THE EFFECT OF LIMB MOVEMENTS ON THE ORIENTING OF ATTENTION AFTER RIGHT HEMISPHERE STROKE

by

Beverly C. Butler

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy

at

Dalhousie University
Halifax, Nova Scotia
August 2006

Your file Votre référence
ISBN: 978-0-494-19585-7
Our file Notre référence
ISBN: 978-0-494-19585-7

DALHOUSIE UNIVERSITY

To comply with the Canadian Privacy Act the National Library of Canada has requested that the following pages be removed from this copy of the thesis:

Preliminary Pages

Examiners Signature Page (pii)

Dalhousie Library Copyright Agreement (piii)

Appendices

Copyright Releases (if applicable)

To My Family…

For their endless support

TABLE OF CONTENTS

List of Tables

List of Figures

List of Figures (cont.)

ABSTRACT

Orienting visual attention involves disengaging attention from its current focus, moving it, and engaging it at a new location. A deficit in disengaging attention from the ipsilesional (right) space in order to re-orient toward the contralesional (left) space occurs after right-hemisphere stroke and has been related to the severity of visuospatial neglect. Active and passive left limb movements in left hemispace improve visual scanning and reduce rightward bias on visual extinction and line bisection tasks in individuals with neglect, but the effect of limb movements on the disengage mechanism underlying covert orienting of attention is unknown. Orienting was assessed with no limb movement and after unilateral active and passive limb movements in groups of younger (n=20) and older (n=20) healthy adults and in right-hemisphere stroke patients with (n=3) and without (n=13) neglect. It was hypothesized that left limb movements would reduce the disengage deficit in some right-hemisphere stroke patients by decreasing reaction time to detect left targets after a right exogenous spatial cue. Results showed no effect of limb movement on covert visuospatial orienting in healthy young adults but active limb movements reduced cueing effects in healthy older adults. A disengage deficit in orienting was observed after right-hemisphere stroke that was related in size to neglect severity. As hypothesized, left limb movement reduced the disengage deficit in one neglect participant with a severe disengage deficit. Left limb movements, however, had little effect on orienting in individual neglect participants with a spatial attention bias (i.e., slower overall left target detection, n=2), a mild-to-moderate disengage deficit (n=2) or no disengage deficit (n=11). The left limb movement effect on orienting was restricted to a neglect participant with ventral fronto-parietal orienting network damage and spared superior parietal lobe and subcortical structures involved in right-hemisphere attention and motor pathways. The efficacy of contralesional limb activation in ameliorating orienting deficits in spatial neglect may be dependent upon the presence of a severe disengage deficit and the availability of neural resources in attentional and motor pathways that are capable of facilitating activation in the orienting network and re-balancing neural activity between the two hemispheres.

ACKNOWLEDGEMENTS

I gratefully acknowledge my supervisor, Dr. Gail Eskes for her support and encouragement during the completion of this thesis. I am also appreciative of the thoughtful comments provided by my PhD Committee members, Dr. Patricia McMullen, Dr. Tracy Taylor-Helmick, and Dr. David Westwood.

I would like to acknowledge Mike Lawrence and Kim Parker for their assistance with technical support and Drs. Ray Klein and John Christie for their comments and 'intellectual aid'.

Funding support during the term of this thesis was provided by an Isaac Walton Killam Memorial Scholarship, a Heart & Stroke Foundation of Canada Doctoral Research Award, a Dalhousie Psychiatry Research Fund Grant, and a Capital Health Research Fund Grant.

Chapter 1

INTRODUCTION

Attention is arguably the most crucial function of the aware and thinking brain. Perception, learning, voluntary recollection, and skill development are some of the cognitive tasks for which attention is important. Attention is required to optimize resource allocation and to minimize interference during the coordination of these activities. The over-arching purpose of attention is to allow and maintain goal-directed behaviour when presented with multiple competing stimuli (Parasuraman, 1998).

The visuospatial attention system has been conceived of as a network of areas, anatomically separate from data processing systems, that interacts with other brain areas to provide rapid and accurate visual perception and action and for maintenance of visual processing ability over time (Posner and Petersen, 1990). Visual attention has been conceptualized as three distinct, yet interactive, functional components: alertness/vigilance, detection/control, and orienting/selection (Parasuraman, 1998; Posner & Petersen, 1990). Alerting or vigilance refers to the ability to develop and sustain a state of mental alertness, which consequently produces more rapid selection, detection, and responding (Posner & Petersen, 1990). The executive control function of attention is utilized during tasks that require internally planned or voluntary actions, overcoming habitual responses, and learning novel sequences of actions, as well as during tasks that require error monitoring and focal attention (Posner & DiGirolamo, 1998). Finally, orienting of visuospatial attention involves the selection of a stimulus or spatial location

from what can be an overwhelming amount of visual information in the environment in order to process some of that information more fully (Posner & Petersen, 1990).

Deficits in visuospatial attention result from lesions in a variety of locations within the networks of the attention system. An important source of information regarding how lesions affect attentional mechanisms comes from the study of attention deficits occurring after neural insult. One of the most widely studied attention deficits resulting from brain damage is a syndrome of spatial attention deficits called 'visuospatial neglect'.

Chapter 2

VISUOSPATIAL NEGLECT

Visuospatial neglect is most commonly defined as a failure to report, respond to, or orient attention toward stimuli located in the space contralateral to a brain lesion, when no sensory or motor deficit can be attributed to the dysfunction (Heilman, Watson, & Valenstein, 1993). It is a common syndrome of attentional deficits following unilateral brain damage (i.e. stroke) to the parietal lobe and/or temporal lobe (Karnath, Ferber, & Himmelbach, 2001; Leibovitch et al., 1998; Mort et al., 2003; Vallar, 2001; Vallar & Perani, 1986), the right inferior frontal lobe and subcortical structures such as the thalamus and basal ganglia (Damasio, Damasio, & Chang, 1980; Karnath, Himmelbach, & Rorden, 2002).

Neglect is both more common and more severe after right-hemisphere damage (left neglect) than after left-hemisphere damage; however, a consistent and accurate estimate of the frequency of neglect has not been determined (Bowen, McKenna, & Tallis, 1999; Halligan & Marshall, 1993). The large degree of variability in reported estimates of neglect (12% to 100% after right-hemisphere damage and 0% to 76% after left-hemisphere damage) is a consequence of different tests and neglect criteria employed and the timing of the assessment post onset (Bowen et al., 1999). In one study comparing the frequency of neglect at approximately twelve weeks post-stroke 48% of right-hemisphere damaged patients showed symptoms of neglect compared to 15% of left-hemisphere damaged patients based on an aggregate score of six tests (Halligan, Marshall, & Wade, 1989). Another study reported neglect frequencies of 15% after right-hemisphere damage and 12% after left-

hemisphere damage in patients tested with a single cancellation task at approximately four years post onset (Halligan, Burn, Marshall, & Wade, 1992). These studies illustrate that the severity of left neglect may lessen with time, but a proportion of right-hemisphere stroke patients may continue to show chronic neglect symptoms for years after the initial lesion event.

Visuospatial neglect is a serious cognitive and behavioral syndrome, that is a significant predictor of poor outcome in stroke patients, in terms of their continuing need for assistance with self-care, mobility, and activities of daily living (Halligan & Marshall, 1993; Kinsella & Ford, 1985). In the acute phase, up to two weeks post-stroke, patients with neglect often show a marked deviation of the head or eyes away from the contralesional field, although they may have full extra-ocular movements to command (Bisiach & Vallar, 1988). Careful examination of eye movements at this stage shows that most scanning saccades are restricted to the ipsilesional field as well. Patients in this state often do not turn to respond to persons on the contralesional side, but respond instead to anyone else who may be located in the ipsilesional field. In both the acute and chronic phases severe neglect is associated with a failure to attend or respond to events and objects in the contralesional side of space. This syndrome may include such symptoms as missing food on one side of a plate, failing to wash or shave one side of the face, and/or colliding with objects on the neglected side while walking or maneuvering a wheelchair (Robertson & Halligan, 1999). In some cases neglect patients fail to recognize contralateral extremities as their own. The neglect patient begins reading or writing in the middle of the page, and when drawing or copying, the contralesional side of objects or scenes are omitted and still the patient is quite satisfied that the figure is complete (Rafal, 1994). This lack of

awareness or denial of their condition is termed anosognosia and occurs frequently in patients with right-hemisphere lesions (Heilman et al., 1993).

In less severely affected individuals, the spatial attention deficit is more subtle and may only be evident under conditions of double simultaneous stimulation. For example, when simultaneously touching both hands of a neglect patient, the patient will only profess to detect the ipsilesional stimulus. This condition is known as extinction, and it has been known to occur, as does neglect, in all three modalities (visual, auditory, and tactile), but double dissociations have been reported between auditory and visual stimuli (Bisiach & Vallar, 1988). Extinction very often occurs even for simultaneous stimuli in the unaffected side of space. For example, with simultaneous tactile stimulation to both the medial and lateral sides of the ipsilesional forearm, extinction will be seen for the most contralateral stimulus of the pair. These findings suggest that simultaneous target events compete for attention, and that unilateral brain damage can drastically bias these competitive interactions in favor of the ipsilesional stimulus, and against the contralesional stimulus (Mattingley, Driver, Beschin, & Robertson, 1997). Both extinction and neglect are characterized as attentional rather than sensory deficits, in part as a result of evidence which shows that neglected or extinguished stimuli are more thoroughly processed than the patients' behaviour would suggest (Driver & Mattingley, 1995).

Chapter 3

SPATIAL ATTENTION DEFICITS IN NEGLECT

The landmark paper written in 1913 by Hermann Zingerle viewed unilateral neglect as a disorder of the conscious representation of one side of the body and space. Research through the late 1970s and early 1980s led to a growing body of data demonstrating that neglect is not confined to the exploration of the external environment and to processing incoming sensory stimuli. Bisiach and his colleagues suggested that neglect was related to a deficit in the cognitive ability to form the necessary representation of contralesional space in the affected hemisphere. It may be worth noting that these authors failed to find indications of representational neglect in the descriptions from memory of a familiar place if the patient was asked to report details of the right and left side of the image in turn. In light of these negative observations it was suggested by the authors that attentional explanations may be used to explain representational neglect, provided the deficit was interpreted a failure of attention to 'read-out' an unimpaired representation or to generate a mental representation (Bisiach & Vallar, 1988).

Neglect is most commonly considered an acquired attention deficit and as such a number of theorized attentional mechanisms for neglect have been introduced. Attentional hypotheses have suggested that neglect is the result of 1) hypoarousal of the attention system in the affected hemisphere (Heilman & Valenstein, 1979), 2) a hemispheric imbalance leading to an ipsilesional attentional bias (Kinsbourne, 1987), 3) a deficit disengaging attention from the ipsilesional space in order to orient attention leftward (Posner, Walker, Friedrich, & Rafal, 1984), or 4) a combination of a spatial attention bias

and a re-orienting deficit caused by an imbalance in hemispheric activation (Corbetta & Shulman, 2002).

One attentional theory of neglect, the arousal hypothesis developed by Heilman and associates suggests that each hemisphere is equipped with an attentional system composed of a complex retino-thalamo-cortico-limbic loop (Heilman & Valenstein, 1979). After unilateral lesions the attention system in the affected hemisphere cannot organize the orienting of responses toward the contralesional space. The assumption in Heilman's hypothesis is that in right-handers the attentional mechanism in the right hemisphere serves the whole egocentric space (right and left visual fields) while the left hemisphere is only related to the contralateral hemispace (right visual field).

In Kinsbourne's (1987) orienting/attentional hypothesis, unilateral neglect is viewed as "a bias in lateral attention, due to an imbalance in a brain stem opponent processor control system for lateral orientation". The hypothesis maintains that each hemisphere is responsible for shifting attention in the contralateral hemispace. In this theory, damage to one hemisphere not only directly affects the ability to attend to the contralateral space but also releases the opposite brain hemisphere from inhibition and creates an imbalance of orienting in favour of the hemispace controlled by the intact hemisphere. Kinsbourne also argues that the rightward directed (left hemisphere) opponent processor is more potent and, when disinhibited by damage in the right hemisphere, generates more extreme lateral orienting tendencies than the disinhibited leftward processor. In terms of the neglect syndrome, damage to the right hemisphere releases the left hemisphere from inhibition and the resultant hyperactivity creates a spatial attentional bias toward the right hemispace. To generate the full syndrome of rightward bias of attention and misevaluation of self and

space, the attentional bias is suggested to manifest at various levels of abstraction from gross orienting to spatial representation (Kinsbourne, 1987).

Consistent with the hemispheric attentional models, a gradient of attentional performance has been shown in participants with left neglect on cancellation tasks using laterally ordered columns of targets amidst distractors (Butler, Eskes, & Vandorpe, 2004; Halligan et al., 1992; Marshall & Halligan, 1989; Small, Cowey, & Ellis, 1994). This linear gradient of performance appears specific to damage to the right hemisphere (Halligan et al., 1992) and its slope is related to the severity of neglect (Butler et al., 2004). Based on differences in the pattern of performance on a target cancellation task following left- and right-hemisphere damage Halligan and colleagues (1992) concluded that the right to left gradient of target detection seen after right brain damage was consistent with the preserved functioning of the left hemisphere attentional network (Halligan et al., 1992). While neglect of stimuli in the contralesional space is the most evident functional impairment many patients will also exhibit neglect for stimuli in ipsilesional space as well (Halligan et al., 1992; Small et al., 1994). The contralesional and ipsilesional deficits in left neglect after damage to the right hemisphere are suggested to result from a rightward spatial bias due to loss of inhibition of attention mechanisms in the left hemisphere, and to a generalized attention deficit which precludes efficient processing in either hemispace (Halligan et al., 1992; Halligan, Manning, & Marshall, 1991; Marshall & Halligan, 1989; Robertson, 1993; Small et al., 1994).

Chapter 4

ORIENTING ATTENTION IN NEGLECT

Discussion of theories of neglect related to visuospatial orienting deficits in neglect, such as difficulty disengaging attention from the right in order to re-orient leftward (Corbetta & Shulman, 2002; Posner et al., 1984), first require an introduction to the orienting functions of the visuospatial attention system and the methods used to measure the efficiency of the individual functions.

Orienting Visuospatial Attention:

The selection of a stimulus from a multitude of sensory inputs requires orienting of attention to modality and to spatial location. Visuospatial orienting can be considered the selection of a object/position in space which involves disengaging, moving, and re-engaging attention from one selected location/item to the next (Klein, Kingstone, & Pontefract, 1992; Posner & Petersen, 1990). When orienting visual attention to a location in space either of two modes may be employed. Orienting can be accomplished with eye movements and foveation of the stimulus (overt orienting) or without eye or head movements (covert orienting). Under conditions demanding high acuity in which discrimination of a stimulus is required the overt orienting mechanism is favored, but in low acuity detection tasks covert mechanisms of attention, not related to eye movements or foveation, are sufficient. Regardless of the mode of orienting, events occurring at an attended location are responded to more rapidly and have lower thresholds for detection than those at unattended locations. However, covert orienting can occur in advance of

overt orienting and detection, as improvements in responses to targets at attended locations occurs within the first 150ms after an event and well before the eyes begin to move (Posner & Petersen, 1990). In addition, during covert orienting, improvements in the speed of target detection at attended locations and reductions in target detection speed at unattended locations do not vary in relation to the eccentricity of stimuli from the fovea (Posner, Snyder, & Davidson, 1980). As reviewed by Posner (1980), evidence from behavioural covert attention studies, findings of no direct relationship between eye movement latencies and shifts of attention, and the ability to move attention in the opposite direction of eye movement programmes suggest that while the overt and covert orienting systems are not completely independent, the covert attention mechanism is not directly related to the eye movement system (Klein et al., 1992; Posner et al., 1980). Furthermore, evidence from functional imaging in humans and single unit recordings in monkeys during visuospatial orienting tasks have shown activation in similar, but not identical frontoparietal networks during covert and overt attention, supporting the hypothesis of interdependence or shared neural substrates between the systems (Corbetta, 1998).

Psychophysical Assessment of Attentional Orienting:

Both overt and covert orienting of attention can be controlled either exogenously, as a reflexive, automatic response to unexpected or peripheral-onset stimuli, or endogenously, by an internal, voluntary movement of attention to a spatial location (Posner, 1980). Covert orienting (endogenous and exogenous) is typically assessed using a cost/benefit paradigm introduced by Posner and his colleagues in which participants

respond to a target that may appear in one of several locations (e.g., Posner, 1980; Posner et al., 1980). In this paradigm attention can be oriented to a spatial location in a number of ways: 1) using a meaningful (endogenous) cue, such as a centrally presented arrow that indicates the likely target location; 2) using a peripheral, non-informative (exogenous) spatial cue presented equally often at any of the potential target locations; 3) using a peripheral cue that indicates the target location with a degree of probability (e.g., 80% valid: mixed endo/exo); or 4) using a neutral cue (e.g., a central plus sign or else multiple spatial cues) to focus attention centrally or equally at all potential target locations. With both endogenous and exogenous orienting, target detection latency and accuracy show a benefit (i.e., faster and more accurate response) when the target appears at a cued (valid) location and a cost (i.e., slower and less accurate response) when the target appears at an uncued (invalid) location, in comparison to neutrally cued detection (Klein et al., 1992). However, the time between cue onset and target onset (i.e., the cue-target stimulus-onset asynchrony: SOA) affects the costs or benefits in this cued target detection paradigm (reviewed in (Vecera & Rizzo, 2003)). With short SOAs (<300ms: (Lupianez, Milliken, Solano, Weaver, & Tipper, 2001; Posner, Rafal, Choate, & Vaughan, 1985), responses are faster at cued locations than uncued locations. This is referred to as a 'validity effect' or 'cueing effect' and reflects the facilitation of perceptual processing by attention to the cued location. In contrast, at SOAs longer than 300ms responses are faster to targets at uncued than cued locations. This reversed pattern is referred to as 'inhibition of return' or IOR (Posner et al., 1985). IOR occurs under exogenous orienting conditions and has been suggested to be due to a bias against attention returning to previously explored/attended locations (Posner & Cohen, 1984)

and/or to a bias against making a motor response to a previously cued location (Klein & Taylor, 1994; Taylor & Klein, 1998, 2000).

The covert orienting paradigm introduced by Posner (1980) relies upon differences in response latencies to visual targets after valid, invalid, and neutral cues (i.e., costs and benefits or cueing effects) to show that attention has been oriented to the location indicated by the cue. The task also provides evidence that the orienting reflex is distinct from the detection of a stimulus. The enhancement of response latencies at cued locations shows that attention can move to a potential location of a target stimulus before the target occurs, making it clear that orienting can occur prior to detection.

Orienting Attention after Right-hemisphere Damage:

The reported deficit in leftward orienting in neglect patients has been linked to a difficulty disengaging the focus of attention from a relative rightward position in order to move it leftward in patients with right parietal damage (Posner et al., 1984). Posner, Walker, Freidrich, and Rafal (1984) tested covert orienting ability in six patients with right parietal lesions (RPL), seven patients with left parietal lesions (LPL), and seven neurological controls (three with frontal lesions: 2 right, 1 left, and four temporal lobectomy patients). The covert orienting task utilized central informative cues (arrow: 80% valid), peripheral informative cues (luminance change: 80% valid), and central non-informative cues (luminance change: neutral) at SOAs of 50ms, 150ms, 550ms, and 1000ms. A significant interaction between cue validity and target side in the analysis of median reaction times to peripheral informative cue trials revealed an 'extinction-like reaction time pattern' of disproportionately slower responses to invalidly-cued

contralesional targets than validly-cued contralesional targets or ipsilesional targets regardless of cue validity. The extinction-like pattern was larger for RPL patients than LPL patients and strongest at the shortest SOA, although the pattern did not differ significantly as a function of increasing SOA. Three patients (2 RPL, 1 LPL) were also tested with central informative arrow cues. Analysis of variance of median reaction times to peripheral targets showed a significant 'cue validity by target side' interaction related to disproportionately long reaction times to invalidly cued contralesional targets compared to the other cue validity-target side conditions. These results indicated that the extinction-like reaction time pattern is also found with a central informative cue and that parietal damage affects covert orienting even when the cue is not presented at a peripheral target location. Finally, six patients were tested with a central non-informative (neutral) cue making up 20% of the experimental trials. These patients also showed the same extinction-like reaction time pattern seen with invalid cues (i.e., longer median reaction times to contralesional than ipsilesional targets) when targets were presented after a neutral cue. This result suggested that the centrally presented non-informative cue engaged the patients' attention at fixation in the same way that informative peripheral and informative central cues engaged attention at peripheral target locations.

Posner et al. (1984) also presented a difference score between contralesional and ipsilesional cueing effects for right-parietal patients (RPL), left-parietal patients (LPL) and control participants at the 50ms SOA to illustrate differences in the magnitude of the 'extinction-like reaction time pattern' between groups. While all right parietal patients showed large extinction-like reaction time patterns at the 50ms SOA with a mean difference in contralesional versus ipsilesional cueing effects for the RPL group of

441ms, only two of seven left parietal patients showed similar magnitudes in the extinction-like reaction time pattern and the mean difference score of the LPL group was 106ms. Of the seven non-parietal-lesion control participants only one showed an advantage for contralesional over ipsilesional targets but the 60ms extinction-like effect was much smaller than that seen in the right parietal patients (Posner et al., 1984).

Recalling that covert orienting is a three step process of disengaging, moving, and then re-engaging attention at a new location, the difference between target detection on valid versus invalid (or neutral) contralesional trials was reported to be due to the need to disengage attention from a location other than the contralesional target location (Posner et al., 1984). Since target detection latency to validly-cued contralesional and ipsilesional targets did not differ and the valid condition did not require attention to be disengaged from the cue position prior to target detection, it was assumed that attention was able to 'move' equally well to either side. The engagement of attention may be measured by differences in reaction time to validly-cued contralesional and ipsilesional targets at long SOAs when sufficient time has elapsed for attention to have moved to the target. The report of no difference in reaction times to left versus right targets following valid cues at longer SOAs in two patients with strong extinction-like reaction time patterns suggested that attentional engagement need not be affected by parietal damage related to the extinction-like reaction time pattern. These findings imply that patients with parietal damage may have a deficit in a neuroanatomical pathway responsible for disengaging attention from stimuli in ipsilesional space that is now referred to as a 'disengage deficit' and can be defined as a disproportionately slow reaction time to invalidly-cued

contralesional targets and confirmed by a significant interaction between cue-validity and target side in analysis of variance (Posner et al., 1984).

Because the patients tested by Posner et al. (1984) had extinction, but did not all have neglect (5 none, 2 minimal, 5 mild, 1 moderate) no direct link between the extinction-like reaction time pattern (disengage deficit) and visuospatial neglect could be concluded. To investigate a potential connection, Morrow and Ratcliff (1988) repeated the experiment of Posner et al. (1984) with 12 right-hemisphere lesioned (RHL) and 10 left-hemisphere lesioned (LHL) patients with parietal damage, neglect, or both using peripheral informative cues (75% valid). Only the median reaction times of the RHL patients showed the disengage deficit pattern, which was stronger at shorter SOAs of 50ms and 150ms. At SOAs of 550ms and 1000ms reaction times to invalidly-cued contralesional targets were faster than at the shorter SOAs and the disengage deficit was reduced indicating that in RHL patients the leftward orienting deficit dissipates as time after an ipsilesional cue increases. For the RHL patients, but not the LHL patients, the disengage deficit at the shortest SOA (50ms) was significantly correlated with a measure of neglect calculated from scores on letter cancellation, line bisection, and a visuoconstruction task. In later re-testing of four right-hemisphere lesioned patients (34 to 94 days after initial testing), two patients showed no improvement on neglect tests and no change in the disengage deficit pattern, while the other two showed improvements on neglect tests as well as a decrease in their disengage deficit pattern. Hence, it was suggested that there is a relationship between the severity of neglect and the magnitude of the disengage deficit in the early stages after lesion onset (Morrow & Ratcliff, 1988). While some patients continue to show a disengage deficit despite showing no signs of

neglect in the years following a right-hemisphere lesion (Posner et al., 1984), patients with right parietal lobe damage and chronic neglect are more likely to show a continuing severe disruption in the disengage operation (Morrow & Ratcliff, 1988).

A further evaluation of the inability to disengage attention from a right cued location to detect a left target after right-hemisphere damage concluded that relative rightward events have an attentional advantage over relative leftward events regardless of the hemispace of presentation (Posner, Walker, Friedrich, & Rafal, 1987). In this cueing paradigm there were six place holders (at 3, 6, and 9° on each side of a central fixation point), which allowed for both between-field and within-field cue-target pairings requiring either leftward or rightward attention shifts to detect invalidly cued targets (60% of trials). Seven patients with parietal lobe damage and a disengage deficit pattern showed a consistent reaction time advantage for ipsilesional field targets compared to contralesional field targets at a 100ms SOA. The analysis of orienting effects within each visual field showed a significant advantage for orienting to relative ipsilesional targets compared to relative contralesional targets, showing that patients had more trouble orienting in the contralesional direction regardless of the visual field of presentation. Therefore, for patients with right parietal damage, once attention is engaged anywhere in the visual field, targets in the leftward direction will have a disadvantage because of the difficulty disengaging attention from a relative rightward location (Posner et al., 1987).

For a disengage deficit to produce neglect, attention must first be engaged at a location that is rightward relative to the target location. D'erme et al. (1992) hypothesized that in right-hemisphere damaged patients with neglect the presentation of boxes in each hemifield marking potential target locations would induce or enhance a rightward

attentional bias. Therefore, location-marking boxes would be equivalent to spatial cues and would result in greater rightward orienting of attention and faster reaction times to right-sided than left-sided stimuli compared to orienting experiments without boxes. To investigate this hypothesis they contrasted Posner's covert orienting paradigm in which peripheral informative cues and targets appeared in peripheral boxes at a short SOA (167ms), to a task in which peripheral informative cues and targets appeared on a blank screen, not surrounded by boxes, and a task in which peripheral boxes but no cues were presented (D'Erme, Robertson, Bartolomeo, Daniele, & Gainotti, 1992). Median reaction times of right brain damaged (RBD) patients with moderate to severe neglect, RBD patients with mild neglect, and left brain damaged (LBD) patients were compared. Analysis of validly cued trials showed that reaction times to left-sided targets were slowed compared to right-sided targets only in the tasks with peripheral boxes, and the presentation of a left cue did not significantly improve leftward orienting in the presence of peripheral boxes. Additionally, RBD patients with moderate to severe neglect showed a disengage deficit in both the 'cues and no boxes' and 'boxes but no cues' conditions, confirming an attentional bias in which the right box itself provided a cue which automatically attracted and engaged attention during covert orienting (D'Erme et al., 1992).

Endogenous versus Exogenous Orienting in Neglect:

Neglect has been shown on tasks such as line bisection and reading to involve defective exogenous/reflexive orienting while endogenous/voluntary orienting remains relatively intact (Luo, Anderson, & Caramazza, 1998). In addition, orienting studies

using the Posner cueing paradigm, have shown that right-hemisphere damaged patients with neglect orient attention equally well, both automatically (exogenously) and voluntarily (endogenously) in the ipsilesional (right) hemifield, but they appear to be more impaired in automatic than in voluntary attentional control when responding to stimuli in the contralesional (left) hemifield (see Bartolomeo & Chokron, 2002 and Losier & Klein, 2001 for reviews). Ladavas, Carletti, and Gori (1994) addressed the issue of exogenous and endogenous orienting in neglect using a target detection task with non-informative peripheral cues (exogenous), central informative cue arrows (endogenous), and central cross cues (neutral) at SOAs of 800ms and 1500ms. Under endogenous cueing conditions this paradigm was expected to produce facilitatory effects to validly cued targets, while the exogenous cueing condition was expected to produce inhibitory effects (IOR) to validly cued targets. Accuracy results from eleven right-hemisphere damaged patients with severe left neglect responding to peripheral visual targets with a button press using their ipsilesional hand showed that central informative cues to the left decreased the number of omissions of left targets, whereas peripheral non-informative cues on the left side had no significant effect (benefit or cost) on target detection accuracy. Due to a large number of omissions in the left visual field (LVF), reaction time analyses were conducted only for the right visual field (RVF). This analysis showed that in the ipsilesional field endogenous and exogenous orienting mechanisms were similar to those of control participants. From these results they concluded that neglect patients were unable to orient their attention leftward exogenously, but they could do so voluntarily (though not as well as in the RVF). Hence, the deficit in neglect was suggested to be related to deficient exogenous orienting toward the left and an additional deficit in

alertness which reduced the effectiveness of voluntary leftward orienting (Ladavas, Carletti, & Gori, 1994).

Other authors have also reported data consistent with deficient exogenous orienting toward contralesional targets with relatively spared endogenous orienting in visuospatial neglect (Bartolomeo, Sieroff, Decaix, & Chokron, 2001). Bartolomeo et al. (2001) explored attentional orienting in left neglect using peripheral cues with varying informative value. Using strictly non-informative peripheral cues they showed a substantially larger cueing effect for left targets in the neglect group (n=6) compared to an age-matched control group at a 150ms SOA (218ms vs. 33ms) confirming a deficit in exogenous orienting of attention. At longer SOAs (550ms and 1000ms) the leftward cueing effect was decreased compared to the 150ms SOA, however validly-cued left targets continued to be detected more quickly than invalidly-cued left targets (i.e., no IOR at longer SOAs) providing support for a deficit of exogenous orienting in neglect (Bartolomeo et al., 2001). Using informative peripheral cues that correctly predicted the location of the target 80% of the time cueing effects to left targets remained large (greater than 200ms) at all SOAs. The authors suggested that with informative peripheral cues the patients' attention was being directed toward right-sided cues both exogenously, by the abrupt onset of the peripheral cue, and endogenously (because of the highly predictive nature of the cue) producing stronger and more persistent attentional engagement on the right side making it more difficult for patients to reorient to left targets. In their third experiment the peripheral cues were predictive of the target location only 20% of the time. In contrast to the non-predictive and 80% predictive peripheral cues, spatially invalid right-sided cues that predicted a left target 80% of the time produced cueing

effects to left targets at the 150ms and 550ms SOAs and IOR to left targets at the longest (1000ms) SOA. It was concluded that given sufficient time (e.g., 1000ms), the neglect patients were able to inhibit their severe attentional bias toward right-sided stimuli using endogenous mechanisms, but they were less efficient than the healthy controls who showed the IOR effect at the 550ms SOA (Bartolomeo et al., 2001).

In summary, behavioural studies suggest that the orienting deficit in left neglect appears to involve exogenous orienting mechanisms to a greater degree than endogenous orienting mechanisms (Bartolomeo & Chokron, 2002; Bartolomeo et al., 2001; Ladavas et al., 1994; Luo et al., 1998). The deficit also appears to involve multiple components, with an initial rightward orienting bias followed by a difficulty disengaging attention from the rightward stimuli in order to reorient attention leftward (Gainotti, D'Erme, & Bartolomeo, 1991; Kinsbourne, 1987; Posner et al., 1984).

Chapter 5

NETWORKS OF VISUOSPATIAL ATTENTION & NEGLECT

Network theories of cognition hypothesize that elementary cognitive/perceptual functions are strictly localized and many brain areas must be networked together to perform even simple cognitive tasks (Mesulam, 1981).

Neural Networks of Visuospatial Attention:

Covert Versus Overt Orienting:

In a review of progress in the field of visuospatial attention using functional imaging studies in humans and single unit recordings in monkeys, Maurizio Corbetta suggested that overlapping neural networks exist for covert and overt visual orienting (Corbetta, 1998). In healthy humans, covert and overt spatial attention were shown to activate similar, but not identical bilateral frontal and parietal areas including the precentral sulcus/gyrus, posterior superior frontal sulcus, postcentral gyrus, and intraparietal sulcus. Segregated areas of functional activity during the covert attention task were seen in the ventral intraparietal sulcus and more anteriorly in the frontal cortex. Eye movements during overt orienting activated exclusive areas in the right precuneus and left postcentral gyrus. Both exogenous and endogenous covert orienting activated similar parietal and frontal regions, although tasks with peripheral cues (exogenous or endogenous) activated additional regions in the right inferior parietal, superior temporal and cingulate cortex. The overlapping frontoparietal networks of covert and overt,

exogenous and endogenous orienting supported the hypothesis of interdependence or shared neural substrates/resources between systems (Corbetta, 1998).

