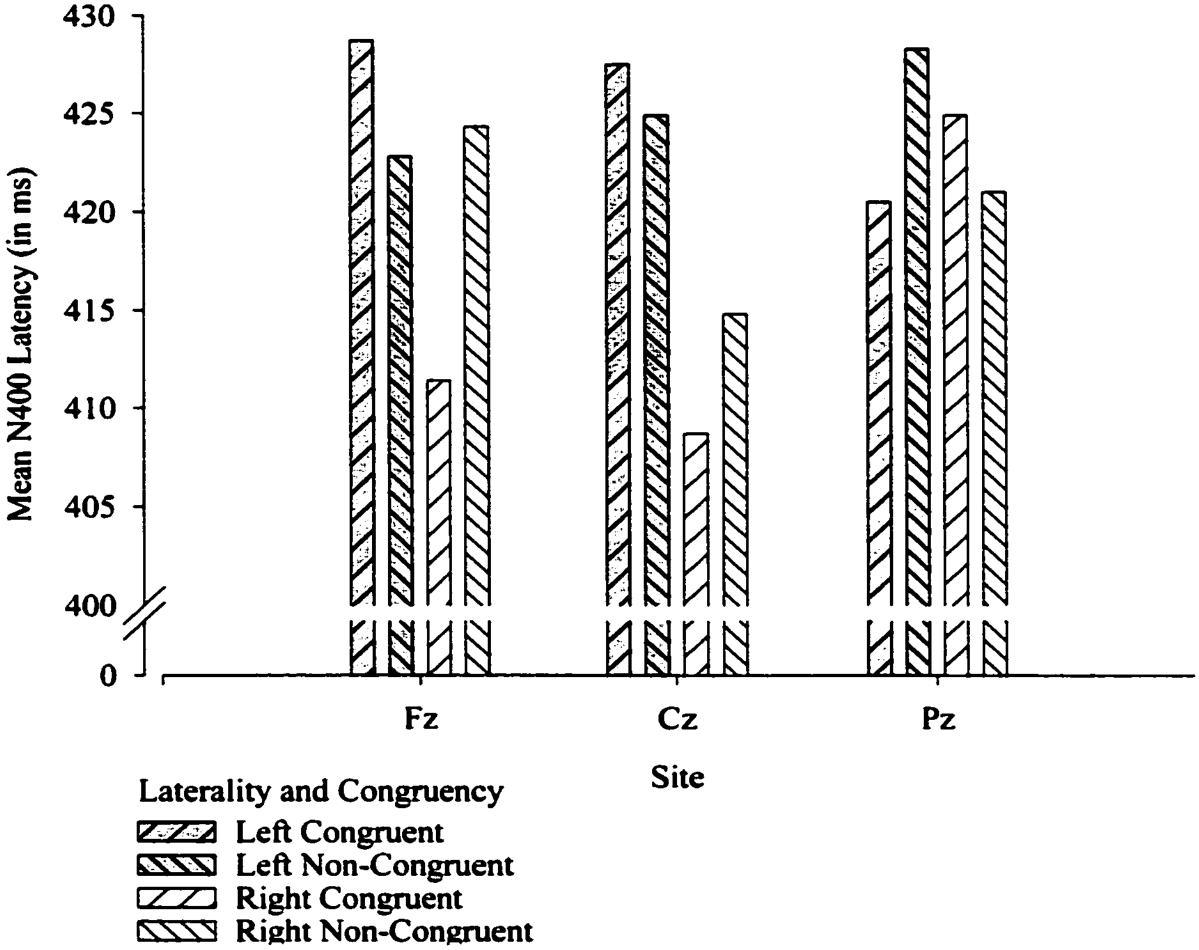
Appendix D1. Analysis of ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect ($N = 9$) and Age-Matched Controls ($N = 13$): The N400 Amplitude (in μV) Group by Recording Site Interaction.



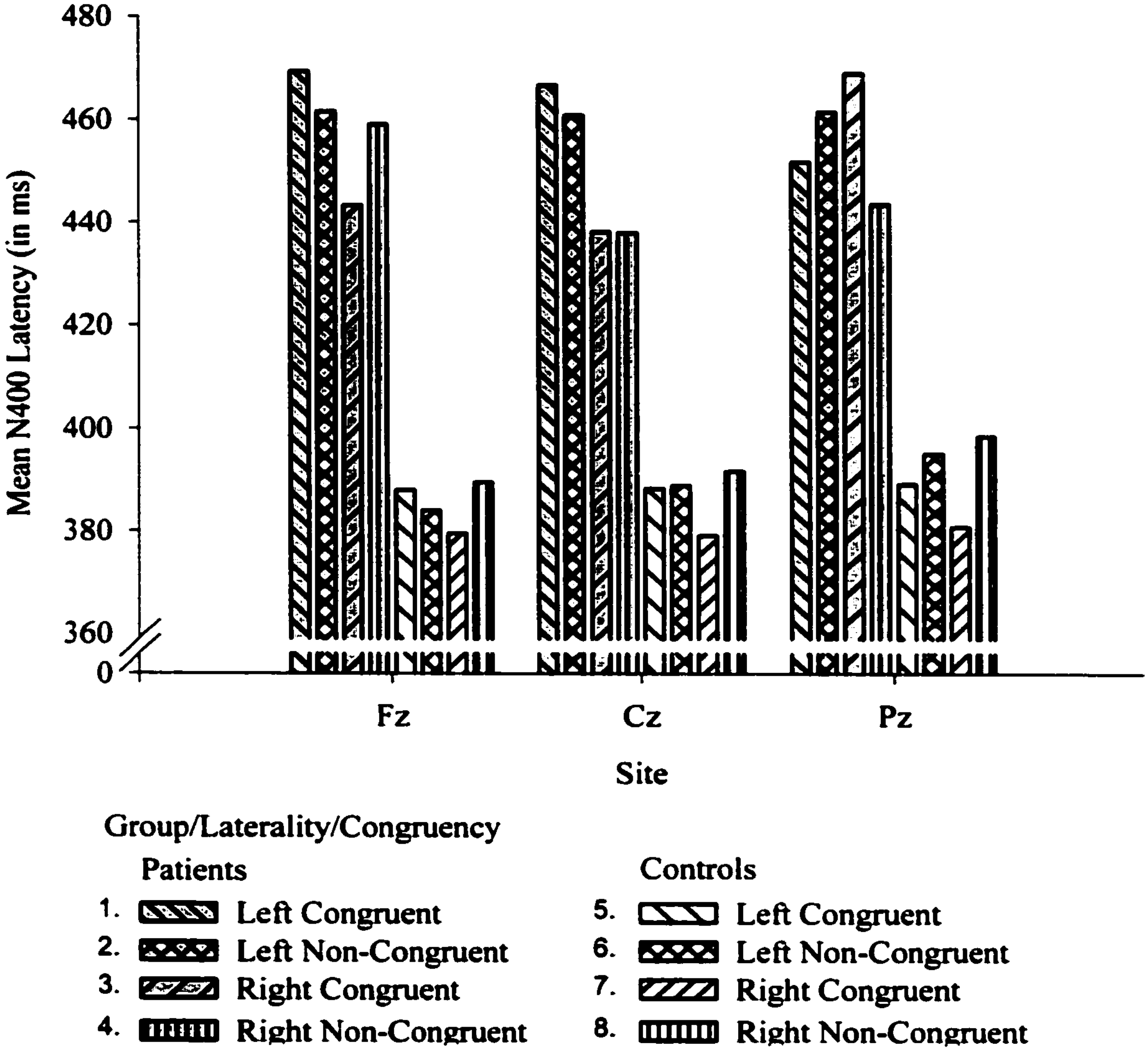
Appendix D2. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect (*N* = 9) and Age-Matched Controls (*N* = 13): The N400 Amplitude (in μV) Group by Congruency of Prime by Recording Site Interaction.



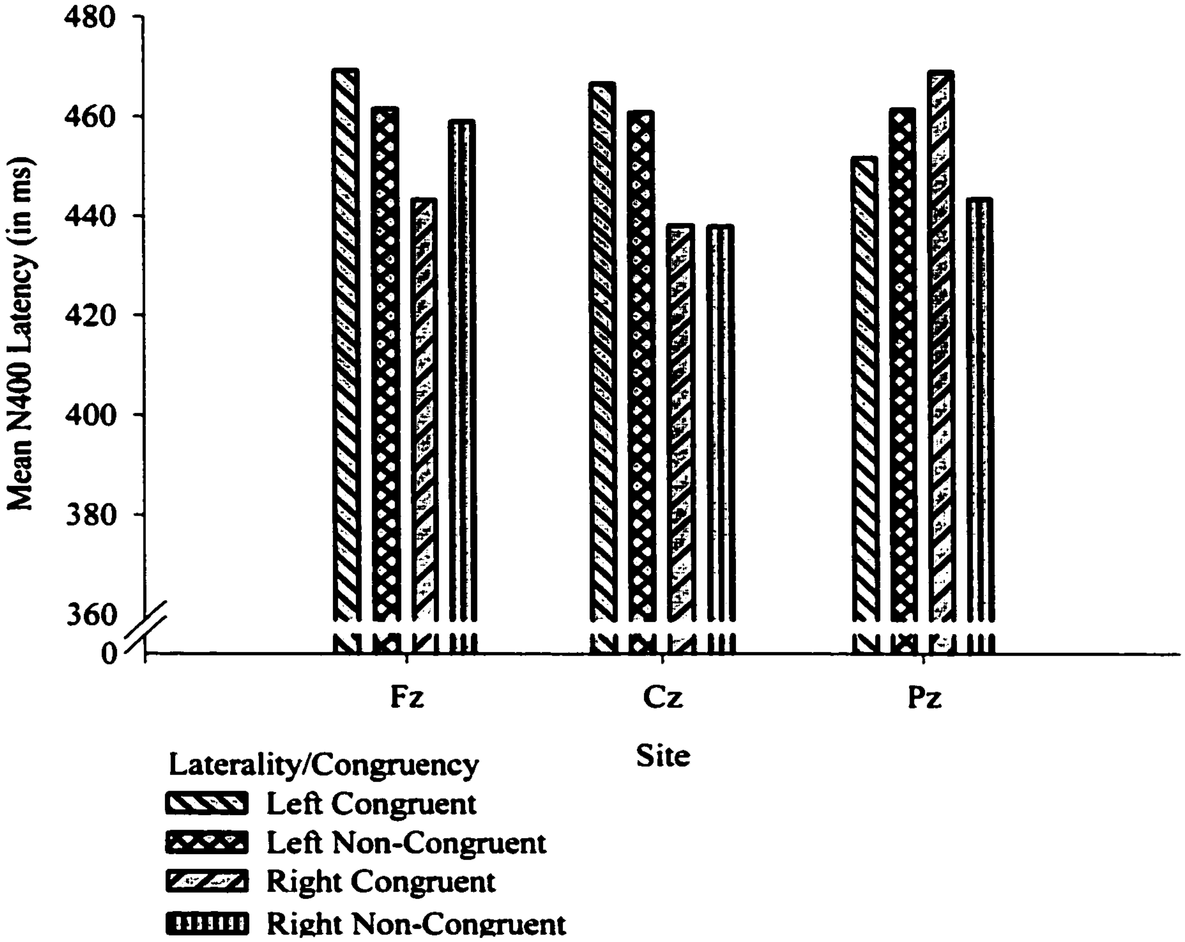
Appendix D3. Analysis of the ERPs of Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect ($N = 9$) and Age-Matched Controls ($N = 13$): The N400 Latency (in *ms*) Congruency of Prime by Laterality of Prime by Recording Site Interaction.



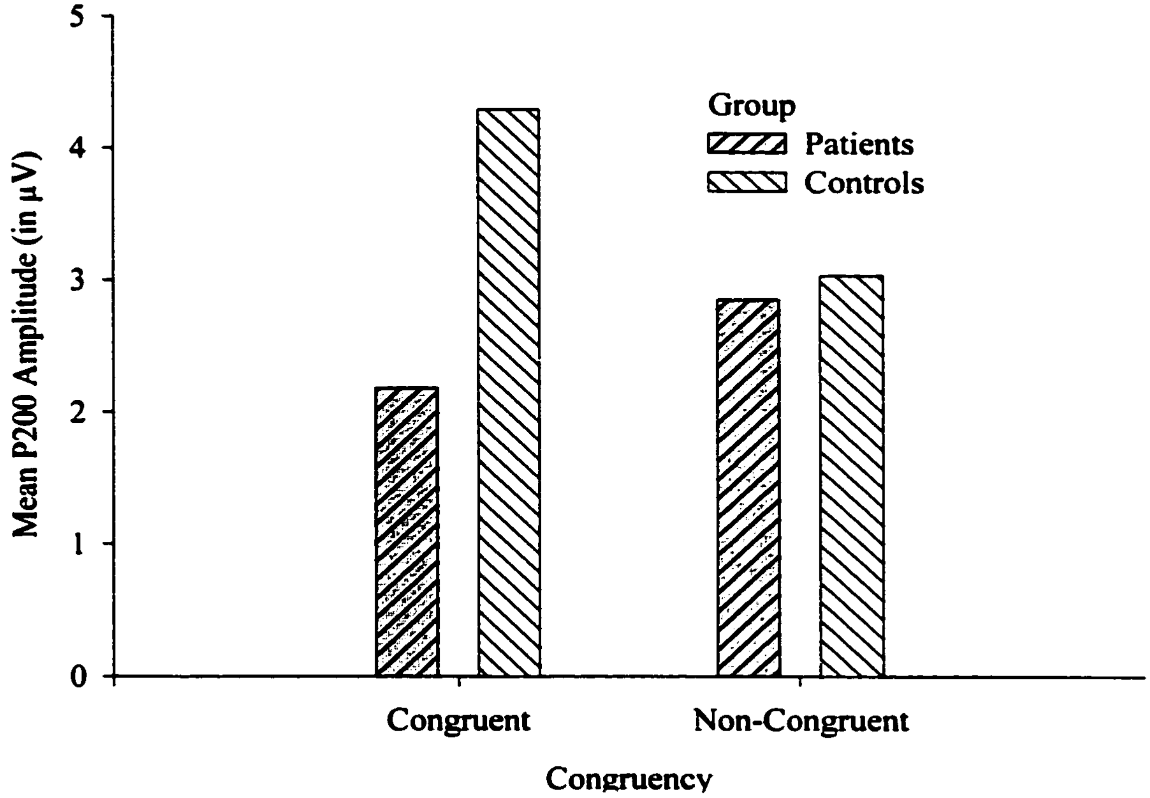
Appendix D4. Analysis of the ERPs of Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect (*N* = 9) and Age-Matched Controls (*N* = 13): The N400 Latency (in *ms*) Group by Congruency of Prime by Laterality of Prime by Recording Site Interaction.