Corbetta and his colleagues followed their early studies with a functional magnetic resonance imaging study of attention and oculomotor processes in a group of six healthy participants (Corbetta et al., 1998). Functional imaging data were acquired during a target detection task with a speeded manual response while participants 1) maintained central fixation while shifting attention along a predictive series of locations (covert orienting), 2) shifted fixation (and presumably attention) to a predictive series of locations (overt orienting), and 3) maintained central fixation with no attention shifts. Highly overlapping activation was apparent in right hemisphere covert and overt networks involving the parietal, frontal, and temporal lobes near intraparietal sulcus (IPS), precentral sulcus (PrCeS), frontal operculum (FO), posterior end of superior frontal sulcus (SFS), medial frontal gyrus (MeFG), superior temporal sulcus (STS), and temporo-occipital sulcus (TOS). Compared to overt eye movement, the covert shifting attention task showed greater activation in the overlapping right fronto-parietal network regions and lateral cerebellum while exclusively activating bilateral inferior frontal gyrus. In contrast, overt eye movement activation was greater than covert activation in the left posterior IPS, occipital lobe and medial cerebellum (Corbetta et al., 1998).

Exogenous Versus Endogenous Covert Orienting:

The processing of visuospatial information through endogenous or exogenous control of orienting is accomplished through the activation of specific brain areas within the network of the visual attention system. In one study with healthy individuals (Rosen

et al., 1999), fMRI was used to investigate brain activation during endogenous and exogenous covert orienting of attention in a cued target detection paradigm with a manual response and SOAs of 400ms, 550ms and 700ms. A central arrow that was 80% predictive of the peripheral target location was used to produce endogenous orienting and a "cue-back" paradigm in which non-informative cues oriented attention first to the periphery and then back to fixation was used to produce exogenous orienting (Rosen et al., 1999). A control condition in which a central neutral cue appeared before the peripheral target was used as a comparison condition to examine benefits and costs of cueing in both exogenous and endogenous orienting. Imaging results showed that, compared to a rest period in which participants passively viewed three horizontal boxes while fixating on the centre box , four areas were activated in all three cueing conditions: the left sensorimotor cortex (consistent with motor response by right index finger), bilateral anterior cingulate/supplementary motor areas (SMA), bilateral temporoparietal junction (TPJ), and bilateral cerebellum, although hemispheric differences were noted in the bilaterally activated areas. While the overall volume of the pre-SMA/cingulate focus was larger on the left, the increase in activation volume on the right for the exogenous (115%) and endogenous (200%) conditions compared to the control condition were much greater than seen on the left (15% difference in endogenous and contrast activation). Activation in the posterior middle temporal gyrus was larger on the right than the left, and extended into the superior temporal and inferior parietal regions (Rosen et al., 1999).

In the same study, Rosen et al. (1999) reported that exogenous and endogenous orienting to peripheral locations compared to cueing to the central location (control) activated bilateral dorsolateral premotor cortex, frontal eye fields (FEF), and superior

(BA 7) and inferior (BA 40) parietal regions, as well as right posterior middle and superior temporal regions. Selective activation in the endogenous condition was noted in the right dorsolateral prefrontal cortex (BA 46) and bilaterally in the globus pallidus and in posterior and medial regions of the cerebellum. In addition, the temporo-parietal junction (TPJ) activation extended more laterally, anteriorly, and superiorly than in the exogenous or control conditions. In the exogenous condition, selective activation was noted in the left ventrolateral nucleus of the thalamus (Rosen et al., 1999).

Rosen et al. (1999) concluded that, with the exception of the right dorsolateral prefrontal area and left thalamus, activation patterns for endogenous and exogenous covert orienting to peripheral locations were comparable. Activation was also greatest in the endogenous condition, followed by the exogenous condition and then the control condition, providing support for the suggestion that endogenous orienting requires control and effort, whereas exogenous orienting is automatic and reflexive. Another major finding from this study indicating bilateral premotor activation during exogenous and endogenous orienting, but not in the control condition, suggested that activation in this area is not the result of motor preparation or execution and is more likely associated with voluntary and reflexive shifts of attention to the periphery. The frontal eye field (FEF) activation in this covert orienting task also suggests that this area is involved in spatial attention regardless of eye movements. Overall, it was concluded that a single spatial attention network involving bilateral dorsal premotor, bilateral superior parietal, right temporoparietal, and right anterior cingulate/SMA mediates both endogenous and exogenous covert orienting and is influenced by the degree of effort involved in shifting attention to a peripheral target (Rosen et al., 1999).

Consistent with lesion studies by Posner and colleagues showing impaired redirection of attention toward targets in the contralesional field when attention is first cued elsewhere in the ipsilesional field after lesions of the right temporoparietal junction (Posner et al., 1984), Corbetta, Kincade, Ollinger, McAvoy, and Shulman (2000) used event-related fMRI (ER-fMRI) to investigate the magnitude and timing of neural activation in healthy participants while covertly attending to a spatial location and when detecting visual targets at attended and unattended locations. An endogenous central arrow cue was presented for 2360 ms directly followed by 1) the end of the presentation (20% of trials), 2) 4720 ms in which no target was presented (20% of trials), 3) a peripheral target at the cued location (valid; 44% of trials), or 4) a peripheral target at the uncued location (invalid; 16% of trials). A manual button-press response was used to measure detection latencies to validly- and invalidly-cued targets. When no target was presented, parietal lobe activation to the endogenous cue was strong and sustained in bilateral intraparietal sulcus (IPs) and spread to the superior parietal lobule. In addition to the IPS, activation during the target period was also seen in the temporoparietal junction (TPJ; superior temporal gyrus and inferior parietal lobule) and precuneus. Comparison of activation to invalid and valid targets showed that the right temporo-parietal junction (TPJ) responded preferentially to targets presented at unattended locations. It was concluded from these results that the intraparietal sulcus is involved in endogenous orienting to spatial locations, while the right temporo-parietal junction region is critical for reorienting attention to unattended locations (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000).

Another study that used ER-fMRI to compare validly and invalidly cued trials in an endogenous orienting task to objects and to locations showed that all brain areas involved in attentional orienting in response to valid cues, were also activated on invalid trials. However, additional right hemisphere regions including the large areas in the temporoparietal junction and inferior frontal cortex, and smaller regions in the middle temporal, middle-/superior frontal gyri,and medial frontal gyrus were recruited on invalid trials and were suspected to reorient attention to the uncued location (Arrington, Carr, Mayer, & Rao, 2000).

In a re-analysis of the data from the original 2000 study (Corbetta et al., 2000), Corbetta et al. (2002) investigated whether the separation of function of the intraparietal sulcus (IPs) and temporo-parietal junction (TPJ) extended to other parts of the neural systems involved (Corbetta, Kincade, & Shulman, 2002). This study showed that bilateral intraparietal and superior frontal cortices mediate endogenous allocation of visual attention and constitute a 'dorsal' fronto-parietal network, while a separate 'ventral' network including the TPJ and inferior frontal cortex is strongly lateralized to the right hemisphere and is activated during detection of novel stimuli (exogenous orienting) and reorienting of attention to unattended visual stimuli. Damage to the 'dorsal' network was thought to impair voluntary orienting while damage to the 'ventral' network impaired reorienting of attention. Corbetta et al. (2002), proposed that the ipsilateral IPs was activated by alerting signals in the TPJ upon detection of a novel event and that the more dorsal frontal eye field-intraparietal sulcus (FEF-IPs) regions may mediate non-lateralized alerting/vigilance processes (Corbetta et al., 2002). Therefore, although these networks are anatomically separate they interact during normal behaviour.

In summary, functional imaging studies of covert and overt orienting (Corbetta, 1998; Corbetta et al., 1998) have shown that both types of orienting activate a fronto-parietal attention network involving precentral and superior frontal areas and intraparietal sulcus. During covert orienting, additional areas in the right inferior frontal lobe and temporoparietal junction are activated that correspond to neural activation generated by reorienting attention after an invalid spatial cue (Arrington et al., 2000; Corbetta, 1998; Corbetta et al., 1998; Corbetta et al., 2000). The reorienting function that redirects attention to novel and behaviourally relevant stimuli (i.e., exogenous orienting) is related to a right lateralized 'ventral' temporoparietal-frontal orienting network, while endogenous orienting of attention to spatial locations are related to a bilateral 'dorsal' superior frontal – intraparietal sulcus/superior parietal spatial attention network (Corbetta et al., 2002; Corbetta & Shulman, 2002).

Neural Networks in Neglect:

Marcel Mesulam's (1981) early review of neglect syndromes in monkeys and humans suggested an integrated network for attention in extrapersonal space that included four cerebral components: 1) a posterior parietal component for providing internal sensory maps of external space, 2) a limbic component in the cingulate gyrus for regulating motivational relevance of spatial stimuli, 3) a frontal component for coordinating spatial motor responses, and 4) a reticular component to provide appropriate levels of arousal and vigilance (Mesulam, 1981). Each of the relevant regions of the network was hypothesized to have a unique functional role and damage to each was suspected to give rise to a different presentation of neglect. Mesulam's proposed network

theory of attention presumed that the four critical network areas were 'intimately interconnected' and each contained a unique set of functionally specialized neurons which were themselves components of their own distinct functional networks (e.g., directed attention, dressing apraxia, and anosognosia). The convergence of the individual functional networks within the critical areas of the larger attention network means that lesions confined to a single cortical region could result in multiple deficits. Furthermore, the same function may be impaired by damage to different cortical areas, and more severe and lasting impairments of individual functions may occur with simultaneous damage to several components in the relevant network (Mesulam, 1981).

Consistent with network theories of cognition and multiple visual processing circuits, neuropsychological (for review see Rafal, 1998) and brain imaging data (e.g., (Corbetta, Miezin, Shulman, & Petersen, 1993; Gitelman et al., 1999) have shown that posterior parietal and frontal premotor areas are important for visuospatial orienting. Early studies of cognition and brain lesion effects related orienting of visuospatial attention to a posterior neural network which included the posterior parietal cortex, the pulvinar of the thalamus, and the midbrain around the superior colliculus (Posner, Cohen, & Rafal, 1982; Posner & Petersen, 1990; Posner, Petersen, Fox, & Raichle, 1988). While these brain areas are related to each other within the posterior attention pathway, damage to each of these areas produces somewhat different deficits of orienting. Damage to the parietal lobe results in abnormally long reaction times to targets contralateral to a lesion, but only after attention has first been cued to a more ipsilesional location (Fernandez-Duque & Posner, 1997; Posner et al., 1984). In contrast, midbrain damage lengthens overall reaction time and increases the time needed to gain an advantage in reaction time

to a cued location compared to an uncued location (Posner et al., 1982). Damage to the thalamus slows reaction times to both cued and uncued targets at contralesional locations (Rafal & Posner, 1987). These lesion studies suggested that the midbrain (superior colliculus) is involved in moving attention, the lateral pulvinar of the thalamus mediates attentional engagement, and the posterior parietal cortex, which receives cholinergic inputs from the basal forebrain, controls the disengagement of attention from a given location (Fernandez-Duque & Posner, 1997; Posner et al., 1982; Posner & Petersen, 1990). More contemporary models have expanded on Posner's model of the functional anatomy of the orienting of spatial attention and emphasize a wider system of neural structures, including anterior cortical regions.

A review of functional neuroimaging studies in humans and neurophysiological studies in monkeys during exogenous and endogenous attention tasks led to a neuroanatomical model of attentional control (Corbetta & Shulman, 2002). Corbetta and his colleagues first noted the lack of a close correlation between the typically ventral lesion anatomy of spatial neglect (i.e., temporoparietal junction and inferior frontal lobe) and patterns of dorsal superior parietal lobe/intraparietal sulcus brain activation accompanying spatial attention and visuomotor behaviour (Corbetta et al., 2002). It was suggested that the sensory-motor bias toward the right side in neglect was related to biases within the dorsal intraparietal sulcus – superior frontal system caused by functional inactivation of the intraparietal sulcus by more ventral temporoparietal junction damage. Inactivation of the ipsilesional intraparietal sulcus would raise the threshold for orienting toward stimuli coded in the contralesional map, creating a spatial imbalance as suggested previously by Kinsbourne (1987). This effect may be compounded by damage or

inactivation of the right intraparietal sulcus and frontal eye field, which code for bilateral visual field locations and modulations in neglect may depend upon functional interactions of the dorsal spatial attention network with the ventral orienting network (Corbetta et al., 2002).

In a recent study using fMRI during an endogenous orienting task in the acute and chronic stages of recovery after right-hemisphere stroke Corbetta and his colleagues were able to show that abnormal functional activation of intact areas of the dorsal and ventral attention networks was related to spatial attention deficits in neglect at approximately four weeks post-stroke (Corbetta, Kincade, Lewis, Snyder, & Sapir, 2005). In addition, recovery of attention deficits at approximately 39 weeks post-stroke was correlated with re-balancing or normalization of neural activity within the bilateral dorsal parietal cortex. The degree of reactivation that also occurred in the ventral temporoparietal junction (superior temporal gyrus) from the acute to the chronic stage was dependent upon the presence of anatomical damage (Corbetta et al., 2005).

While the majority of neglect patients (7 of 11) in the Corbetta et al. (2005) study had lesions centered in the right perisylvian region (i.e., superior temporal gyrus, frontal operculum, insula and putamen), weak or no task-related activity was seen in large portions of right-hemisphere occipital visual cortex, posterior parietal cortex (intraparietal sulcus and superior parietal lobe) and dorsolateral prefrontal cortex; even though these regions had suffered no physical damage. Decreased activation was also seen in occipital visual cortex and prefrontal cortex of the intact left hemisphere; however, enhanced activation was apparent in the left hemisphere parietal cortex and sensory motor cortex. It was determined that the imbalance in activity between the hyperactive left and

hypoactive right dorsal parietal cortices (intraparietal sulcus and superior parietal lobe) mediated the rightward spatial bias in neglect represented by an impairment detecting targets in the left visual field. In addition, dysfunctional re-orienting to unattended locations in neglect was related to delayed activation of the left and right superior temporal gyrus (STG) and stronger activation of the STG was related to slower responses to targets at unattended locations (Corbetta et al., 2005).

Corbetta and colleagues concluded that focal brain injury may result in local dysfunction as well as deactivation, hyperactivity or hemispheric imbalance of intact structures in connected networks. Furthermore, they suggest that a combination of structural and functional damage to both the dorsal and the ventral attention networks is required for neglect to occur. Consequently, damage to the temporoparietal junction is capable of producing neglect through functional disconnection of the dorsal network leading to a rightward attentional bias and structural damage to the ventral re-orienting network (Corbetta et al., 2005).

In summary, early lesion studies of the neglect syndrome suggested an integrated network for spatial attention that included posterior parietal, frontal, limbic, and reticular involvement (Mesulam, 1981), while orienting of visuospatial attention involved a posterior neural network including the posterior parietal cortex, the thalamus, and the midbrain (Posner et al., 1982; Posner & Petersen, 1990; Posner et al., 1988). More recent functional imaging data have related the attentional deficits in neglect to damage within dorsal and ventral parieto-frontal networks (Corbetta et al., 2002). Damage in the right temporoparietal junction may produce two separate neglect symptoms: a reduction in exogenous stimulus-driven attentional capture and an imbalance between the spatial

orienting mechanisms in left and right intraparietal sulcus. Respectively, the disengage deficit and spatial attention bias in neglect are related to dysfunction of the exogenous/stimulus-driven mechanism located in the right temporoparietal junction and inefficiency of the endogenous/top-down mechanisms of attention located bilaterally in the intraparietal sulcus/superior parietal lobe (Corbetta et al., 2005). Re-activation and re-balancing of activation with the dorsal parietal lobe was related to reduced neglect symptoms and greater left superior parietal lobe activity was related to a larger spatial bias in chronic right-hemisphere stroke. Re-activation of the ventral temporoparietal junction in the chronic stage was dependent upon damage to the area (Corbetta et al., 2005).

Chapter 6

ATTENTION-MOTOR INTERACTIONS

Behavioural Evidence from Neglect:

In addition to the orienting and alerting mechanisms of the frontal-parietal network, cognitive theories also relate attention to motor performance, in that attention appears to be involved in the operations that control action systems. Behavioural evidence for a motor-attention interaction began with reports of improved leftward visuo-motor target detection and line cancellation when the contralesional arm was used for pointing or drawing compared to when the ipsilesional arm was used (Joanette, Brouchon, Gauthier & Samson, 1986; Halligan & Marshall, 1989a). Further evidence has come from studies of neglect rehabilitation based on Halligan and Marshall's (1991) spatio-motor cueing study, which involved cueing the patient to make an active motor response (e.g., moving a finger or clenching and unclenching a fist) with the contralesional limb while performing a visual task. The spatio-motor cueing hypothesis evolved from studies of neglect patients that contrasted contralesional and ipsilesional limb use in line bisection performance when the start position of the limb was in the corresponding hemispace (Halligan et al., 1991; Halligan & Marshall, 1989b) or in the opposite hemispace (Halligan et al., 1991) and when direction of limb movement was congruent or incongruent with the direction of the bisection tool (Halligan & Marshall, 1989b). These early studies of peripheral motor effects on neglect suggested that left limb movements beginning in left hemispace ameliorate the visuospatial deficit in neglect by biasing attention toward the side of space ipsilateral to the responding limb.

Another relevant theory of attention-motor interactions was introduced following a review of hypotheses relating attention and neglect (e.g., Heilman & Valenstein, 1979 and Mesulam, 1981); the inability of these hypotheses to address findings of the anatomical independence of the multiple lesion sites resulting in neglect and congruent attention and motor deficits in neglect. Rizzolatti's (1987) "premotor theory" of spatial attention assumes that attention may be captured in a passive, effortless way by the characteristics of the stimulus (passive attention), or it may be actively directed by the individual (active attention). This theory of neglect involves a series of parallel circuits that program motor plans in a spatial framework; it proposes that attention is a consequence of the activation of premotor neurons, which facilitate sensory cells functionally related to them (Rizzolatti & Camarda, 1987). The premotor theory suggests that neglect can result from damage to the sensory/attentional components (related to orienting attention) or the premotor/intentional components (related to programming movements) of the neural circuits that direct attention to the spatial location of a motor response. Evidence in favor of the network of parallel circuits is very strong, one of the main facilitating points being that neglect results following lesions in a multiplicity of brain centres, some of which are loosely connected or not connected at all. Findings in a variety of studies indicate a multiplicity of sensorimotor circuits with a similar functional organization. The link between attentional and motor programming is based on the following observations: (1) motor deficits are consistently present after lesions of "attentional" brain areas; (2) attentional and motor deficits are congruent in term of the space involved; and (3) the major function of brain areas whose lesions produce neglect are considered to be the organization of movements. Thus,

although the evidence is not conclusive, it strongly suggests a close link between motor preparation and attention (Rizzolatti & Gallese, 1988).

The publication of spatio-motor cueing studies (Halligan et al., 1991; Halligan & Marshall, 1989b) and the "premotor theory" (Rizzolatti & Camarda, 1987) stimulated further study of limb movement effects on the attentional deficits in neglect. Ian Robertson first investigated the effect of left versus right hand responding on response latency in a simple target detection task (Robertson, 1991). Of the six right-hemisphere stroke patients tested, all of whom had leftward errors on cancellation tasks, only one showed faster responses to leftward targets with a left hand response. This result was considered to support Halligan et al's spatio-motor cueing hypothesis (Robertson, 1991).

Following this initial study Robertson and his colleagues showed, using case studies, that active left limb movement in left hemispace that is irrelevant to a visuospatial task (i.e., finger flexion and extension or pressing a button) can significantly reduce neglect compared to right-sided movement as measured by visual scanning and cancellation errors (Robertson & North, 1992, 1993; Robertson, North, & Geggie, 1992). However, left-sided movements in right hemispace, right-sided movements in either left or right hemispace (Robertson, 1991; Robertson & North, 1992) and passive movement (e.g., experimenter manipulation of the hand, (Robertson & North, 1993) did not result in improved scanning or cancellation ability. The reduction in rightward bias with active left limb movement (i.e., pressing a button or clenching and unclenching the left hand) was also obtained in personal (body) space and extrapersonal (beyond reaching) space in tasks such as combing hair and walking through corridors and doorways (Robertson, Hogg, & McMillan, 1998; Robertson, Tegner, Goodrich, & Wilson, 1994). While improved motor function was evident for

months after completion of limb activation training (Robertson, McMillan, MacLeod, Edgeworth, & Brock, 2002), the maintenance of positive effects on attention were seen for more than one week, but only in peripersonal space (Robertson et al., 1998). These studies suggested that the limb activation effect was contingent upon an intentional activation of left motor outputs in left hemispace.

In contrast to Robertson's reported lack of passive movement effect (Robertson & North, 1993), other studies of passive left-limb movement in left hemispace (i.e., experimenter-assisted finger movements, mechanically-assisted elbow movement, or functional electrical stimulation of finger extensors) have shown improved scanning and line bisection (Eskes, Butler, McDonald, Harrison, & Phillips, 2003; Frassinetti, Rossi, & Ladavas, 2001; Ladavas, Berti, Ruozzi, & Barboni, 1997) in groups of neglect patients. These positive passive limb movement results suggest that activation of the damaged hemisphere by movement of the contralesional limb may be related to proprioceptive and kinesthetic input and does not necessitate the involvement of intentional motor plans for limbs (Ladavas et al., 1997) or saccades (Brown, Walker, Gray, & Findlay, 1999).

The above studies suggested that the mechanism of the limb movement effect was the activation of integrated perception-action (attentional-motor) circuits involved in both personal space (the 'body schema') and peripersonal (reaching) space as suggested by the premotor theory (Rizzolatti & Camarda, 1987). In addition, the inability to show improvements in neglect with the left hand in right hemispace or the right hand in left hemispace suggested that synchronous activation of two spatial circuits (personal and peripersonal) was required to obtain the left hand advantage (Robertson & North, 1994). The question then arose regarding the likelihood of an extinction-like phenomenon

occurring for the left limb advantage when the right limb is concurrently activated on the right side of space. Robertson and North (1994) investigated this question by having patients with left neglect read all of the numbers and letters they could see (maximum 40) on a scanning sheet in front of them during no limb movement, left movement on the left, left and right movement on the left, left and right movement on the right, bilateral congruent-hemispace limb movement, and right movement on the right (Robertson & North, 1994). Results showed a significant decrease in omissions with the left hand moving in left hemispace alone that was nearly eliminated by the addition of right hand movements in either left or right hemispace confirming the presence of 'motor extinction'. It was suggested that left hand movements in left hemispace on their own activated left sided personal and peripersonal spatial systems, but this increased awareness was eliminated by activation of the dominant right side of the body schema (Robertson & North, 1994).

In an effort to expand the previous findings from case studies to a group of neglect patients and to determine whether left hand movements improve selective attention to the left side of space, Cubelli et al. (1999) tested ten patients with left neglect on visual scanning and cancellation tasks during movement of the left and/or right limbs in a number of spatial orientations (i.e., congruent or incongruent hand and space, both hands in left hemispace) or after visual perceptual cueing to the left (Cubelli, Paganelli, Achilli, & Pedrizzi, 1999). Equivocal results were reported in that only one neglect patient showed a significant decrease in the total number of omissions with left hand movements in left hemispace in all experiments. In addition, the left hand movement advantage for targets in left hemispace was shown for the group in only one of three

experiments. While it was concluded that left hand movement can enhance target detection in neglect in some cases, the low frequency of the effect (10%) gave insufficient evidence to confirm whether the facilitatory effect was due to spatio-motor cueing (Halligan et al., 1991), or to a shift in covert attention related to the spatial sector in which hand movements are programmed (Rizzolatti & Camarda, 1987).

Another more recent study investigated the effect of active left limb movements in left and right hemispace on cancellation performance in a group of seven neglect patients (Gainotti, Perri, & Cappa, 2002). The authors of this study hypothesized, based on Kinsbourne's (1987) 'interhemispheric imbalance hypothesis', that activation of the damaged right hemisphere by left limb movement would reduce the number of omissions on the cancellation task irrespective of the hemispace in which they were moved (Gainotti et al., 2002). Contrary to this hypothesis, but consistent with previous studies (Robertson, 1991; Robertson & North, 1992, 1993; Robertson et al., 1992), Rizzolatti's 'premotor theory' (Rizzolatti & Camarda, 1987), and Halligan and Marshall's 'spatio-motor cueing hypothesis' (Halligan et al., 1991), only left hand movements in left hemispace reduced neglect severity on the cancellation task. As in Cubelli et al. (1999), it was concluded that evidence from studies of limb movement effects on neglect have not provided unequivocal support for the mechanisms by which left hand movements reduce the severity of neglect and that further evaluations are required to end the controversy regarding the major theoretical models of visuospatial neglect.

Limb activation studies have typically used tasks that require eye movements, such as cancellation, line bisection, or visual search. However, covert orienting tasks can be used to determine the effect of limb movement on attention without the possible

influence of saccadic motor systems. In a single-case study on the effect of limb activation on covert visual attention (Mattingley, Robertson, & Driver, 1998), a stroke patient with left-sided extinction was tested on a computerized extinction task in which she either made no movement or she started each trial by pressing a key with her left or right hand in left or right hemispace. On all trials the patient focused on a central fixation cross and quarter-segments were subsequently removed from target circles either bilaterally, unilaterally, or not at all (catch trials) and she responded verbally to targets. Significant improvement was seen detecting left-sided targets on bilateral trials, relative to the no-movement trials, when the patient moved either hand in left hemispace. However, movement of the left hand in left hemispace had the greatest effect and hand movements in ipsilesional (right) space had no beneficial effect (Mattingley et al., 1998). The results of this limb movement study were suggested by the authors to indicate that, in accord with Rizzolatti's premotor account (Rizzolatti & Camarda, 1987) active/intentional movement of the contralesional limb in contralesional space has a direct influence on visuospatial orienting and increases the patient's ability to detect contralesional visual stimuli.

In summary, behavioural evidence has shown that active and passive left limb movements in left hemispace have the ability to reduce leftward attentional deficits in patients with neglect and/or extinction (Eskes et al., 2003; Frassinetti et al., 2001; Halligan et al., 1991; Halligan & Marshall, 1989b; Ladavas et al., 1997; Mattingley et al., 1998; Robertson, 1991; Robertson & North, 1992, 1993; Robertson et al., 1992). This positive limb activation effect is by no means consistent across all patients with right-hemisphere damage and neglect, however (see Cubelli et al., 1999). While the results of

many of these behavioural studies support Rizzolatti's premotor theory of the facilitation of sensory cells by the activation of premotor neurons related to them (Mattingley et al., 1998; Robertson & North, 1992, 1993; Robertson et al., 1992), the lack of consistency of the limb activation effect requires further exploration.

Neurophysiological and Functional Imaging Evidence:

Neurophysiological studies of visuospatial attention and preparatory activity in monkeys have determined that there are both attention-related and intention-related cells in the dorsal premotor area of the superior frontal lobe (PMd: BA6) located ventral to the supplementary motor area (SMA) (Lebedev & Wise, 2001; Wise, Boussaoud, Johnson, & Caminiti, 1997). Areas in the superior parietal lobe, which receive visual and other sensory input, including areas located within and around the intraparietal sulcus project anteriorly to the dorsal premotor area. There are also direct and indirect inputs from the parieto-occipital cortex (PO) to the dorsal premotor area that are important for both target localization and detection in covert and overt orienting (Wise et al., 1997). While most visual information to dorsal premotor cortex comes from the superior parietal lobe, projections to the dorsolateral prefrontal cortex (ventral to the PMd) come from the inferior parietal lobe. Prefrontal inputs to dorsal premotor cortex appear to be concentrated in the rostral area (PMdr). Thus a prefrontally mediated route could indirectly provide part of PMd with visual information from both superior and inferior parietal lobe (Wise et al., 1997).

In monkeys, arm position in space and arm posture have been shown to influence activity in dorsal premotor cortex; however, the mechanism was suggested to use

proprioceptive information as well as information on arm position, target location and other factors in the generation of an output. It was recognized that there are interactions between visual signals and motor signals and a preference for visuomotor signals in dorsal premotor cortex. In addition, the activity of many cells in dorsal premotor cortex is modulated by both motor and attentional signals. However, the visuospatial attentional information influences the dorsal premotor cortex to a greater extent than does the intended limb movement and PMd activity within the first 200ms or so of stimulus onset reflects primarily visuospatial information (Wise et al., 1997).

More recent reports of the physiology of the monkey dorsal premotor cortex have emphasized rostral-caudal variations in the activity of the PMd. Activation of the dorsal premotor cortex during the planning and execution of voluntary limb movements was shown to be concentrated more caudally (posteriorly) than neural activity occurring when the animal is attending to a visual stimulus (Lebedev & Wise, 2001). In addition, the caudal dorsal premotor cortex (PMdc) is activated during arm movements, but not saccades, to visual targets, while the rostral region of the dorsal premotor cortex (PMdr) contains equal proportions of cells coding saccades to the target, arm movements, or both (Fujii, Mushiake, & Tanji, 2000) as well as neurons coding the orientation of spatial attention regardless of targeted response by saccade or hand movement (Lebedev & Wise, 2001). In a functional magnetic resonance imaging study comparing premotor activation during a covert spatial attention/memory task and a motor preparation task a similar functional organization was found in the dorsal premotor cortex in monkeys and humans (Boussaoud, 2001). In the covert spatial attention/memory task white squares were flashed 4, 8, or 12 times at various locations. After the last square two adjacent

coloured squares (red and green) appeared and a two-choice manual button-press response (index or middle finger) had to be made to the coloured square that appeared at the location of the last white square. In the intention task a single white square cued the location for attention then there was 250ms delay followed by the presentation of a colored movement cue indicating what finger to respond with at the movement cue offset 1 – 5.5 seconds later. Within the PMd (superior parietal lobe), attention-related activity was located rostrally and medially while intention-related activity was located caudally (Boussaoud, 2001).

A recent fMRI analysis of covert orienting in humans compared areas of activation during a spatial attention and memory task with those activated during a similar motor preparation task (Simon et al., 2002). During the spatial attention and memory paradigm the ten participants had to attend to and remember successive positions of a spatial cue, while maintaining central fixation, in order to perform a spatial matching judgment and indicate which of two colored target stimuli appeared in the same spatial position as the prior cue. During the motor preparation paradigm, a colored motor instructional cue was presented for variable periods of time (1-5.5 s) at the location of a prior spatial attention cue and participants were to prepare to make the correct motor response while the colored cue was visible, but to withhold any response until the offset of the cue. Simon et al. (2002) reported evidence of a bilateral cortical network involving activation of the lateral premotor cortex (rostral/anterior), medial premotor cortex, inferior prefrontal cortex, and posterior parietal cortex (intraparietal sulcus and precuneus) during the spatial attention task. In contrast, the cortical network activated during the motor preparation task was predominantly frontal, including bilateral lateral

premotor cortex (caudal/posterior), medial premotor cortex, left primary motor cortex (M1), and the right middle and inferior prefrontal cortex. Subcortically, the caudate was activated bilaterally in both tasks and the right thalamus was activated during the motor preparation task. Some overlap between the two tasks occurred in the head of the caudate nucleus and the medial frontal gyrus/cingulate cortex (pre-SMA), but no lateral premotor area was activated by both tasks (Simon et al., 2002).

Brain regions preferentially activated during the spatial attention and memory task included the dorsal premotor cortex within the right superior precentral sulcus, and bilateral activation centered on the posterior intraparietal sulcus and precuneus, extending into the anterior intraparietal sulcus (IPS) in the right hemisphere and into the parieto-occipital sulcus in the left hemisphere. In addition, activation in the dorsal premotor cortex (PMd) was shown to be more anterior during the spatial attention task than the motor preparation task. Results from Simon et al. (2002) provide evidence of a similar functional segregation of the dorsal premotor cortex in humans, with anterior/rostral PMd involved in orienting attention to and maintaining visuospatial information relevant for action regardless of motor effector, while posterior/caudal PMd is associated with control of specific arm or body movements.

In addition to the distributed frontal-parietal attention-motor network and frontal areas involved in response preparation to spatial cues, brain areas activated during active and passive limb movements that do not constitute a spatially-directed response are also relevant. A PET study of active and passive right elbow flexion and extension revealed similarities and differences in cerebral blood flow between the two types of movement (Weiller et al., 1996). Equivalently large levels of activation in the contralateral pre- and

postcentral gyri, representing motor output and somatosensory components (i.e., propioceptive feedback and exteroceptive sensory afferents) of the movements, were seen with both active and passive elbow movements. While the supplementary motor area was also activated during both active and passive movements, greater motor output and muscle force during active movements were implicated in blood flow measurements that were stronger and more inferior, extending into the dorsal anterior cingulate gyrus. Activations of the basal ganglia during only active movements were related to muscle selection, a function that is not relevant during passive movement. The contralateral precuneus and bilateral posterior putamen were also activated during active but not passive movements. Bilaterally, in the parietal lobes activation during active movement was centered rostrally in the supramarginal gyrus (BA 40) while maximum activation during passive movements was deep in the central sulcus within the upper bank of the sylvian fissure (area SII – a 'relay area' for sensation; Weiller et al., 1996).

Another PET study investigated brain activation during active and passive finger movements in order to separate the planning/execution components from the propioceptive components (Mima et al., 1999). Brain activation during repetitive flexion-extension of the right middle finger showed clear active-passive differences. Passive finger movement showed very weak activation in contralateral somatosensory cortex (SI) and inferior parietal cortex (SII). In contrast to passive movement, active movement showed much stronger SI activation and both contralateral and ipsilateral SII activation, potentially related to attention to the moving hand. Left supplementary motor area and dorsal pre-motor cortex activation during active, but not passive finger movements was suspected to result from the internal control of the timing, direction, and amplitude of

movements and the potential contribution of cutaneous and proprioceptive inputs. Expected movement-related activation of the bilateral basal ganglia and ipsilateral cerebellum were also evident during active movements and the lack of similar activation during passive movements was posited to be due to the lack of tactile input, conscious discrimination of stimuli, and an active response to stimuli.

In summary, the dorsal premotor cortex (PMd) in the superior frontal lobe has been shown to be activated by both covert spatial attention/memory tasks and motor preparatory tasks in monkeys and humans (Boussaoud, 2001; Lebedev & Wise, 2001; Simon et al., 2002; Wise et al., 1997). Preferential activation occurred for attention and motor preparation tasks; however, rostral dorsal premotor cortex was engaged by visuospatial attention and caudal dorsal premotor cortex was engaged by preparation for a manual button-press response (Boussaoud, 2001; Simon et al., 2002). In addition, in response to a visual target active, but not passive finger movements also activated dorsal premotor cortex (Mima et al., 1999). In contrast to this dorsal premotor activation related to motor preparation and active finger movements, active and passive flexion and extension of the elbow that was not initiated in response to a visual target was found to activate pre- and postcentral gyri and distinct parietal regions. While passive movement activated area SII within the upper bank of the sylvian fissure, active/intentional elbow movement preferentially activated the supramarginal gyrus bilaterally (Weiller et al., 1996); an area of the ventral orienting network that is important for orienting attention to novel visual events and for re-orienting attention to unattended locations (Corbetta & Shulman, 2002).

Chapter 7

STATEMENT OF THE PROBLEM

Visuospatial neglect is a common syndrome of attentional deficits that frequently follows right-hemisphere brain damage/stroke (Karnath et al., 2001) and manifests as a failure to orient attention in order to detect and respond to stimuli in the contralesional (left) space (Heilman et al., 1993). Orienting is a component of visuospatial attention that involves disengaging attention from its current focus, moving it, and engaging it at a new location (Posner & Petersen, 1990). Patients with right-hemisphere lesions show a deficit disengaging attention from the ipsilesional space in order to re-orient toward the contralesional space on covert visuospatial orienting tasks (Posner et al., 1984). This re-orienting deficit is called the 'disengage deficit' and it is related to the severity of visuospatial neglect (Losier & Klein, 2001).

There is a general consensus that the right hemisphere plays a dominant role in controlling visuospatial attention (Kinsbourne, 1987; Mesulam, 1981) and that the right superior frontal and posterior parietal regions in and around the temporoparietal junction and intraparietal sulcus/superior parietal lobule are most prominently activated during orienting tasks (Arrington et al., 2000; Corbetta et al., 1998; Corbetta et al., 2000; Corbetta et al., 2002; Gitelman et al., 1999; Rosen et al., 1999). While neglect is reported to occur after damage to a variety of cortical and subcortical structures (Damasio et al., 1980; Karnath et al., 2001; Karnath et al., 2002; Leibovitch et al., 1998; Mort et al., 2003; Vallar, 2001; Vallar & Perani, 1986), it frequently occurs after damage to ventral brain regions including the inferior frontal lobe and temporoparietal junction - areas that are

also involved in exogenous orienting of attention to novel stimuli and re-orienting attention to currently unattended locations (Corbetta et al., 2005). Furthermore, re-balancing of hemispheric activation within the bilateral dorsal spatial attention networks has been related to reduced neglect symptoms in chronic right-hemisphere stroke patients (Corbetta et al., 2005).

Studies of active and passive left limb movements in patients with right-hemisphere lesions have also shown improved visual scanning toward the left and reduced neglect symptoms on visuospatial scanning and orienting tasks in some individuals (Cubelli et al., 1999; Frassinetti et al., 2001; Gainotti et al., 2002; Ladavas et al., 1997; Mattingley et al., 1998; Robertson & North, 1992; Robertson et al., 1992). The premotor theory of attention suggests that activation of premotor neurons will facilitate the activation of spatial attention neurons related to them in attention-action circuits (Rizzolatti & Camarda, 1987). Recent neurophysiological studies of attention-motor interactions in monkeys (Lebedev & Wise, 2001; Wise et al., 1997) and functional imaging studies in humans have elucidated distinct cortical and subcortical areas involved in a frontoparietal network that are activated during attention and manual response preparation tasks (Boussaoud, 2001; Mima et al., 1999; Simon et al., 2002; Weiller et al., 1996). The dorsal premotor cortex is active during spatial attention, preparatory motor tasks, and active finger movements that are not produced in response to a visual target (Boussaoud, 2001; Mima et al., 1999; Simon et al., 2002), whereas the supramarginal gyrus is activated during re-orienting of attention and active elbow flexion/extension that is not initiated as a response to a visual target (Weiller et al., 1996). Therefore, the interaction of the motor and attention systems in the frontal and posterior

parietal cortex may underlie the efficacy of limb activation effects in neglect. The link between the effects of limb movements on specific components of attention in neglect has not yet been established, however.

The current research investigated the effects of active and passive limb movements, compared to a baseline no movement condition, on covert visual orienting in young and older healthy adults and in right-hemisphere stroke patients with and without neglect. The comparison of right- and left-sided limb movements was used to assess whether attentional effects related to the disengage function of orienting are modulated by the side of the limb movement. In addition, differences in limb movement effects, lesion locations, and neuropsychological test results allowed inferences to be made regarding the underlying mechanism(s) and localization of the proprioceptive and/or premotor effect on orienting.

Hypotheses:

It was hypothesized that in the baseline no movement condition, some participants with right-hemisphere damage would show a leftward disengage deficit on the orienting task relative to healthy older controls. The disengage deficit in the lesioned group was expected to be related in size to neglect severity and to the extent of damage in the posterior ventral network (temporoparietal junction). Further hypotheses were related to limb movement effects on the orienting of spatial attention in neglect. Active and passive left limb movements were expected to decrease the disengage deficit compared to the no movement or right limb movement conditions. The reduction of the disengage deficit was

expected to be related to improved detection (i.e., reduced reaction times) of left-sided targets in the invalid cue condition.

For the healthy adult groups it was hypothesized that each group would show positive cueing effects at the 100ms SOA, while a negative cueing effect/inhibition of return (IOR) would be obtained at the 500ms SOA. Furthermore, it was hypothesized that the reaction times of the healthy older adults in the no movement condition would be slower overall than those of the healthy young adults (Faust & Balota, 1997; Festa-Martino, Ott, & Heindel, 2004). As participants in each of the control groups were free of any known brain damage, no difference in detection of targets presented in the left and right visual fields and no effects of lateralized limb movements were expected in the younger and older healthy control groups.

Chapter 8

GENERAL METHOD

Participants:

Three groups were tested in this study: young healthy adults, older healthy adults and right-hemisphere stroke patients. Healthy young-adult control participants were recruited from psychology courses at Dalhousie University and each earned two credit points for participation. Healthy older-adult control participants were recruited from the community to serve as an age-matched control sample for the right-hemisphere stroke patients and were offered $6/hour and free parking for their participation in this study. All control participants reported no history of brain injury or stroke and normal or corrected-to-normal visual acuity, except one older control participant who had been blinded in the left eye by a childhood accident. Because this participant had no difficulty meeting the requirements of a covert visual field perimetry test his data were included in analyses. Two healthy older adult participants did not complete all experimental conditions due to neck and shoulder pain and are not included in the data analysis.

Right-hemisphere stroke patients were identified from the Stroke Service at the Queen Elizabeth II Health Sciences Centre in Halifax, Nova Scotia or the participant database of Dr. Gail Eskes. All stroke patients were at least one month post-stroke and had a CT- or MRI-confirmed diagnosis of right-hemisphere stroke. All stroke participants had normal or corrected-to-normal visual acuity. Four right-hemisphere stroke participants did not complete the experimental testing and are not included in the data analysis (two withdrew due to extensive left hemiparesis, one due to left homonymous hemianopia, and one due to travel difficulties).

Exclusion criteria for all participants included:

1. Diagnosis of Parkinson's disease, Huntington's disease, Multiple Sclerosis, or any other extrapyramidal motor system dysfunction as determined by interview or health chart.
2. Current diagnosis or treatment of severe psychiatric disorder that would interfere with testing (e.g., depression or anxiety) determined by self report and/or the health chart.
3. Dementia or global aphasia as determined by interview, the health chart, or cognitive screening.
4. Homonymous hemianopia without central sparing as determined by health chart or computerized visual field testing.

Apparatus:

The perimetry test and covert orienting trials were displayed on an iMac computer (OS 9.2, 512MB of RAM) using PsyScope version 1.0 software (Cohen, MacWhinney, Flatt, & Provost, 1993) with connected button box and microphone as input devices.

Stimulus Display:

Each participant was seated at a table with his or her eyes approximately 60 cm from a computer screen. The covert orienting computer presentation consisted of a white background with a black central fixation cross and black-outlined squares (3cm x 3cm; ~3° of visual angle) centered at 7 cm (~7°) to the left and right of fixation. At the beginning of each trial, after the participant had fixated on the central cross, a 'start button' was pressed either by the participant (active movement) or by the experimenter

(passive- and no-movement) and a tone played over external speakers placed to the left and right of the display monitor indicated the beginning of the trial. After a further 250ms of fixation a non-informative peripheral cue (bolding of the outline of one square) appeared for 300ms, and a target (black pinwheel shape, 2.2 cm in diameter; ~2° of visual angle) appeared in one of the peripheral squares randomly at one of two prescribed stimulus onset asynchronies (SOAs: 100ms, 500ms). The target appeared in the cued location on 45.5% of the trials, in the uncued location on 45.5% of the trials, and in 9% of the trials no target appeared (catch trials). The participants were instructed to respond verbally (say 'now'), as soon as they saw a target appear on the screen and to withhold a response on trials in which no target appeared. To avoid the confounding effect of manual responses in an investigation of limb movement effects on orienting, verbal responses were collected by a microphone hanging around the participant's neck and positioned in front of the mouth. Verbal reaction times (RTs) were collected using the PsyScope software. The peripheral boxes, fixation cross and targets remained visible until a response was given or for 3000ms, at which time the screen went blank for 300ms indicating the end of the trial. The fixation screen (cross and boxes) then reappeared in preparation for the next trial (see Appendix A).

Inclined Armboard for Limb Movement Conditions:

During all blocks of trials, participants had either their left or their right forearm and hand positioned (with velcro straps) onto a padded, inclined board with a hinged joint at the elbow. This apparatus was placed to allow the forearm to move in a plane parallel to the midsagittal plane and line of sight to create large movements designed to produce

sufficient neural activation to affect visuospatial orienting of attention. The hinged forearm section could be depressed by elbow extension of the participant (active movement: AM) or by the experimenter (passive movement: PM) and returned to its original position with release of pressure. A 'start button' situated on the table beneath the inclined board was pressed with sufficient downward movement of the board (~7cm, 11.29°). Arm movements were initiated and reached their maximum angle of extension 250ms prior to the cue presentation on each covert orienting trial[1]. During the no movement (NM) condition, the participant's forearm did not move on the inclined board. In this condition, covert orienting trials were started by the experimenter pressing the start button when the participant had fixated on the central fixation cross. A tone indicated the beginning of each trial when the start button was pressed. The armboard was shielded from the participants' view by black curtains surrounding the apparatus.

Electro-oculogram (EOG) to measure eye movements:

Single-use, snap-type, pre-pasted $Ag/AgCl_2$ electrodes (~50mm diameter) were placed on the left and right temple and in the center of the participant's forehead. These electrodes were connected to a Micromedical Technologies EOG5 preamp which measured changes in the electrical signal at the temple electrodes (i.e., from the negatively charged retinas) relative to the forehead electrode on each orienting trial. EOG data were passed through a DT9800 Series USB I/O board and collected on a Toshiba

[1] In healthy adults neural activity related to intentional movements (i.e., a key press) was associated with general readiness to act that lasted at least 300ms after the completion of the movement (Keller et al., 2006). In addition, older adults show a sustained blood oxygen level dependent (BOLD) hemodynamic response in motor regions after a key press (Aizenstein et al., 2004).

Satellite Laptop (4-M 1.9 GHz CPU; 256 MB of RAM; Microsoft Windows XP Version 2002) using Data Translation Measure Foundry software version 4.0.5.16. Eye movements were defined as near instantaneous (<0.05 sec) changes in fixation to the left or right that were obvious to the examiner (i.e., duration at least 250ms) and were at least 0.3 mv in magnitude as measured by the EOG.

Procedure:

Following the informed consent procedure, a health questionnaire and baseline tests, that together took approximately one hour, were completed with each participant. Baseline tests were selected to determine the current level of general cognitive functioning, general attentional functioning, visual and proprioceptive sensory functioning, and the presence and severity of visual extinction and visuospatial neglect. The experimental covert orienting task (see below) was completed on the same day or the following day and took approximately two hours. CT scans were performed on the right-hemisphere stroke participants within one day of testing in most cases. Right-hemisphere stroke participants who had either a CT or MRI scan within one month of testing for clinical purposes did not have a repeat scan.

Baseline Tests:

General cognitive functioning:

Orientation: This subtest of the Neurobehavioral Cognitive Status Examination (Cognitstat) (Mysiw, Beegan, & Gatens, 1989; Osmon, Smet, Winegarden, & Gandhavadi, 1992) assessed orientation to time and place, which are the most common

impairments of awareness after brain disease in which attention or retention is significantly affected (Lezak, 1995).

North American Adult Reading Test (NAART): This reading test provided an estimate of premorbid intellectual functioning (Blair & Spreen, 1989).

Shipley Institute of Living Scale. Revised (Vocabulary subtest): An easily administered paper-and-pencil test typically used to screen for brain dysfunction (Lezak, 1995). This test provided age-corrected T-scores and percentile scores for evaluating cognitive deficiency (Zachary, 1986).

General attentional functioning:

Elevator Counting (subtest of The Test of Everyday Attention): This continuous performance test is an audio-tape presented tone-counting procedure designed to assess deficits in sustained attention, which are common after right hemisphere stroke (Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994).

Sensory Functioning:

Proprioception: Joint position sense (JPS) of each limb was tested by grasping each of the fingers of the hand individually at the sides and moving the digit up or down 12 times. The participant reported the direction of each movement from the previous position. As errors are rare in healthy individuals, JPS was scored as: normal if there were fewer than 3 errors in 60 trials (for each hand), slight deficit (3 to 8 errors in 60 trials), moderate deficit (9 to 14 errors in 60 trials), and severe deficit (15 or more errors in 60 trials).

Visual Field Test (Perimetry): This task involves detecting visual stimuli on the computer screen at eccentricities similar to those used in the orienting task. The target detection task consisted of 32 trials in which a target (black pinwheel shape; 2.2cm in diameter; ~2° of visual angle) appeared randomly in one of 16 positions and remained on the screen until the participant responded or for a maximum of 2 seconds. The 16 possible target positions (6 left, 4 central, and 6 right positions) were arranged around two imaginary concentric circles at approximately 3° and 6° of visual angle from a central fixation cross. Participants fixated on the central fixation cross and indicated with a verbal response ('now') when each target appeared. Participants who detected fewer than four of twelve targets in positions on the left (i.e., left visual field defect) did not participate in the covert orienting task.

Visuospatial Neglect:

Behavioural Inattention Test (BIT: conventional subtests): This is a standardized test of neglect, which uses a range of visuomanual measures to determine the presence/absence of neglect (e.g. star cancellation, line bisection). A cutoff score for the presence of neglect (<129/146) has been determined from healthy elderly controls (Stone, Wilson et al., 1991). Lower BIT scores reflect more severe neglect (Stone, Halligan, Greenwood, & Marshall, 1991). Failure on at least three of six subtests of the BIT (Butler et al., 2004) is the operational definition of neglect used in the current study.

Visual Extinction Task: This task involves single or double simultaneous stimulation (index finger movement) in the left and right visual fields of the participant (5 times in single condition on each side, 5 times in double condition). The participants are

asked to report where they see movement (left, right, or both sides); some right-hemisphere stroke patients fail to report the stimulus on the left when a stimulus is simultaneously presented on the right (left-sided extinction). Extinction was defined as two or more right-only responses on double-simultaneous stimulation trials, in the presence of at least 4 out of 5 correct single left trials.

Experimental Paradigm (Covert Orienting Task):

Prior to the experimental session a block of at least 44 practice trials was completed for each arm in which the participants practiced the covert orienting task in each limb movement condition (active: AM, passive: PM, and no movement: NM). The order of the limb movement conditions was randomly assigned such that each movement condition received at least twelve successive practice trials until the participant was comfortable with each condition and was prepared to proceed. The active movement condition typically received more trials as it required more participant control.

For each movement condition (no, passive, active) the orienting task consisted of two blocks of 176 randomly presented experimental trials such that validly- and invalidly-cued left and right targets at either the 100ms or 500ms SOA were equally likely on each trial. The blocks were separated by a two-minute break. In each block of trials either the left or right arm of the participant was positioned on the inclined board. The order of the movement conditions (no, passive, active) and the order of blocks (left or right arm on armboard) were counterbalanced across participants.

Of the 176 orienting trials per block, 80 trials were validly cued (40 cue-left and target-left, 40 cue-right and target-right), 80 trials were invalidly cued (40 cue-left and

target-right, 40 cue-right and target-left), and 16 were catch trials (8 cued left and 8 cued right with no target presented). Half of the targets were presented at 100ms after onset of the cue (SOA) and half were presented with a 500ms SOA resulting in 20 target present trials and 2 catch trials in each of the 48 experimental conditions. Stimulus onset asynchronies (SOAs) of 100ms and 500ms were chosen to provide variability in the target presentation latency that would allow for investigation of reductions in disengage deficit scores in the right-hemisphere stroke group as seen in the literature (Losier & Klein, 2001). These SOAs also enabled the presence of cueing effects at the 100ms SOA and IOR at the 500ms SOA to be assessed in the group of healthy young individuals to determine the efficacy of the program to produce expected orienting effects (Klein et al., 1992; Posner, 1980; Posner et al., 1980) prior to use in limb movement and disengage deficit analyses.

Participants were instructed, and reminded if necessary, to maintain fixation on the centrally presented cross during all target detection trials. An electro-oculogram (EOG) was used along with visual inspection to monitor eye movements and assess adequate central fixation during covert orienting trials.

The experiment had a mixed factorial 3 X 3 X 2 X 2 X 2 X 2 design with a between-subjects factor of Group (YHC, OHC, RHS) and within-subjects factors of Movement (no, passive, active), Arm (L, R), Cue (Valid, Invalid), Target (L, R), and SOA (100ms, 500ms).

Data Analyses:

The dependent variable was a measure of the verbal response time (RT) from target onset in milliseconds. Reaction times shorter than 100ms and longer than 2000ms were removed from the analyses. To determine whether data were lost differentially across conditions and groups in each study error data were collapsed over type of error ($RT < 100ms$, $RT > 2000ms$, miss) and analyzed using a repeated measures ANOVA with between-subjects factor of group (YHC vs. OHC or OHC vs RHS) and within-subjects factors of movement (no, passive, active), arm (L, R), cue (valid, invalid), target (L, R), and SOA (100ms, 500ms). The raw error data for each group are presented in Appendix C3.

Individual trials in which eye movements to the cue occurred were also removed from the analyses. Eye movements to targets were not excluded as they were considered to occur about 150ms after attention was oriented to the target and a response was being formed (Posner & Petersen, 1990). See raw eye movement data for each group in tables C3.4, C3.5 and C3.6 in Appendix C. Following removal of error trials in each participants' reaction time data outliers within each condition were trimmed using a z-score cut-off value of 3.29 ($p < 0.001$; Tabachnick & Fidell, 2001, pp.67). Only those results with $p \leq 0.01$ will be discussed as significant within- and between-group findings due to the large number of statistical tests being performed on reaction time data from the experimental task. For between-groups analyses of demographic and baseline neuropsychological measures as well as determination of significant individual disengage deficit scores statistical significance was set at the $p \leq 0.05$ level as fewer statistical tests will be performed on these factors.

Initially, the mean reaction time data for the young healthy controls (YHC), older healthy controls (OHC), and right-hemisphere stroke participants (RHS) were analyzed with an omnibus repeated measures ANOVA with group as a between-subjects factor and within-subjects factors of movement (no, passive, active), arm (L,R), cue (valid, invalid), target (L, R), and SOA (100ms, 500ms). The results of this omnibus ANOVA are reported in Appendix D. However, only the outcome of the 6-way interaction and theoretically relevant simple effects and contrasts of that interaction will be reported. Because this study is primarily interested in the effect of movement and arm on the cueing and IOR effects in each group, separate theoretically important analyses were completed to investigate the a-priori hypotheses regarding 1) the effect of aging on orienting, 2) the effect of limb movement on orienting in healthy individuals, 3) the effect of right-hemisphere stroke on orienting, and 4) the effect of limb movements on orienting after right-hemisphere stroke.

To more simply present the results and interpretation of aging, right-hemisphere stroke and limb movement effects on orienting of attention, this thesis was divided into two "studies". The first study compared data from the groups of younger and older healthy adults to determine the effects of aging and lateralized limb movements on orienting in healthy participants. The second study compared data from the same older healthy adult group and the right-hemisphere stroke participants to determine the effects of right-hemisphere stroke on the orienting of attention and the effect of limb movements on attentional orienting deficits after right-hemisphere stroke.

Study 1: Effects of age and limb movement on orienting of attention in healthy adults:

Analysis of variance of reaction time data of the younger (YHC) and older (OHC) healthy control groups with group as a between-subjects factor and within-subjects factors of movement (no, passive, active), arm (L,R), cue (valid, invalid), target (L, R), and SOA (100ms, 500ms) was completed to confirm the simple effect of SOA on orienting (i.e., cueing and IOR effects). Separate analyses at the 100ms and 500ms SOA with a between-subjects factor of group (YHC, OHC) and within-subjects factors of movement (no, passive, active), arm (L,R), cue (valid, invalid), and target (L,R) were planned to determine the effect of age and limb movements on visual orienting at each SOA.

To correct occasional sphericity violations, the Greenhouse-Geisser epsilon was used to adjust the degrees of freedom for the within-subjects factor of movement. Post-hoc ANOVAs and paired t-tests were used to assess significant interactions involving within-subject factors.

Study 2: Effects of right-hemisphere stroke and limb movements on orienting of attention:

The mean reaction time data of the right-hemisphere stroke participants (RHS) were analyzed in a repeated measures ANOVA with group (OHC, RHS) as a between-subjects factor and within-subjects factors of movement (no, passive, active), arm (L,R), cue (valid, invalid), target (L, R), and SOA (100ms, 500ms). Subsequent to this omnibus analysis the hypothesized effects of right-hemisphere stroke on orienting of attention in the no movement condition were investigated using a repeated measures ANOVA with group (OHC, RHS) as a between-subjects factor and within-subjects factors of arm (L,R),

cue (valid, invalid), target (L, R), and SOA (100ms, 500ms). Post-hoc ANOVAs and/or paired t-tests were used to assess significant interactions.

Significantly longer reaction time (RT) to invalidly-cued targets appearing in the affected (left) visual field compared to invalidly-cued targets in the right visual field and validly-cued targets in the left field represented a deficit in the disengage function of attentional orienting. Because the relevant hypotheses involving limb movement effects on orienting in this study were related to the disengage deficit, further analyses of movement effects were assessed using disengage deficit scores. As described by Losier and Klein (2001), a disengage deficit score (DDS) was calculated for each participant in each movement/arm condition (no movement-left, no movement-right, passive movement-left, passive movement-right, active movement-left, active movement-right) at each SOA by subtracting the mean cueing effect for right targets (CER) from the mean cueing effect for left targets (CEL) [i.e., DDS = (CEL – CER) = (Invalidly-cued Left RT – Validly-cued Left RT) - (Invalidly-cued Right RT – Validly-cued Right RT)].[2] The overall disengage deficit score in each movement condition (no, passive, active) was calculated by averaging the relevant disengage deficit scores of each arm used and each SOA.

[2] A large positive disengage deficit score in right-hemisphere stroke patients is indicative of a leftward disengage deficit as it reflects larger cueing effects to left versus right targets, and the larger cueing effect is indicative of slower reaction time to invalidly-cued than validly-cued targets.

To determine the effect of lateralized movement and SOA on leftward orienting, disengage deficit scores of the stroke group and the healthy older control group were compared using a repeated measures Analysis of Variance (ANOVA) with a between-subjects factor of Group (RHS, OHC) and within-subject factors of Movement (no, passive, active), Arm (L, R) and SOA (100ms, 500ms). Significant interactions were followed by post-hoc ANOVAs and/or paired t-tests.

To assess the relationship between the disengage deficit score and neglect severity in the right-hemisphere stroke participants, correlational analyses (Pearson's) were performed between disengage deficit scores in the no movement condition and neglect severity (as indicated by scores on the Behavioural Inattention Test). Following the group comparisons further analyses of individual right-hemisphere stroke participants were warranted to determine which individuals' disengage deficit scores were different from the older healthy control group and how limb movements affected the orienting ability of those individuals. Using the modified t-test illustrated by (Crawford & Howell, 1998) disengage deficit scores of individual stroke participants were compared to the mean of the older healthy control group. Positive disengage deficit scores in the no movement condition that were significantly larger ($p \leq 0.05$) than the mean disengage deficit score of the older healthy control group were investigated further to confirm the presence of a disengage deficit response pattern, i.e., a significant cue validity by target side interaction related to disproportionately slower reaction times to invalidly-cued left targets than validly-cued left targets and invalidly-cued right targets (Morrow & Ratcliff, 1988; Posner et al., 1984). Prior to comparisons of the means (of multiple trials) of relevant cue and target conditions within each individual autocorrelations (lag = 1) of all conditions

(n=48) were performed to confirm the relative independence of individual trials ($p > 0.001$). Analyses of variance of reaction times in the no movement condition with within-subjects factors of Cue (valid, invalid) and Target (L, R) were then performed using the multiple trials as the between-subjects variance term.

Participants with a significantly large disengage deficit score as well as a significant disengage deficit response pattern were considered to have a severe disengage deficit (RHS/DD++). Participants with a significantly large disengage deficit score who did not meet the statistical criteria for the disengage deficit response pattern were considered to have a mild-moderate disengage deficit (RHS/DD+). Right-hemisphere stroke participants with a disengage deficit score not significantly different than the older healthy control group in the no movement condition were designated as 'RHS/DD-'.

To determine the effect of limb movement conditions on disengage deficit scores in the 'no disengage deficit' group (RHS/DD-), an ANOVA with within-subjects factors of Movement condition (no, passive, active), Arm (L, R), and SOA (100ms, 500ms) was conducted. Significant interactions were followed by post-hoc paired t-tests.

Separate analyses of variance were planned to further investigate the effect of lateralized limb movements on the disengage deficit scores and reaction time data of individual stroke participants with a disengage deficit (RHS/DD++ and RHS/DD+). Disengage deficit scores were calculated across all trials to allow for repeated measures analyses across movement conditions. For each of these individuals' mean disengage deficit scores repeated measures ANOVAs with within-subjects factors of Movement (no, passive, active), Arm (L, R), and SOA (100ms, 500ms) were conducted. Significant main effects or interactions involving the movement or arm conditions on the disengage

deficit score were followed by comparisons of reaction-time data using repeated measures ANOVAs with within-subjects factors of Movement (no, passive, active), Arm (L, R), Cue (valid, invalid) and Target (L, R) and SOA (100ms, 500ms). This reaction time analysis was theoretically important to determine whether left limb movement differentially affected response latencies to invalidly-cued left targets as hypothesized. Therefore only a significant 4-way interaction in this reaction time analysis was investigated further by post-hoc ANOVAs and/or paired t-tests.

Refer to tables C1.1, C1.2 and C1.3 in Appendix C for raw reaction time data and tables C2.1, C2.2 and C2.3 in Appendix C for cueing effects and disengage deficit scores in all conditions (i.e., no, passive, and active movement; 100ms and 500ms SOA; left arm and right arm use) for younger and older healthy control groups, the 'no disengage deficit' stroke group, and each stroke participant with a disengage deficit.

Chapter 9

STUDY ONE

Effects of Aging and Limb Movement on Orienting of Attention in Healthy Adults

Aging and Attentional Orienting:

Among the many aspects of attention studied is the effect of aging on selective attention. There is some evidence in the attention literature regarding general slowing of reaction times during visuospatial orienting through adulthood and into old age (Faust & Balota, 1997; Festa-Martino et al., 2004). There is also evidence from covert orienting studies that aging increases cue validity effects (i.e., valid cue RT vs. invalid cue RT), although individual costs and benefits of spatial cues compared to a neutral/non-informative cue do not differ with age (Faust & Balota, 1997; Festa-Martino et al., 2004; Greenwood, Parasuraman, & Haxby, 1993; Hartley & Kieley, 1995).

One early study of covert orienting of attention over the adult lifespan (19 to 79 years) utilized valid and invalid central arrow cues (endogenous) or a central non-informative asterisk (neutral) to indicate probable locations of a target letter 'X' appearing at SOAs of 200ms, 500ms, or 2000ms. Reaction times in the covert target detection task were measured using manual button-press responses. For analyses of aging effects six groups of fifteen participants were created to correspond to the age decades from the second to the seventh (i.e., 20s, 30s, 40s, etc.). Results of the covert target detection task revealed that reaction time increased with increasing age, and that the increase was greater for neutrally-cued trials than validly- or invalidly-cued trials. No change in the endogenous cueing effect (invalid RT – valid RT) was seen across the

decades of the adult lifespan at any of the SOAs, although the overall cueing effect at the 2000ms SOA was smaller than at the 500ms SOA (Greenwood et al., 1993). From these endogenous orienting results Greenwood et al. (1993) concluded that the efficiency of shifts of spatial attention by visual cues was not significantly affected through adulthood up to 79 years of age.

Other studies using peripheral cues (purely exogenous or mixed exo/endo) have shown slower overall response times and larger cueing effects at short SOAs with increased age (Faust & Balota, 1997; Hartley & Kieley, 1995). In one orienting study, Faust and Balota (1997) investigated the effect of aging and Alzheimer's disease on inhibition of return compared to healthy older participants (n = 51, mean age = 76.7 years) and healthy young participants (aged under 25 years). In Experiment One, a covert orienting task utilized manual responses to peripheral targets presented 100ms and 800ms after the onset of peripheral informative cues (mixed exo/endo; 60% of trials valid, 20% of trials invalid) or bilateral, uninformative cues (neutral; 20% of trials). On this task, healthy older participants were shown to detect validly- and invalidly-cued targets more slowly overall than healthy young participants at both short (100ms) and long (800ms) SOAs. At the 100ms SOA, the significant costs for invalidly-cued targets and significant benefits for validly-cued targets did not differ with age. While significant cueing effects were apparent for both groups at the 100ms SOA, the cueing effect of the healthy older group was larger than that of the younger group. At the 500ms SOA, there were neither significant costs nor significant benefits for the two groups. In addition, no differences in IOR effects were found between healthy younger and older adults, despite significantly large IOR for younger but not for older adults. Despite larger cueing effects for the older

healthy adults at the 100ms SOA, the decline in cueing effects from the shorter to the longer SOA and similar IOR effects for the younger and older healthy adults were interpreted to indicate a comparable ability to reorient attention over time in healthy aging (Faust & Balota, 1997).