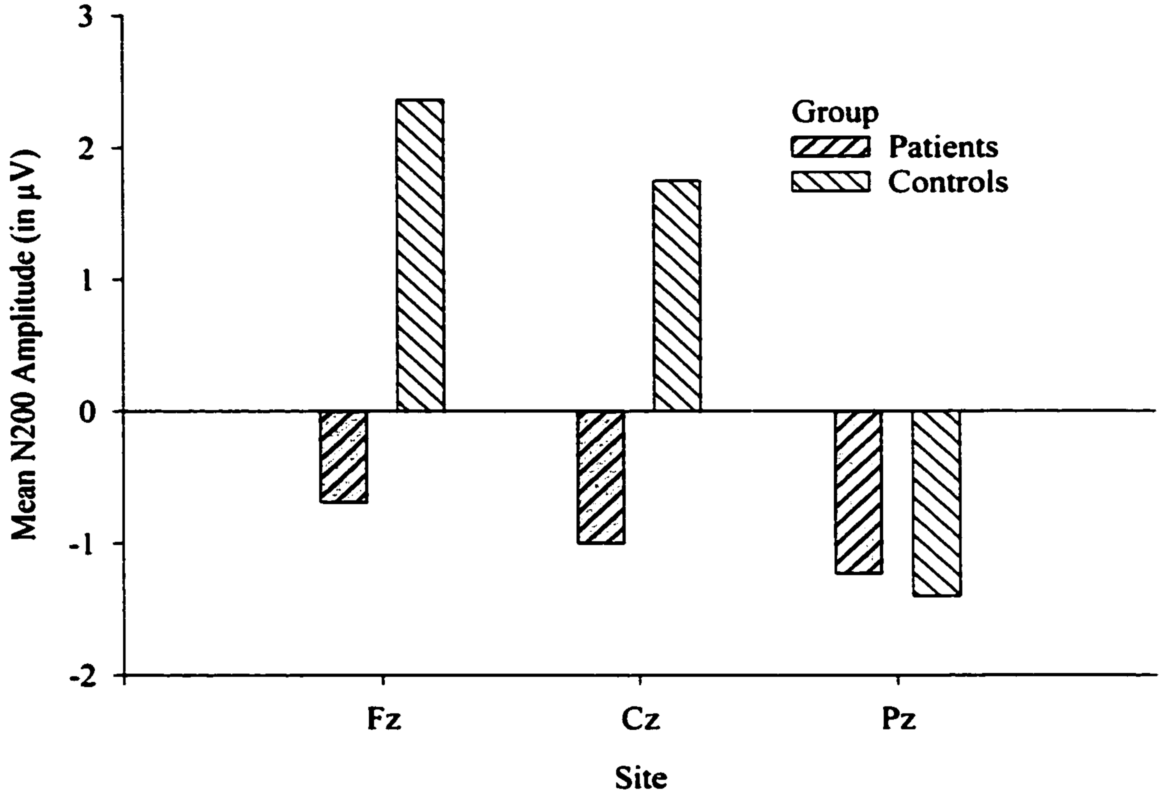
Appendix D4a. Follow up Analysis of the ERPs Elicited by Centralized Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect (*N* = 9): The N400 Latency (in *ms*) Congruency of Prime by Laterality of Prime by Recording Site Interaction.



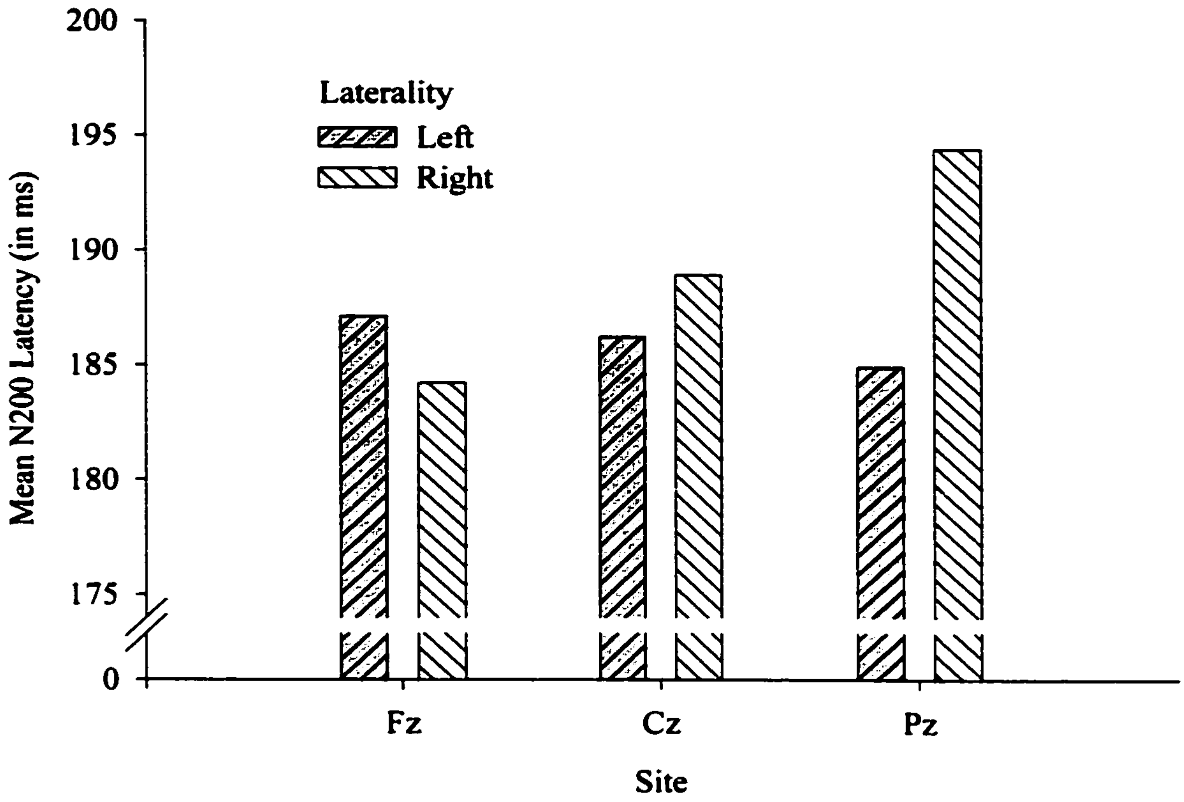
Appendix D5. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect ($N = 9$) and Age-Matched Controls ($N = 13$): The P200 Amplitude (in μV) Group by Congruency of Prime Interaction.



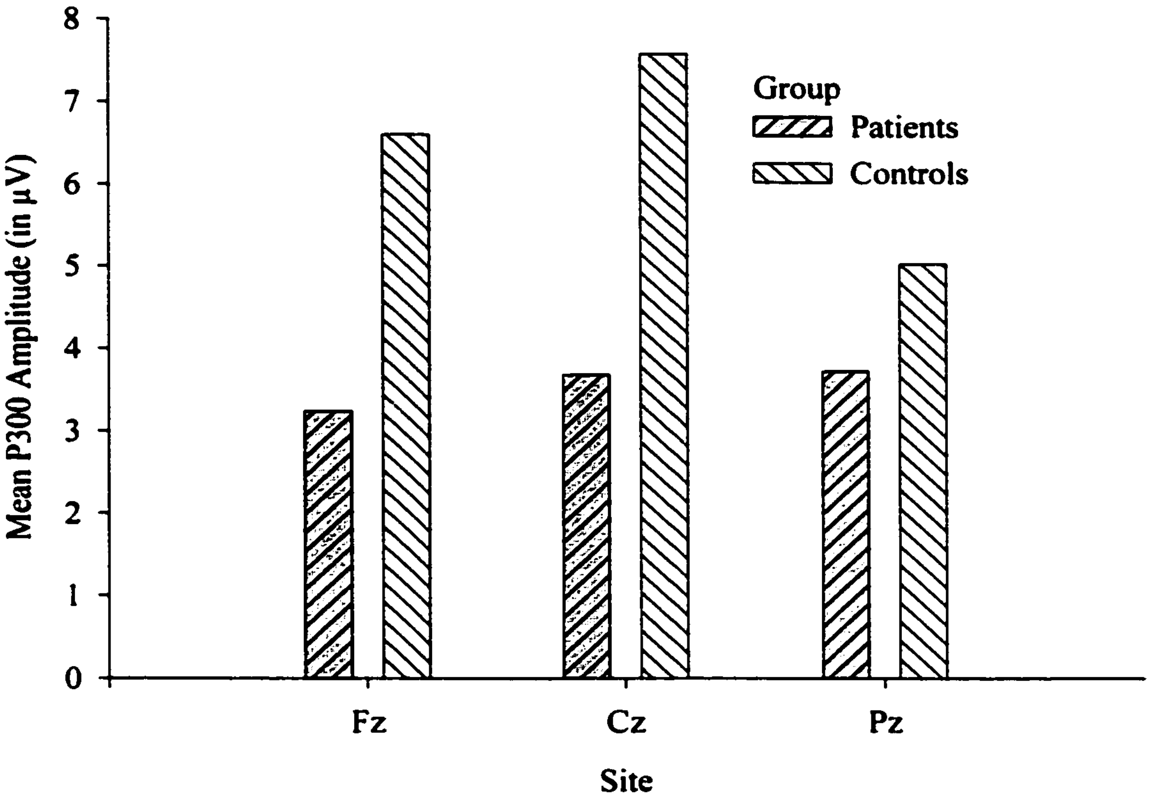
Appendix D6. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect ($N = 9$) and Age-Matched Controls ($N = 13$): The N200 Amplitude (in μV) Group by Recording Site Interaction.



Appendix D7. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect (*N* = 9) and Age-Matched Controls (*N* = 13): The N200 Latency (in *ms*) Laterality of Prime by Recording Site Interaction.



Appendix D8. Analysis of the ERPs Elicited by Centralised Picture Targets from the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect ($N = 9$) and Age-Matched Controls ($N = 13$): The P300 Amplitude (in μV) Group by Recording Site Interaction.



Appendix E1 (page.1). Individual Mean N400 Amplitude and Difference Scores (in μV) Elicited by the Centralized Picture Targets of the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect ($N = 9$).

Patient Data Recorded at Fz.

Prime Lat	ID	Congruent Condition (C)		Non-Congruent Condition (NC)		Diff Score (C - NC)	*t*	*df*	*p*
		M	*SD*	*M*	*SD*				
Right	101	0.0	4.16	-2.4	3.24	2.4	2.29	50	*
	103	-2.5	4.45	-2.5	4.60	0.0	0.0	32	.
	106	-2.7	6.50	-3.3	6.53	0.6	0.34	51	.
	107	7.1	19.45	0.4	11.80	6.7	1.41	44	.
	109	-0.4	4.67	-1.6	6.90	1.2	0.64	38	.
	110	-2.0	4.29	-2.5	4.74	0.5	0.38	46	.
	112	-5.1	9.23	-1.3	10.25	-3.8	-1.34	45	.
	113	-3.8	16.97	-4.6	17.79	0.8	0.17	51	.
	114	-4.8	15.06	-1.0	7.60	-3.8	-1.12	47	.
Left	101	-1.4	4.09	-1.9	4.41	0.5	0.44	53	.
	103	-0.2	5.49	0.0	4.21	-0.2	-0.11	27	.
	106	-3.2	6.30	-4.8	8.67	1.6	0.78	52	.
	107	3.1	14.17	-3.5	11.10	6.6	1.63	37	.
	109	3.9	6.94	-0.1	5.74	4.0	2.16	45	*
	110	-1.2	4.02	-2.0	3.05	0.8	0.75	44	.
	112	-2.6	7.08	-2.7	6.73	0.1	0.05	40	.
	113	-5.6	14.80	-8.6	18.82	3.0	0.66	53	.
	114	-3.2	10.80	-6.9	8.74	3.7	1.30	47	.

Note. Each centralized picture target depicted an exemplar of an animal or clothing and was preceded by a semantically congruent (C) or non-congruent (NC) picture prime that was lateralized to the left or right of central fixation. An asterisk (*) denotes 1-tailed statistical significance at $p \leq .05$.

Appendix E1.(page 2).

Patient Data Recorded at Cz.

Prime Lat	ID	Congruent Condition (C)		Non-Congruent Condition (NC)		Diff Score (C - NC)	*t*	*df*	*p*
		M	*SD*	*M*	*SD*				
Right	101	0.8	3.81	-2.4	5.18	3.2	2.56	50	*
	103	-1.6	5.08	-2.1	3.37	0.5	0.33	32	.
	106	-3.4	6.14	-3.3	6.07	-0.1	-0.06	51	.
	107	9.0	16.19	1.4	14.32	7.6	1.69	44	*
	109	-1.0	4.99	-2.0	8.17	1.0	0.47	38	.
	110	-3.1	4.44	-2.5	6.39	-0.6	-0.38	46	.
	112	-5.6	10.14	-2.6	9.73	-3.0	-1.03	45	.
	113	0.0	20.42	-3.8	19.03	3.8	0.70	51	.
	114	-2.9	9.48	-1.3	8.93	-1.6	-0.61	47	.
Left	101	-1.6	5.39	-2.9	5.02	1.3	0.92	53	.
	103	-0.6	6.27	-0.6	5.34	0.0	0.00	27	.
	106	-3.4	5.80	-3.9	7.15	0.5	0.28	52	.
	107	-2.9	13.57	-5.6	14.01	2.7	0.61	37	.
	109	4.8	8.34	-0.2	6.50	5.0	2.31	45	*
	110	-1.8	4.70	-2.2	4.33	0.4	0.30	44	.
	112	-0.8	10.20	-3.7	7.13	2.9	1.05	40	.
	113	-6.9	18.53	-9.8	19.96	2.9	0.56	53	.
	114	-2.6	9.71	-6.8	9.43	4.2	1.53	47	.

Note. Each centralized picture target depicted an exemplar of an animal or clothing and was preceded by a semantically congruent (C) or non-congruent (NC) picture prime that was lateralized to the left or right of central fixation. An asterisk (*) denotes 1-tailed statistical significance at $p \leq .05$.

Appendix E1 (page 3).

Patient Data Recorded at Pz.

Prime Lat	ID	Congruent Condition (C)		Non-Congruent Condition (NC)		Diff Score (C - NC)	*t*	*df*	*p*
		M	*SD*	*M*	*SD*				
Right	101	-1.0	3.91	-1.4	4.71	0.4	0.34	50	.
	103	-1.3	4.45	-1.5	4.96	0.2	0.12	32	.
	106	-3.2	5.34	-3.7	5.43	0.5	0.34	51	.
	107	8.7	18.24	5.2	17.83	3.5	0.66	44	.
	109	-1.8	4.77	-2.5	6.93	0.7	0.37	38	.
	110	-2.0	4.92	-1.6	5.13	-0.4	-0.28	46	.
	112	-5.5	9.70	-4.4	9.11	-1.1	-0.4	45	.
	113	1.5	19.49	-1.4	16.41	2.9	0.58	51	.
	114	-2.2	7.59	-2.5	9.59	0.3	0.12	47	.
Left	101	-0.3	5.13	-2.4	5.54	2.1	1.46	53	.
	103	-2.2	3.52	-0.9	6.25	-1.3	-0.70	27	.
	106	-3.3	4.92	-3.4	7.01	0.1	0.06	52	.
	107	-7.1	16.83	-4.6	150	-2.5	-0.49	37	.
	109	2.7	5.77	-1.8	4.60	4.5	2.98	45	*
	110	-0.5	3.67	-1.1	4.14	0.6	0.52	44	.
	112	-1.3	11.68	-2.8	7.09	1.5	0.49	40	.
	113	-6.2	14.68	-4.7	19.20	-1.5	-0.33	53	.
	114	-1.4	7.01	-4.3	9.40	2.9	1.24	47	.