Unfortunately, the lack of clear aging effects on IOR in Faust and Balota's (1997) first experiment cannot be interpreted strictly in terms of exogenous or endogenous spatial attention mechanisms because of the use of peripheral informative cues that activate both exogenous and endogenous mechanisms of orienting during target detection. In a second experiment designed to further investigate age- and Alzheimer-related changes in IOR, covert orienting was assessed with a "cue-back" paradigm (i.e., a peripheral non-informative cue followed by a central non-informative cue) at SOAs of 800ms, 1300ms, or 1800ms from the first cue to the target. The mixed exo/endo single cue condition from the first experiment (with a 200ms SOA) was also used. Similar to the first experiment, the healthy older group was slower overall than the healthy younger group and the cueing effect at the 200ms SOA was greater for the older than the younger group. In addition, IOR was significant and greater at the 1300ms SOA than the 800ms or 1800ms SOAs, but there was no difference in the IOR effect among the groups. It was clear in this experiment, as shown previously by Hartley and Kieley (1995) that under exogenous orienting conditions older healthy adults showed larger cueing effects and equivalent IOR effects to younger healthy adults (Faust & Balota, 1997).

Other recent studies comparing purely exogenous orienting in younger and older healthy adults and in patients with Parkinson's disease (Kingstone et al., 2002) or Alzheimer's disease (Festa-Martino et al., 2004) yield more equivocal evidence for the

effect of aging on orienting of attention. Kingstone et al. (2002) explored both purely volitional and purely reflexive covert orienting in older (mean age of 62 years) and younger healthy adults (undergraduate students) and in Parkinson's patients using endogenous, exogenous, and neutral cues in a covert target-detection paradigm. Endogenous orienting results showed that for all three groups there were significant cueing effects and the cueing effects did not vary significantly across groups or SOA (288ms and 576ms). In contrast, the results of an exogenous orienting experiment with the same groups revealed a significant interaction between cue (valid, invalid) and SOA (72ms, 288ms) reflecting significant IOR at the long SOA and an absence of cueing effect at the short SOA when cue offset and target onset were simultaneous. While other authors have reported slower reaction times and larger cueing effects for older adults in covert orienting tasks with an exogenous component (Faust & Balota, 1997; Festa-Martino et al., 2004; Hartley & Kieley, 1995), the older adult group (n=8) investigated by Kingstone et al. (2002) did not differ significantly from the younger adult group in overall reaction time or cueing effect magnitude in either the exogenous or endogenous orienting condition.

Another recent exogenous orienting study by Festa-Martino and colleagues (2004) employed a covert orienting paradigm with exogenous, bilateral neutral, or no cue presented 260ms to 340ms prior to peripheral target. The response in this task was a speeded button press with the left or right index finger to indicate the corresponding target location. Results revealed significantly slower response times overall in the older healthy participants (n = 19; mean age = 77.1 years, SD = 4.6 years) compared to younger participants (n = 15; mean age = 18.3 years, SD = 0.5 years). However, despite

the overall increase in reaction time with age, both older and younger participants exhibited a significant cueing effect (i.e., valid cue condition faster than invalid cue condition), a significant alerting effect (i.e., bilateral cue condition faster than no cue condition), and a cost associated with invalid cueing (i.e., invalid cue condition slower than bilateral cue condition). Differences between the groups were also reported. A benefit of spatial cueing over non-selective alerting (i.e., valid faster than bilateral cue) was apparent in the older group, but not the younger group. The authors concluded that when phasic alerting was maximal (in the younger adults) no benefit of spatial cues could be detected, but as phasic alerting decreased with age the benefits of spatially selective exogenous orienting became apparent (Festa-Martino et al., 2004).

In summary, a general slowing of response latencies on covert orienting tasks is frequently associated with increasing age (Faust & Balota, 1997; Festa-Martino et al., 2004; Greenwood et al., 1993) regardless of whether endogenous or exogenous spatial cues are used. It appears, however, that strictly endogenous covert orienting is not significantly affected by advancing age (Greenwood et al., 1993; Kingstone et al., 2002). In contrast, exogenous cueing effects and the benefit of spatial cues seem to be more apparent in older adults than younger adults (Faust & Balota, 1997; Festa-Martino et al., 2004), although this is not always the case (Kingstone et al., 2002). A lack of substantial aging effects on IOR, however, suggests that the attentional reorienting mechanism is not substantially affected by aging (Faust & Balota, 1997).

The current experiment was designed to compare the exogenous covert orienting ability of healthy younger and older adults and to investigate the effect of lateralized limb movements on visual orienting in the two groups. Decades of information on visual

orienting in healthy adults (Faust & Balota, 1997; Festa-Martino et al., 2004; Lupianez et al., 2001; Posner & Cohen, 1984; Posner et al., 1985; Vecera & Rizzo, 2003) led to the hypothesis that in the no movement condition each group would show a positive cueing effect (i.e., respond faster to validly cued targets than invalidly cued targets) at the 100ms SOA, while a negative cueing effect/inhibition of return (IOR) would be obtained at the 500ms SOA (e.g., invalidly cued targets would be responded to more quickly than validly cued targets). Furthermore, it was hypothesized that the reaction times of the healthy older adults in the no movement condition would be slower overall than those of the healthy young adults (Faust & Balota, 1997; Festa-Martino et al., 2004). Because participants in each of the control groups were free of any known brain damage, it was also hypothesized that participants in the two groups would respond equally well to targets presented in the left and right visual fields and no effects of lateralized limb movements were expected.

METHOD

Participants:

Young Healthy Control Group (YHC):

Twenty right-handed, healthy young adults (7 men and 13 women; mean age 20.6 years, SD = 2.7 years) participated in this experiment. See Table 1 for demographic data.

Older Healthy Control Group (OHC):

Twenty right-handed, healthy older adults (14 men and 6 women; mean age 61.7 years, SD = 12.1 years) participated in the experiment. See Table 1 for demographic data.

The YHC group was significantly younger than the OHC group ($t_{38} = -14.77$, $p < 0.001$), but the two groups did not differ on level of education (Table 1, $t_{38} = -0.54$, $p = 0.593$).

RESULTS

Baseline Testing:

Participants completed baseline tests of general cognitive functioning, general attentional functioning, sensory functioning, and visuospatial neglect as described in the general method section. There were no differences in the baseline neuropsychological test results of the two groups. In addition, sensory measures of proprioception and mean reaction times to the uncued appearance of left- and right-sided targets during computerized visual field testing did not differ between the younger and older adults. A 2 X 2 (Group x Target-side) analysis of variance of mean reaction times by the younger and older healthy adults to left or right target presentations in the visual field testing paradigm revealed no differences between side of target detection or between the older and younger healthy control groups and no interaction between the factors of visual field and group [all $F(1, 38) < 2.7$, all $p > 0.10$]. Accuracy in the perimetry task, as determined by the number of targets missed (# out of 12) on the left and right of fixation, was assessed in a mixed two-way ANOVA with factors of Group and Visual field. Accuracy did not differ in relation to group or visual field and there was no interaction between the factors [all $F(1, 38) = 1.0$, all $p > 0.30$]. Results of baseline testing are presented in Table 1.

Analyses of Reaction Time and Eye Movement Errors during Covert Orienting:

For the purpose of analysis, the error data in each of the 48 experimental conditions were averaged over three types of error (miss, RT < 100ms, RT > 2000ms) and percent error for all participants was analyzed using a mixed ANOVA with a between-subjects factor of Group (YHC, OHC) and within-subjects factors of Movement (no, passive, active), Arm (L, R), Cue (valid, invalid), Target (L, R), and SOA (100ms, 500ms). This analysis revealed no significant differences in percent errors made by the two groups; together the younger and older healthy adults had more errors at the 500ms SOA than the 100ms SOA (2.3% vs. 1.4%). However, a significant movement-by-SOA interaction showed that more errors were made at the 500ms SOA in the no movement and active movement conditions (2.2% and 3.0% respectively) compared to the other movement/SOA conditions (NM 100ms = 1.4%, PM 100ms = 1.5%, AM 100ms = 1.4%, PM 500ms = 1.8%). See tables C3.1 and C3.2 in Appendix C for error data and table D2 in Appendix D for ANOVA results.

The mean percentage of trials removed from the data analyses as a result of eye movements was low and did not differ significantly between the older adults and the younger adults (OHC vs. YHC, mean ± S.E.M = 1.8 ± 0.5% vs. 0.6 ± 0.3%, $F(1,38) = 5.01$, $p = 0.031$). Analysis of the percentage of trials with eye movements were completed within each group using repeated measures ANOVA with within-subjects factors of Movement (no, passive, active), Arm (L, R), Cue (valid, invalid), Target (L, R), and SOA (100ms, 500ms). See raw eye movement data in tables C3.4 and C3.5 in Appendix C. In the young healthy control group there were no differences in the percentage of eye-movement trials removed in any of the experimental conditions. In contrast, a significant

Arm-by-Cue-by-SOA interaction ($p < 0.01$) was seen in the older healthy control group analysis. Post-hoc paired t-tests of the 3-way interaction showed that the percent of eye movements at the 100ms SOA during left arm use was marginally greater for invalidly-cued than validly-cued targets (LInv100 vs. LVal100: $2.0 \pm 0.6\%$ vs. $0.8 \pm 0.3\%$, $t_{19} = 2.73$, $p = 0.013$), while other comparisons did not reach significance (all $t_{19} < 2.6$, all $p > 0.015$).

The percentage of false alarms (i.e., mistakenly indicating that a target appeared on a catch trial) was quite high, but did not differ significantly between the two groups (OHC vs. YHC: $20.1 \pm 3.9\%$ vs. $13.9 \pm 3.0\%$, $t_{38} = -1.29$, $p = 0.21$). This measure may have been artificially elevated by inadvertent sounds made by participants (e.g., sighing, clearing throat) that were captured by the microphone during the 3000 ms during which the target was absent.

Aging and limb movement effects on orienting in healthy adults:

An omnibus ANOVA with a between-subjects factor of Group (YHC, OHC) and within-subjects factors of Movement (no, passive, active), Arm (L, R), Cue (valid, invalid), Target (L, R), and SOA (100ms, 500ms) was initially conducted. The ANOVA showed a significant main effect of SOA, significant two-way interactions between Movement and SOA, and between Cue and SOA, and a 4-way interaction among Arm, Cue, Target, and Group. See ANOVA table D3 in Appendix D. Further theoretically motivated investigations of age and limb movement effects were completed utilizing the six factors.

Aging effects on the orienting of attention in healthy adults in the no movement condition:

To determine the effect of age on visual orienting the mean reaction times of the younger and older healthy adults in the no movement (NM) condition were analyzed in a repeated measures ANOVA with Group as a between-subjects factor and within-subjects factors of Arm (L, R), Cue (valid, invalid), Target (L, R), and SOA (100ms, 500ms). This analysis revealed a significant main effect of SOA and significant Group-by-SOA, Cue-by-SOA and Group-by-Cue-by-SOA interactions. See ANOVA table D4.1 in Appendix D.

To analyze the significant 3-way interaction among Group, Cue, and SOA two-way ANOVAs (Cue X SOA) and post-hoc paired t-tests of each group comparing validly-cued and invalidly-cued targets at each SOA were completed. See ANOVA tables D4.2 and D4.3 in Appendix D. Analysis of the younger healthy control group revealed a significant main effect of SOA and a significant cue-by-SOA interaction. Overall, the response latency of the younger adults was faster at the 500ms SOA than the 100ms SOA (100ms SOA RT vs. 500ms SOA RT: 425 ± 21ms vs. 351 ± 15ms). The cue-by-SOA interaction revealed expected differences in orienting at the short and long SOAs. A significant positive cueing effect was seen at the 100ms SOA, i.e., validly-cued targets were detected more quickly than invalidly-cued targets (valid RT vs. invalid RT: 418 ± 21ms vs. 432 ± 22ms; $t_{19} = 3.52$, $p = 0.002$). In contrast, significant IOR was present at the 500ms SOA, i.e., invalidly-cued targets were detected more quickly than validly-cued targets (valid RT vs. invalid RT: 358 ± 15ms vs. 343 ± 15ms; $t_{19} = 4.73$, $p < 0.001$). See figure 1.

Analysis of the older healthy control group also revealed a significant main effect of SOA and a significant Cue-by-SOA interaction. Overall, response latency was faster at the 500ms SOA than the 100ms SOA (100ms SOA RT vs. 500ms SOA RT: 465 ± 17ms vs. 426 ± 16ms). In addition, the expected significant positive cueing effect (i.e., facilitation) was apparent at the 100ms SOA. Validly-cued targets were detected more quickly than invalidly-cued targets (valid RT vs. invalid RT: 446 ± 16ms vs. 484 ± 19ms; $t_{19} = 7.63$, $p < 0.001$). At the 500ms SOA the difference between validly-cued and invalidly-cued targets did not reach criterion for significance, although the difference was in the expected direction for IOR (valid RT vs. invalid RT: 435 ± 16ms vs. 417 ± 17ms; $t_{19} = 2.65$, $p = 0.016$). A caveat to the not-quite-significant IOR, however, is that the power to detect a medium size IOR effect (15-20ms) in the older healthy adult group at an alpha level of 0.01 was low (0.16-0.34). See figure 1.

Further independent t-test analyses of the response latencies of the groups to validly-cued and invalidly-cued targets at each SOA were completed. These analyses revealed that there were no significant differences between the older and younger healthy control groups' reaction times to validly-cued or invalidly-cued targets at the 100ms SOA (validly-cued OHC vs. YHC: 446 ± 16ms vs. 418 ± 21ms; $t_{38} = 1.82$, $p = 0.076$; invalidly-cued OHC vs. YHC: 484 ± 19ms vs. 432 ± 22ms; $t_{38} = 1.02$, $p = 0.315$). The cueing effect for the older healthy group was significantly larger than that of the younger healthy adults, however (YHC CE vs. OHC CE: 14 ± 4ms vs. 39 ± 5ms, $t_{38} = -3.85$, $p < 0.001$). In contrast to the 100ms SOA results, the older healthy control group was significantly slower responding to both validly-cued and invalidly-cue targets at the 500ms SOA compared to the younger healthy control group (validly-cued OHC vs. YHC:

435 ± 16ms vs. 358 ± 15ms; $t_{38} = 3.22$, $p = 0.003$; invalidly-cued OHC vs. YHC: 417 ± 17ms vs. 343 ± 15ms; $t_{38} = 3.39$, $p = 0.002$). The magnitude of the IOR effect did not differ between the groups (YHC IOR vs. OHC IOR: -16 ± 3ms vs. -17 ± 7ms, $t_{38} = 0.25$, $p = 0.803$). See figure 1.

Limb movement effects on orienting in healthy adults:

Active and passive limb movement effects on the orienting of attention in healthy adults were assessed through analyses of reaction times at each SOA using ANOVAs with Group (YHC, OHC) as a between-subjects factor and within-subjects factors of Movement (no, passive, active), Arm (L, R), Cue (valid, invalid) and Target (L, R).

100ms SOA limb movement analyses in healthy adult groups:

The ANOVA of reaction time data at the 100ms SOA revealed main effects of Movement and Cue, and significant Group-by-Cue and Group-by-Movement-by-Cue interactions, as well as a marginally significant Movement-by-Cue-by-Target interaction. See ANOVA table D5.1 in Appendix D. The interaction among Group, Movement, and Cue was analyzed further by separate repeated measures ANOVAs for each group with within-subjects factors of Movement and Cue (averaged across arm and target-side). See ANOVA table D5.2 in Appendix D.

Analysis of the young healthy control group data revealed only a significant main effect of Cue, such that validly-cued targets were detected faster than invalidly cued targets (valid RT vs. invalid RT: 424 ± 26ms vs. 441 ± 26ms). There were no significant effects of Movement condition on reaction time for the younger control group and cueing

effects were similar across the three movement conditions (NM: 14 ± 4ms, PM: 21 ± 3ms, AM: 18 ± 4ms; all $t_{19} < 1.5$, all $p > 0.30$). See figure 2a.

Analysis of the older healthy control group data revealed significant main effects of Movement and Cue as well as a significant Movement-by-Cue interaction. See ANOVA table D5.3 in Appendix D. Post-hoc paired t-test analyses of the interaction showed significant positive cueing effects in all movement conditions (NM valid cue vs. invalid cue: 446 ± 16ms vs. 484 ± 19ms, PM valid cue vs. invalid cue: 473 ± 22ms vs. 504 ± 22ms, AM valid cue vs. invalid cue: 505 ± 23ms vs. 525 ± 24ms; all $t_{19} > 4.0$, all $p < 0.001$). However, reaction time to validly-cued targets after active limb movements was significantly slower than in the no movement condition (valid RT vs. invalid RT: 446 ± 16ms vs. 505 ± 23ms, $t_{19} = 3.5$, $p = 0.002$). As a consequence, the cueing effect after active movement was significantly smaller than in the no movement condition (NM vs. AM: 39 ± 5ms vs. 19 ± 5ms; $t_{19} = 3.6$, $p = 0.002$). The passive movement cueing effect was intermediate and did not differ from the other movement conditions (PM: 30 ± 4ms; all $t_{19} < 2.1$, all $p > 0.05$). See figure 2b.

500ms SOA limb movement analyses in healthy adult groups:

The ANOVA of reaction time data at the 500ms SOA with Group (YHC, OHC) as a between-subjects factor and within-subjects factors of Movement (no, passive, active), Arm (L, R), Cue (valid, invalid) and Target (L, R) revealed main effects of Group and Cue, and significant Cue-by-Target and Arm-by-Cue-by-Target-by-Group interactions. There were no significant effects or interactions involving the limb movement condition. See ANOVA table D6.1 in Appendix D. Overall, the older healthy

control group responded more slowly than the younger healthy control group (YHC vs. OHC: 347 ± 17ms vs. 431 ± 17ms). Further analysis of the significant 4-way interaction among Arm, Cue, Target, and Group was accomplished with individual repeated measures ANOVAs for each group.

Analysis of variance of reaction times of the younger control group with within-subjects factors of Arm (L, R), Cue (valid, invalid), and Target (L, R) averaged across movement condition revealed a significant main effect of Cue and a marginally significant main effect of Target. See ANOVA table D6.2 in Appendix D. The main effect of Cue showed significant IOR with faster detection of invalidly-cued than validly-cued targets (valid RT vs. invalid RT: 355 ± 17ms vs. 339 ± 17ms). See figure 3a.

Similar analysis of the older adult group revealed only a significant interaction between Cue and Target. See ANOVA table D6.3 in Appendix D. Post-hoc t-test analyses of the Cue-by-Target interaction revealed IOR only for left targets (validly-cued left target vs. invalidly-cued left target: 443 ± 17ms vs. 418 ± 17ms; $t_{19} = 3.86$, $p = 0.001$; validly-cued right target vs. invalidly-cued right target: 436 ± 17ms vs. 428 ± 19ms; $t_{19} = 1.15$, $p = 0.266$). See Figure 3b.

To further assess the overall IOR effect between the younger and older healthy adult groups independent t-test analyses were performed on the IOR effects to left and right targets (averaged over limb movement condition). These analyses showed no difference between the groups in the magnitude of the IOR effects to left targets (YHC vs. OHC: -19 ± 3ms vs. -25 ± 6ms; $t_{38} = 0.80$, $p > 0.40$) or to right targets (YHC vs. OHC: -12 ± 3ms vs. -8 ± 7ms; $t_{38} = -0.45$, $p > 0.60$).

Summary of orienting and limb movement analyses in healthy controls

In analyses of the no movement condition, significant cueing effects were apparent at the 100ms SOA for both younger and older healthy adults, but the cueing effect of the older adults was larger than that of the young adults. At the 500ms SOA the IOR effect did not differ between the two groups, although the effect was weaker and not quite significant in the older healthy adult group. In addition, the hypothesized slowed responding of the older healthy adult group compared to the younger healthy adult group was apparent only at the 500ms SOA. As expected, there were no lateralized effects of target-side in the no movement condition.

Effects of passive and active limb movements differed between groups and across SOAs. At the 100ms SOA, limb movements had no significant effect on covert visuospatial orienting in the younger healthy controls. In contrast, active limb movement prior to visual orienting at the 100ms SOA reduced the cueing effect in the older group as a result of slower detection of validly-cued targets compared to the no movement condition. At the 500ms SOA, there were no effects of limb movement on IOR in either the younger or the older healthy adult group. While IOR to left and to right targets was equivalent for both groups over all limb movement conditions, the IOR effect to right targets was not significant in the older healthy adult group.

DISCUSSION

The present study compared covert orienting without and with lateralized limb movements in younger and older healthy adults. There were no differences in baseline

testing of general cognitive and sensory abilities between the two groups. During the experimental visual orienting paradigm, the percentage of targets detected was similar for healthy older and younger adults. The high percentages of false alarms reported by the older and younger adults suggest that each group was equally unlikely to inhibit vocalization during the three-second interval after a spatial cue when no target was presented. Of the errors (i.e., anticipatory or late responses and misses) a higher percentage were found at the 500ms SOA in the no movement and active limb movement conditions compared to other movement and SOA conditions.

Within the older healthy control group faster response times and a greater percentage of response errors at the 500ms SOA compared to the 100ms SOA may suggest a speed-accuracy trade-off. However, faster response times at longer SOAs have been well documented in the literature in the absence of increased error rates (Fernandez-Duque & Posner, 1997; Hartley & Kieley, 1995); they represent a typical foreperiod effect wherein reaction times decrease with increasing SOA due to decreasing temporal uncertainty for target onset and alerting. Furthermore, compared to the younger healthy control group the longer overall response latency of the older healthy control group at the 500ms SOA suggests that older adults showed less efficient alerting at the longer SOA. Taken together, less efficient alerting and more response errors argue against a significant speed-accuracy trade-off. In addition, the variability in the percentage of trials removed due to eye movements over Arm, Cue, and SOA conditions was not mirrored by reductions in reaction times that would suggest a speed-accuracy trade-off.

Effects of aging on orienting in healthy adults (No Movement analyses):

Overall, the results from baseline testing and covert orienting in the no movement condition of the present study confirmed the hypotheses that cueing would be apparent at the short SOA and IOR would be apparent at the long SOA in an exogenous covert orienting paradigm with a voice response. Consistent with previous research, facilitation of target detection by an exogenous spatial cue at a short SOA was apparent in both younger and older healthy adults, but cueing effects were significantly larger in the older healthy adult group (Faust & Balota, 1997; Hartley & Kieley, 1995). At the 500ms SOA the magnitude of IOR was equivalent in the younger and older adults. Results clearly demonstrated that both older and younger groups were able to utilize cues at the short SOA to improve target detection and both groups were able to reorient attention away from the cued location at the longer SOA in a similar manner (Faust & Balota, 1997; Hartley & Kieley, 1995).

While response latencies between the younger and older adults did not differ at the shorter (100ms) SOA, the older adult group responded significantly more slowly than the younger adult group at the longer (500ms) SOA. This finding is consistent with previous research using both shorter SOAs (100ms, (Faust & Balota, 1997); 300ms, (Festa-Martino et al., 2004) and similar or longer SOAs (450ms to 800ms, (Faust & Balota, 1997; Hartley & Kieley, 1995) in exogenous cueing paradigms. In addition, similar reaction times between the two groups to un-cued peripheral targets during computerized visual field testing and after auditory and spatial cues at the 100ms SOA in the covert orienting task indicated that the alerting ability of cues decayed more quickly in older adults than younger adults.

As the reaction time difference between groups at the 500ms SOA was not affected by cue validity or target side it seems likely that there was a reduction over time of the phasic alerting effect of the auditory 'start' signal and/or the spatial cue for the older adult group (Festa-Martino et al., 2004). While the spatial cue remained present for 200ms during target presentation at the 100ms SOA, it was absent for 200ms prior to target presentation at the 500ms SOA. With the same 200ms inter-stimulus interval (cue offset to target onset) as the present study Festa-Martino et al. (2004) found that the alerting effect of a bilateral precue was smaller in older healthy adults than in their younger counterparts (Festa-Martino et al., 2004). Increased reaction times across all orienting conditions at the 500ms SOA in the current study suggests that an age-related breakdown was not restricted to the posterior attention system and subsequent inefficiency orienting visuospatial attention (Festa-Martino et al., 2004).

The current data reflecting larger cueing effects but equivalent overall response latencies at the 100ms SOA in addition to equivalent IOR but slower overall response latencies at the 500ms SOA for older compared to younger adults suggest an interaction between the attentional networks for alerting and orienting . Presuming efficient functioning of both networks in healthy young adults, these results can be explained by reductions in the efficiency of these two systems over time in the older adults. At the short SOA equivalent overall response latencies for older and younger adults suggest that the older adults are able to use alerting cues effectively. Larger cueing effects for the older adults, however, suggest an alteration in the orienting network with age, although without a neutral cue to provide an indication of costs versus benefits of spatial cues the direction of change cannot be shown definitively. At the long SOA, longer overall

response latencies for older versus younger adults suggest that the alerting network has lost efficiency, while equivalent IOR effects between the groups suggest that spatial orienting is efficient.

The connection between alerting and orienting networks has been shown in reports that alerting cues improve response latencies on orienting tasks in young healthy adults (Callejas, Lupianez, & Tudela, 2004). According to Reuter-Lorenz, Stanczak, & Miller (1999), the inefficiency of networks in normal aging leads to the recruitment of other brain areas. Furthermore, in older adults the limits of processing capacity are attained at an earlier stage than in young adults. The recruitment of additional brain regions appears to reflect first, an inability in older brains to sufficiently engage specialized brain regions or pathways with reduced processing efficiency and second, an increased use of other cortical networks to compensate for this inefficiency (Grady et al., 1994; Reuter-Lorenz et al., 1999).

It is possible that due to the inefficiency of neural networks in older adults (Reuter-Lorenz et al., 1999) the spatial orienting network reaches its maximum processing capacity during orienting at short SOAs and begins to recruit resources from the alerting network with which it interacts. The recruitment of neural alerting resources by the orienting network may be what is reflected in the improved orienting efficiency and decreased alerting efficiency of older adults at longer SOAs. Further study utilizing functional neuroimaging techniques may be able to elucidate changes in activation between the two attentional systems that is relevant to the hypothesized neural recruitment.

Limb movement effects on visual orienting in healthy adults:

While there has been a great deal of evidence presented in the past regarding the positive effects of left limb movements on leftward spatial attention in individuals with right-hemisphere damage and visuospatial neglect (Halligan et al., 1991; Halligan & Marshall, 1989a; Joanette et al., 1986; Mattingley et al., 1998; Robertson & Hawkins, 1999; Butler, Eskes, Harrison, & MacDonald, 1999; Eskes et al., 2003; Robertson et al., 2002), the current study investigates the effect of limb movements prior to covert orienting in healthy adults using a verbal response.

The present data indicate that limb movements did not affect cueing or IOR in young healthy adults. In contrast, limb movement effects on covert orienting ability were apparent in the healthy older control group at both short and long cue-target onset asynchronies. At a short SOA (100ms) active limb movement by the older healthy adults reduced the cueing effect compared to the baseline no movement condition, to a level comparable to the younger adult group. The shift of attention from the active limb movement back to the visual covert orienting task may have reduced the facilitatory effect of visuospatial cues and slowed detection latencies for validly-cued visuospatial stimuli. As predicted by the premotor theory (Rizzolatti & Camarda, 1987) and shown in healthy young adults (Eimer, Forster, Van Velzen, & Prabhu, 2005) attentional shifts are triggered by unimanual response preparation. The aging brain suffers from inefficiencies in neural functioning (Reuter-Lorenz et al., 1999) that may increase the susceptibility of the visuospatial attention system to interference during attention switching between tasks. Recruitment of attentional neurons by the intentional motor activation (Reuter-Lorenz et al., 1999; Rizzolatti & Camarda, 1987) may have reduced the available attentional

resources and consequently slowed attentional re-engagement to the location of the spatial cue reducing its facilitatory effects.

Whereas limb movement effects on covert orienting were seen at the short SOA, no effect of limb movements was apparent at the longer SOA in either age group. Differences in orienting efficiency to left and right targets were apparent, however, at the 500ms SOA. IOR was seen in both younger and older adults after limb movements; however, in the older adults it was significant only for left targets and not right targets (24.9ms vs. 8.5ms). In addition, the younger healthy controls showed a marginally significant slower response latency to left targets than right targets (RT difference = 5.6ms).

Previous studies of covert orienting in healthy individuals often involved only healthy young adults; they rarely reported response latencies or cueing effects to left and right targets separately, and typically used right- or dominant-hand button-press responses that required lateralized motor preparation and initiation during and after, rather than prior to each trial of the spatial orienting task. Consequently, there was no available evidence of prior limb movement effects on orienting in healthy adults and very few instances of lateralized differences in orienting with which to contrast the current findings.

One study by Faust and Balota (1997) reported faster target detection on the right than the left for a healthy older control group compared to a group of younger adults using a mixed endogenous-exogenous cueing paradigm and a right manual button-press response. The bias for right targets in older adults was suggested by the authors to be the result of either an age-related decline of right hemisphere function or reduced efficiency

of interhemispheric transfer necessary for the right hand to respond to targets in the left visual field (Faust & Balota, 1997). However, their results are confounded by the stimulus-response compatibility of a lateralized manual response to a target detection task; i.e., faster response to targets on the same side of space as the responding limb (see Lu and Proctor, 1995 for review).

Other recent studies have reported greater IOR in the left visual field than the right visual field (24ms vs 12ms) in a group of older healthy adults, without further comment on statistical differences (Sapir, Hayes, Henik, Danziger, & Rafal, 2004). Another study, which defined IOR in relation to the location of the precue (i.e., left IOR = left cue/right target – left cue/left target) reported lateral asymmetries in the direction of movement of attention (left vs. right IOR = 63ms vs. 40ms; Spalek & Hammad, 2004). When re-calculated using the more typical IOR subtraction (i.e., left IOR = right cue/left target – left cue/left target), however, the reported difference in left-to-right versus right-to-left IOR becomes far smaller and not likely significant (53ms vs. 50ms; left vs. right IOR). This non-significant effect of target-side is common in covert orienting studies using salient but conceptually and semantically meaningless stimuli (e.g., asterisk, filled circle, filled square), and a single known instance of significant IOR for left but not right targets in healthy young adults remains an unpublished finding[3] (personal communication from Dr. R. Klein and Dr. J. Christie). Although the lateralized orienting difference at the

[3] From the undergraduate honours thesis of Jeff MacLeod, supervised by Dr. R. Klein at Dalhousie University: 'Although the interaction between cue condition and [TARGET] location was not significant at the conventional $p = .05$ level, the effect of cue condition was tested separately for each location because there is some precedent for increased left visual field (LVF) IOR in English speaking participants (Spalek & Hammad, 2005). T-tests revealed that IOR was significant for LVF targets, $t(37) = 2.293$, $p = 0.0276$, but not for right visual field (RVF) targets, $t(37) = 0.702$, $p = 0.4868$.'

500ms SOA in the current study is an interesting finding, it is not relevant to the hypotheses of the study and will not be discussed further in this thesis.

In summary, data from Experiment 1 of this covert orienting study support an age-related inefficiency of attentional functioning (see Ellis and Oscar-Berman, 1989 for review). In healthy aging the efficiency of the posterior orienting system and perhaps the anterior alerting network (Posner & Petersen, 1990) was reduced, such that alerting effects of auditory and visuospatial cues decayed more quickly, response latencies increased, and orienting of visuospatial attention was susceptible to interference by further recruitment of attentional networks by limb movements making switching of attention to visual cues less efficient (Eimer et al., 2005; Reuter-Lorenz et al., 1999; Rizzolatti & Camarda, 1987). It is important to note however that the novel methodology of limb movements prior to orienting and a vocal response differs from published orienting studies. Therefore, the age- and movement-related effects on covert orienting of attention shown in the present study require replication using similar methodology and perhaps functional neuroimaging for confirmation of these findings.

Chapter 10

STUDY TWO

Effects of Right-hemisphere Stroke and Limb Movement on Orienting of Attention

This experiment was designed to explore lateralized limb movement effects on covert orienting in right-hemisphere stroke participants with and without neglect compared to a healthy age-matched control group. The difference between left and right cueing effects was used to compute a disengage deficit score which revealed the degree of leftward disengage deficit exhibited by each right-hemisphere stroke participant in the no-limb-movement condition. Changes in the disengage deficit and verbal response latencies to validly- and invalidly-cued left and right targets after lateralized passive and active limb movements that occurred prior to the covert orienting task were then assessed. It was hypothesized that:

1. In the baseline no movement condition, some patients with right-hemisphere damage would show a leftward disengage deficit (larger positive DDS) relative to healthy older controls on the orienting task.
    a. Sub hypothesis 1: The DDS in the lesioned group would be related in size to neglect severity.
    b. Sub-hypothesis 2: The DDS in the lesioned group would be related to lesion location; specifically, greater damage in the posterior parietal lobe would be related to larger positive disengage deficit scores.

2. Active and passive left limb movements would decrease the DDS compared to the no movement or right limb movement conditions by improving detection (i.e., reducing reaction times) of left-sided targets in the invalid cueing condition.

METHOD

Participants:

Right-hemisphere Stroke Participants (RHS):

Sixteen right-hemisphere stroke patients with and without neglect (13 men and 3 women) completed the baseline tests and the experimental orienting task. Of these, three male stroke participants had neglect defined as at least three BIT subtests at or below the cutoff value (RHS/N+: #1022, #1385, and #1045). The remaining 13 stroke participants formed the right-hemisphere lesioned control group (RHS/N-). See Table 1 for demographic data.

Older Healthy Control Group (OHC):

The twenty older healthy participants described in Experiment 1were used as a healthy age-matched comparison group for the right-hemisphere stroke participants.

The groups (OHC, RHS/N-, RHS/N+) did not differ in mean age or education and stroke patients with and without neglect did not differ in length of time post-stroke (see table 1).

CT Scans

Stroke patients received a computed tomography (CT) scan of their brain on the day of testing. CT scans consisted of continuous 3mm axial slices in the AC-PC plane (anterior commissure-posterior commissure) through the complete volume of the brain. CT scans were analyzed visually using a detailed lesion localization checklist (see Appendix B). In addition, lesions were traced by hand on individual slices of each digitized CT scan prior to the whole brains and the separate regions of interest (i.e., lesions) being standardized to a brain template (colin27 – a high detail MRI dataset of one brain that was matched to the MNI305 template; Collins et al., 1998). Digitized regions of interest were loaded onto an automated anatomical labelling template (Tzourio-Mazoyer et al., 2002) in MRIcro (http://www.sph.sc.edu/comd/rorden/mricro.html) to determine the number of $1mm^3$ voxels involved in relevant neuroanatomical areas. The analysis of anatomical overlap of lesions for groups of individuals with and without a disengage deficit in the no movement condition involved simultaneously opening the regions of interest for individuals in MRIcro to produce overlapping voxel counts in specific anatomical areas.

RESULTS

Baseline Testing:

Performances on baseline tests of general cognitive functioning, general attentional functioning, sensory functioning, and visuospatial neglect were analyzed between all groups with a one-way ANOVA followed by post-hoc Newman-Keuls with the significance level set to $p<0.05$. Refer to Table 1. While no differences were found

between groups in mean FSIQ assessed with the NAART, the neglect (RHS/N+) participants had a significantly lower mean percentile score on the Shipley Vocabulary subtest than all other groups. In addition, the neglect participants failed more subtests and had lower total scores (more severe neglect) on the BIT than other groups as well as having a higher proportion of visual extinction (2 of 3 participants) and more difficulty with a sustained attention and working memory task (i.e., lower TEA-elevator counting scores).

On tests of sensory functioning, the neglect group exhibited a significantly lower score on a measure of proprioception in the contralesional (left) hand than all other groups. Sensory testing of the non-neglect group revealed an overall moderate level of proprioceptive dysfunction of the left hand that was not different from the mean score of the healthy control group. Inspection of the raw data from the non-neglect participants showed the group's moderate deficit was due to three individuals with less than maximal performance, one with a moderate deficit (#1034) and two with severe deficits (#1388, #1047) in left hand proprioception.

Ability of individual right-hemisphere stroke participants to perform the left elbow extension required in the active limb movement condition was tested prior to beginning the experimental covert orienting task. Two of the three stroke participants with neglect (#1022, #1385) and three stroke participants without neglect (#1384, #1388, #1047) had left hemiplegia at the time of testing and showed effortful left limb movement during the active movement condition (e.g., slow initiation and/or use of shoulder and elbow joints together to produce movement). The remaining eleven stroke participants had no difficulty performing the active left limb movement task.

Reaction time and target detection accuracy (# detected out of 12) for left and right targets in the visual field testing paradigm were analyzed in separate one-way ANOVAs comparing the groups (OHC, RHS/N-, RHS/N+). The ANOVAs revealed significant differences between groups for mean reaction times to left and right target presentations in the visual field testing paradigm [all $F(2, 33) > 6.0$, all $p < 0.01$]. Post-hoc Newman-Keuls revealed that the neglect participants had significantly longer reaction times to left targets than all other groups and both stroke groups (with and without neglect) had longer reaction times to right targets than the older healthy control group. There were no differences in left or right target detection accuracy between the groups [all $F(2, 33) < 2.3$, all $p > 0.10$]. Furthermore, there were no significant differences between reaction times or accuracy between left and right targets within any of the groups (all $t < 2.0$, all $p > 0.10$). See Table 1.

Error analyses:

Analysis of percent errors collapsed over error type (miss, RT < 100ms, RT > 1000ms) was completed using a mixed ANOVA with a between-subjects factor of Group (OHC, RHS) and within-subjects factors of Movement (no, passive, active), Arm (L, R), Cue (valid, invalid), Target (L, R), and SOA (100ms, 500ms). The ANOVA revealed a significant main effect of SOA and a Movement-by-Arm-by-SOA-by-Group interaction. Post-hoc Movement-by-Arm-by-SOA repeated measures ANOVA of the older healthy control group showed a significant main effect of SOA and a significant interaction between Movement and SOA. The percent errors after active limb movement were greater at the 500ms SOA than at the 100ms SOA (3.4% vs. 1.6%, $t19 = 3.53$, $p = 0.002$),

while the other movement conditions did not differ (NM 100ms = 1.5%, NM 500ms = 1.6%, PM 100ms = 1.3%, PM 500ms = 1.5%; all t19 < 2.80, all p > 0.01). In contrast to the difference in percent error across conditions in the older healthy control group, the right-hemisphere stroke group error data collapsed over type of error (miss, RT < 100ms, RT > 2000ms) showed no significant differences over the experimental conditions (all p > 0.01). See tables C3.2 and C3.3 in Appendix C for error data and tables D7.1, D7.2 and D7.3 in Appendix D for ANOVA results.

The mean percentage of trials removed from the data analyses as a result of eye movements was not different for the right-hemisphere stroke participants and the older adults (6.1 ± 1.5% vs. 1.8 ± 1.3%; $F(1,34) = 4.86$, $p = 0.034$). Analysis of the right-hemisphere stroke group revealed that the percent of trials eliminated because of eye movements was marginally greater at the 500ms SOA than the 100ms SOA (500ms vs. 100ms: 8.2 ± 2.7% vs. 4.1 ± 1.5%, $F(1,15) = 8.13$, $p = 0.012$). As reported in study one, the percent of eye movements in the older healthy control group at the 100ms SOA during left arm use was marginally greater for invalidly-cued than validly-cued targets (LInv100 vs. LVal100: 2.0 ± 0.6% vs. 0.8 ± 0.3%, $t_{19} = 2.73$, $p = 0.013$). See raw eye movement data in tables C3.5 and C3.6 in Appendix C. The proportion of false alarms also did not differ significantly between groups (OHC: 20.1 ± 3.9%, RHS: 17.5 ± 3.0%; $t_{34} = 0.51$, $p = 0.611$).

Effects of right-hemisphere stroke and limb movements on covert orienting of attention:

An initial omnibus ANOVA of mean reaction times with a between-subjects factor of Group (OHC, RHS) and within-subjects factors of Movement (NM PM, AM),

Arm (L,R), Cue (valid, invalid), Target (L, R), and SOA (100ms, 500ms) was completed. See ANOVA table D8 in Appendix D. This analysis revealed significant main effects of Group, Cue, and SOA, as well as significant Movement-by-Cue, Movement-by-SOA, Cue-by-SOA, and Group-by-Movement-by-Cue-by-Target interactions. Further analyses were undertaken to determine the theoretically important effects of right-hemisphere stroke on orienting in the no movement condition and the effect of passive and active left limb movements on orienting after right-hemisphere stroke.

Effect of right-hemisphere stroke on orienting of attention (no movement analyses):

The effect of right-hemisphere stroke on visual orienting in the no movement (NM) condition was analyzed using a repeated measures ANOVA of reaction time data with a between-subjects factor of Group (OHC, RHS) and within-subjects factors of Arm (L,R), Cue (valid, invalid), Target (L, R), and SOA (100ms, 500ms). SOA was maintained as a factor given the known effect of SOA on orienting (i.e., cueing versus IOR; Lupianez et al., 2001; Posner et al., 1985) and the significant interaction between Cue and SOA in the omnibus ANOVA.

The ANOVA revealed significant main effects of Group, Cue and SOA as well as significant Group-by-Cue, Cue-by-SOA, and Group-by-Cue-by-Target interactions. See ANOVA table D9 in Appendix D. The main effect of Group confirmed that the right-hemisphere stroke group responded more slowly overall than the older healthy control group (RHS vs. OHC: 577 ± 23ms vs. 445 ± 21ms). The significant 3-way interaction among Group, Cue, and Target suggested that the difference in orienting between groups was not affected by SOA. Because of the significant Cue-by-SOA interaction, however,

post-hoc analyses of orienting in the no movement condition were conducted at each SOA using ANOVAs with group (OHC, RHS) as a between-subjects factor and within-subjects factors of Cue (valid, invalid) and Target (L, R) averaged over arm used. See ANOVA tables D10.1 and D10.2 in Appendix D.

Results from analysis of reaction times at the 100ms SOA showed significant main effects of Group and Cue, but no significant interactions. The right-hemisphere stroke group responded significantly more slowly overall than the older healthy control group (RHS vs. OHC: 603 ± 25ms vs. 465 ± 22ms). The main effect of Cue indicated that significant cueing effects were produced at the 100ms SOA, as overall reaction times were faster to validly-cued than invalidly-cued targets (valid RT vs. invalid RT: 509 ± 15ms vs. 559 ± 18ms). See Figure 4a.

Analysis of reaction times at the 500ms SOA revealed a significant main effect of Group and a significant 3-way interaction between Group, Cue, and Target. Post-hoc 2 X 2 ANOVAs of reaction times in each group with within-subjects factors of Cue (valid, invalid) and Target (L, R) were conducted. The older healthy adult group ANOVA showed a significant interaction between Cue and Target, such that significant IOR was seen only to left targets at the 500ms SOA (valid L vs. invalid L: 438 ± 16ms vs. 410 ± 16ms; $t_{19} = 4.21$, $p < 0.001$; valid R vs. invalid R: 432 ± 17ms vs. 424 ± 19ms; $t_{19} = 0.96$, $p = 0.348$). See ANOVA table 10.3 in Appendix D and Figure 4b.

A comparable post-hoc 2 X 2 ANOVA of reaction times in the right-hemisphere stroke group showed no significant main effects or interactions between Cue (valid, invalid) and Target (L, R). See ANOVA table 10.4 in Appendix D. Of note: while all

cueing effects were positive for the right-hemisphere stroke group at the 500ms SOA, none were significant (all $t_{15} < 2.3$, all $p > 0.03$). See Figure 4b.

Further independent t-test analyses of cueing effects/IOR to left and right targets at the 500ms SOA showed that the positive cueing effect of the right-hemisphere stroke group to left targets was significantly larger in magnitude than the significant negative cueing effect (IOR) to left targets in the older healthy control group (RHS vs. OHC: 49 ± 28ms vs. -27 ± 6ms; $t_{34} = 2.87$, $p = 0.007$). Cueing/IOR effects to right targets did not differ between the two groups (RHS vs. OHC: 3 ± 9ms vs. -8 ± 8ms; $t_{34} = 0.89$, $p = 0.382$). See Figure 4b.

In summary, in the baseline no movement condition the right-hemisphere stroke group responded more slowly overall than the older healthy control group at both the 100ms and 500ms SOA. The right-hemisphere stroke group (RHS) showed significant cueing effects at the 100ms SOA that did not differ from the mean of the older healthy control group (OHC). Cueing effects to left and right targets were positive but non-significant for the right-hemisphere stroke group at the 500ms SOA. While the magnitude of the cueing effect to left targets was significantly larger for the right-hemisphere stroke group than the significant IOR seen in the older healthy control group at the 500ms SOA, there was no difference between the groups in cueing effects to right targets. Of interest, there was no significant disengage deficit pattern of responding (i.e., a significant Cue-by-Target interaction due to differentially slowed reaction time to invalidly-cued left targets, Losier & Klein, 2001; Posner et al., 1984) seen in the analysis of the entire right-hemisphere stroke group at either the 100ms or 500ms SOA.

Limb Movement Effects on Disengage Deficit Scores:

Because the disengage deficit score was the focus of the limb movement effect in this study, further analyses of the significant movement-by-cue-by-target-by-group interaction from the omnibus ANOVA of reaction time data were conducted on disengage deficit scores. Disengage deficit scores were calculated for each right-hemisphere stroke and older healthy control participant in each arm and movement condition (no movement-left, no movement-right, passive movement-left, passive movement-right, active movement-left, active movement-right) at each SOA by subtracting the mean cueing effect for right targets (CER = Invalid right – Valid right) from the mean cueing effect for left targets (CEL = Invalid left – Valid left), i.e., DDS = (CEL – CER) = (InvL RT - ValL RT) - (InvR RT - ValR RT). Larger disengage deficit scores represent larger cueing effects for left targets than for right targets. Arm and SOA were maintained as factors in the initial disengage deficit analysis as arm was theoretically relevant and SOA interacted with movement and cue in the omnibus reaction time analyses.

Disengage deficit scores (DDS) of the older healthy control group and right-hemisphere stroke group were first analyzed using an omnibus mixed ANOVA with Group (OHC, RHS) as the between-subjects factor and within-subjects factor of Movement (NM, PM, AM), Arm (L, R) and SOA (100ms, 500ms). See ANOVA table D11 in Appendix D. This analysis revealed a significant Group-by-Movement interaction and a marginally significant Group-by-Arm interaction. As there were no significant main effects or interactions involving SOA, disengage deficit scores were averaged over SOA for each older healthy control and right-hemisphere stroke participant.

Post-hoc independent samples t-test analyses of the Group-by-Movement interaction compared the mean disengage deficit scores of the two groups (OHC, RHS) in each movement condition. Analysis of the no movement condition revealed that, as hypothesized, the overall disengage deficit score of the right-hemisphere stroke group was significantly larger than that of the older healthy control group (RHS DDS vs. OHC DDS: 39 ± 20ms vs. -14 ± 5ms; $t_{34} = 3.27$, $p = 0.002$). In contrast to the no movement condition, there were no significant differences between disengage deficit scores of the right-hemisphere stroke group and the older healthy control group in either the passive movement (PM) or the active movement (AM) condition (PM, RHS vs. OHC: 18 ± 19ms vs. -15 ± 5ms; $t_{34} = 1.84$, $p = 0.074$; AM, RHS vs. OHC: -13 ± 16ms vs. 4 ± 8ms; $t_{34} = 1.02$, $p = 0.314$). See Figure 5.

Further ANOVAs comparing disengage deficit scores across movement conditions for each group, revealed no effect of movement in the older healthy control group [$F(2,38) = 4.10$, $p = 0.025$]. In contrast, analysis of variance of the right-hemisphere stroke group showed a significant effect of movement condition [$F(2,30) = 6.61$, $p = 0.004$]. Post-hoc paired t-tests confirmed that the mean disengage deficit score in the active movement condition was significantly smaller than in the no movement condition while the passive movement disengage deficit score did not differ from the other two movement conditions (NM vs. AM: $t_{15} = 3.54$, $p = 0.003$; NM vs. PM: $t_{15} = 1.40$, $p = 0.182$; PM vs. AM: $t_{15} = 2.27$, $p = 0.038$). See Figure 5.

Disengage Deficit Scores versus Standardized Neglect Scores of Stroke Participants:

In the baseline no movement condition the overall disengage deficit scores of the lesioned group were related in size to neglect severity (i.e., lower scores) on the BIT Total score (see figure 6). Pearson correlations revealed that disengage deficit scores of the right-hemisphere stroke participants (n = 16) were significantly negatively correlated with their BIT total scores, BIT Line Cancellation scores, Line Bisection scores, and Drawing scores and significantly positively correlated with the number of BIT subtests failed (see Table 2).[4]

Analyses of Disengage Deficit Scores of Individual Stroke Participants:

Statistical analyses of mean disengage deficit scores in the no movement condition (averaged over arm used and SOA) using the modified t-test illustrated by (Crawford & Howell, 1998) confirmed that five right-hemisphere stroke participants (#1022, #1045, #1385, #1379, #1380) had disengage deficit scores that were significantly larger than the mean of the older control group [RHS/DD: all $t_{19} > 2.0$, all $p < 0.05$]. The eleven right-hemisphere stroke participants with disengage deficit scores that were not significantly different from the older healthy control group were consequently included in a 'no disengage deficit' group (RHS/DD-). See Table 3.

[4] Additional correlational analyses of disengage deficit scores of only the right-hemisphere stroke participants without neglect, as defined by the BIT (RHS/N-, n=13), revealed that overall disengage deficit scores were significantly negatively correlated with BIT Letter Cancellation and correlations could not be computed on the Line Cancellation and Drawing subtests because maximum scores were reported for all RHS/N- participants (see Table 2).

Large positive disengage deficit scores are presumed to be due to the disengage deficit pattern of attentional orienting (i.e., a significant Cue-by-Target interaction due to differentially slowed reaction time to invalidly-cued left targets, Losier & Klein, 2001; Posner et al., 1984). It was important to this study, however, to confirm the presence or absence of the disengage deficit pattern in each of the right-hemisphere stroke participants.

As stated in the Methods/Data Analysis, for each individual stroke participant autocorrelations (lag = 1) were performed on reaction times for individual trials in each experimental condition. Of 768 autocorrelations performed, thirteen conditions in the data from eight participants were significant at the $p < 0.01$ level. As no single condition was shown to be consistently affected across participants in the autocorrelation analyses, further investigation of the disengage deficit pattern of response latencies was subsequently sought in individual statistical analyses of the right-hemisphere stroke participants. Reaction time data in the no movement condition were assessed using repeated measures ANOVAs with within-subjects factors of Cue (valid, invalid) and Target (L, R) followed by post-hoc paired t-tests comparing reaction times to validly- and invalidly-cued left and right targets.

Eight of the sixteen right-hemisphere stroke participants showed the disengage deficit pattern of response, although the pattern was statistically significant only in the two participants with the largest disengage deficit scores (#1022: 283.9ms and #1045: 144.3ms). While these two right-hemisphere stroke participants were considered to have a severe disengage deficit (RHS/DD++), the other three stroke participants with significantly large disengage deficit scores that did not meet these stringent statistical

criteria were considered to have mild-to-moderate disengage deficits (RHS/DD+). None of the relevant statistical comparisons regarding the disengage deficit were significant for the older healthy control group ($p > 0.05$). See Table 4 and Table D12 in Appendix D.

Of note, four right-hemisphere stroke participants showed a rightward spatial bias (i.e., impaired target detection in the left visual field; Corbetta et al., 2005) as defined by slowed orienting to both validly- and invalidly-cued left targets compared to right targets. Of the participants with a spatial bias, one had neglect and a severe disengage deficit (RHS/DD++ #1045); one had visuospatial neglect and a mild-to-moderate disengage deficit (i.e., a large disengage deficit score, but a non-significant disengage deficit pattern, RHS/DD+ #1385); and the final two did not have visuospatial neglect or a disengage deficit (RHS/DD- #1047 and #1388). See Table 4.

In summary, five of the sixteen individual right-hemisphere stroke participants, including the three with visuospatial neglect on standardized tests, had disengage deficit scores that were significantly larger than the mean of the older healthy control group. A significant disengage deficit pattern (i.e., severe disengage deficit) was seen in two individuals with neglect and a large disengage deficit score. A spatial bias was apparent in two stroke participants with neglect and a disengage deficit (one severe, one mild-to-moderate) and two stroke participants without neglect or a disengage deficit.

Limb movement effects on the disengage deficit:

To determine if there was a differential effect of limb movements on disengage deficit scores of the groups of stroke participants with and without a disengage deficit a repeated measures ANOVA with a between-subjects factor of Group (OHC, RHS/DD-,

RHS/DD) and within-subjects factors of Movement (NM, PM, AM) and Arm (L, R) was conducted. SOA was not included as a separate factor in these analyses as it was not significant in the previous omnibus mixed ANOVA and was not theoretically relevant to the study hypotheses. This analysis revealed significant main effects of Group and Movement as well as a significant Group-by-Movement interaction. See ANOVA table D13 in Appendix D. The main effect of Group followed by post-hoc independent t-tests confirmed that the mean overall disengage deficit score of right-hemisphere stroke participants with a disengage deficit was significantly larger than both the older healthy control group and the right-hemisphere stroke participants without a disengage deficit (RHS/DD: 80 ± 16ms, OHC: -8 ± 8ms, RHS/DD-: -14 ± 11ms; RHS/DD vs. OHC: $t_{23} = 4.20$, $p < 0.001$; RHS/DD vs. RHS/DD-: $t_{14} = 3.50$, $p = 0.004$), while the latter two did not differ ($t_{29} = 0.89$, $p = 0.382$).

The significant Group-by-Movement interaction was followed by post-hoc ANOVAs of each group which showed that there were no significant differences among movement conditions in any of the groups (OHC: $F(2,38) = 4.10$, $p = 0.025$, RHS/DD: $F(2,8) = 3.19$, $p = 0.096$, RHS/DD-: $F(2,20) = 4.54$, $p = 0.024$). See Figure 7. In contrast to the within-group post-hoc analyses, ANOVAs comparing the disengage deficit scores between the groups within each movement condition were all significant (NM: $F(2,33) = 27.97$, $p < 0.001$, PM: $F(2,33) = 6.23$, $p = 0.005$, AM: $F(2,33) = 5.85$, $p = 0.007$). Post-hoc Tukey HSD comparisons between the groups showed that in the no movement condition the disengage deficit score of the disengage deficit group (RHS/DD) was significantly larger than both the older healthy control group and the 'no disengage deficit' group while the latter two did not differ (NM: RHS/DD = 128 ± 94ms, RHS/DD-

= -2 ± 14ms, OHC = -14 ± 24ms; RHS/DD vs. OHC $p < 0.001$, RHS/DD vs. RHS/DD- $p < 0.001$, RHS/DD- vs. OHC $p = 0.675$). In the passive movement condition the 'disengage deficit' group only had a larger disengage deficit score than the older healthy control group (PM: RHS/DD = 71 ± 123ms, RHS/DD- = -5 ± 31ms, OHC = -15 ± 23ms; RHS/DD vs. OHC $p = 0.004$, RHS/DD vs. RHS/DD- $p = 0.018$, RHS/DD- vs. OHC $p = 0.862$). The significant difference between groups in the active movement condition was related to a larger disengage deficit score in the DD group than the DD- group, while the disengage deficit score of the older healthy control group was intermediate and did not differ from either of the stroke groups (AM: RHS/DD = 39 ± 81ms, RHS/DD- = -37 ± 37ms, OHC = 4 ± 35ms; RHS/DD- vs. RHS/DD $p = 0.008$, RHS/DD- vs. OHC $p = 0.048$, RHS/DD vs. OHC $p = 0.254$). See Figure 7.

Limb movement analyses of individuals with a disengage deficit:

Data from each of the five individuals with a disengage deficit (RHS/DD++, RHS/DD+) were analyzed to determine the individual effects of Limb Movement (NM, PM, AM) and Arm (L, R) on the disengage deficit. To further investigate the hypothesized effect of left limb movements on response latencies to invalidly-cued left targets data from each participant were analyzed in individual ANOVAs with within-subjects factors of Movement (NM, PM, AM), Arm (L, R), Cue (valid, invalid), and Target (L, R). Participants with a significant 4-way Movement-by-Arm-by-Cue-by-Target interaction in this reaction time analysis were assessed further with post-hoc ANOVAs and paired t-tests.

RHS/DD++ #1022:

The repeated measures ANOVA of disengage deficit scores for RHS/DD++ participant #1022 revealed a significant Movement-by-Arm interaction. See Appendix C2 for disengage deficit scores and ANOVA table D14.1 in Appendix D. Post-hoc t-test analyses showed that active movement of the left arm significantly reduced the disengage deficit score compared to the no movement and passive movement of the left arm as well as active right arm movement (AM_L arm: -58 ± 50ms, NM_L arm: 305 ± 64ms, PM_L arm: 279 ± 53ms, AM_R arm: 300 ± 66ms; AM_L arm vs. NM_L arm: $t_{19} = 4.92$, $p < 0.001$; AM_L arm vs. PM_L arm: $t_{19} = 4.75$, $p < 0.001$; AM_L arm vs. AM_R arm: $t_{19} = -4.96$, $p < 0.001$). In contrast, there were no differences in disengage deficit scores between movement conditions with right arm use (all $t < 2.2$, all $p > 0.05$). See figure 8.

To further examine the source of the effects of limb movement on the disengage deficit, the reaction time data underlying the disengage deficit were analyzed using a repeated measures ANOVA with within-subjects factors of Movement (NM, PM, AM), Arm (L, R), Cue (Valid, Invalid), Target (L, R) and SOA (100ms, 500ms). See raw reaction time data in Appendix C1 and ANOVA table D14.2 in Appendix D. SOA was maintained as a factor in this analysis to determine whether limb movements would differentially affect cueing effects by inducing IOR at longer SOAs. The analysis revealed significant main effects of Arm, Cue, Target, and SOA as well as a number of significant interactions including the theoretically significant four-way interaction among Movement, Arm, Cue, and Target. Post-hoc analyses of the significant four-way interaction were conducted using separate analyses of variance and paired t-tests of reaction time after right and left arm use.

The ANOVA of reaction times after right arm use (see ANOVA table D14.3 in Appendix D) revealed a main effect of Movement such that active right arm movements significantly increased overall reaction time compared to the no movement condition while passive movement was intermediate and did not differ from the other conditions (NM: 613 ± 20ms, PM: 682 ± 18ms, AM: 689 ± 17ms; NM vs. AM: $t_{19} = 3.01$, $p = 0.007$; NM vs. PM: $t_{19} = 2.46$, $p = 0.024$; PM vs. AM: $t_{19} = -0.39$, $p = 0.700$). In addition, there were significant main effects of Cue and Target as well as a significant interaction between Cue and Target. Post-hoc paired t-tests revealed the classic disengage deficit pattern with right arm use - significantly slower reaction time to invalidly-cued left targets than invalidly-cued right targets and validly-cued left targets (invalid left: 865 ± 38ms, invalid right: 604 ± 11ms, valid left: 606 ± 16ms, invalid left vs. invalid right: $t_{19} = 7.39$, $p < 0.001$, valid left vs. invalid left: $t_{19} = 6.20$, $p < 0.001$). See Figure 9a.

The ANOVA of reaction times after left arm use (see ANOVA table D14.4 in Appendix D) showed significant main effects of Movement, Cue, and Target, and a number of significant interactions including a the three-way interaction among Movement, Cue, and Target. Post-hoc cue-by-target ANOVAs in each movement condition revealed the classic disengage deficit pattern in the no movement and passive left-limb movement conditions. Significant Cue-by-Target interactions [all $F(1,19) > 20.0$, all $p < 0.001$] and slower reaction times to invalidly-cued left targets than invalidly-cued right or validly-cued left targets were apparent in these conditions (NM invalid left: 866 ± 45ms, invalid right: 607 ± 16ms, valid left: 537 ± 23ms, invalid left vs. invalid right: $t_{19} = 4.98$, $p < 0.001$, invalid left vs. valid left: $t_{19} = 6.59$, $p < 0.001$; PM invalid left: 809 ± 50ms, invalid right: 528 ± 17ms, valid left: 487 ± 25ms, invalid left vs. invalid

right: $t_{19} = 6.00$, $p < 0.001$, invalid left vs. valid left: $t_{19} = 5.42$, $p < 0.001$) . In contrast, after active left-limb movement the Cue-by-Target interaction was not significant [$F(1,19) = 1.34$, $p = 0.261$]. Furthermore, reaction times to invalidly-cued left targets were significantly reduced compared to the no movement condition (AM invalid left RT vs. NM invalid left RT: 628 ± 27ms vs. 866 ± 45ms, $t_{19} = 4.11$, $p = 0.001$) such that there was no significant difference between invalidly-cued left and right targets after active left limb movement (AM invalid left RT vs. AM invalid right RT: 628 ± 27ms vs. 624 ± 23ms, $t_{19} = 0.10$, $p = 0.918$) and the disengage deficit pattern of responding was no longer apparent. See Figure 9b.

In summary, RHS/DD++ participant #1022 showed a disengage deficit pattern of orienting and large positive disengage deficit scores in most limb movement conditions. Active left arm movement eliminated the disengage deficit, however, by producing a faster mean response latency to invalidly-cued left targets.

RHS/DD++ #1045

A RM ANOVA of the disengage deficit scores of RHS/DD++ participant #1045 with within subjects factors of Movement (NM, PM, AM) and Arm (L, R) revealed no significant main effects or interactions. See Appendix C2 for disengage deficit scores and ANOVA table D15.1 in Appendix D.

For consistency in the individual analyses and confirmation on the effects of lateralized limb movement on attentional orienting analysis of reaction time data was completed. A repeated measures ANOVA with within-subjects factors of Movement (NM, PM, AM), Arm (L, R), Cue (Valid, Invalid), Target (L, R) and SOA (100ms,

500ms) revealed significant main effects of Arm, Cue, Target, and SOA and significant two-way interactions between Movement and Cue, Movement and Target, Arm and Target, and Target and SOA. See raw reaction time data in Appendix C1 and ANOVA table D15.2 in Appendix D. As anticipated, the 4-way Movement-by-Arm-by-Cue-by-Target interaction relevant to the left limb movement effect on invalidly-cued left targets was not significant. In addition, the 3-way Movement-by-Arm-by-Target interaction that may indicate a differential effect of left limb movement on the spatial bias seen in this participant was not significant.

RHS/DD+ #1385, #1379, #1380:

Individual analyses of variance of the disengage deficit scores of RHS/DD+ participants # 1385, #1379, #1380, and #1047 revealed no significant main effects or interactions involving Movement and Arm. See Appendix C2 for disengage deficit scores and ANOVA tables D16.1, D17.1, and D18.1 in Appendix D.

In the analyses of limb movement effects on reaction time for these three participants there were no significant 4-way Movement-by-Arm-by-Cue-by-Target interactions and therefore no indication of left limb movement effects on orienting in right-hemisphere stroke participants without a disengage deficit pattern of response latencies. In addition, the 3-way Movement-by-Arm-by-Target interactions were not significant in these participants; indicating no differential effect of left limb movement on the spatial bias seen in participant #1385. See raw reaction time data in Appendix C1 and ANOVA tables D16.2, D17.2, and D18.2 in Appendix D.

Summary of limb movement effects on disengage deficit scores:

The right-hemisphere stroke group and the older healthy control group showed different effects of limb movements on disengage deficit scores. While there were no significant effects of limb movement on the disengage deficit scores of the older healthy control group, the mean disengage deficit score of the right-hemisphere stroke group overall was significantly smaller after active limb movement compared to the no movement condition. Comparison of disengage deficit scores of individual right-hemisphere stroke participants to the older healthy control group revealed a group of five participants with disengage deficit scores in the no movement condition that were larger than the mean of the older healthy control group (RHS/DD). The remaining eleven right-hemisphere stroke participants were included in a 'no disengage deficit' group (RHS/DD-). Within each of the right-hemisphere stroke groups separated by disengage deficit score (RHS/DD-, RHS/DD) there were no significant effects of limb movement. The trend on visual inspection toward decreasing magnitude of disengage deficit scores across movement conditions, however, showed the largest difference in disengage deficit scores between the no movement and the active movement conditions in both groups - a difference that was significant in the right-hemisphere stroke group as a whole. In addition, disengage deficit scores were equivalent for the older healthy control group and the 'no disengage deficit' group in all movement conditions. In contrast, the 'disengage deficit' group had significantly larger scores than the older healthy control group in the no movement and passive movement conditions, but active limb movement reduced the disengage deficit score to a level that did not differ from the older healthy control group.