Note. Each centralized picture target depicted an exemplar of an animal or clothing and was preceded by a semantically congruent (C) or non-congruent (NC) picture prime that was lateralized to the left or right of central fixation. An asterisk (*) denotes 1-tailed statistical significance at $p \leq .05$.

Appendix E2 (page 1). Individual Mean N400 Amplitude and Difference Scores (in μV) Elicited by the Centralized Picture Targets of the Lateralized Semantic Priming Paradigm of Experiment One for Patients with Left Visual Hemineglect ($N = 9$).

Control Data Recorded at Fz.

Prime Lat	ID	Congruent Condition (C)		Non-Congruent Condition (NC)		Diff Score (C - NC)	*t*	*df*	*p*
		M	*SD*	*M*	*SD*				
Right	201	5.1	12.32	1.8	18.25	3.3	0.61	34	.
	202	2.5	10.54	4.5	7.36	-2.0	-0.70	40	.
	207	-0.6	8.97	-1.2	9.86	0.6	0.21	43	.
	208	0.8	12.63	1.2	9.52	-0.4	-0.13	46	.
	209	-0.5	11.71	-3.5	9.32	3.0	1.02	49	.
	213	1.0	10.20	2.9	9.19	-1.9	-0.63	39	.
	214	1.1	7.35	3.7	9.15	-2.6	-1.06	45	.
	215	0.9	9.96	2.6	2.81	-1.7	-0.81	46	.
	216	5.4	9.44	7.2	8.41	-1.8	-0.67	42	.
	217	12.0	9.56	7.8	12.28	4.2	1.34	48	.
	218	5.9	11.59	-0.4	9.51	6.3	2.08	47	*
	219	-4.2	14.66	-2.6	14.46	-1.6	-0.34	36	.
	224	-0.9	6.55	-0.2	9.59	-0.7	-0.29	46	.
Left	201	0.5	11.04	4.5	14.98	-4.0	-0.9	32	.
	202	7.0	10.31	8.2	11.09	-1.2	-0.36	39	.
	207	-0.3	7.19	-2.0	7.81	1.7	0.75	42	.
	208	6.0	12.12	8.3	12.72	-2.3	-0.61	41	.
	209	1.9	7.88	-1.8	10.43	3.7	1.29	40	.
	213	-3.4	11.86	-0.4	13.67	-3.0	-0.73	37	.
	214	1.2	8.52	3.8	8.28	-2.6	-1.04	43	.
	215	3.1	9.71	-2.0	6.89	5.1	1.92	38	*
	216	6.5	9.77	4.0	9.57	2.5	0.80	36	.
	217	7.6	12.05	3.7	9.46	3.9	1.19	42	.
	218	2.6	16.23	-3.9	13.73	6.5	1.44	43	.
	219	1.2	15.77	-8.7	20.17	9.9	1.56	30	.
	224	0.3	11.01	-1.1	8.93	1.4	0.46	42	.

Note. Each centralized picture target depicted an exemplar of an animal or clothing and was preceded by a semantically congruent (C) or non-congruent (NC) picture prime that was lateralized to the left or right of central fixation. An asterisk (*) denotes 1-tailed statistical significance at $p \leq .05$.

Appendix E2.(page2).

Control Data Recorded at Cz.

Prime Lat	ID	Congruent Condition (C)		Non-Congruent Condition (NC)		Diff Score (C - NC)	*t*	*df*	*p*
		M	*SD*	*M*	*SD*				
Right	201	6.3	23.64	6.0	17.62	0.3	0.04	34	.
	202	2.8	12.61	2.7	7.86	0.1	0.03	40	.
	207	1.0	7.14	-2.3	10.50	3.3	1.23	43	.
	208	2.0	11.82	1.2	10.15	0.8	0.25	46	.
	209	-1.1	14.01	-5.5	10.48	4.4	1.28	49	.
	213	0.8	10.78	4.1	9.19	-3.3	-1.05	39	.
	214	2.0	9.37	-0.1	9.28	2.1	0.77	45	.
	215	5.0	18.79	2.8	2.99	2.2	0.57	46	.
	216	4.3	9.29	2.9	8.91	1.4	0.51	42	.
	217	13.4	10.22	8.3	8.57	5.1	1.92	48	*
	218	3.9	11.17	1.2	9.04	2.7	0.93	47	.
	219	-0.5	12.70	-1.2	16.24	0.7	0.15	36	.
	224	-1.3	8.46	0.3	11.26	-1.6	-0.55	46	.
Left	201	-2.1	18.26	2.5	18.25	-4.6	-0.73	32	.
	202	6.5	10.64	7.2	11.94	-0.7	-0.20	39	.
	207	0.3	9.08	-1.3	8.96	1.6	0.59	42	.
	208	5.7	11.64	6.7	11.87	-1.0	-0.28	41	.
	209	0.1	9.43	-3.8	9.20	3.9	1.36	40	.
	213	0.1	11.35	0.9	10.73	-0.8	-0.22	37	.
	214	0.7	8.71	0.7	8.77	0.0	0.00	43	.
	215	-1.0	16.27	0.8	15.95	-1.8	-0.35	38	.
	216	1.5	9.40	-3.8	6.28	5.3	2.06	36	*
	217	8.8	9.26	3.2	10.66	5.6	1.86	42	*
	218	-2.0	17.08	-5.5	13.56	3.5	0.75	43	.
	219	3.7	12.68	-5.8	11.35	9.5	2.20	30	*
	224	0.7	11.03	-2.2	10.86	2.9	0.88	42	.

Note. Each centralized picture target depicted an exemplar of an animal or clothing and was preceded by a semantically congruent (C) or non-congruent (NC) picture prime that was lateralized to the left or right of central fixation. An asterisk (*) denotes 1-tailed statistical significance at $p \leq .05$.

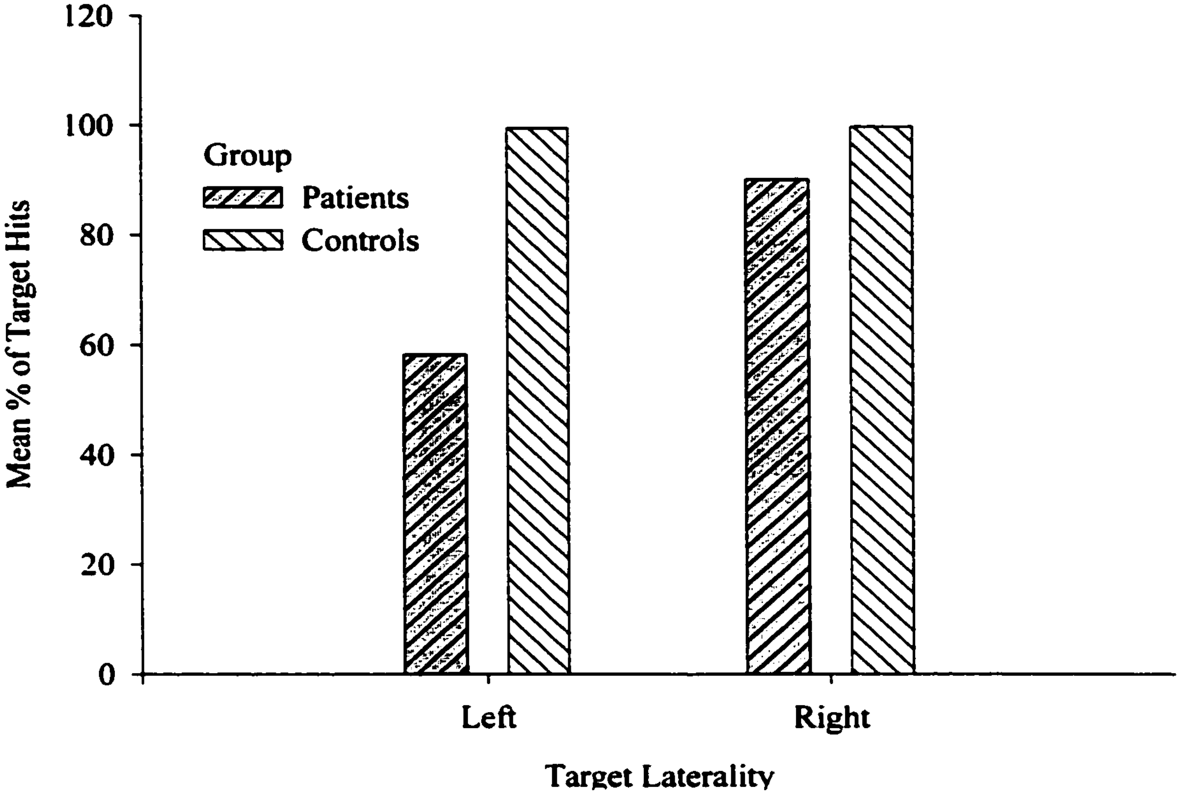
Appendix E2.(page 3).

Control Data Recorded at Pz.

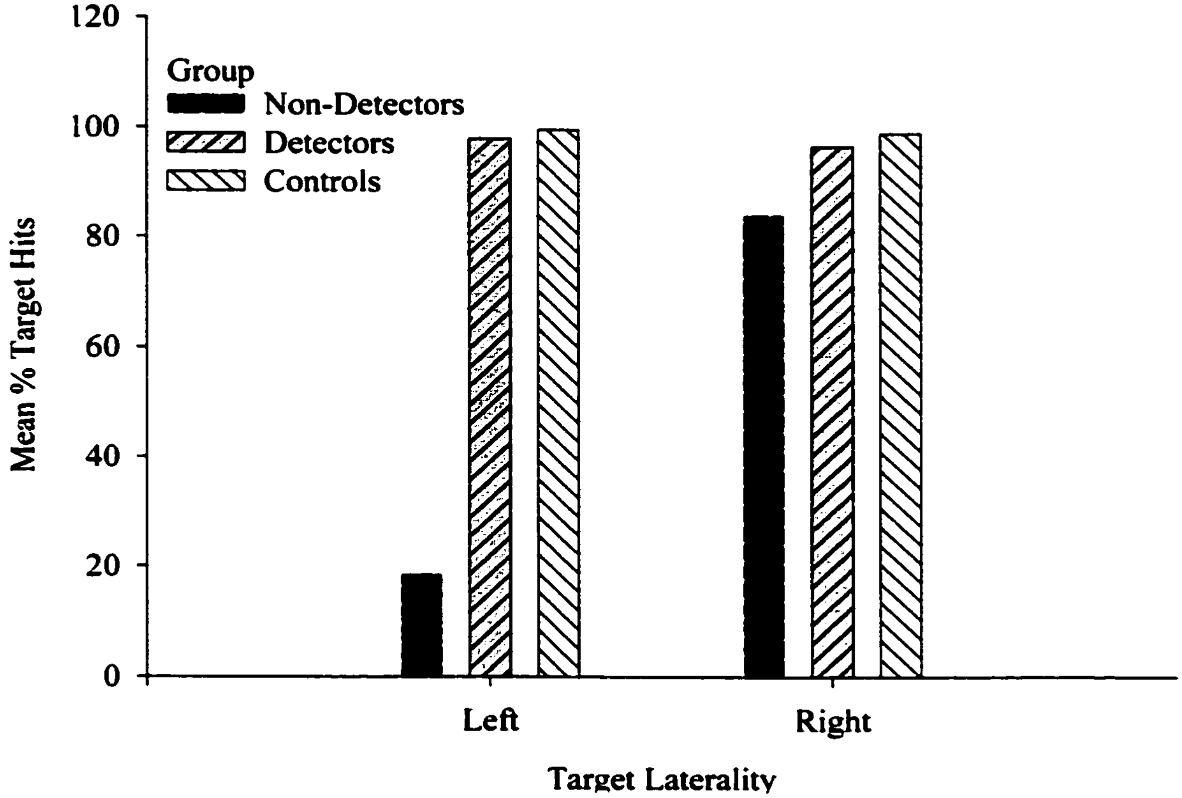
Prime Lat	ID	Congruent Condition (C)		Non-Congruent Condition (NC)		Diff Score (C - NC)	*t*	*df*	*p*
		M	*SD*	*M*	*SD*				
Right	201	6.2	24.92	3.2	14.29	3.0	0.46	34	.
	202	0.0	13.13	-1.9	8.75	1.9	0.54	40	.
	207	1.2	7.68	-1.6	10.43	2.8	1.02	43	.
	208	-3.9	8.09	-5.9	9.52	2.0	0.78	46	.
	209	-4.0	11.60	-9.0	10.84	5.0	1.59	49	.
	213	-1.4	10.16	-2.3	10.85	0.9	0.27	39	.
	214	-2.4	7.52	-5.3	7.80	2.9	1.29	45	.
	215	-1.5	10.60	0.9	1.06	-2.4	-1.10	46	.
	216	0.4	11.29	-1.3	8.69	1.7	0.57	42	.
	217	5.9	8.41	1.8	5.27	4.1	2.08	48	*
	218	0.0	10.97	-4.7	10.88	4.7	1.51	47	.
	219	-2.1	13.48	-5.1	13.96	3.0	0.67	36	.
	224	-2.4	7.86	-2.6	8.20	0.2	0.09	46	.
Left	201	-0.8	12.33	5.7	16.57	-6.5	-1.31	32	.
	202	1.3	15.74	-4.3	26.23	5.6	0.83	39	.
	207	1.6	9.46	-0.6	9.91	2.2	0.75	42	.
	208	1.5	9.56	-1.4	13.27	2.9	0.82	41	.
	209	-1.8	10.42	-4.4	9.07	2.6	0.86	40	.
	213	-5.8	9.61	-4.7	9.37	-1.1	-0.36	37	.
	214	-3.4	6.06	-4.8	7.42	1.4	0.70	43	.
	215	1.4	8.63	-2.1	8.16	3.5	1.32	38	.
	216	-3.0	8.10	-5.2	7.61	2.2	0.86	36	.
	217	1.5	7.51	-1.9	7.81	3.4	1.47	42	.
	218	-4.1	15.40	-6.7	12.57	2.6	0.62	43	.
	219	3.1	14.38	-10.2	10.60	13.3	2.90	30	*
	224	-3.2	8.94	-7.0	7.59	3.8	1.51	42	.

Note. Each centralized picture target depicted an exemplar of an animal or clothing and was preceded by a semantically congruent (C) or non-congruent (NC) picture prime that was lateralized to the left or right of central fixation. An asterisk (*) denotes 1-tailed statistical significance at $p \leq .05$.

Appendix F1. The Percentage of Target Hits on the Lateralized Oddball Paradigms of Experiment Two for the Patients with Left Visual Hemineglect (*N* = 10) and Age-Matched Controls (*N* = 13): The Group by Target Laterality Interaction.