Analysis of the pattern of reaction time data of the five individuals with large disengage deficit scores revealed two participants with severe disengage deficits and three with mild-to-moderate disengage deficits. Four of these five individuals showed no significant effects of limb movement on disengage deficit scores and no indication that left limb movement influenced orienting toward invalidly-cued left targets. In contrast, the participant with the largest disengage deficit score (RHS/DD++ #1022) showed the classic disengage deficit pattern of response latencies in all conditions except after active left limb movement where responses to invalidly-cued left targets were significantly faster than in the other movement conditions and the disengage deficit was ameliorated.

Visuospatial neglect and the disengage deficit are related to parietal damage in the right hemisphere (Losier & Klein, 2001; Posner et al., 1984). Therefore, investigations of the neuroanatomical lesions of stroke participants were undertaken to determine if lesion location differentially influenced the disengage deficit and the effect of left limb movement on the disengage deficit in right-hemisphere stroke participants.

Disengage deficit scores versus lesion location:

Pearson correlations between mean disengage deficit scores and the number of $1mm^3$ voxels of damaged brain tissue in relevant neuroanatomical areas were assessed for all right-hemisphere lesioned participants (n=16). In contrast to the stated hypothesis, the amount of damage in areas of interest in the parietal lobe was not significantly correlated with disengage deficit scores. Instead, these analyses showed that larger disengage deficit scores were related to larger overall lesion size and to more extensive damage in temporal

cortex and the perisylvian region (i.e., inferior frontal lobe, insular cortex, putamen and globus pallidus). See Table 5.

Further analysis of the lesion anatomy of the five right-hemisphere damaged participants with sufficiently large disengage deficit scores revealed that they all had lesions in the insular cortex, which overlapped in the majority of participants (80%) along with lesions involving the putamen, and rolandic operculum (RO). The second greatest overlap was seen in 60% of subjects (3 of 5) and covered a large area surrounding the temporoparietal junction (TPJ) and perisylvian region, including supramarginal gyrus (SMG), superior temporal gyrus (STG), middle temporal gyrus (MTG), inferior parietal lobe (IPL), precentral gyrus (PrCe), middle frontal gyrus (MFG), and globus pallidus. See table 6.

Anatomical regions of damage in the eleven right-hemisphere damaged participants without a disengage deficit (RHS/DD-) were diffuse with the majority having damage in the insular cortex (91%), putamen (82%), inferior frontal operculum (73%), and precentral gyrus (64%). See table C4 in Appendix C. However, the small area of maximum lesion overlap included only 54% of the participants and was in the corona radiata at the level of the body of the caudate and the lateral ventricle. The next largest degree of overlap in this group (45%) was in the area surrounding the temporoparietal junction (TPJ) and perisylvian region including the superior temporal gyrus (STG), supramarginal gyrus (SMG), rolandic operculum (RO), insular cortex, and putamen (table 6 and figure 10a).

Independent t-tests of the number of $1mm^3$ voxels of damage in each anatomical region of interest and the total lesion size revealed no significant differences in mean lesion magnitude between the RHS/DD and RHS/DD- groups [all $t_{14} < 2.5$, all $p > 0.05$]

Lesion analyses related to limb movement effects on the disengage deficit:

The investigation of lesion anatomy in relation to limb movement effects on the disengage deficit was accomplished through comparison of the lesion anatomy of the positive responder to left limb movement (RHS/DD++ #1022) and the combined lesions of the four null responders in the disengage deficit group (RHS/DD #1045, #1385, #1379, #1380). The lesion of the positive responder #1022 encompassed the ventral attention network areas anteriorly in the perisylvian region (i.e., the inferior frontal lobe, precentral gyrus, putamen and globus pallidus) and posteriorly in the temporoparietal junction (i.e., superior and middle temporal gyri and supramarginal gyrus extending into the inferior parietal lobe and angular gyrus). Damage to the dorsal attention network, however, was restricted to the dorsolateral prefrontal region (i.e., middle and superior frontal gyri) with no superior parietal involvement. See table 6 and figure 10b.

The four disengage deficit participants whose disengage deficit scores were not significantly altered by limb movements had variable lesions with the maximum overlap (3 of 4) seen in the insular cortex, rolandic operculum, putamen, and centrum semiovale (figure 10c). The one individual within this non-responding group who showed the disengage deficit pattern of orienting (RHS/DD++ #1045) had a very large lesion encompassing areas of the ventral and dorsal attention networks as well as subcortical structures involved in attention and motor pathways (i.e., thalamus and caudate nucleus).

Another individual in this non-responding group (RHS/DD+ #1385) had damage to the temporoparietal junction, perisylvian region, and inferior and superior parietal lobe but not to the superior frontal lobe. The final two individuals whose disengage deficit scores did not change with lateralized limb movements had circumscribed lesions in the insular cortex extending into the putamen (RHS/DD+ # 1379) or the rolandic operculum (RHS/DD+ #1380). See table 6.

DISCUSSION

Analysis of demographic and baseline neuropsychological variables revealed neglect in three of sixteen right-hemisphere stroke participants. Only neglect participants (2/3) showed evidence of visual extinction on confrontation testing. The stroke groups with and without neglect (RHS/N+, RHS/N-) did not differ in time post-stroke and these two groups did not differ in age or education from the healthy older-adult control group (OHC). In addition, the stroke group without neglect did not differ from the older healthy control group on any of the baseline tests of cognitive or sensory functioning. In contrast, the participants with neglect had lower scores on the Shipley Vocabulary subtest than the other two groups. In light of the nature of this test – requiring horizontal visual scanning, however, and the lack of difference between the groups on other tests of premorbid intellectual functioning (i.e., the NAART and orientation), it is unlikely that the groups differed in general cognitive functioning. General attentional functioning, however, was lower for the neglect group than the other two groups as assessed by scores on the TEA-elevator counting task.

In accord with decreased general attentional functioning, neglect, and extinction, results from a computerized visual perimetry task showed the neglect group was slower than both the healthy control group and the non-neglect group responding to targets presented on the left of fixation. The neglect and non-neglect groups did not differ on target detection latencies to right targets, but both stroke groups were slower than the older healthy controls responding to targets on the right of fixation. Sensory testing revealed a severe proprioceptive deficit of the left hand in the neglect participants, which was significantly worse than the other two groups, and an overall moderate level of proprioceptive dysfunction of the left hand in the non-neglect group that was not different from the mean score of the healthy control group.

There were no differences in the percentage of errors (miss, RT < 100ms, RT > 2000ms) on the experimental orienting task across conditions in the right-hemisphere stroke group. In addition, the right-hemisphere stroke group did not differ from the older healthy control group in the overall percentage of errors, false alarms or trials removed from analyses because of eye movements.

Effects of right-hemisphere stroke on covert orienting of attention:

Consistent with previous research (Robertson, 1993), the right-hemisphere stroke group responded more slowly overall than the older healthy control group on the covert orienting task, providing evidence for a non-lateralized attention deficit after right-hemisphere damage. As a group, however, the spatial orienting ability of right-hemisphere stroke participants at the short SOA (i.e., significant cueing effects) did not differ from the older healthy control group. In addition, cueing effects to left and right

targets remained positive, although not significant, for the right-hemisphere stroke group at the longer (500ms) SOA. In previous research with right-hemisphere stroke patients, the pattern of reduced cueing effects, but no IOR in either contralesional or ipsilesional visual field at longer SOAs, was related to the presence of a disengage deficit in patients with thalamic lesions and right parietal lesions (Rafal & Posner, 1987). In the current right-hemisphere stroke group the disengage deficit pattern of response (i.e., a Cue-by-Target interaction due to disproportionately long reaction times to invalidly-cued left targets) was not significant at either the short or the long SOA. In comparison to the older healthy control group, however, significantly larger cueing effect to left targets and no difference between the groups in cueing effects to right targets, suggested that a reduction in the efficiency of leftward orienting for the right-hemisphere stroke group became apparent at the longer SOA.

The inefficient visuospatial orienting ability of the right-hemisphere damaged individuals was also described with a disengage deficit score calculated by subtracting cueing effects to right targets from cueing effects to left targets (Losier & Klein, 2001). The disengage deficit score is expected to be equivalent to zero when orienting of attention is accomplished equally well to both sides of space and positive for right-hemisphere damaged individuals who have difficulty disengaging attention from the right in order to orient leftward (Losier & Klein, 2001; Posner et al., 1984). In accord with current hypotheses and previous research (Bartolomeo et al., 2001; Posner et al., 1984), results confirmed that the mean disengage deficit score of the right-hemisphere stroke group (averaged over arm used and SOA) was positive and significantly larger than that of the healthy older control group in the baseline no limb-movement condition.

In the no movement condition, the range of overall disengage deficit scores of the individual right-hemisphere stroke participants (-28.3ms to 283.9ms) was in keeping with disengage deficit scores calculated from reported reaction time data in other studies of covert orienting after right-hemisphere damage (Bartolomeo et al., 2001; D'Erme et al., 1992; Friedrich, Egly, Rafal, & Beck, 1998; Morrow & Ratcliff, 1988; Posner et al., 1984). Consistent with previous reports (Losier & Klein, 2001) and the current hypotheses, disengage deficit scores increased with the severity of neglect in the right-hemisphere stroke participants.

The pattern of response latencies in the covert orienting task in the individual right-hemisphere stroke participants revealed that a significant disengage deficit pattern was found only in participants with neglect (2/3), but not all neglect participants had a significant disengage deficit pattern. In addition to the disengage deficit response pattern, a rightward spatial bias pattern (i.e., significantly slower responding overall to left targets than right targets) was also apparent in one participant with a severe disengage deficit and neglect and in one participant with a mild-to-moderate disengage deficit and neglect. Neglect was not necessary for the spatial bias, however, as two participants without neglect, or a significantly large disengage deficit score, also showed a rightward spatial bias. It is possible that these two individuals, over the months since the onset of their strokes (24 and 59 months) had learned to compensate for a spatial bias on the visual scanning and drawing tasks used to define neglect, but were unable to use the same compensatory strategies to reduce their spatial biases on the novel and more sensitive orienting task requiring speeded responses.

Relationship of lesion location to orienting deficits:

Two types of orienting deficit were apparent in the response latencies to targets in the covert orienting task, a disengage deficit and a rightward spatial bias. In addition, there were a number of individuals with right-hemisphere stroke (11/16) who showed no pattern of orienting deficit on this task.

Consistent with previous studies, greater damage in the ventral attentional orienting network, including the perisylvian/retrorolandic region (Bartolomeo & Chokron, 2002) and the temporoparietal junction (Corbetta et al., 2005; Morrow & Ratcliff, 1988), i.e., inferior frontal lobe, superior temporal gyrus, insular cortex, and lenticular formation extending into the middle temporal and fusiform gyri, was related to the largest disengage deficit scores in individuals with right-hemisphere damage. There were no perisylvian or temporoparietal junction areas, however, whose damage distinguished participants with severe or mild-to-moderate disengage deficits from those without a disengage deficit.

In contrast to current hypotheses, however, there was no area within the parietal lobe where amount of damage was significantly correlated with larger disengage deficit scores in the group of right-hemisphere damaged participants. Instead, superior parietal lobe damage was present in all participants with a spatial bias and in only one participant without a spatial bias. The exceptional case was a participant noted in hospital records to have shown severe left neglect in the acute stage after stroke onset. In the 56 months since his stroke, however, he had over-learned compensatory strategies to reduce neglect symptoms to such an extent that he showed a leftward bias with a trend toward faster left-sided than right-sided target detection. Over time, spontaneous healing mechanisms in

addition to consistent endogenous attentional activation may have been sufficient to reactivate dysfunctional right-hemisphere neural pathways and thus re-balance hemispheric attentional mechanisms ameliorating neglect symptoms such as the spatial bias (Corbetta et al., 2005).

Further investigation of orienting ability and lesion location in the five right-hemisphere stroke participants with a disengage deficit revealed variability in the orienting deficits among participants that was related to damage of the ventral and dorsal attention networks. The lesion in the individual with the largest disengage deficit score and the classic disengage deficit pattern of responding (#1022), was consistent with damage to the ventral orienting pathway (Corbetta et al., 2005) as the largest areas of damage were in the temporo-parietal junction (STG and SMG) and the perisylvian region (STG, IF, precentral gyrus, insula, putamen) extending minimally to the dorsolateral prefrontal region (MFG & SFG) and not at all into the superior parietal lobe.

In contrast, the individual with neglect and the second largest disengage deficit score (#1045, 144.3ms) showed two deficient orienting functions: 1) disengaging attention from the right and 2) a spatial bias to the right (Corbetta et al., 2005) or difficulty engaging attention on the left (Rafal & Posner, 1987). These orienting deficits are consistent with this individual's large lesion involving the ventral orienting network (STG, SMG, IFO, RO, inferior precentral gyrus; Corbetta & Shulman, 2002; Posner & Petersen, 1990; Posner et al., 1984), anterior and posterior regions of the dorsal spatial attention network (SFG, MFG, Superior Precentral gyrus, SPL; Corbetta et al., 2005), and subcortical structures (thalamus; Rafal & Posner, 1987, and caudate nucleus).

The third right-hemisphere damaged individual with neglect had a mild-to-moderate disengage deficit (#1385) with no difference in cueing effects between the left and right visual field but consistently slower response latencies for left visual field targets than right visual field targets, suggesting a spatial bias to the right (Corbetta et al., 2005) or a deficit engaging attention on the left (Rafal & Posner, 1987). As the lesion in this individual involved ventral orienting network structures (STG, SMG, IFO, RO, precentral gyrus) and superior parietal lobe but not superior frontal lobe or thalamus, the orienting deficit is consistent with a spatial bias to the right brought on by an imbalance in superior parietal lobe functioning (Corbetta et al., 2005).

The final two individuals with disengage-deficit scores larger than the mean of the older healthy control group (#1379 and #1380) had no significant orienting deficit. These individuals had small circumscribed lesions involving the right insular cortex and putamen (#1379) or rolandic operculum (#1380). Orienting results from these participants suggest that a minor imbalance in hemispheric activation in the perisylvian region was sufficient to result in slightly larger cueing effects to left targets than right targets. With an intact temporoparietal junction; however, the damage was insufficient to result in statistically significant differences in orienting between the left and right hemispace.

Effects of limb movements on the disengage deficit after right-hemisphere stroke:

In the right-hemisphere stroke group as a whole, active limb movement significantly reduced the disengage deficit score compared to the no movement condition. In contrast, there was no effect of limb movement on disengage deficit scores of the older

healthy adult group. The right-hemisphere stroke group results suggest that intentional, and to a lesser degree passive, limb movements prior to orienting could affect the disengagement of attention, but further analysis of individual stroke patients was required to determine whether limb movement effects on individuals with a disengage deficit was related to a decrease in reaction time to invalidly-cued left targets after left limb movements as hypothesized.

The lack of significant limb movement effects on disengage deficit scores overall in the stroke groups with and without a disengage deficit (RHS/DD+, RHS/DD-) was potentially due to a lack of power in the analyses of these small groups (n=5 and n=11 respectively). One indication of such was the significant reduction in the disengage deficit score after active movement in the right-hemisphere stroke group as a whole. In addition, the disengage deficit of the disengage deficit group was reduced to a level no different from the older healthy control group after active limb movement, while scores in the no movement and passive movement condition were significantly larger than the older healthy control group. Furthermore, active limb movement reduced the disengage deficit score of the 'no disengage deficit' group to a level below that of the disengage deficit group in the active movement condition.

Further investigations of individual right-hemisphere stroke participants with severe or mild-moderate disengage deficits showed variable effects of limb movement that appeared dependent upon the level of disengage dysfunction and lesion location in areas of relevant attention and motor pathways. Consistent with a previous case study of prior limb movement in left hemispace improving detection of left-sided targets in a bilateral presentation (Mattingley et al., 1998) and in accord with current hypotheses,

active left limb movement decreased the disengage deficit in one individual with a severe disengage impairment, RHS/DD++ #1022, by decreasing reaction time to invalidly-cued left targets compared to the no movement condition. However, passive movement of the left arm or any right arm movement did not significantly alter the disengage deficit pattern of response on the covert orienting task. While damage to the ventral attention network (i.e., temporo-parietal junction and perisylvian region) is the suspected cause of the disengage deficit seen in this individual, the ability to re-orient attention efficiently after intentional left limb movements indicates that the mechanism to accomplish this orienting function was available under the correct set of circumstances.

In healthy individuals, the planning and execution of intentional unilateral limb movements have been shown to activate a number of contralateral cortical and subcortical areas that are also related to the dorsal and ventral attention networks including pre- and post-central gyri (Weiller et al., 1996), dorsal premotor cortex (Boussaoud, 2001), middle and inferior prefrontal cortex (Simon et al., 2002), supramarginal gyrus (Weiller et al., 1996), and putamen (Weiller et al., 1996). A previous report of identical contralateral sensorimotor cortex activation during active and passive right elbow movement, but preferential activation of the supramarginal gyrus, basal ganglia, and cingulate gyrus during active movement (Weiller et al., 1996), suggests that increased efficiency re-orienting attention after active but not passive left limb movement is related to the increase in activation of the right supramarginal gyrus (Weiller et al., 1996). In addition, increased activation in the perisylvian region during active movement would theoretically enhance orienting ability by further re-balancing hemispheric activity in the ventral network (Corbetta et al., 2005). Contrary to predictions based on the

premotor theory (Rizzolatti & Gallese, 1988), passive left limb movement, which has been shown to activate the contralateral dorsal premotor cortex (Boussaoud, 2001) and area SII in the inferior parietal cortex (Weiller et al., 1996), did not have the same positive effect on the disengage deficit, although the trend was in the correct direction. It should be recalled, however, that this individual had a severe proprioceptive deficit in the left hand. The indication here is that, the network of brain areas activated during passive limb movements are related to proprioceptive functioning (Mima et al., 1999) and they are anatomically separate from and have little cross-connection with the ventral orienting network and therefore little direct effect on any hemispheric imbalance relevant to orienting attention (Corbetta & Shulman, 2002; Mima et al., 1999; Weiller et al., 1996).

While a second individual had a severe disengage deficit based on the criteria set forth in this study (RHS/DD++ #1045), this individual also had a simultaneous spatial attention bias. The lack of effect of limb movements on the disengage deficit in this case was consistent with structural damage to areas of proprioception and motor control in the right hemisphere including supplementary motor area, cingulate gyrus, caudate nucleus and thalamus (Weiller et al., 1996) which were not damaged in the individual with a positive effect of left limb movement on orienting.

The remaining three stroke participants with disengage deficit scores larger than the older healthy control group did not show any evidence of limb movement effects on disengage deficit scores. Because these individuals did not have the 'classic' disengage deficit response pattern during orienting of attention, no improvement in attentional disengagement from the right by left limb movement would be expected based on the current limb movement hypothesis. Taken together, the limb movement results of the five

right-hemisphere stroke participants discussed here strongly suggest that in the presence of a deficit disengaging attention and the availability of neural resources in contralateral motor and attention networks, unilateral active limb movements may enhance functioning of the contralateral ventral orienting network but not the dorsal spatial attention network.

Chapter 11

GENERAL DISCUSSION

In summary, the main findings of this dissertation were as follows:

Study 1: The effects of aging and limb movements on orienting in healthy adults.

A) As reported in the literature on exogenous covert orienting of attention (Faust & Balota, 1997; Festa-Martino et al., 2004; Hartley & Kieley, 1995; Lorenzo-Lopez et al., 2002; Posner & Petersen, 1990; Posner et al., 1985), significant cueing effects were produced at the 100ms SOA and the cueing effect was larger for the older healthy adults than the younger healthy adults. At the 500ms SOA, the magnitude of the IOR effect was not affected by aging from the second to the sixth decade, although the effect did not reach statistical criterion in the older adults. In addition, despite generally faster target detection latencies at the longer SOA than the shorter SOA, the older healthy control group was slower than the younger healthy control group to respond to targets at the 500ms SOA.

B) Unilateral passive or active limb movements had no effect on the orienting ability of the healthy young adult group. In contrast, the older group showed reduced facilitation by valid spatial cues and had smaller cueing effects in the covert orienting task at the 100ms SOA after actively moving either one of their arms compared to no limb movement. There were no effects of limb movements on orienting at the 500ms SOA in the older healthy adult group. These results suggested that the orienting inefficiency seen at the short SOA after active limb movements was related to switching attention from the limb movement back to the visual orienting task and this effect

dissipated over time between the short and long SOAs. In relation to the lack of limb movement effect in the younger adult group, changes in cueing effects in the older healthy adults also suggested that there may have been more initial neural recruitment of attentional resources by active limb movement in the older healthy adult group than the younger healthy adult group.

Study 2: Effects of right-hemisphere stroke and limb movements on covert orienting of attention

A) Right-hemisphere stroke participants showed significant cueing at the short SOA and positive but non-significant cueing effects at the 500ms SOA. As hypothesized, the mean disengage deficit score of the right-hemisphere stroke group was larger than that of the older healthy control group. In addition, within the right-hemisphere stroke group disengage deficit scores were positively correlated with neglect severity. There was, however, no significant disengage deficit pattern of responding (Posner et al., 1984) in the right-hemisphere stroke group overall (i.e., a significant Cue-by-Target interaction due to differentially slowed reaction time to invalidly-cued left targets, Losier & Klein, 2001; Posner et al., 1984).

B) There were two patterns of orienting deficits apparent in individual stroke participants' responses to the orienting task: a disengage deficit pattern and a rightward spatial bias (i.e., slower reaction times to all targets in the left visual field compared to those in the right visual field regardless of cue validity). The disengage deficit pattern was dependent upon the presence of neglect, but neglect also occurred in the absence of a significant disengage deficit pattern. In contrast, neglect was equally likely to be present

or absent in participants with a spatial bias and the spatial bias was not present in all neglect participants.

C) Disengage deficit scores were not correlated with the number of $1mm^3$ voxels damaged in the right parietal lobe as expected, but were positively correlated with the amount of damage to areas within the ventral orienting network, i.e., right perisylvian region including the inferior frontal lobe, superior temporal gyrus, insular cortex and lenticular formation (putamen and globus pallidus). The spatial bias was attributed to damage in the right superior parietal lobe. Variability in covert orienting ability among the five participants with large disengage deficit scores, i.e., a disengage deficit response pattern, a rightward spatial bias or no lateralized orienting deficit, was related to the amount of damage in the ventral orienting network and/or the dorsal spatial attention network.

D) Active limb movements significantly decreased the disengage deficit scores of the right-hemisphere stroke group compared to no limb movement, to a level equivalent to the older healthy control group. There was variability in limb movement effects, however, between stroke groups with and without a disengage deficit. Limb movement effects in the 'no disengage deficit' group were not different from the older healthy control group, while active limb movement in the disengage deficit group reduced disengage deficit scores to the level of the older healthy control group from significantly larger scores in the no movement condition. There were no significant changes in disengage deficit scores after passive limb movements, although the trend was in the expected direction.

In accord with current hypotheses, left limb activation decreased the disengage deficit in one individual with neglect and a severe disengage deficit (RHS/DD++ #1022) whose lesion involved the ventral orienting network but not the superior parietal region of the dorsal spatial attention network. Active left limb movements initiated prior to covert orienting ameliorated the disengage deficit that was apparent in all other limb movement conditions (i.e., no movement and passive movement of either arm and active movement of the right arm) by reducing response latencies to invalidly-cued left targets.

In contrast, left limb movements prior to orienting did not reduce the severe disengage deficit in a second individual who also had neglect and a rightward spatial bias (RHS/DD++ #1045), whose stroke lesion encompassed anterior and posterior aspects of the ventral and the dorsal attention networks as well as subcortical regions involved in attention and motor pathways. In addition, unilateral limb movements did not affect orienting in individual right-hemisphere stroke participants with mild-to-moderate disengage deficits, i.e., no evidence of disproportionately slow responses to invalidly-cued left targets.

The overall interpretation of these results requires an understanding of the networks of brain areas involved in covert visuospatial orienting of attention as well as the dysfunction seen in these networks when orienting deficits are apparent, in particular the disengage deficit hypothesized in visuospatial neglect after right-hemisphere damage. Secondly, it is important to understand the activating effects of limb movements in regard to both empirical data from imaging studies and the theorized mechanisms for the amelioration of neglect by left limb movements in left hemispace. The relevant theoretical approaches include Rizzolatti's Premotor Theory (Rizzolatti & Camarda,

1987; Rizzolatti & Gallese, 1988), the Hemispheric Imbalance hypotheses of Kinsbourne (1987) and Corbetta et al. (2005), and the Recruitment hypothesis espoused by Reuter-Lorenz et al. (1999).

Aging and Right-hemisphere Stroke Effects on Orienting of Attention

The covert orienting paradigm in this study utilized exogenous spatial cues to orient attention to the left or right side of a central fixation cross prior to the presentation of a left or right target, which required a verbal response. While orienting attention with exogenous cues enables a preferential response to targets at attended locations within about the first 300ms of the onset of the cue, after this time period response to the cued location is inhibited in relation to the uncued location and IOR results (Klein et al., 1992; Posner & Cohen, 1984; Posner et al., 1985; Vecera & Rizzo, 2003). Although these effects of cueing on attention are typically shown with a manual 'button press' response by healthy young adults, the current data show that similar orienting effects in young healthy adults can be exhibited using a timed vocal response. Previously reported effects of normal aging such as slowed response latency (Festa-Martino et al., 2004) and inefficient orienting of attention (Faust & Balota, 1997; Hartley & Kieley, 1995) were also replicated using the vocal response methodology in the current study.

Aging effects such as slowed response latencies and inefficient orienting of attention are consistent with the recruitment hypothesis which suggests that older adults show differential neural activation (greater in some areas, less in others) compared to younger adults on the same task (Reuter-Lorenz et al., 1999). In addition, there is evidence from studies of neural recruitment that the decline in neural efficiency with age

is inconsistent with the hypothesis of greater right-hemisphere than left-hemisphere decline (Goldstein & Shelley, 1981 as cited in Reuter-Lorenz et al., 1999). However, in assessing neural recruitment in ventral and dorsal visual pathways by older adults, Grady et al. (1994) showed greater slowing of reaction time in a location-matching task than a face-matching task that suggested spatial abilities may be particularly affected by aging.

In the present exogenous orienting study, longer response latencies and a weak IOR effect at a 500ms SOA in healthy aging suggested a decrease in the efficiency of the posterior orienting system and perhaps the anterior alerting network (Posner & Petersen, 1990). In the orienting literature with young healthy adults, the time course of IOR has been shown to be dependent upon experimental conditions. For example, Lupianez et al. (2001) reported late emergence of IOR for discrimination tasks but not detection tasks, and suggested that differences in the time course of cueing effects depend on the processing demands of the task not the response selection requirements. In contrast, the early emergence of IOR has also been reported. In an exogenous target detection task, Pratt and Fischer (2002) showed that IOR was present at a 200ms SOA when a fixation cue was presented following a peripheral cue, but not when the fixation cue was absent or if the fixation cue onset coincided with the peripheral cue offset. These authors suggested that fixation cues advance the timing of IOR but 'a minimum amount of time is required to disengage attention after it has been captured by a peripheral cue'. They concluded that their results were consistent with the idea that facilitation and inhibition are separate processes each with its own particular time course, as espoused by Danziger and Kingstone (1999).

In the present study using a 500ms SOA, a non-significant IOR effect in older adults and a small positive cueing effect in right-hemisphere stroke participants without a disengage deficit are consistent with slowing of the time course of the IOR effect in relation to inefficient or dysfunctional attentional systems. The reported cue-to-target SOA threshold, before which cueing effects are apparent and after which IOR is apparent (approximately 300ms; Lupianez et al., 2001; Posner et al., 1985), appeared to be lengthened by aging and by right-hemisphere damage such that IOR was inconsistent for older healthy adults and absent for right-hemisphere stroke participants at the 500ms SOA. This result is consistent with previous orienting studies with right-hemisphere stroke participants who continue to show positive though declining cueing effects at SOAs up to and including 1000ms (Bartolomeo et al., 2001; Morrow & Ratcliff, 1988; Posner et al., 1984). Previous studies investigating aging effects on IOR using peripheral informative cues (mixed exo/endo) however, reported positive cueing effects at 500ms and 700ms SOAs (Lorenzo-Lopez et al., 2002) and IOR at an 800ms SOA (Faust & Balota, 1997). Together current results and previous research suggest that IOR may have been more robust for the older healthy control group if another longer SOA (e.g., 800ms or 1000ms) was used, while cueing effects would likely still have been apparent in the right-hemisphere stroke group. The inefficiency of alerting cues seen in the older healthy control group (Festa-Martino et al., 2004; Grady et al., 1994; Reuter-Lorenz et al., 1999) appeared to be compounded by right-hemisphere damage in some cases, leading to inefficiencies in visuospatial attention, such as a rightward spatial bias, a deficit disengaging attention from the right hemispace, and spatial neglect (Mattingley et al., 1997; Corbetta et al., 2005; Posner et al., 1984; Riddoch & Humphreys, 1994).

Neglect is frequently seen after lesions of the right temporoparietal junction, especially the superior temporal gyrus, supramarginal gyrus, and the angular gyrus (Corbetta et al., 2005; Karnath et al., 2001; Leibovitch et al., 1998; Mort et al., 2003; Vallar, 2001; Vallar & Perani, 1986), but it has also been related to damage in the right inferior frontal lobe, thalamus, and basal ganglia (Damasio et al., 1980; Karnath et al., 2002). The subcortical damage related to neglect has been associated with the anatomical connections between these areas and the superior temporal gyrus (Karnath et al., 2002). In addition, the neuroanatomical connection between neglect and ventral stream orienting deficits was illustrated recently by Corbetta et al. (2005). These authors suggested that damage or dysfunction within both the dorsal spatial attention and ventral orienting networks are necessary for the manifestation of neglect and furthermore, that direct damage to the temporoparietal junction may cause both neglect and an orienting deficit through a functional disconnection of the dorsal spatial attention network and structural damage to the ventral re-orienting network (Corbetta et al., 2005).

Consistent with Corbetta's work, the three right-hemisphere stroke participants with neglect (#1022, #1045, #1385) in the present study all had damage to the perisylvian region (inferior frontal lobe, anterior superior temporal gyrus, insular cortex, and lenticular formation) and the temporoparietal junction (superior and middle temporal gyri and supramarginal gyrus) and they all had larger disengage deficit scores than the older healthy control group. Damage in the perisylvian region and temporoparietal junction, however, was not restricted to those participants with neglect and the disengage deficit pattern of response latencies. The positive correlations between the magnitude of the disengage deficit scores of the stroke participants and the severity of chronic neglect and

the amount of structural damage in the ventral orienting network are consistent with results of the meta-analysis of disengage deficit scores reported by (Losier & Klein, 2001) and with hemispheric imbalance hypotheses (Corbetta & Shulman, 2002; Kinsbourne, 1987). As the level of structural and functional inactivation in right-hemisphere attention networks increases, the relative hyper-activation in the left hemisphere also increases and the greater activation imbalance between the two hemispheres is reflected in more severe neglect and greater disengage deficits (Corbetta et al., 2005; Corbetta & Shulman, 2002; Kinsbourne, 1987).

In accord with Corbetta's account of reactivation of attention networks in later stages of stroke recovery (Corbetta et al., 2005), one participant with a large lesion involving ventral and dorsal attention networks (#1034) did not exhibit neglect, a disengage deficit, or a spatial bias more than four years post-stroke. In contrast, the presence of both a rightward spatial bias and a disengage deficit in a patient with similar areas of damage (#1045), who was also more than four years post-stroke, indicated that activation within the hemispheres remained imbalanced in the chronic stages of this patient's recovery and that the available auditory and visuospatial cues were unable to enhance orienting ability or diminish a spatial attention bias.