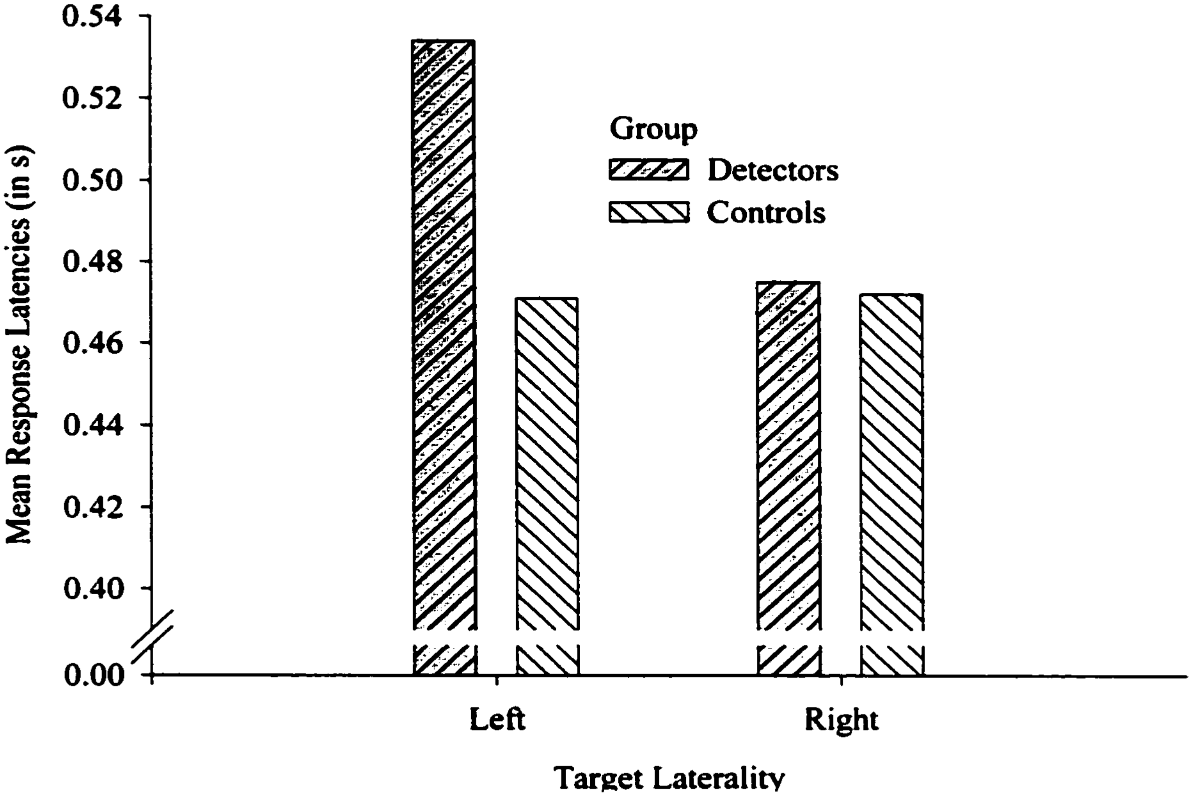


Appendix F2. Mean Percentage Accuracy and False Positive Scores on the Lateralized Oddball Paradigms of Experiment Two for the Two Subgroups of Patients with Left Visual Hemineglect and the Age-Matched Controls.



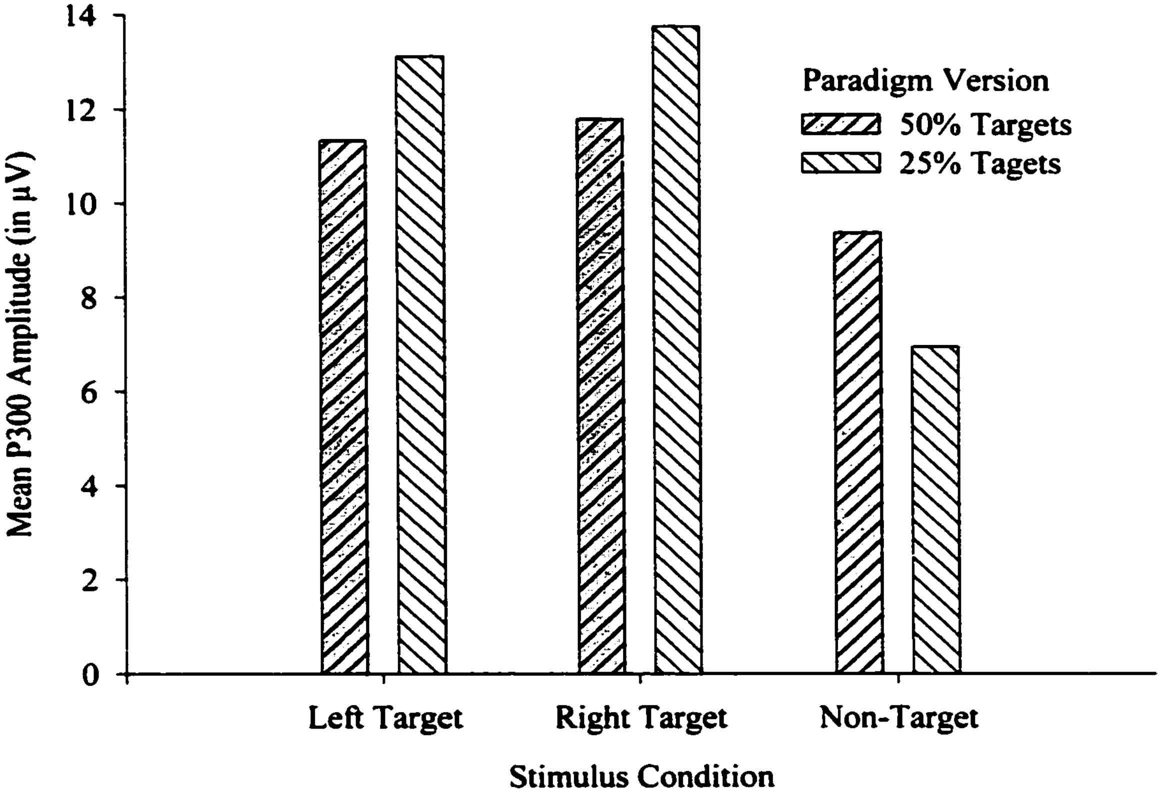
Note. For the patient subgroups, the Non-Detectors (*N* = 5) were the patients who omitted more left then right targets and the Detectors (*N* = 5) were patients who detected left and right targets. There were 13 controls.

Appendix F3. **The Mean Log_{10} Transformed Target Response Latencies from the Lateralized Semantic Priming Paradigm of Experiment Two for the Patients with Left Visual Hemineglect who Detected Left Targets (Detectors, *N* = 5) and the Age-Matched Controls (*N* = 13): The Group by Target Laterality Interaction.**



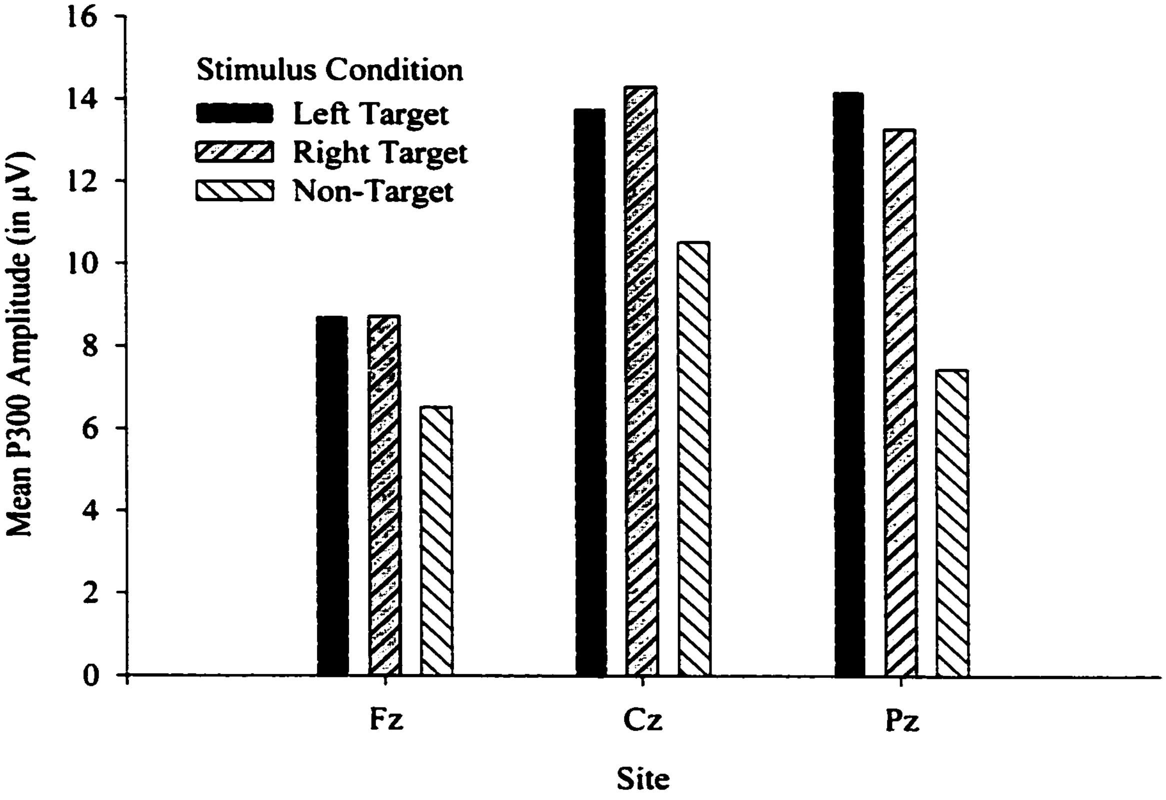
Note. The Detectors (*N* = 5) were the patients who detected left and right targets. They differed from the patients who omitted more left then right targets (Non-Detectors, *N* = 5).

Appendix F4. Preliminary Validation of the Lateralized Oddball Paradigms of Experiment Two Using ERPs from the Age-Matched Controls ($N = 13$): The P300 Amplitude (in μV) Paradigm Version by Stimulus Condition Interaction.

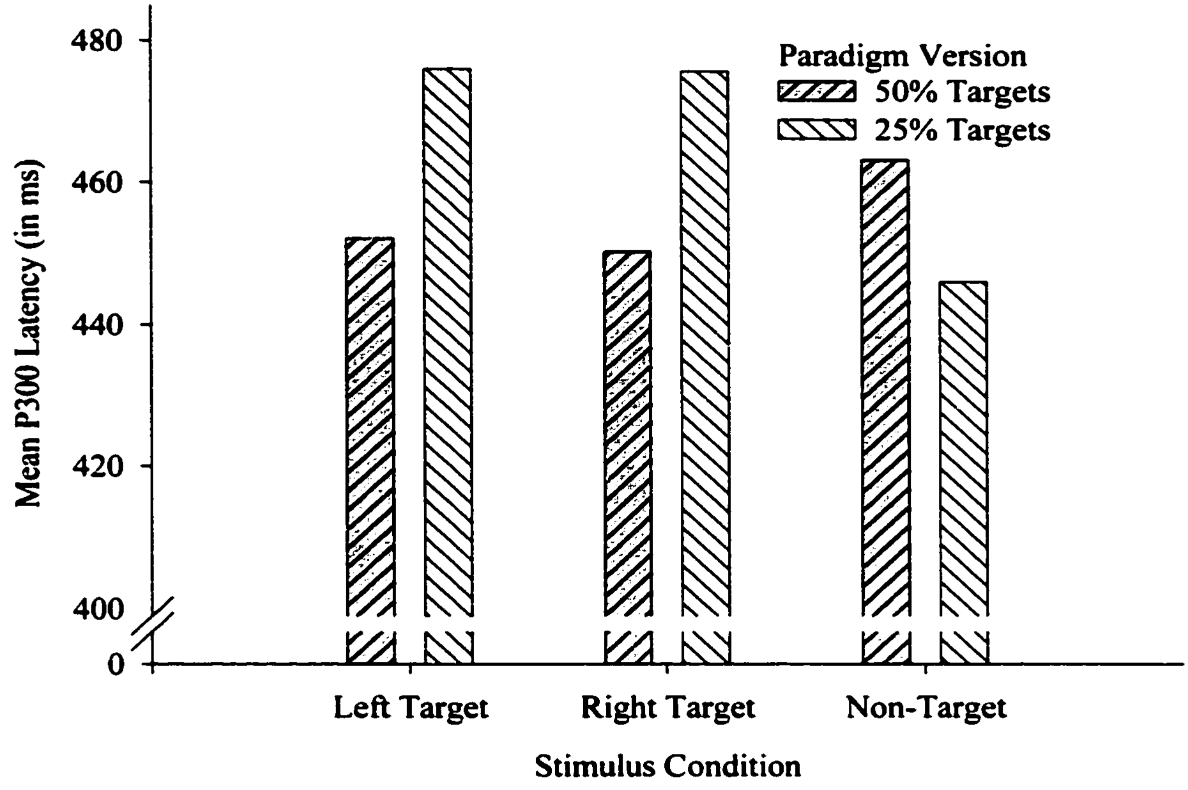


Note. The 50% Target Version = 25% Left Targets, 25% Right Targets, and 50% Non-Targets. The 25% Target Version = 12.5% Left Targets, 12.5% Right Targets, and 75% Non-Targets. Each version had a total of 200 randomised trials.

Appendix F5. Preliminary Validation of the Lateralized Oddball Paradigms of Experiment Two Using ERPs from the Age-Matched Controls (*N* = 13): The P300 Amplitude (in *μV*) Stimulus Condition by Recording Site Interaction.

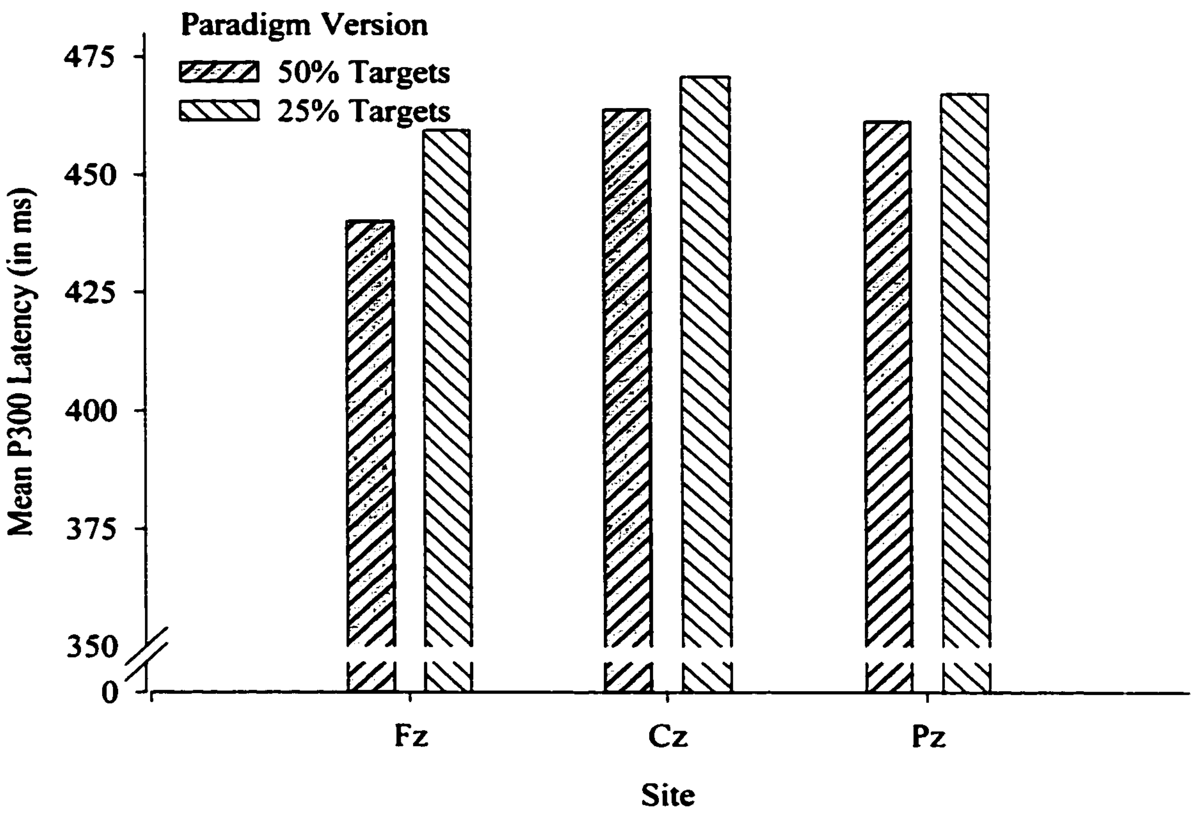


Appendix F6. Preliminary Validation of the Lateralized Oddball Paradigms of Experiment Two Using ERPs from the Age-Matched Controls (*N* = 13): The P300 Latency (in *ms*) Paradigm Version by Stimulus Condition Interaction.