Despite the likelihood of an age-related reduction in efficiency of intact attentional pathways (Festa-Martino et al., 2004), the ability to re-orient attention in a participant with ventral network and superior parietal lobe damage (#1385) is consistent with the availability of neural resources within the anterior alerting network, which enhance visuospatial orienting (Callejas et al., 2004). Presumably the functional alerting network assisted in the reactivation of dysfunctional areas of the temporoparietal junction

that were not structurally damaged (Corbetta et al., 2005). This may describe how the chronic hemispheric imbalance in the orienting network was decreased and the ability to disengage attention from the right to re-orient leftward was relatively restored. As this participant continued to manifest a spatial bias, however, it appears that activation of the alerting network by auditory and spatial cues and neural reactivation in the chronic stage of recovery were insufficient to reactivate the damaged superior parietal lobe to the same degree that alerting and reactivation improved the re-orienting function related to the temporoparietal junction.

Participants with significant disengage deficit scores, who had circumscribed lesions in the right subcortical perisylvian area (i.e., putamen and insular cortex/rolandic operculum), but no specific orienting or spatial attention deficits may have been slowed by the 'normal' aging effects of neural recruitment and inefficient spatial abilities (Grady et al., 1994; Reuter-Lorenz et al., 1999). While attention to left-sided stimuli may have been further reduced by the hemispheric activation imbalance related to the presence of chronic right-hemisphere lesions (Corbetta et al., 2005; Kinsbourne, 1987), this imbalance was tempered by the lack of damage in posterior regions of the right ventral attention network (i.e., the temporoparietal junction). Hence, the disengage deficit scores were larger than the mean of the older healthy control group but the hemispheric orienting differences were not large enough to be statistically significant.

The speculation in each of these cases about the relative hemispheric imbalance in the dorsal and ventral attention networks and the potential ameliorating effect of auditory and visuospatial alerting cues cannot be confirmed with the present data. Confirmation of individual differences in baseline activation and re-activation in the structurally and

functionally damaged networks requires further study with functional imaging to elucidate relevant activation patterns during an exogenous covert orienting task.

Limb Movement Effects on Orienting in Healthy Aging and Right-hemisphere Stroke

Active and passive limb movements prior to orienting had no effect on target detection latencies in young healthy adults; however, a decline in cueing effects at the short SOA was seen in older adults when active limb movements were initiated prior to visual orienting. This reduced orienting efficiency is suspected to be due to difficulty switching attention from the motor task to the visual task. This difficulty likely results from a decrease in available orienting resources as already inefficient attentional pathways (Festa-Martino et al., 2004) are recruited by the unilateral active limb movement (Grady et al., 1994; Reuter-Lorenz et al., 1999). The lack of effect of limb movement in the younger healthy adult group was likely because interference caused by multiple tasks using the same brain areas has a more pronounced effect on functioning as the brain ages, principal networks become less efficient, and more brain areas are recruited to complete tasks (Reuter-Lorenz et al., 1999). This finding of a negative effect of limb movements on orienting in healthy older adults merits further research as it is in direct opposition to the hypothesis of increased right-hemisphere activation and a positive left limb movement effect on leftward orienting after right-hemisphere damage.

In accord with present limb movement hypotheses, active limb movement by the right-hemisphere stroke group reduced the disengage deficit score in comparison to the no movement condition. The positive effect did not interact with side of limb movement, however, indicating that active right limb movement also decreased the disengage deficit,

at least to some degree, in this group. The hypothesized positive left limb movement effect on leftward orienting was apparent, however, after active movement by a participant who had a severe disengage deficit and neglect, and whose lesion involved the right ventral orienting network but did not affect the superior parietal lobe.

The significant positive effect of active limb movement on the disengage function of orienting can be explained by the re-balancing hypothesis introduced by Corbetta et al. (2005). A large disengage deficit score in the no movement condition is related to a hemispheric imbalance resulting from the right-hemisphere lesion and resultant decrease in activation in the right-hemisphere attention networks compared to the intact left hemisphere (Corbetta & Shulman, 2002; Kinsbourne, 1987). Therefore, reduction of the disengage deficit score after active limb movement may occur by rebalancing activation between the attention networks in the two hemispheres (Corbetta et al., 2005; Corbetta & Shulman, 2002). To rebalance activation between the hemispheres and reduce the disengage deficit score the right hemisphere activation must increase and/or the left hemisphere activation must decrease. Active right limb movement in the right-hemisphere stroke group as a whole may be responsible for the recruitment of neural resources (Reuter-Lorenz et al., 1999) required by the ventral orienting network in the undamaged left hemisphere (e.g., supramarginal gyrus; Weiller et al., 1996), resulting in a decrease in available attention resources in the left hemisphere similar to the hypothesized effect in the older healthy adult group. In contrast, active left limb movement may increase activation and improve efficiency of the damaged right-hemisphere attentional networks related to orienting attention. Either (or both) of these theorized processes may result in a reduction in the disengage deficit score by active limb

movement through rebalancing of the hemispheric attentional networks (Corbetta et al., 2005; Corbetta & Shulman, 2002). However, as reported in a previous behavioural study on the effects of limb movement on left target detection accuracy in bilateral trials of a computerized visual extinction task after right-hemisphere stroke (Mattingley et al., 1998), left limb movement is expected to have a greater attentional effect than right limb movement. With left limb movement the left hemisphere continues to function at its maximal level and activation increases in the right hemisphere, while there is a combination of defective right hemisphere attentional functioning and the hypothesized decrease in activation in the left hemisphere attention network with right limb movement. These relevant theoretical arguments require further study using functional imaging techniques to confirm the hypothesized increase in activation in the damaged right hemisphere attention network and decrease in activation in the intact left hemisphere attention network with active limb movement.

Of the remaining four disengage deficit participants, who did not benefit from limb movement, one had a rightward spatial attention bias as well as a disengage deficit, which was consistent with evidence of extensive right hemisphere damage involving the dorsal spatial attention and ventral orienting networks as well as subcortical motor areas. The lack of left limb movement effect on the disengage deficit in this individual is likely due to the damaged and inefficient right-hemisphere cortical and subcortical motor networks preventing neural activation in shared orienting and motor areas (e.g., supramarginal gyrus; Mima et al., 1999; Weiller et al., 1996). Damage to motor pathways that is sufficient to disrupt facilitation of spatial attention networks related to them (Rizzolatti & Camarda, 1987; Rizzolatti & Gallese, 1988) may be a partial explanation

for the inconsistent effect of left limb movements on neglect symptoms in behavioural studies (Cubelli et al., 1999; Eskes et al., 2003; Robertson, 1991).

In addition to insufficient motor pathway activation, the lack of statistically significant left limb movement effects on the spatial attention bias or in those participants without a significant lateralized orienting deficit after right-hemisphere stroke, suggests that there is a specific deficit in disengaging attention that benefits from lateralized limb movements. It appears that active left limb movements specifically enhanced the disengage function of covert orienting when the appropriate hemispheric motor and attentional resources were available.

In contrast to the positive effect of active limb movement on the disengage deficit score, response latencies after passive movement were frequently intermediate between the no movement and active movement conditions and not statistically significant. The lack of a significant effect of prior passive limb movement on orienting or spatial attention, suggests that the relatively weak activation of the pre- and post-central gyri, supplementary motor area and inferior parietal cortex after passive movement (Mima et al., 1999; Weiller et al., 1996) was insufficient in strength or location to result in effective re-balancing of hemispheric activation within the attention networks. Contrasting evidence from passive movement studies that found a positive effect on neglect using line bisection and visual scanning tasks (Eskes et al., 2003; Frassinetti et al., 2001; Ladavas et al., 1997) suggests that task demands (i.e., visual scanning vs. cued target detection) and the related attentional mechanisms (i.e., endogenous vs. exogenous) have a significant effect on the ability of passive limb movements to influence attention. In previously published group studies reporting a positive effect of passive limb movements there was

no separation of dorsal and ventral network damage and participants with neglect had damage to variable brain regions, including frontal, subcortical, parietal, temporal, and combinations of these areas (Eskes et al., 2003; Frassinetti et al., 2001; Ladavas et al., 1997).

Rizzolatti's premotor theory (Rizzolatti & Camarda, 1987; Rizzolatti & Gallese, 1988), the hemispheric imbalance hypothesis of Kinsbourne (1987) and Corbetta's re-balancing hypothesis (Corbetta et al., 2005; Corbetta & Shulman, 2002) are all relevant in explaining decreased response latencies to left targets after a right cue and the concomitant reduction of the disengage deficit after active left limb movements in a stroke participant with right ventral network damage and minimal dorsal network and motor pathway damage. The specific reduction of the disengage deficit after active left limb movement suggests that increased activation of the damaged right-hemisphere ventral orienting network provides a mechanism for improved leftward orienting of attention in the chronic stage of stroke recovery. This active left limb movement result is consistent with the re-balancing of hemispheric activation through increased right superior temporal gyrus and supramarginal gyrus activation, which are areas shown to be activated during visuospatial orienting tasks and active, but not passive, limb movements (Corbetta et al., 2005; Corbetta & Shulman, 2002; Karnath et al., 2001; Karnath et al., 2002; Mima et al., 1999; Weiller et al., 1996).

Chapter 12

CONCLUSION

In the exogenous covert orient paradigm with a verbal response employed in this dissertation research, cueing effects were apparent at a short SOA and IOR was apparent at a long SOA in healthy participants. However, older healthy control participants were slower to respond in the covert orienting task than younger healthy participants, a result consistent with age-related reductions in the efficiency of attentional networks (Festa-Martino et al., 2004). In addition, prior contralateral limb movements interfered with the alerting and orienting functions of visuospatial attention in healthy older adults by recruiting resources from the already inefficient attentional networks (Reuter-Lorenz et al., 1999).

In participants with right-hemisphere damage, disengage deficit scores, which are related to the severity of neglect (Losier & Klein, 2001), were influenced differentially by damage to the dorsal spatial attention network that coincided with ventral orienting network damage. Four patterns of orienting deficits and the relevant differences in lesion locations were described: 1) a disengage deficit response pattern with no rightward spatial bias was seen after ventral orienting network damage and no superior parietal lobe damage; 2) a disengage deficit response pattern superimposed on a rightward spatial bias was seen after damage to anterior and posterior regions of the dorsal and ventral attentional networks; 3) a rightward spatial bias with no disengage deficit pattern of response was seen after ventral network damage and greater dorsal parietal than dorsal frontal damage; and 4) a relatively mild dysfunction in leftward compared to rightward

visuospatial orienting was seen after circumscribed damage to the perisylvian region of the ventral orienting network. The orienting deficits present in significantly large disengage deficit scores reflect the level of structural and functional inactivation in particular aspects of the right-hemisphere attention networks and the hypothesized relative hemispheric activation imbalance (Corbetta et al., 2005; Corbetta & Shulman, 2002; Kinsbourne, 1987).

In accord with Rizzolatti's premotor theory (Rizzolatti & Camarda, 1987; Rizzolatti & Gallese, 1988), the limb movement effect on attention appeared dependent upon the availability of neural resources within the motor network as well as the location of neural damage within the dorsal and ventral attention networks. Furthermore, active limb movements had a specific positive effect on the disengage function of attentional orienting, reducing response latencies to invalidly-cued ipsilateral targets only in the participant who showed the disengage pattern of response latencies in the no movement condition. Intermediate, non-significant effects of passive limb movement suggest that further study is necessary to determine whether passive limb movements affect specific orienting functions or the spatial attention bias that are related to the ventral and dorsal networks respectively. However, it seems likely that any limb movement effect on attention will be related to the availability of attentional and motor resources in the damaged hemisphere and the ability of the movement to recruit neurons within the affected attentional network in order to re-balance hemispheric activation within the affected system (Corbetta et al., 2005).

In conclusion, this dissertation supports an age-related inefficiency in spatial attentional functioning. In addition, lateralized, self-initiated limb movements prior to

visuospatial orienting have the ability to interfere with the orienting of attention in otherwise healthy older adults, presumably as a result of the recruitment of already inefficient attentional resources by the related motor activation. In contrast, attentional functioning after right-hemisphere damage was related to the degree of damage in the dorsal spatial attention and ventral orienting networks. On the exogenous covert orienting task disengage deficit scores were larger for the right-hemisphere stroke group than the healthy older controls. Disengage deficit scores in the stroke group were also related in magnitude to the severity of neglect and the amount of damage in right temporal, frontal, and subcortical regions of interest, while damage in the right perisylvian region and temporoparietal junction which form the ventral orienting network was greater in those stroke participants with than without a disengage deficit. In the presence of the disengage deficit pattern of response after right-hemisphere damage active limb movement provided sufficient activation within the contralateral ventral orienting network to re-balance the hypothesized hemispheric imbalance and ameliorate the disengage deficit. In addition, active limb movements had a greater effect on orienting than passive limb movements presumably because more brain areas involved in spatial attention were activated during active than passive limb movements. These limb movement effects appeared dependent upon the availability of sufficient neural resources within the attentional and motor networks of the affected hemisphere.

Table 1. Demographic and baseline test data (means and standard deviations) for young healthy controls (YHC), older healthy controls (OHC), right-hemisphere stroke participants without neglect (RHS/N-), and right-hemisphere stroke participants with neglect (RHS/N+).

	YHC (n=20)	OHC (n=20)	RHS/N- (n=13)	RHS/N+ (n=3)
Gender	7M	14M	10M	3M
Age: years	20.6 (2.7)*	61.7 (12.1)	60.5 (10.9)	65.3 (6.5)
Education: years	13.8 (2.0)	14.3 (3.6)	13.2 (4.5)	11.0 (1.0)
Months post-stroke	N/A	N/A	26.6 (20.4)	46.3 (21.0)
Orientation: mean / 12	11.95 (0.2)	11.9 (0.3)	11.9 (0.4)	12.0 (0.0)
NAART: FSIQ	104.9 (9.1)	105.0 (8.8)	106.4 (10.5)	95.6 (8.1)
Shipley Vocabulary: %ile	65.2 (20.9)	73.8 (21.3)	65.0 (25.7)	33.7 (42.7)*
BIT: # failed	0.1 (0.3)	0.3 (0.4)	0.7 (0.8)	5.0 (1.0)*
BIT: total score	145.4 (1.1)	144.5 (1.5)	143.5 (2.3)	118.7 (18.8)*
# with Extinction	0	0	0	2
TEA-EC: correct / 7	6.8 (0.4)	6.95 (0.2)	6.92 (0.3)	5.0 (2.0)*
JPS (left): correct / 60	60.0 (0.0)	60.0 (0.0)	50.1 (21.6)	7.0 (4.4)*
Perimetry (left): RT	403 (143)	395 (95)	497 (124)	940 (362)@
Perimetry (right): RT	432 (179)	401 (98)	558 (190)@	612 (88)@
Perimetry (left): # / 12	12.0 (0.00)	11.95 (0.05)	11.77 (0.05)	11.33 (0.67)
Perimetry (right): # / 12	11.95 (0.05)	11.95 (0.05)	11.77 (0.17)	12.0 (0.00)

NAART: North American Adult Reading Test, BIT: Behavioral Inattention Test, TEA-EC: Test of Everyday Attention-Elevator Counting subtest, JPS: Joint position sense (test of proprioception).
Based on ANOVA with post-hoc Newman-Keuls:
@ - significantly different from OHC group ($p < 0.05$)
* – significantly different from all other groups ($p < 0.05$)

Table 2. Pearson correlations (r) of disengage deficit scores in the no movement condition (NMDDS) and standardized measures of neglect for all right-hemisphere stroke participants (RHS, n=16) and for right-hemisphere stroke participants without neglect (RHS/N-, n=13).

	NMDDS	
	RHS (n=16)	**RHS/N-** (n=13)
BIT Total score	-0.534*	-0.511
BIT Line Cancellation	-0.593*	N/A#
BIT Letter Cancellation	-0.380	-0.696**
BIT Star Cancellation	-0.428	-0.141
BIT Figure Copy	-0.436	-0.209
BIT Line Bisection	-0.769**	-0.132
BIT Drawing	-0.838**	N/A#
BIT subtests failed/6	0.713**	0.287

* $p \leq 0.05$, ** $p \leq 0.01$
NMDDS – overall disengage deficit score in no movement condition
- correlation cannot be computed because variable is a constant (max score)

Table 3. Results of modified t-test analyses (illustrated by Crawford & Howell, 1998) of mean disengage deficit scores in the no movement condition (NMDDS) for individual right-hemisphere stroke participants compared to the mean disengage deficit score (± SD) of the older healthy control group.

	NMDDS (ms)	**T statistic (df=19)**
OHC group (n=20)	-14 (24)	
RHS/DD		
#1022 (N+)	284 (261)	12.21**
#1045 (N+)	145 (213)	6.48**
#1385 (N+)	93 (209)	4.37**
#1379	77 (159)	3.69**
#1380	43 (107)	2.32*
RHS/DD-		
#1386	20 (108)	1.40
#1047	19 (81)	1.36
#1382	8 (87)	0.89
#1387	0 (70)	0.58
#1375	0 (51)	0.55
#1384	-2 (144)	0.47
#1378	-2 (141)	0.47
#1381	-4 (142)	0.39
#1034	-8 (69)	0.21
#1376	-19 (101)	-0.20
#1388	-28 (197)	-0.60
DD- Group (n=11)	-2 (4)	$t_{29} = -1.55$

* $p \leq 0.05$, ** $p \leq 0.01$ (one-tailed)
RHS/DD: right-hemisphere stroke participants with a disengage deficit
RHS/DD-: right-hemisphere stroke participants without a disengage deficit
N+: Right-hemisphere stroke participants with neglect

Table 4. Mean reaction times, cueing effects, and disengage deficit scores in the No Movement condition (averaged over arm used and SOA). Reaction times and cueing effects that are significantly larger for left-sided than right-sided targets are in bold type.

	RT (ms) Left targets		Left Cuing Effect (ms)	RT (ms) Right targets		Right Cuing Effect (ms)	DDS (ms)
	Valid cue	Invalid cue	(Inv LT– Val LT)	Valid cue	Invalid cue	(Inv RT– Val RT)	(CE_LT-CE_RT)
OHC group (n=20)							
	442	446	4	437	455	18	-14
RHS/DD++ Severe disengage deficit							
#1022	532	**853****	**321****	550	588	38	**283****
#1045	**805****	**974****	**169****	402	426	24	**145****
RHS/DD+ Mild-to-moderate disengage deficit							
#1385	**776****	**948****	172	607	686	79	**93****
#1379	663	726	63	722	708	-14	**77****
#1380	674	728*	54	690	701	11	**43***
RHS/DD- No disengage deficit							
#1386	522	567	45	515	540	25	20
#1047	**530****	**557****	27	485	493	8	19
#1382	432	462	30	414	436	22	8
#1387	421	429	8	424	432	8	0
#1375	385	372	-13	374	361	-13	0
#1384	489	528	39	493	534	41	-2
#1378	631	677	46	595	643	48	-2
#1381	532	558	26	528	558	30	-4
#1034	500	508	8	538	554	16	-8
#1376	547	584	37	547	603	56	-19
#1388	**797****	**784****	-13	624	639	15	-28
DD- group (n=11)							
	526	548	22	503	527	24	-2

* - $p < 0.05$, ** - $p < 0.01$. RT – reaction time, CE_LT – cueing effect: left targets, CE_RT – cueing effect: right targets, Inv LT – invalidly-cued left target, Inv RT – invalidly-cued right target, Val LT – validly-cued left target, Val RT – validly-cued right target.

Table 5. Pearson correlations (r) between damage in neuroanatomical areas relevant to visuospatial orienting of attention (# of $1mm^3$ voxels damaged) and mean disengage deficit scores in the no movement condition for the right-hemisphere damaged participants (RHS; n=16).

Neuroanatomical region	n/16 : Median # voxels	Pearson r	p value
FRONTAL			
Rolandic operculum(18;112)	10 : 5064	0.549*	0.028
Inferior Frontal operculum(16;18)	11 : 2822	0.514*	0.042
Precentral Gyrus(16;18;112)	10 : 3257	0.513*	0.042
Middle Frontal Gyrus(2;16;18;39;112)	8 : 1444	0.428	0.098
Superior Frontal Gyrus(2;18;39)	6 : 240	0.404	0.121
Supplementary Motor Area(18;39;112)	3 : 10	0.352	0.181
Medial Superior Frontal Gyrus(16;39)	1 : 4970	0.352	0.181
Anterior Cingulate Gyrus(39;112)	2 : 1513	0.352	0.181
TEMPORAL			
Middle Temporal Gyrus (2;17;18;39;112)	8 : 11359	0.675**	0.004
Insular Cortex(18;39)	15 : 1311	0.661*	0.010
Sup. Temporal Gyrus(16-19;**35**;39;112)	8 : 16847	0.562*	0.023
Fusiform Gyrus(17;18;30;39)	5 : 836	0.673**	0.004
PARIETAL (84; 91)			
Supramarginal Gyrus(18;19;39;112)	8 : 9018	0.412	0.113
Precuneus(17;18;39)	4 : 2976	0.138	0.610
Superior Parietal Lobe(17;30;39;112)	5 : 2068	0.090	0.740
Inferior Parietal Lobe(2;16-19;**35**;112)	7 : 4839	0.024	0.930
Angular Gyrus(112)	6 : 7620	-0.082	0.762
SUBCORTICAL			
Globus Pallidus(18;39)	7 : 186	0.688**	0.003
Putamen(18;39)	13 : 969	0.634**	0.008
Caudate Nucleus(18;39)	7 : 147	0.152	0.574
Thalamus(18;39;**95**)	2 : 1595	-0.152	0.574
NON-CORTICAL	16 : 3326	0.451	0.080
TOTAL LESION SIZE	16 : 11402	0.541*	0.030

* $p \leq 0.05$, ** $p \leq 0.01$. References in bold type indicate behavioural studies, while plain type font refers to functional imaging studies.

Table 6. Number of $1mm^3$ voxels of damage in right-hemisphere neuroanatomical regions of interest for each of the five right-hemisphere stroke participants with a significant disengage deficit in the no movement condition (RHS/DD+). The right-most columns represent the mean number of damaged voxels in each neuroanatomical area for the RHS/DD+ group and the 'no disengage deficit' group (RHS/DD-, n=11).

Right-hemisphere Neuroanatomical region	RHS/DD+ participants Number of $1mm^3$ voxels damaged					RHS/ DD+	RHS/ DD-
	1022	1045	1385	1379	1380	mean # voxels	mean # voxels
FRONTAL							
Rolandic operculum[a]	9643	10145	10155	0	183	6025	2536
Inf. Frontal operculum[a]	4908	10428	9627	0	0	4993	1524
Precentral Gyrus[a]	8145	23242	12355	0	0	8748	1797
Middle Frontal Gyrus	1854	25250	4995	0	0	6420	383
Superior Frontal Gyrus[b]	1153	18066	12	0	0	3846	44
Suppl. Motor Area	11	16879	0	0	0	3378	1
Med. Sup. Frontal Gyr.	0	4970	0	0	0	994	0
Ant. Cingulate Gyrus	0	3022	0	0	0	604	0
TEMPORAL							
Mid. Temporal Gyrus[a]	17407	20157	19126	0	0	11338	2604
Insular Cortex[a]	12648	13247	13251	59	576	7956	2268
Sup. Temporal Gyrus[a]	20334	17710	21201	0	0	11849	4746
Fusiform Gyrus	1885	4126	638	0	0	1330	122
PARIETAL							
Supramarginal Gyrus[a]	9373	12520	11862	0	0	6751	2938
Precuneus	0	5829	0	0	0	1166	549
Superior Parietal Lobe[b]	0	5884	355	0	0	1248	861
Inferior Parietal Lobe	271	8014	2206	0	0	2098	1759
Angular Gyrus	70	6983	724	0	0	1555	2455
SUBCORTICAL							
Globus Pallidus	539	124	673	0	0	267	52
Putamen	4427	4949	7188	302	0	3373	870
Caudate Nucleus	0	256	486	4	0	149	54
Thalamus	0	62	0	0	0	12	284
NON-CORTICAL	37555	88582	36259	1304	755	32891	13383
TOTAL LESION SIZE	179253	451408	217895	1669	1848	170415	47598

Data from automated anatomical labelling template (Tzourio-Mazoyer et al., 2002) in MRIcro (http://www.sph.sc.edu/comd/ rorden/mricro.html).

[a] – ventral orienting network

[b] – dorsal spatial attention network

1) No Movement, Group-by-Cue-by-SOA interaction.

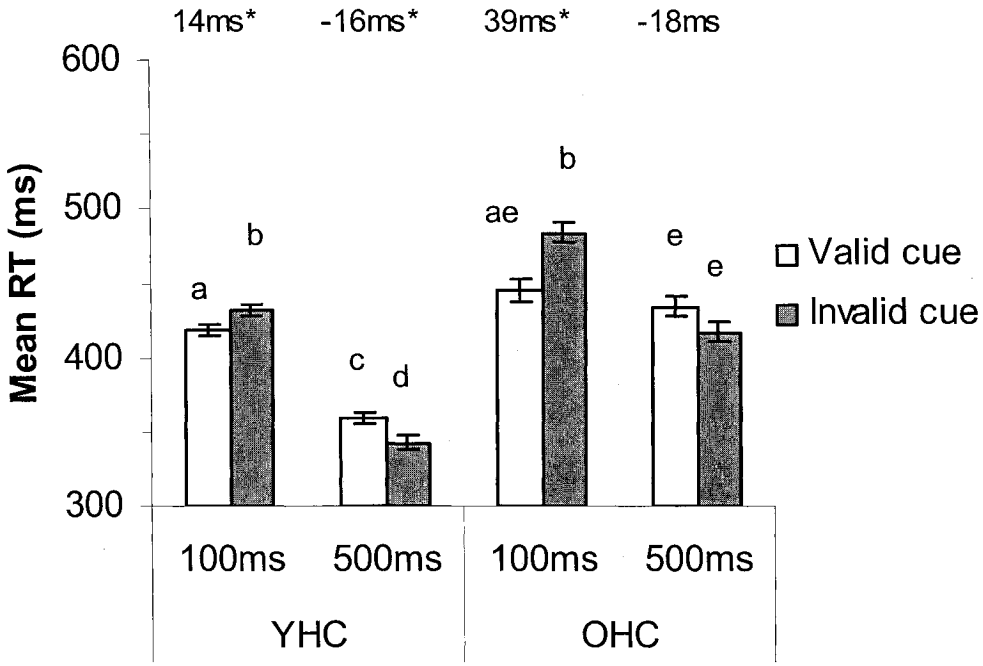
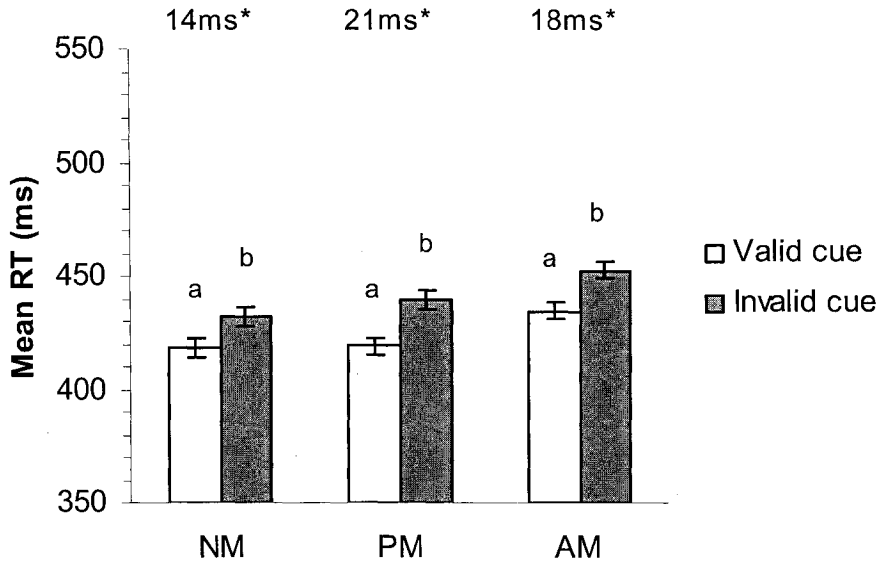


Figure 1. Mean reaction times to validly- and invalidly-cued targets at the 100ms and 500ms SOAs for each group (averaged over arm, and target-side). Corresponding cueing effects (CE = Invalid RT – Valid RT) at each SOA are shown at the top of the graph. Significant differences ($p \leq 0.01$) in RT between cue conditions, i.e., significant facilitation / IOR, are noted with asterisks. Conditions labeled with different letters (a, b, c, d) differ significantly ($p \leq 0.01$). Conditions with shared letters in their labels do not differ significantly. Error bars represent the within-subjects 95% confidence interval as specified by Masson & Loftus (2003).