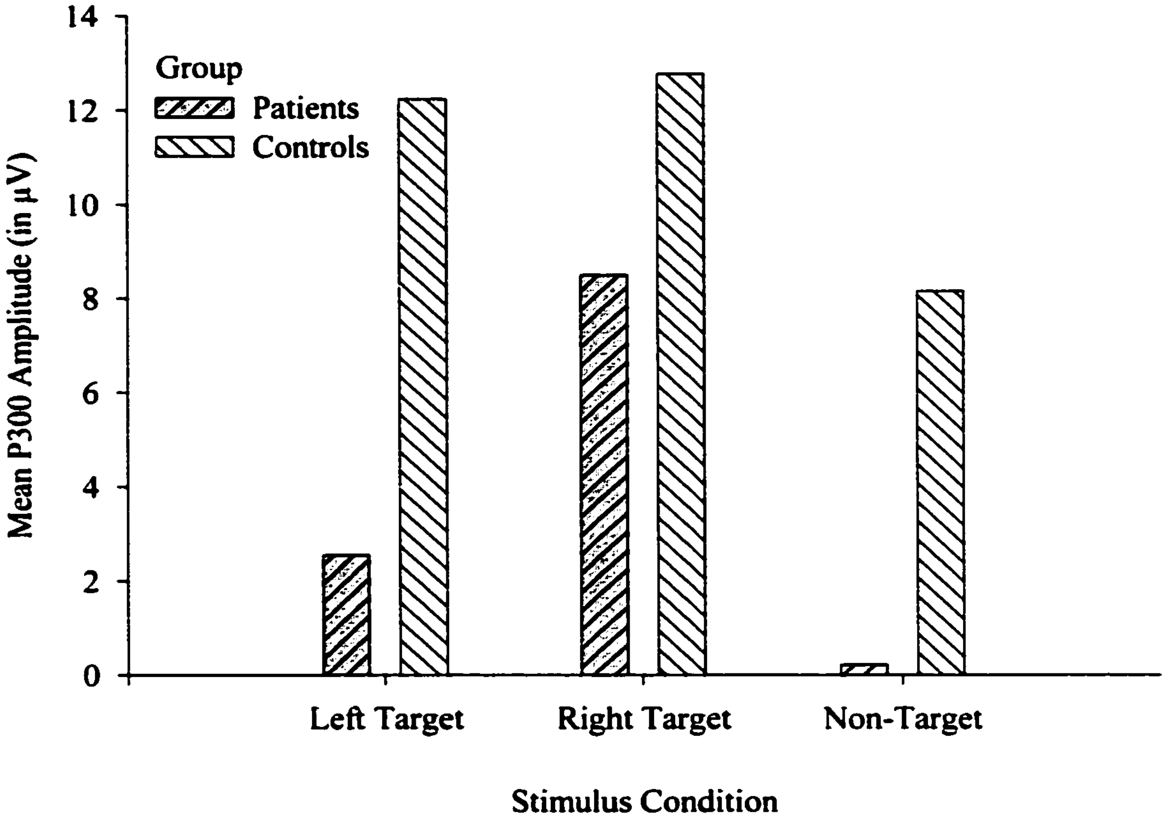


Note. The 50% Target Version = 25% Left Targets, 25% Right Targets, and 50% Non-Targets. The 25% Target Version = 12.5% Left Targets, 12.5% Right Targets, and 75% Non-Targets. Each version had a total of 200 randomised trials.

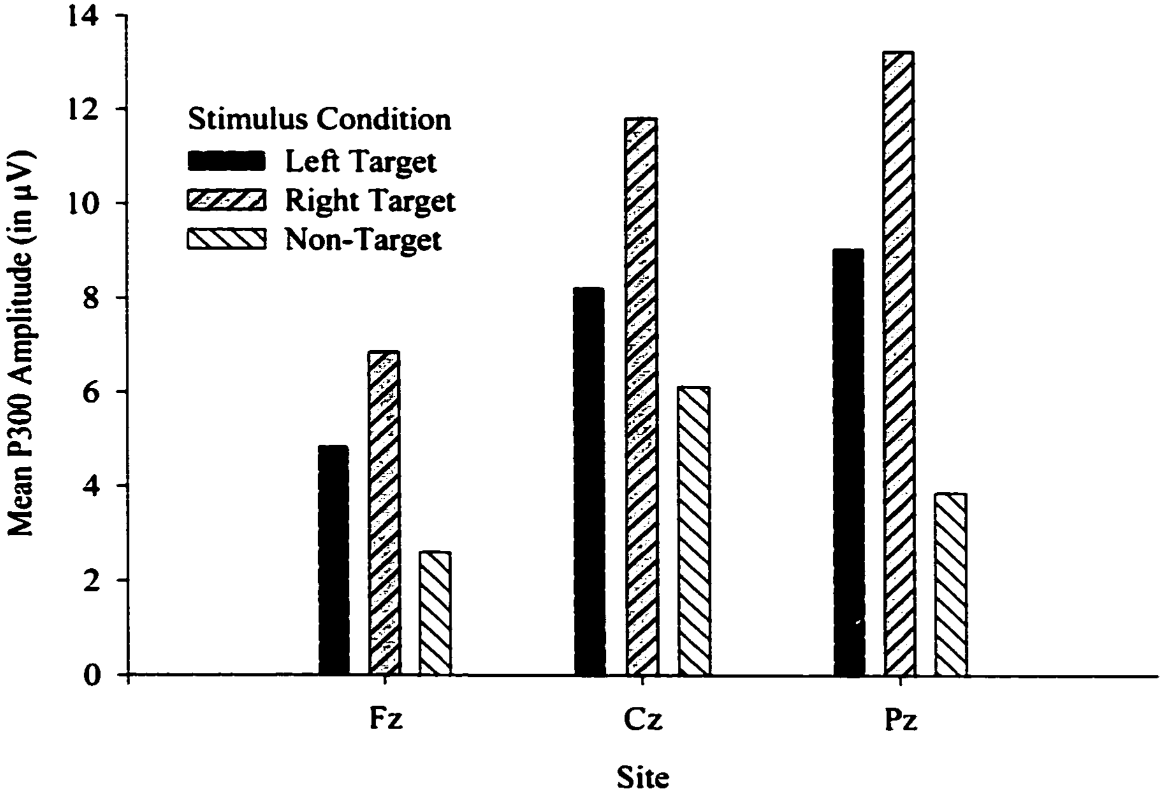
Appendix F7. Preliminary Validation of the Lateralized Oddball Paradigms of Experiment Two Using ERPs from the Age-Matched Controls (*N* = 13): The P300 Latency (in ms) Paradigm Version by Recording Site Interaction.



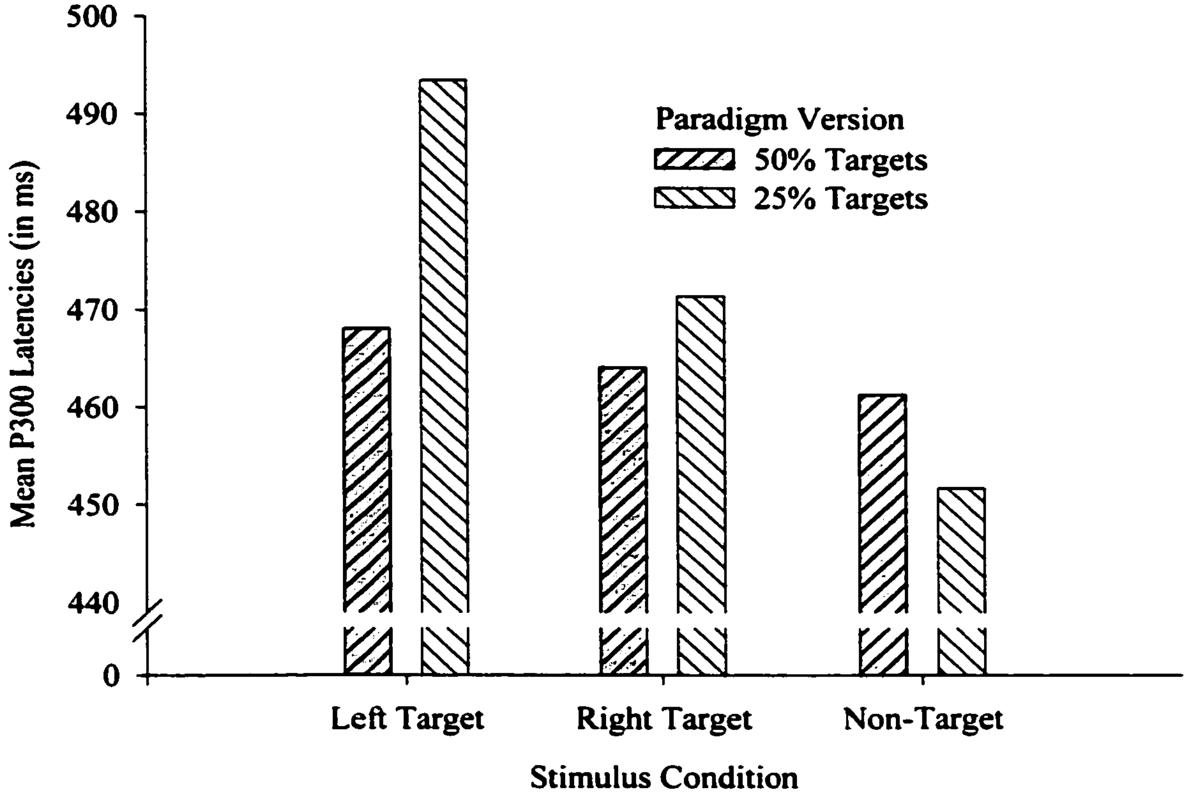
Appendix F8. Full Analysis of ERPs from Patients with Left Visual Hemineglect (N = 10) and Age-Matched Controls (N = 13) on the Lateralized Oddball Paradigms of Experiment Two: The P300 Amplitude (in μV) Group by Stimulus Condition Interaction.



Appendix F9. Full Analysis of ERPs from Patients with Left Visual Hemineglect (N = 10) and Age-Matched Controls (N = 13) on the Lateralized Oddball Paradigms of Experiment Two: The P300 Amplitude (in μV) Stimulus Condition by Recording Site Interaction.

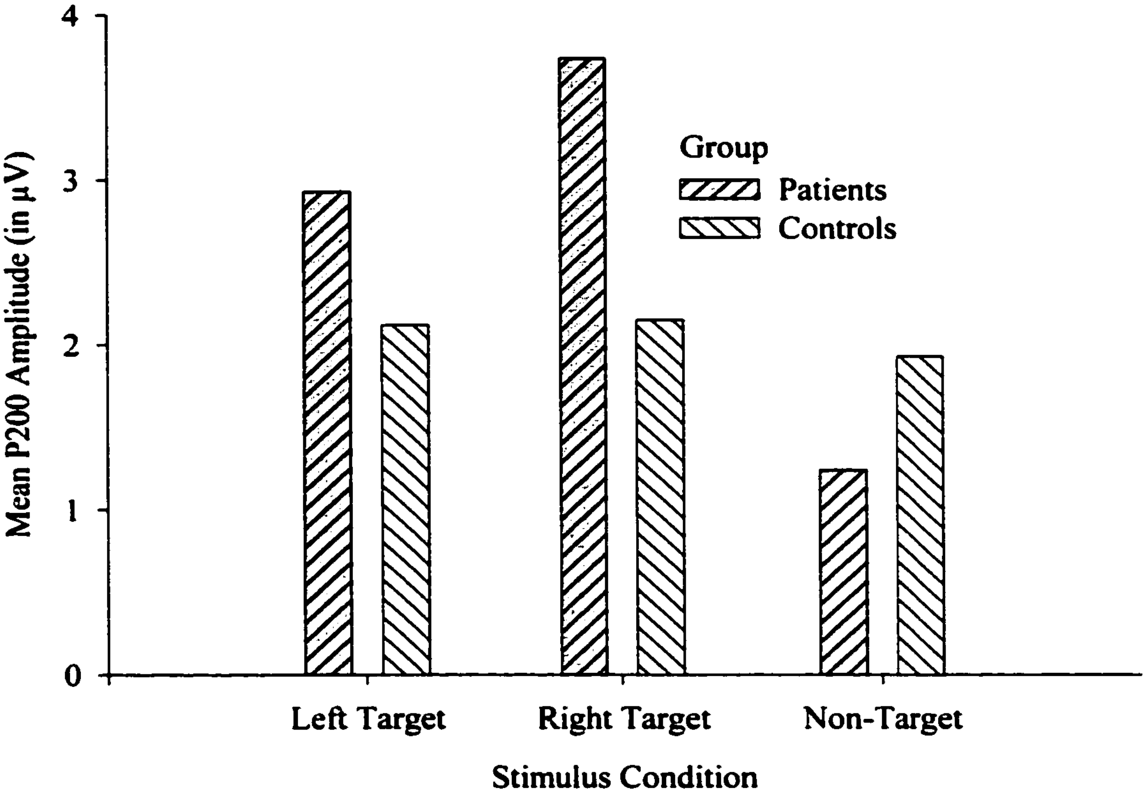


Appendix F10. Full Analysis of ERPs from Patients with Left Visual Hemineglect (N = 10) and Age-Matched Controls (N = 13) on the Lateralized Oddball Paradigms of Experiment Two: The P300 Latency (in *ms*) Paradigm Version by Stimulus Condition Interaction.

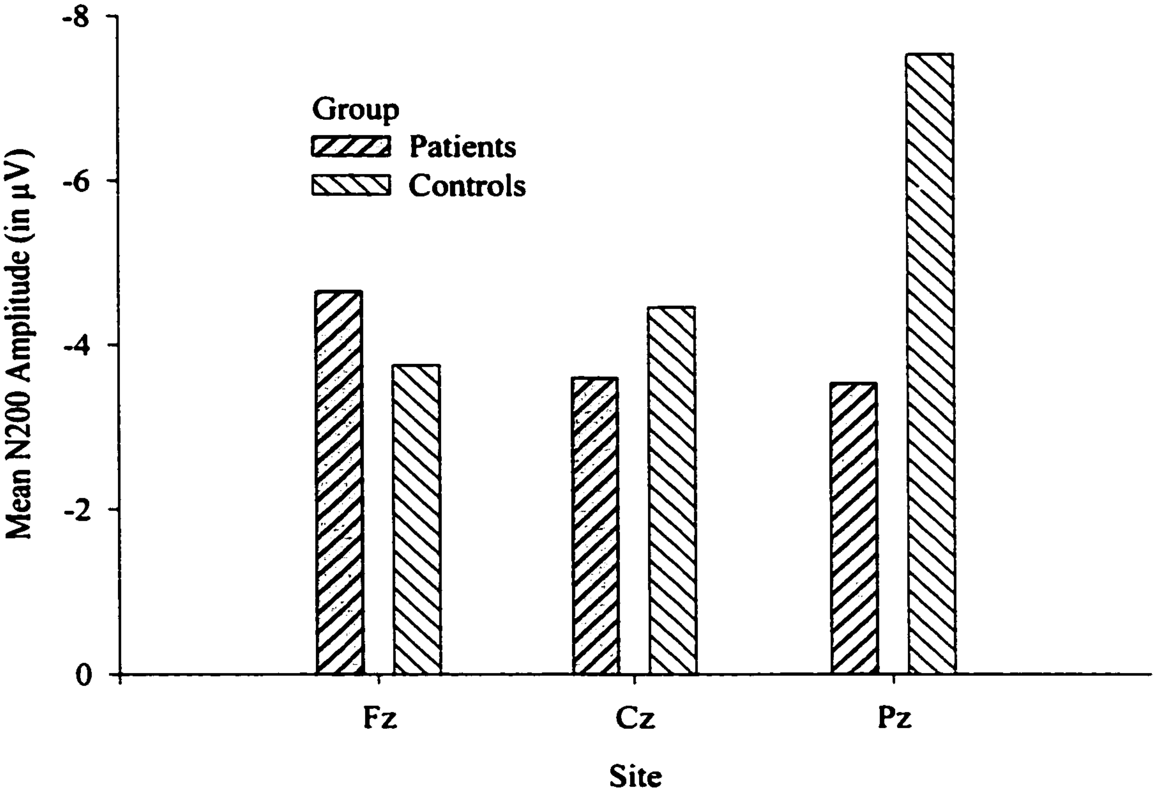


Note. The 50% Target Version = 25% Left Targets, 25% Right Targets, and 50% Non-Targets. The 25% Target Version = 12.5% Left Targets, 12.5% Right Targets, and 75% Non-Targets. Each version had a total of 200 randomised trials.

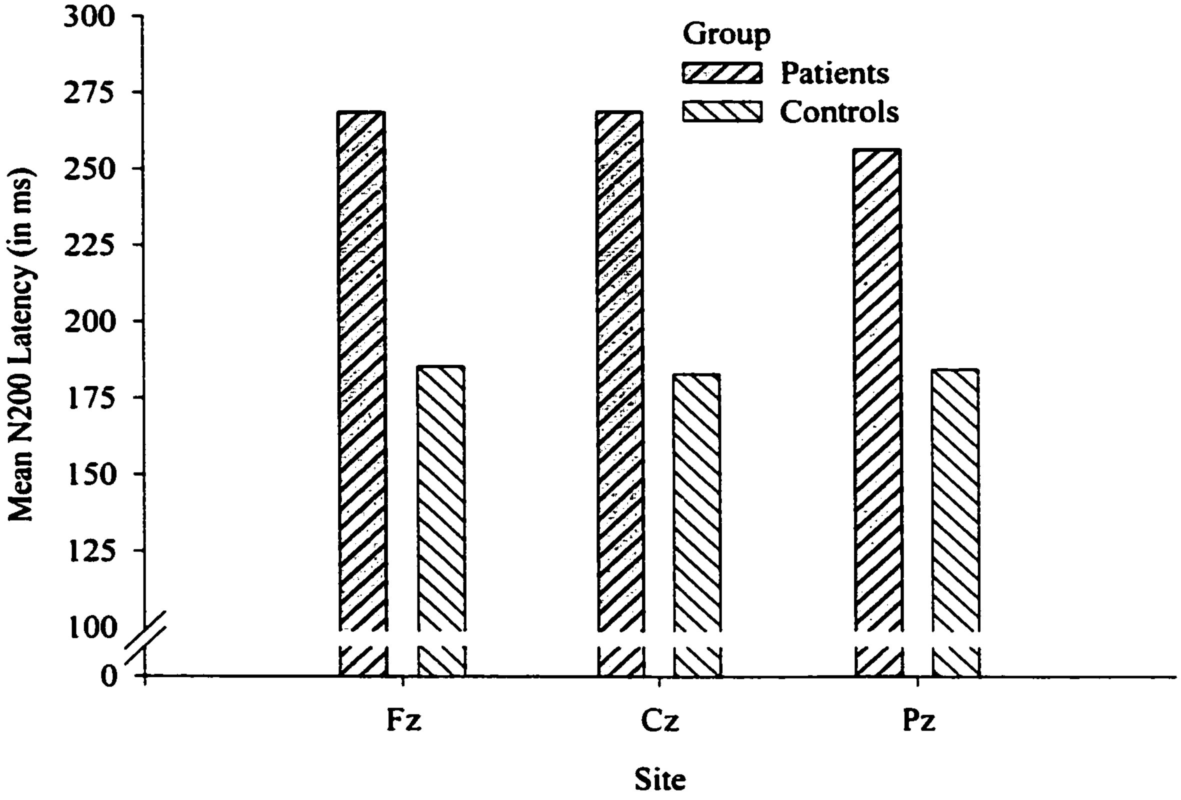
Appendix F11. Full Analysis of ERPs from Patients with Left Visual Hemineglect (*N* = 10) and Age-Matched Controls (*N* = 13) on the Lateralized Oddball Paradigms of Experiment Two: The P200 Amplitude (in μV) Group by Stimulus Condition Interaction.



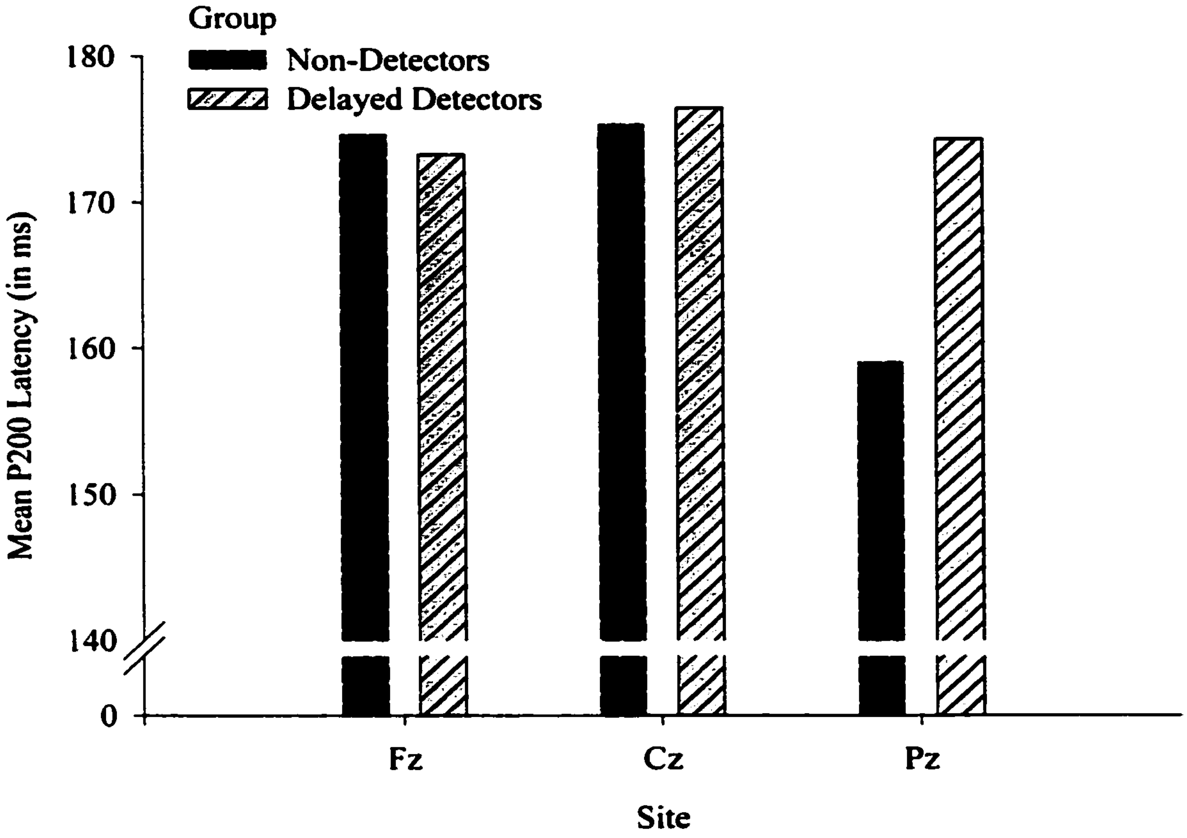
Appendix F12. Full Analysis of ERPs from Patients with Left Visual Hemineglect (*N* = 10) and Age-Matched Controls (*N* = 13) on the Lateralized Oddball Paradigms of Experiment Two: The N200 Amplitude (in *μV*) Group by Recording Site Interaction.



Appendix F13. Full Analysis of ERPs from Patients with Left Visual Hemineglect ($N = 10$) and Age-Matched Controls ($N = 13$) on the Lateralized Oddball Paradigms of Experiment Two: The N200 Latency (in *ms*) Group by Recording Site Interaction.

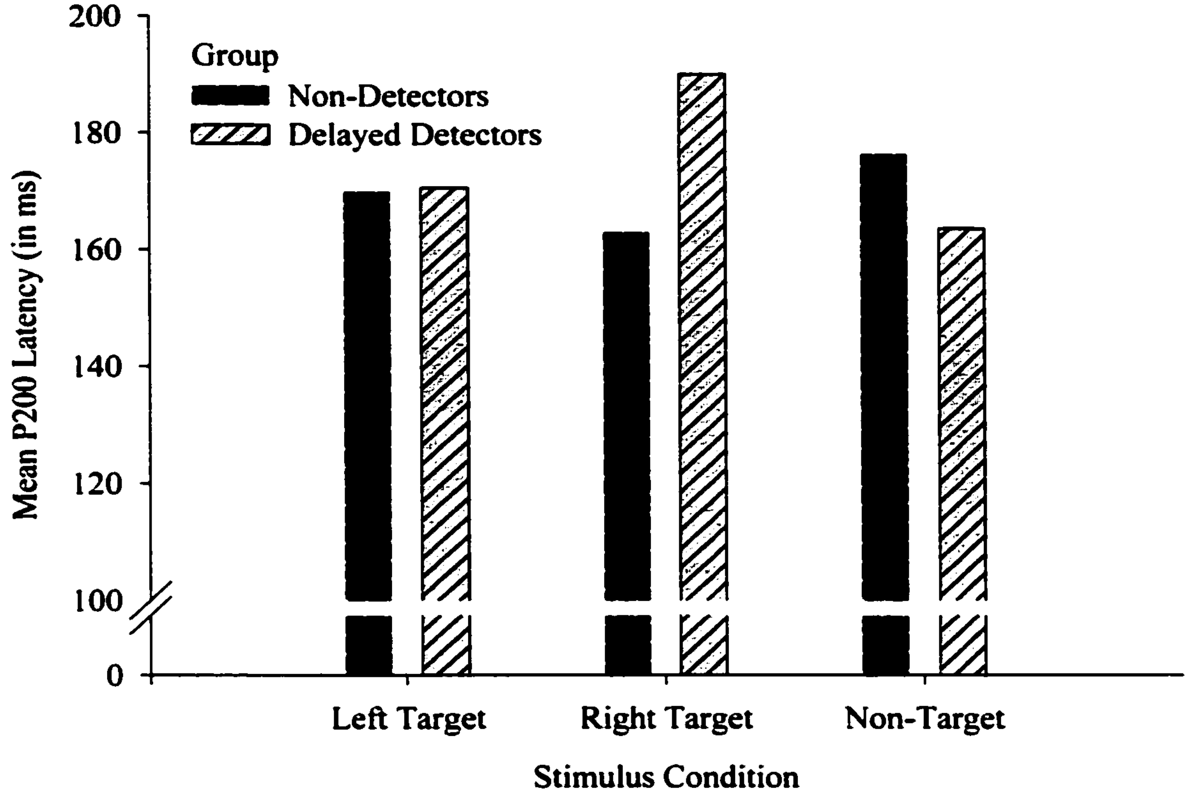


Appendix F14. Follow-up Analysis of ERPs from the two Subgroups of Patients with Left Visual Hemineglect on the Lateralized Oddball Paradigms of Experiment Two: The P200 Latency (in *ms*) Subgroup by Recording Site Interaction.



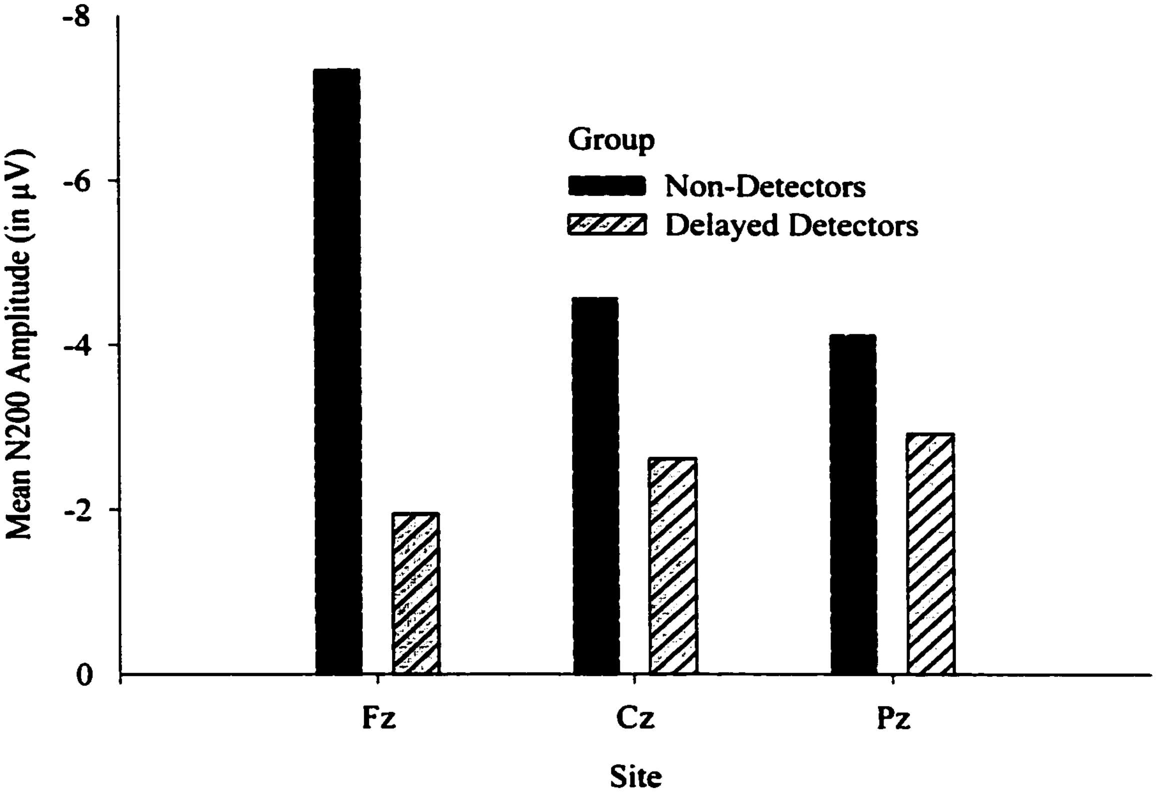
Note. Non-Detectors (*N* = 5) were patients who omitted more left then right targets. Delayed Detectors (*N* = 5) were patients who detected left targets more slowly than right targets.

Appendix F15. Follow-up Analysis of ERPs from the two Subgroups of Patients with Left Visual Hemineglect on the Lateralized Oddball Paradigms of Experiment Two: The P200 Latency (in *ms*) Subgroup by Stimulus Condition Interaction.



Note. Non-Detectors ($N = 5$) were patients who omitted more left then right targets. Delayed Detectors ($N = 5$) were patients who detected left targets more slowly than right targets.

Appendix F16. Follow-up Analysis of ERPs from the two Subgroups of Patients with Left Visual Hemineglect on the Lateralized Oddball Paradigms of Experiment Two: The N200 Amplitude (in μV) Subgroup by Recording Site Interaction.



Note. Non-Detectors ($N = 5$) were patients who omitted more left then right targets. Delayed Detectors ($N = 5$) were patients who detected left targets more slowly than right targets.

Appendix G1 (page 1). Individual Mean P300 Amplitude and Difference Scores (in μV) Elicited During the Lateralized Oddball Paradigms of Experiment Two for the Age-Matched Control's ($N = 13$).

Right Visual Field Stimuli Recorded at Fz.

Version / ID	Right Target Condition (RT)		Non-Target Condition (NT)		Diff Score (RT - NT)	*t*	*df*	*p*
	M	*SD*	*M*	*SD*	*M*			
50% Target Version								
201	8.5	20.2	15.1	13.9	-6.6	-2.12	122	
202	19.0	11.6	17.4	10.5	1.6	0.74	114	
207	3.6	18.2	3.0	16.6	0.6	0.18	110	
208	12.5	11.3	11.1	13.2	1.4	0.62	140	
209	14.7	11.0	12.1	11.4	2.6	1.22	118	
211	7.4	13.6	12.2	13.4	-4.8	-1.84	120	
213	5.3	10.4	8.2	9.0	-2.9	-1.61	116	
215	-0.1	12.5	-3.0	12.9	2.9	1.20	122	
216	1.7	12.0	-4.6	12.4	6.3	2.83	131	*
217	12.1	18.5	14.9	16.2	-2.8	-0.92	135	
218	-3.1	15.9	1.7	13.8	-4.8	-1.82	133	
219	2.4	15.0	4.4	18.9	-2.0	-0.57	113	
224	11.8	18.1	10.2	13.0	1.6	0.57	127	
25% Target Version								
201	9.0	12.9	11.4	14.8	-2.4	-0.71	161	
202	21.3	9.9	15.0	10.4	6.3	2.57	134	*
207	13.4	13.3	10.8	16.6	2.6	0.62	106	
208	13.6	18.7	6.8	14.3	6.8	1.94	159	*
209	22.2	14.6	10.0	13.9	12.2	3.48	149	*
211	7.0	12.3	5.8	14.5	1.2	0.37	125	
213	11.2	9.1	3.1	11.4	8.1	3.11	152	*
215	-1.1	12.5	-0.1	13.4	-1.0	-0.30	140	
216	23.0	9.3	8.1	11.2	14.9	6.02	157	*
217	11.9	7.9	6.1	7.6	5.8	3.25	162	*
218	-1.4	14.7	-6.3	13.6	4.9	1.52	151	
219	-9.4	11.5	-9.2	17.3	-0.2	-0.05	146	
224	10.4	8.3	5.1	12.1	5.3	2.02	149	*

Note. 50% Target Version = 25% LT, 25% RT, and 50% NT. 25% Target Version = 12.5% LT, 12.5% RT, and 75% NT. An asterick (*) denotes 1-tailed significance at $p \leq .05$.

Appendix G1 (page 2).

Left Visual Field Stimuli Recorded at Fz.

Version / ID	Left Target Condition (LT)		Non-Target Condition (NT)		Diff Score (LT - NT)	*t*	*df*	*p*
	M	*SD*	*M*	*SD*	*M*			
50% Target Version								
201	7.2	14.2	15.1	13.9	-7.9	-3.00	125	
202	18.3	10.3	17.4	10.5	0.9	0.43	112	
207	6.6	14.1	3.0	16.6	3.6	1.18	113	
208	12.4	12.7	11.1	13.2	1.3	0.56	142	
209	15.2	10.2	12.1	11.4	3.1	1.51	119	
211	8.4	10.4	12.2	13.4	-3.8	-1.56	120	
213	7.0	9.6	8.2	9.0	-1.2	-0.70	118	
215	0.4	13.5	-3.0	12.9	3.4	1.35	120	
216	-2.7	13.9	-4.6	12.4	1.9	0.81	131	
217	12.1	16.8	14.9	16.2	-2.8	-0.92	130	
218	-6.4	13.6	1.7	13.8	-8.1	-3.22	132	
219	1.9	20.4	4.4	19.0	-2.5	-0.67	116	
224	15.2	16.1	10.2	13.0	5.0	1.91	130	*
25% Target Version								
201	8.2	20.8	11.4	14.8	-3.2	-0.94	165	
202	20.6	12.6	15.0	10.4	5.6	2.15	133	*
207	18.0	16.0	10.8	16.7	7.2	1.41	100	
208	10.5	13.7	6.8	14.3	3.7	1.20.	163	
209	17.5	11.9	10.0	13.9	7.5	2.34	152	*
211	8.8	9.4	5.8	14.5	3.0	0.85	120	
213	7.8	9.2	3.1	11.4	4.7	1.95	156	*
215	0.8	7.1	-0.1	13.4	0.9	0.27	139	
216	20.0	17.1	8.1	11.2	11.9	4.32	157	*
217	10.6	8.2	6.1	7.8	4.5	2.61	164	*
218	-0.4	11.5	-6.3	13.6	5.9	1.96	153	*
219	-2.2	16.4	-9.2	17.3	7.0	1.73	146	*
224	10.6	7.3	5.1	12.1	5.5	2.03	147	*

Note. 50% Target Version = 25% LT, 25% RT, and 50% NT. 25% Target Version = 12.5% LT, 12.5% RT, and 75% NT. An asterick (*) denotes 1-tailed significance at $p \leq .05$.

Appendix G1 (page 3).

Right Visual Field Stimuli Recorded at Cz.

Version / ID	Right Target Condition (RT)		Non-Target Condition (NT)		Diff Score (RT - NT)	*t*	*df*	*p*
	M	*SD*	*M*	*SD*	*M*			
50% Target Version								
201	5.1	19.6	13.8	22.6	-8.7	-2.09	122	
202	21.6	11.1	19.9	11.6	1.7	0.75	114	
207	6.5	9.7	6.5	11.4	0.0	0.00	110	
208	9.2	13.8	8.2	12.2	1.0	0.44	140	
209	15.9	9.8	10.7	10.6	5.2	2.66	118	*
211	10.1	11.3	13.9	13.3	-3.8	-1.54	120	
213	11.0	10.3	7.2	9.1	3.8	2.10	116	*
215	8.2	11.9	1.3	12.8	6.9	2.91	122	*
216	10.5	10.3	5.1	11.4	5.4	2.70	131	*
217	30.9	17.1	27.0	14.3	3.9	1.43	135	
218	3.6	12.6	8.8	14.0	-5.2	-2.12	133	
219	17.4	14.3	14.6	15.9	2.8	0.92	113	
224	26.4	16.0	20.4	14.2	6.0	2.14	127	*
25% Target Version								
201	1.9	13.8	14.2	18.3	-12.3	-2.95	161	
202	26.9	9.6	16.8	11.0	10.1	3.95	134	*
207	13.2	9.5	6.8	8.7	6.4	2.81	106	*
208	16.2	14.8	6.7	12.7	9.5	3.14	159	*
209	23.8	17.7	10.6	12.0	13.2	4.11	149	*
211	8.6	11.4	6.2	11.6	2.4	0.90	125	
213	14.2	7.7	4.8	10.1	9.4	4.09	152	*
215	9.2	11.7	6.1	13.7	3.1	0.91	140	
216	24.3	9.4	8.5	11.8	15.8	6.09	157	*
217	26.7	6.0	18.5	7.7	8.2	4.79	162	*
218	4.2	16.5	2.2	13.7	2.0	0.61	151	
219	9.0	10.5	4.2	14.2	4.8	1.48	146	
224	17.4	10.8	10.8	13.5	6.6	2.22	149	*

Note. 50% Target Version = 25% LT, 25% RT, and 50% NT. 25% Target Version = 12.5% LT, 12.5% RT, and 75% NT. An asterick (*) denotes 1-tailed significance at $p \leq .05$.

Appendix G1 (page 4).

Left Visual Field Stimuli Recorded at Cz.

Version / ID	Left Target Condition (LT)		Non-Target Condition (NT)		Diff Score (LT - NT)	*t*	*df*	*p*
	M	*SD*	*M*	*SD*	*M*			
50% Target Version								
201	7.2	23.6	13.8	22.6	-6.6	-1.53	125	
202	19.0	11.8	19.9	11.6	-0.9	-0.38	112	
207	6.0	11.7	6.5	11.4	-0.5	-0.22	113	
208	12.8	9.1	8.2	12.2	4.6	2.30	142	*
209	17.2	9.4	10.7	10.6	6.5	3.40	119	*
211	9.1	12.4	13.9	13.3	-4.8	-1.89	120	
213	10.9	10.0	7.2	9.1	3.7	2.10	118	*
215	6.7	15.0	1.3	12.8	5.4	2.07	120	*
216	6.8	14.1	5.1	11.4	1.7	0.75	131	
217	29.1	16.6	27	14.3	2.1	0.75	130	
218	4.4	11.5	8.8	14.0	-4.4	-1.82	132	
219	15.8	17.7	14.6	15.9	1.2	0.38	116	
224	27.7	12.8	20.4	14.2	7.3	2.86	130	*
25% Target Version								
201	13.6	18.2	14.2	18.3	-0.6	-0.15	165	
202	19.4	11.1	16.8	11.0	2.6	0.98	133	
207	8.2	13.9	6.8	8.7	1.4	0.48	100	
208	9.6	13.2	6.7	12.7	2.9	1.05	163	
209	16.3	12.3	10.6	12.0	5.7	2.02	152	*
211	13.1	10.2	6.2	11.6	6.9	2.38	120	*
213	9.7	9.2	4.8	10.1	4.9	2.26	156	*
215	11.4	9.3	6.1	13.7	5.3	1.54	139	
216	17.8	13.6	8.5	11.8	9.3	3.42	157	*
217	26.8	9.4	18.5	7.7	8.3	4.74	164	*
218	8.2	12.9	2.2	13.7	6.0	1.96	153	*
219	17.0	15.8	4.2	14.2	12.8	3.76	146	*
224	14.5	9.6	10.8	13.5	3.7	1.21	147	

Note. 50% Target Version = 25% LT, 25% RT, and 50% NT. 25% Target Version = 12.5% LT, 12.5% RT, and 75% NT. An asterick (*) denotes 1-tailed significance at $p \leq .05$.

Appendix G1 (page 5).

Right Visual Field Stimuli Recorded at Pz.

Version / ID	Right Target Condition (RT)		Non-Target Condition (NT)		Diff Score (RT - NT)	*t*	*df*	*p*
	M	*SD*	*M*	*SD*	*M*			
50% Target Version								
201	18.4	17.3	9.4	14.7	9.0	3.02	122	*
202	25.0	21.4	16.7	15.4	8.3	2.39	114	*
207	7.2	12.2	3.0	12.5	4.2	1.71	110	*
208	7.0	11.4	3.8	12.0	3.2	1.51	140	
209	17.9	10.1	9.8	11.4	8.1	3.90	118	*
211	7.6	11.2	7.2	11.8	0.4	0.18	120	
213	16.6	10.7	4.2	9.8	12.4	6.45	116	*
215	7.5	10.8	-1.1	12.5	8.6	3.79	122	*
216	8.8	9.7	1.8	10.2	7.0	3.83	131	*
217	23.3	13.7	16.5	11.7	6.8	3.07	135	*
218	3.7	10.7	2.8	13.1	0.9	0.40	133	
219	18.3	18.4	14.1	19.2	4.2	1.12	113	
224	26.6	14.6	17.5	10.5	9.1	4.03	127	*
25% Target Version								
201	20.1	14.2	11.3	14.1	8.8	2.66	161	*
202	22.2	13.9	13.5	14.7	8.7	2.52	134	*
207	14.7	8.7	6.1	9.0	8.6	3.72	106	*
208	15.2	13.7	4.7	11.9	10.5	3.69	159	*
209	24.9	16.4	8.4	13.3	16.5	4.80	149	*
211	8.1	11.9	0.9	11.1	7.2	2.77	125	*
213	12.8	8.7	3.4	9.6	9.4	4.23	152	*
215	4.3	10.8	-0.3	10.5	4.6	1.74	140	*
216	20.7	8.7	7.4	10.9	13.3	5.54	157	*
217	27.5	5.4	12.1	7.0	15.4	9.89	162	*
218	6.2	13.0	1.6	12.6	4.6	1.55	151	
219	10.3	11.5	4.7	19.4	5.6	1.28	146	
224	22.8	11.8	14.2	10.3	8.6	3.61	149	*

Note. 50% Target Version = 25% LT, 25% RT, and 50% NT. 25% Target Version = 12.5% LT, 12.5% RT, and 75% NT. An asterick (*) denotes 1-tailed significance at $p \leq .05$.

Appendix G1 (page 6).

Left Visual Field Stimuli Recorded at Pz.

Version / ID	Left Target Condition (LT)		Non-Target Condition (NT)		Diff Score (LT-NT)	*t*	*df*	*p*
	M	*SD*	*M*	*SD*	*M*			
50% Target Version								
201	16.6	20.1	9.4	14.7	7.2	2.30	125	*
202	19.5	16.6	16.7	15.4	2.8	0.88	112	
207	5.1	9.9	3.0	12.5	2.1	0.93	113	
208	10.0	10.6	3.8	12.0	6.2	3.04	142	*
209	19.4	11.2	9.8	11.4	9.6	4.50	119	*
211	8.8	11.2	7.2	11.8	1.6	0.71	120	
213	15.4	10.4	4.2	9.8	11.2	5.97	118	*
215	4.9	10.9	-1.1	12.5	6.0	2.59	120	*
216	7.9	12.9	1.8	10.2	6.1	2.99	131	*
217	22.3	10.7	16.5	11.7	5.8	2.76	130	*
218	4.7	9.5	2.8	13.1	1.9	0.87	132	
219	11.3	24.5	14.1	19.2	-2.8	-0.69	116	
224	28.0	9.9	17.5	10.5	10.5	5.50	130	*
25% Target Version								
201	21.4	15.8	11.3	14.1	10.1	3.23	165	*
202	18.4	18.2	13.5	14.7	4.9	1.33	133	
207	8.7	11.8	6.1	9.0	2.6	0.99	100	
208	8.0	13.2	4.7	11.9	3.3	1.25	163	
209	17.2	11.7	8.4	13.3	8.8	2.86	152	*
211	11.7	10.8	0.9	11.1	10.8	3.82	120	*
213	11.8	8.6	3.4	9.6	8.4	4.09	156	*
215	8.9	8.0	-0.3	10.5	9.2	3.49	139	*
216	16.9	9.8	7.4	10.9	9.5	3.91	157	*
217	26.4	7.2	12.1	7.0	14.3	9.24	164	*
218	9.4	11.3	1.6	12.6	7.8	2.78	153	*
219	15.5	26.9	4.7	19.4	10.8	2.23	146	*
224	20.9	9.8	14.2	10.3	6.7	2.78	147	*

Note. 50% Target Version = 25% LT, 25% RT, and 50% NT. 25% Target Version = 12.5% LT, 12.5% RT, and 75% NT. An asterick (*) denotes 1-tailed significance at $p \leq .05$.

Appendix G2 (page1). Individual Mean P300 Amplitude and Difference Scores (in μV) Elicited During the Lateralized Oddball Paradigms of Experiment Two for the Patients with Left Visual Hemineglect (N = 10).

Right Visual Field Stimuli Recorded at Fz.

Version / ID	Right Target Condition (RT)		Non-Target Condition (NT)		Diff Score (RT - NT)	*t*	*df*	*p*
	M	*SD*	*M*	*SD*	*M*			
50% Target Version								
Non-Detector (*n*=5)								
105	4.0	22.4	1.6	23.5	2.4	0.46	93	
107	6.1	10.5	4.6	19.0	1.5	0.37	106	
112	4.6	19.8	4.2	18.7	0.4	0.12	131	
113	-12.0	40.8	-15.1	25.3	3.1	0.49	107	
114	-11.1	22.9	-14.6	21.6	3.5	0.62	71	
Delayed Detector (*n*=5)								
101	7.0	10.6	4.3	8.9	2.7	0.95	45	
103	7.5	11.8	5.3	11.6	2.2	1.02	129	
109	36.6	12.3	-5.0	26.0	41.6	8.97	105	*
110	9.3	8.6	1.6	8.3	7.7	4.95	124	*
116	-12.1	32.2	-7.7	25.0	-4.4	-0.86	129	
25% Target Version								
Non-Detector (*n*=5)								
105	1.5	20.1	-1.4	17.7	2.9	0.70	154	
107	13.1	16.2	3.1	19.8	10.0	1.56	135	
112	12.1	23.1	2.6	19.7	9.5	2.08	131	*
113	-3.3	42.3	-16.7	32.7	13.4	1.42	109	
114	5.1	20.5	-9.0	16.8	14.1	2.85	106	*
Delayed Detector (*n*=5)								
101	7.8	6.1	7.2	10.1	0.6	0.21	109	
103	0.3	13.2	4.1	10.1	-3.8	-1.53	153	
109	16.7	10.3	5.9	17.5	10.8	2.32	101	*
110	7.4	8.5	0.0	8.3	7.4	3.8	154	*
116	-1.2	22.6	-1.2	23.6	0.0	0.0	152	

Note. 50% Target Version = 25% LT, 25% RT, and 50% NT. 25% Target Version = 12.5% LT, 12.5% RT, and 75% NT. Non-Detector = patient who *omitted* LTs. Delayed Detector = patient who detected LTs *more slowly* than RTs. An asterisk (*) denotes 1-tailed statistical significance at $p \leq .05$.

Appendix G2 (page 2).

Left Visual Field Stimuli Recorded at Fz.

Version / ID	Left Target Condition (LT)		Non-Target Condition (NT)		Diff Score (LT - NT)	*t*	*df*	*p*
	M	*SD*	*M*	*SD*	*M*			
50% Target Version								
Non-Detector (*n*=5)								
105	9.0	24.7	1.6	23.9	7.4	1.40	94	
107	12.1	20.9	4.6	19.0	7.5	1.49	100	
112	2.1	17.5	4.2	18.7	-2.1	-0.42	101	
113	-16.3	29.6	-15.1	25.3	-1.2	-0.23	113	
114	-7.8	32.1	-14.6	21.6	6.8	1.07	72	
Delayed Detector (*n*=5)								
101	7.9	8.0	4.3	8.9	3.6	1.24	38	
103	2.6	10.4	5.3	11.6	-2.7	-1.33	132	
109	-4.0	29.4	-5.0	26.0	1.0	0.18	105	
110	3.6	8.4	1.6	8.3	2.0	1.24	118	
116	-3.2	26.5	-7.7	25.0	4.5	0.95	130	
25% Target Version								
Non-Detector (*n*=5)								
105	5.2	28.0	-1.4	17.7	6.6	1.48	154	
107	10.9	11.8	3.1	19.8	7.8	1.23	135	
112	2.5	25.4	2.6	19.7	-0.1	-0.02	129	
113	-4.2	33.7	-16.7	32.7	12.5	1.41	110	
114	-11.9	23.7	-9.0	16.8	-2.9	-0.57	106	
Delayed Detector (*n*=5)								
101	3.1	11.5	7.2	10.1	-4.1	-1.26	107	
103	1.0	9.6	4.1	10.1	-3.1	-1.31	153	
109	16.9	15.3	5.9	17.5	11.0	2.29	101	*
110	2.3	8.1	0.0	8.3	2.3	1.19	154	
116	-11.4	17.5	-1.2	23.6	-10.2	-2.02	152	

Note. 50% Target Version = 25% LT, 25% RT, and 50% NT. 25% Target Version = 12.5% LT, 12.5% RT, and 75% NT. Non-Detector = patient who *omitted* LTs. Delayed Detector = patient who detected LTs *more slowly* than RTs. An asterisk (*) denotes 1-tailed statistical significance at $p \leq .05$.

Appendix G2 (page3).

Right Visual Field Stimuli Recorded at Cz.

Version / ID	Right Target Condition (RT)		Non-Target Condition (NT)		Diff Score (RT - NT)	*t*	*df*	*p*
	M	*SD*	*M*	*SD*	*M*			
50% Target Version								
Non-Detector (*n*=5)								
105	10.7	26.1	7.8	32.2	2.9	0.43	93	
107	5.9	16.1	6.3	17.3	-0.4	-0.10	106	
112	2.2	18.6	3.0	22.3	-0.8	-0.21	131	
113	7.2	27.0	1.0	26.1	6.2	1.14	107	
114	-3.6	8.0	-16.8	18.6	13.2	3.35	79	*
Delayed Detector (*n*=5)								
101	7.0	18.1	4.3	16.3	2.7	0.54	45	
103	7.5	9.6	5.3	10.4	2.2	1.17	129	
109	36.6	13.5	-5.0	27.5	41.6	8.40	105	*
110	9.3	9.9	1.6	10.3	7.7	4.09	124	*
116	-12.1	29.9	-7.7	25.0	-4.4	-0.88	129	
25% Target Version								
Non-Detector (*n*=5)								
105	10.4	18.7	2.8	21.3	7.6	1.58	154	
107	5.6	20.3	5.5	17.6	0.1	0.02	135	
112	7.9	22.2	3.8	23.5	4.1	0.78	131	
113	19.7	37.4	-3.9	29.4	23.6	2.78	109	*
114	19.3	19.6	0.7	15.6	18.6	4.02	106	*
Delayed Detector (*n*=5)								
101	7.8	7.6	7.2	11.2	0.6	0.19	109	
103	0.3	10.5	4.1	9.1	-3.8	-1.74	153	
109	16.7	11.6	5.9	16.4	10.8	2.44	101	*
110	7.4	10.3	0.0	9.3	7.4	3.33	154	*
116	-1.2	21.9	-1.2	20.4	0.0	0.00	152	

Note. 50% Target Version = 25% LT, 25% RT, and 50% NT. 25% Target Version = 12.5% LT, 12.5% RT, and 75% NT. Non-Detector = patient who *omitted* LTs. Delayed Detector = patient who detected LTs *more slowly* than RTs. An asterisk (*) denotes 1-tailed statistical significance at $p \leq .05$.

Appendix G2 (page 4).

Left Visual Field Siimuli Recorded at Cz.

Version / ID	Left Target Condition (LT)		Non-Target Condition (NT)		Diff Score (LT - NT)	*t*	*df*	*p*
	M	*SD*	*M*	*SD*	*M*			
50% Target Version								
Non-Detector (*n*=5)								
105	9.0	23.3	7.8	32.2	1.2	0.19	94	
107	9.8	21.2	6.3	17.3	3.5	0.75	100	
112	4.3	20.0	3.0	22.3	1.3	0.22	101	
113	-0.6	34.9	1.0	26.1	-1.6	-0.28	113	
114	-2.0	26.6	-16.8	18.6	14.8	2.87	79	*
Delayed Detector (*n*=5)								
101	7.9	21.1	4.3	16.3	3.6	0.59	38	
103	2.6	8.6	5.3	10.4	-2.7	-1.52	132	
109	-4.0	28.4	-5.0	27.7	1.0	0.17	105	
110	3.6	10.0	1.6	10.3	2.0	1.01	118	
116	-3.2	22.4	-7.7	25.0	4.5	1.00	130	
25% Target Version								
Non-Detector (*n*=5)								
105	7.0	25.8	2.8	21.3	4.2	0.83	154	
107	3.8	13.3	5.5	17.6	-1.7	-0.30	135	
112	3.5	27.9	3.8	23.5	-0.3	-0.05	129	
113	8.5	34.8	-3.9	29.4	12.4	1.52	110	
114	3.5	15.7	0.7	15.6	2.8	0.63	106	
Delayed Detector (*n*=5)								
101	3.1	13.9	7.2	11.2	-4.1	-1.13	107	
103	1.0	7.9	4.1	9.1	-3.1	-1.47	153	
109	16.9	13.8	5.9	16.4	11.0	2.45	101	*
110	2.3	11.0	0.0	9.3	2.3	1.03	154	
116	-11.4	17.1	-1.2	20.4	-10.2	-2.30	152	

Note. 50% Target Version = 25% LT, 25% RT, and 50% NT. 25% Target Version = 12.5% LT, 12.5% RT, and 75% NT. Non-Detector = patient who *omitted* LTs. Delayed Detector = patient who detected LTs *more slowly* than RTs. An asterisk (*) denotes 1-tailed statistical significance at $p \leq .05$.

Appendix G2 (page 5).

Right Visual Field Stimuli Recorded at Pz.

Version / ID	Right Target Condition (RT)		Non-Target Condition (NT)		Diff Score (RT-NT)	*t*	*df*	*p*
	M	*SD*	*M*	*SD*	*M*			
50% Target Version								
Non-Detector (*n*=5)								
105	3.0	26.1	0.4	27.8	2.6	0.43	93	
107	8.3	20.5	5.1	17.0	3.2	0.78	106	
112	11.7	19.9	5.3	19.7	6.4	1.78	131	*
113	7.8	34.5	-4.4	29.3	12.2	1.90	107	*
114	8.2	21.4	-4.4	21.1	12.6	2.21	59	*
Delayed Detector (*n*=5)								
101	12.1	38.1	0.6	27.7	11.5	1.20	45	
103	10.8	10.8	1.8	13.1	9.0	3.94	129	*
109	41.0	18.6	-2.1	26.9	43.1	8.52	105	*
110	13.8	8.8	1.7	12.1	12.1	5.95	124	*
116	-17.7	33.3	-24.4	24.0	6.7	0.93	62	
25% Target Version								
Non-Detector (*n*=5)								
105	15.6	19.3	5.5	23.1	10.1	1.94	154	*
107	8.0	22.9	5.3	19.3	2.7	0.42	135	
112	9.3	21.5	3.2	21.4	6.1	1.26	131	
113	18.0	30.4	-4.9	29.4	22.9	2.80	109	*
114	13.8	19.6	-7.6	16.5	21.4	4.81	113	*
Delayed Detector (*n*=5)								
101	5.3	11.3	3.3	14.4	2.0	0.48	109	
103	10.7	6.8	4.4	9.5	6.3	2.93	153	*
109	13.5	10.3	8.5	16.5	5.0	1.13	101	
110	12.8	9.6	0.5	10.5	12.3	5.06	154	*
116	18.3	21.6	7.5	18.8	10.8	2.52	152	*

Note. 50% Target Version = 25% LT, 25% RT, and 50% NT. 25% Target Version = 12.5% LT, 12.5% RT, and 75% NT. Non-Detector = patient who *omitted* LTs. Delayed Detector = patient who detected LTs *more slowly* than RTs. An asterisk (*) denotes 1-tailed statistical significance at $p \leq .05$.

Appendix G2 (page 6)

Left Visual Field Stimuli Recorded at Pz.

Version / ID	Left Target Condition (LT)		Non-Target Condition (NT)		Diff Score (LT - NT)	*t*	*df*	*p*
	M	*SD*	*M*	*SD*	*M*			
50% Target Version								
Non-Detector (*n*=5)								
105	5.0	30.0	0.4	27.8	4.6	0.74	94	
107	10.6	20.3	5.1	17.0	5.5	1.20	100	
112	6.8	20.8	5.3	19.7	1.5	0.28	101	
113	-1.1	37.1	-4.4	29.3	3.3	0.52	113	
114	-20.3	17.5	-4.4	21.1	-15.9	-2.67	54	
Delayed Detector (*n*=5)								
101	-8.5	29.4	0.6	27.7	-9.1	-0.96	38	
103	9.8	12.0	1.8	13.1	8.0	3.48	132	*
109	-1.4	28.5	-2.1	26.9	0.7	0.12	105	
110	5.8	11.0	1.7	12.1	4.1	1.81	118	*
116	3.2	22.0	-24.4	24.0	27.6	4.39	59	*
25% Target Version								
Non-Detector (*n*=5)								
105	10.5	23.4	5.5	23.1	5.0	0.94	154	
107	2.7	17.2	5.3	19.3	-2.6	-0.41	135	
112	4.7	25.3	3.2	21.4	1.5	0.29	129	
113	11.6	36.6	-4.9	29.3	16.5	2.01	110	*
114	-13.3	30.1	-7.6	16.5	-5.7	-1.10	111	
Delayed Detector (*n*=5)								
101	2.3	17.2	3.3	14.4	-1.0	-0.21	107	
103	10.4	8.4	4.4	9.5	6.0	2.74	153	*
109	20.8	11.9	8.5	16.5	12.3	2.76	101	*
110	8.9	12.0	0.5	10.5	8.4	3.35	154	*
116	10.4	15.7	7.5	18.8	2.9	0.71	152	

Note. 50% Target Version = 25% LT, 25% RT, and 50% NT. 25% Target Version = 12.5% LT, 12.5% RT, and 75% NT. Non-Detector = patient who *omitted* LTs. Delayed Detector = patient who detected LTs *more slowly* than RTs. An asterisk (*) denotes 1-tailed statistical significance at $p \leq .05$.

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