2a) YHC: 100ms SOA limb movement analyses



2b) OHC: 100ms SOA limb movement analyses

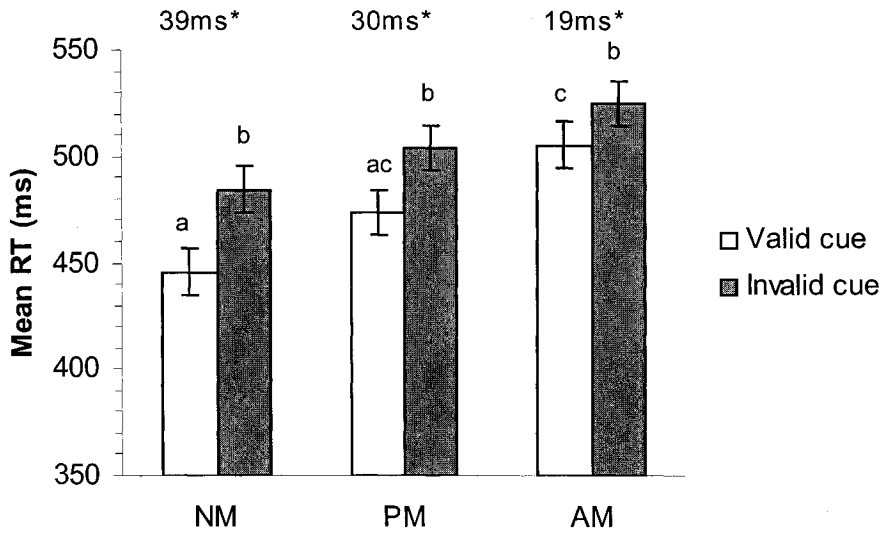
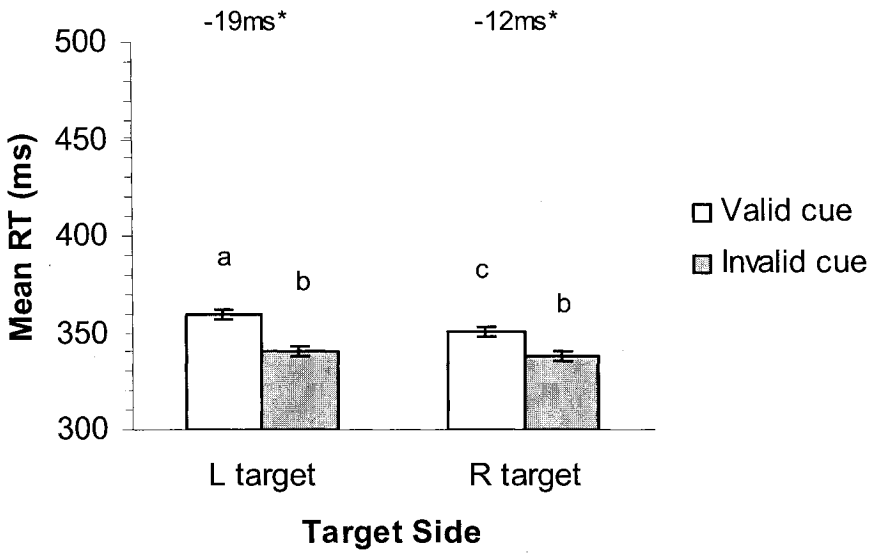


Figure 2. Mean reaction times of validly- and invalidly-cued targets in the no (NM), passive (PM), and active (AM) limb movement conditions at the 100ms SOA for the (a) younger control group (YHC) and (b) older control group (OHC). Corresponding cueing effects (CE = Invalid RT – Valid RT) at each SOA are shown at the top of the graph. Significant differences ($p \leq 0.01$) in RT between cue conditions, i.e., significant facilitation / IOR, are noted with asterisks. Conditions labeled with different letters (a,b,c) differ significantly ($p \leq 0.01$). Conditions with shared letters in their labels do not differ significantly. Error bars represent the within-subjects 95% confidence interval for the cue condition (a) and the interaction (b).

note mean RT scale

3a) YHC 500ms SOA limb movement analyses



3b) OHC 500ms SOA limb movement analyses

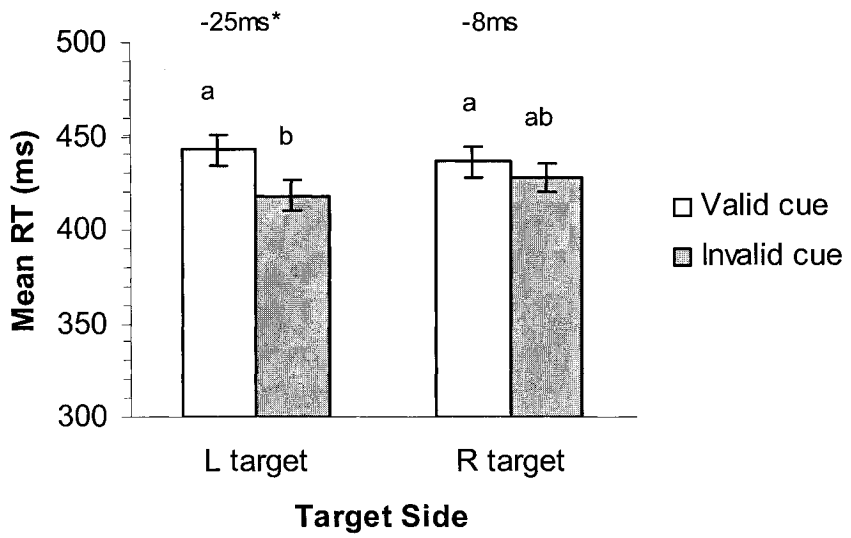
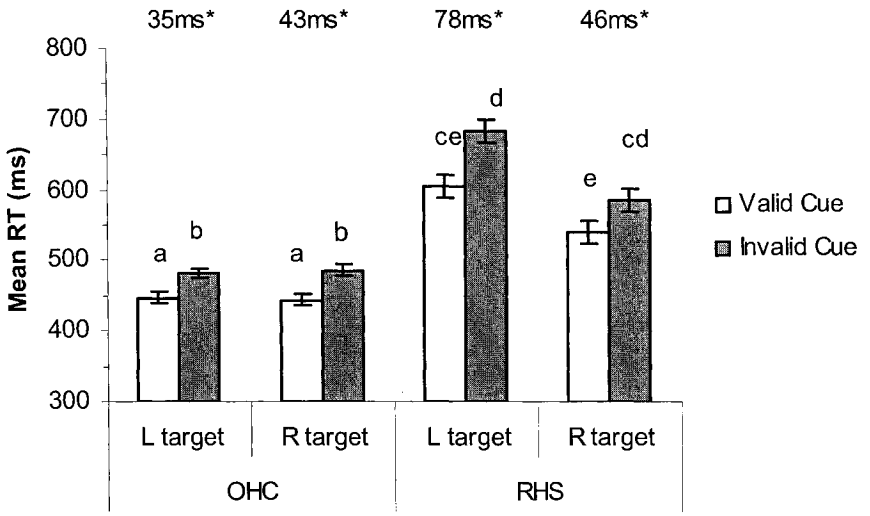


Figure 3. Mean reaction times of validly- and invalidly-cued left and right targets at the 500ms SOA averaged over movement and arm for the (a) younger healthy control group (YHC) and the (b) older healthy control group (OHC). Corresponding cueing effects (CE = Invalid RT – Valid RT) for each target are shown at the top of the graph. Significant differences ($p \leq 0.01$) in RT between cue conditions, i.e., significant IOR, are noted with asterisks. Conditions labeled with different letters (a,b,c) differ significantly ($p \leq 0.01$). Conditions with shared letters in their labels do not differ significantly. Error bars represent the within-subjects 95% confidence interval for the interaction.

4a) 100ms SOA, No Movement analyses



4b) 500ms SOA, No Movement analyses

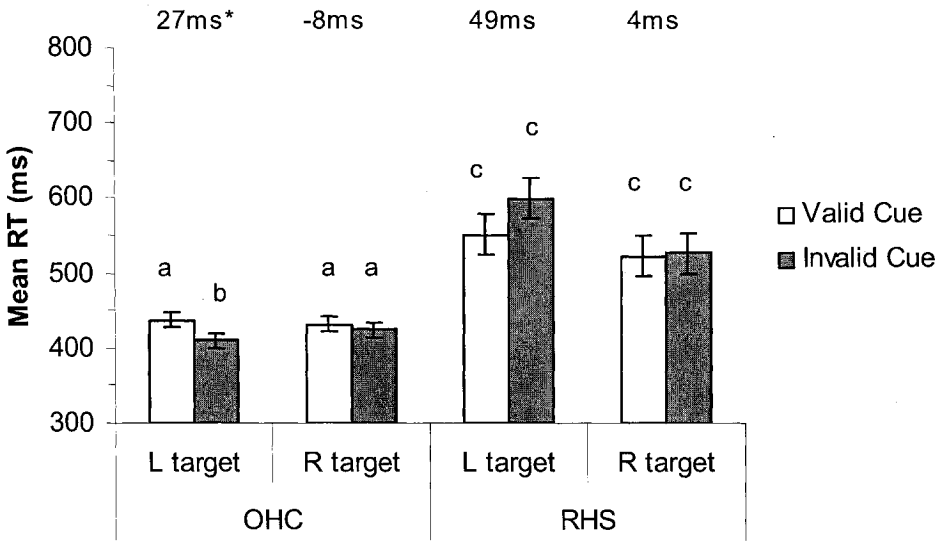


Figure 4. Mean reaction times at the (a) 100ms and (b) 500ms SOA in the no movement condition for the right-hemisphere stroke and older healthy control groups (RHS and OHC), collapsed over arm used. Corresponding cueing effects (CE = Inv RT – Val RT) for each target location are shown at the top of the graph. Significant cueing effects and IOR ($p \leq 0.01$) are noted with asterisks. Conditions labeled with different letters (a-e) differ significantly ($p \leq 0.01$). Conditions with shared letters in their labels do not differ significantly. Error bars represent the within-subjects 95% confidence interval for each group.

note mean RT scale

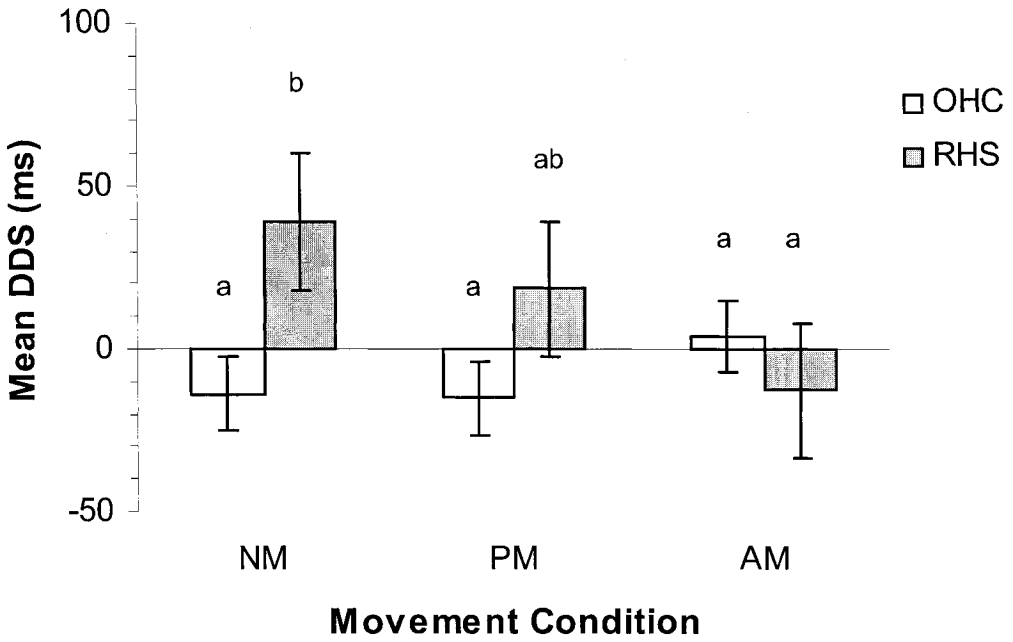


Figure 5. Mean disengage deficit scores (DDS) of the OHC group (n=20) and the RHS group (n=16) in the three limb movement conditions (NM, PM, AM) averaged over arm (L, R) and SOA (100ms, 500ms). Conditions labeled with different letters (a,b) differ significantly ($p \leq 0.01$) while conditions with shared letters in their labels do not differ significantly. Error bars represent the within-subjects 95% confidence interval of the effect of movement for each group.

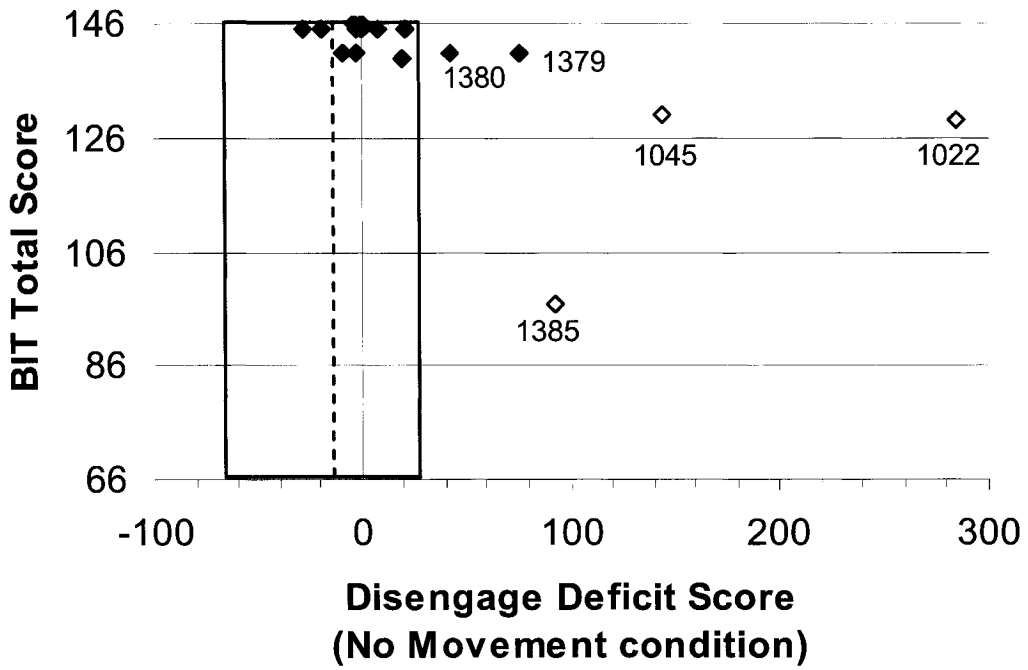


Figure 6. Scatter plot of disengage deficit scores (DDS) in the no movement condition (collapsed over Arm and SOA) versus BIT Total scores for the right-hemisphere stroke participants (RHS, n=16). The dashed line and boxed area represents the mean ± 2SD of the disengage deficit scores of the older healthy controls. Open diamonds represent scores of the three right-hemisphere stroke participants with neglect (#1385, #1045, #1022). Solid diamonds represent scores of the right-hemisphere stroke participants without neglect. Red diamonds represent individuals with a mean disengage deficit score significantly larger than the older healthy control mean (RHS/DD; $p \leq 0.05$).

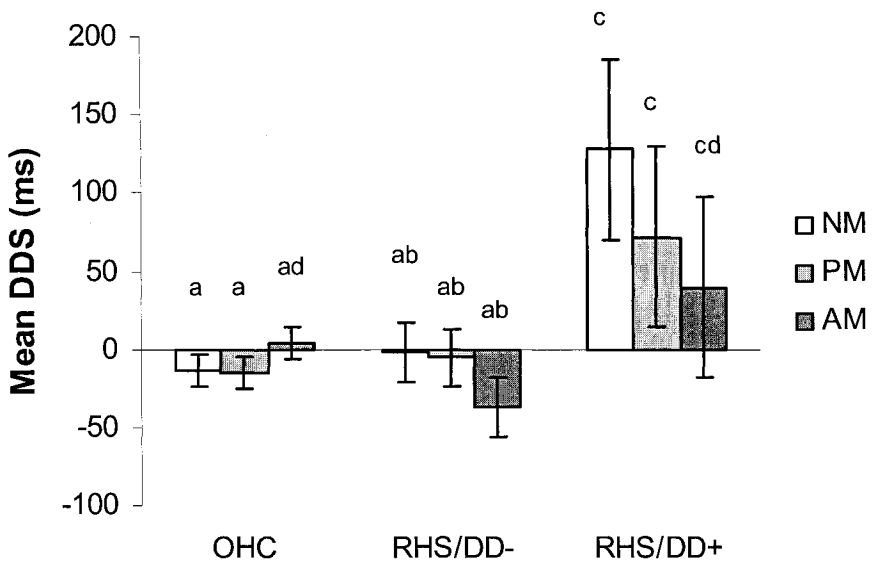


Figure 7. Mean disengage deficit scores (DDS) of the OHC group (n=20), the RHS/DD- group (n=11), and the RHS/DD+ group (n=5) in the three limb movement conditions (NM, PM, AM) averaged over arm (L, R) and SOA (100ms, 500ms). Conditions labeled with different letters (a-d) differ significantly ($p \leq 0.01$) while conditions with shared letters in their labels do not differ significantly. Error bars represent the within-subjects 95% confidence interval of the effect of movement for each group.

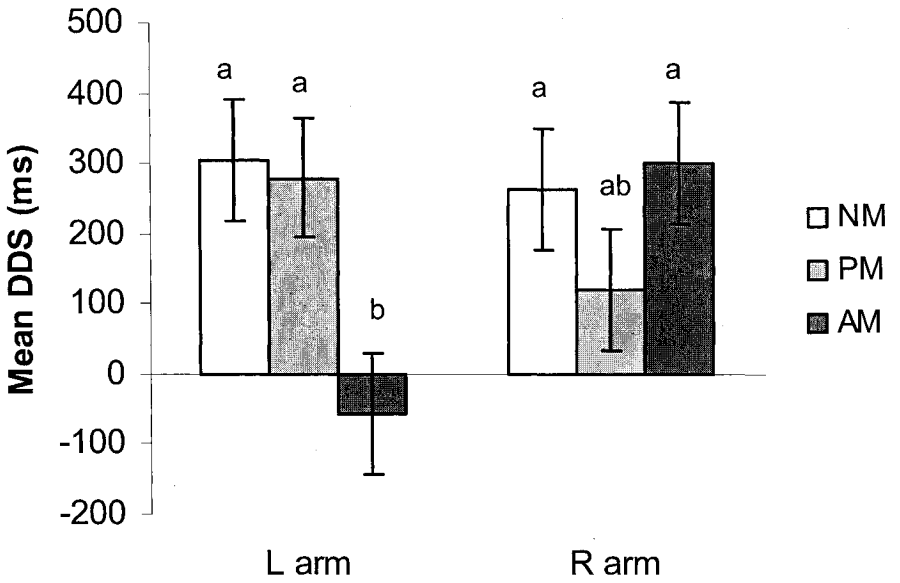
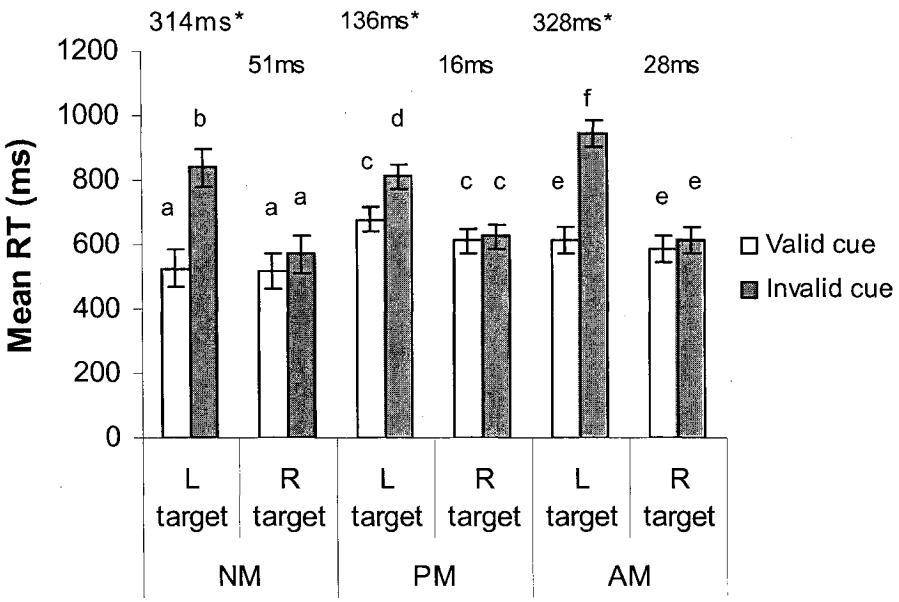


Figure 8. Mean disengage deficit scores (DDS) of RHS/DD+ participant #1022 during left and right arm use in the three movement conditions (NM, PM, AM) collapsed over SOA. Conditions labeled with different letters (a,b) differ significantly ($p \leq 0.01$) while conditions with shared letters in their labels do not differ significantly. Error bars represent the within-subjects 95% confidence interval of the interaction.

9a) RHS/DD++ #1022: Right arm



9b) RHS/DD++ #1022: Left arm

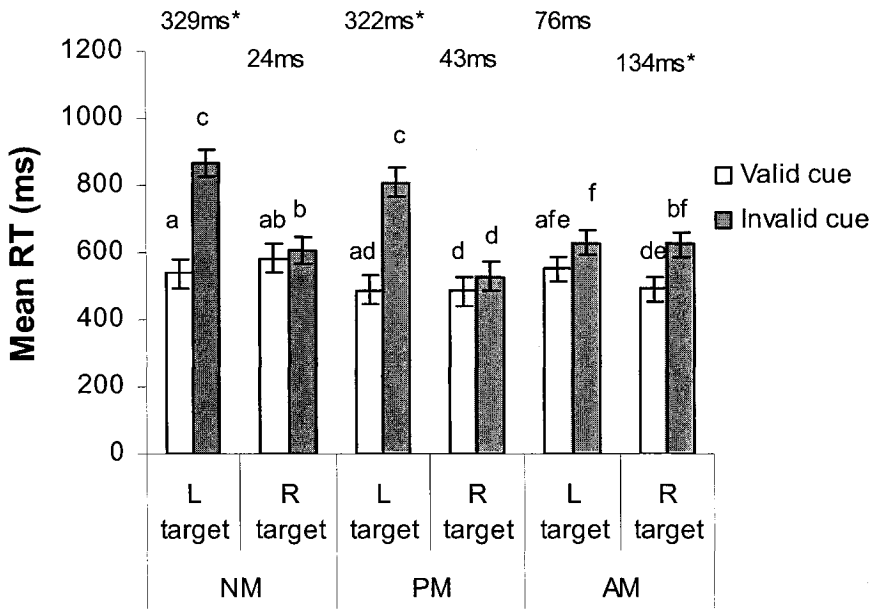


Figure 9. Mean reaction times (ms) to validly- and invalidly-cued targets averaged across SOA during (a) right- and (b) left-arm use for RHS/DD++ participant #1022. Corresponding cueing effects (CE = Inv RT – Val RT) for each target position are shown at the top of each graph. Significant differences ($p \leq 0.01$) in RT between cue conditions, i.e., significant cueing, are noted with asterisks. Within each movement condition, conditions labeled with different letters (a-g) differ significantly ($p \leq 0.01$). Conditions with shared letters in their labels do not differ significantly. Error bars represent the within-subjects 95% confidence interval for the cue-by-target interaction in each movement condition.

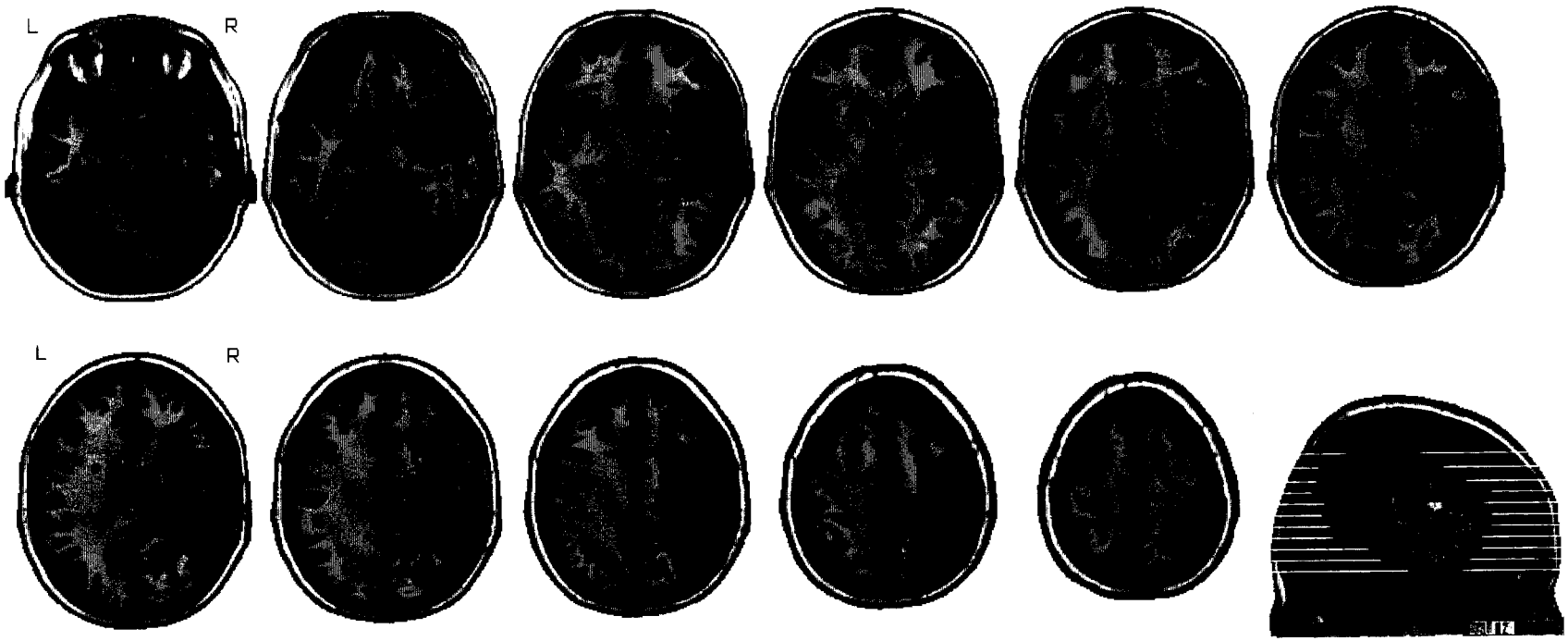


Figure 10a. Graphic representation of the overlap of lesions of DD- participants (n=11). Overlapping lesions are represented by the color bar on the bottom right of the figure (9% to 100%). The region of greatest overlap (54%) is in the corona radiata (corona). Superior temporal gyrus (STG), middle temporal gyrus (MTG), inferior frontal lobe (IFL), postcentral gyrus (postCe), supramarginal gyrus (SMG), centrum semiovale (CS), angular gyrus (ANG), inferior parietal lobe (IPL), middle frontal gyrus (MFG), superior parietal lobe (SPL).

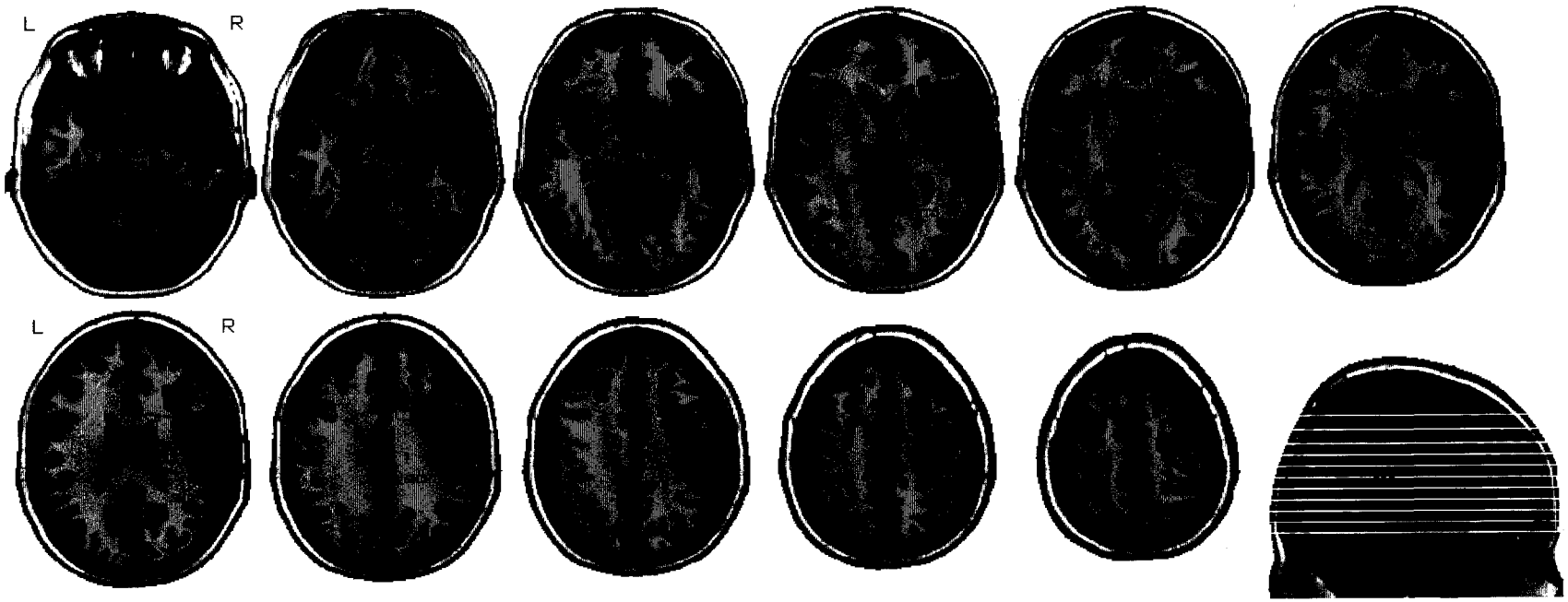


Figure 10b. Graphic representation of the lesion of RHS/DD++ participant #1022. Superior temporal gyrus (STG), middle temporal gyrus (MTG), globus pallidus (GP), rolandic operculum (RO), inferior frontal lobe (IFL), precentral gyrus (PrCe), supramarginal gyrus (SMG).

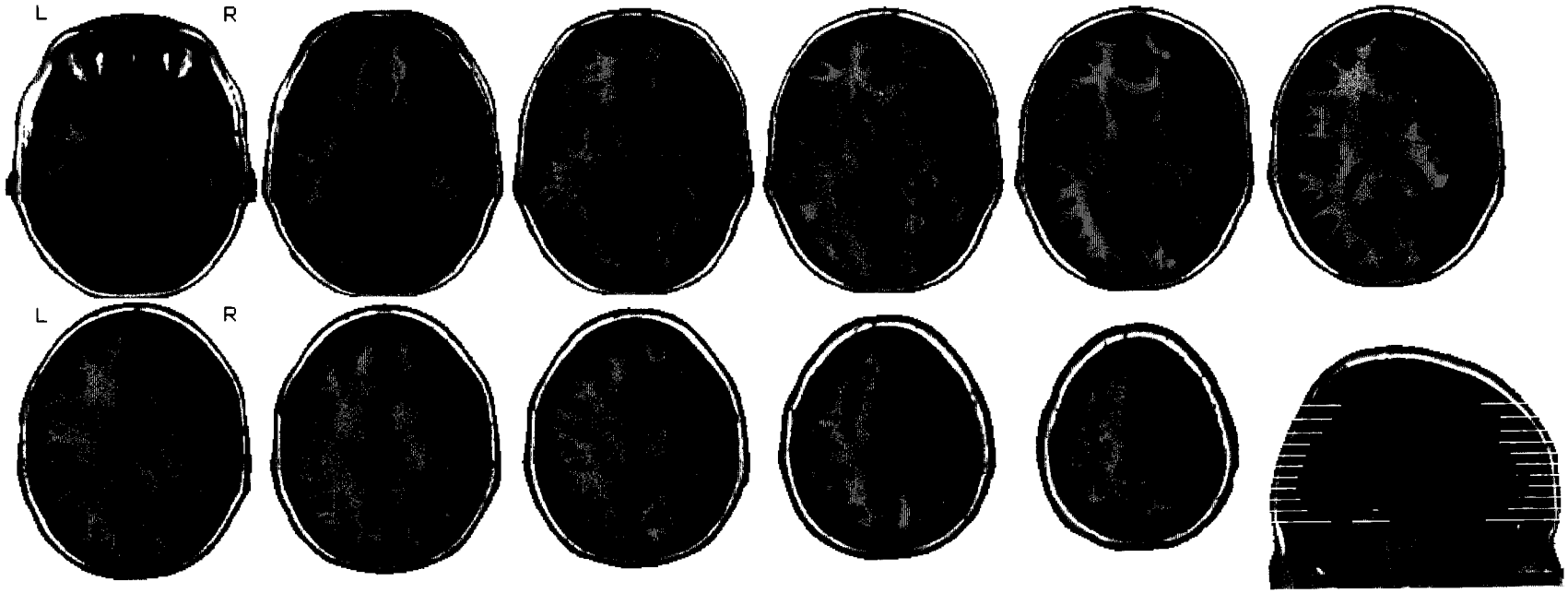


Figure 10c. Graphic representation of the overlap of lesions of the four RHS/DD participants who experienced no positive effect of limb movement on the disengage deficit. Overlapping lesions are represented by the color bar on the bottom right of the figure (25% to 100%). Region of greatest overlap are in green (75%). Superior temporal gyrus (STG), middle temporal gyrus (MTG), inferior frontal lobe (IFL), rolandic operculum (RO), precentral gyrus (PrCe), supramarginal gyrus (SMG), centrum semiovale (CS), angular gyrus (ANG), middle frontal gyrus (MFG), inferior parietal lobe (IPL), superior parietal lobe (SPL).

REFERENCES

1. Aizenstein, H. J., Clark, K. A., Butters, M. A., Cochran, J., Stenger, V. A., Meltzer, C. C., et al. (2004). The BOLD hemodynamic response in healthy aging. *Journal of Cognitive Neuroscience, 16*(5), 786-793.
2. Arrington, C. M., Carr, T. H., Mayer, A. R., & Rao, S. M. (2000). Neural mechanisms of visual attention: Object-based selection of a region in space. *Journal of Cognitive Neuroscience, 12*(Supplement 2), 106-117.
3. Bartolomeo, P., & Chokron, S. (2002). Orienting of attention in left unilateral neglect. *Neuroscience and Biobehavioral Reviews, 26*, 217-234.
4. Bartolomeo, P., Sieroff, E., Decaix, C., & Chokron, S. (2001). Modulating the attentional bias in unilateral neglect: The effects of the strategic set. *Experimental Brain Research, 137*, 432-444.
5. Bisiach, E., & Vallar, G. (1988). Hemineglect in humans. In F. Boller & J. Grafman (Eds.), *Handbook of Neuropsychology* (Vol. 1, pp. 195-222): Elsevier Science Publishers B.V.
6. Blair, J. R., & Spreen, I. (1989). Predicting premorbid IQ: A revision of the National Adult Reading Test. *The Clinical Neuropsychologist, 3*(2), 129-136.
7. Boussaoud, D. (2001). Attention versus intention in the primate premotor cortex. *NeuroImage, 14*, S40-S45.
8. Bowen, A., McKenna, K., & Tallis, R. (1999). Reasons for variability in the reported rate of occurrence of unilateral spatial neglect after stroke. *Stroke, 30*, 1196-1202.
9. Brown, V., Walker, R., Gray, C., & Findlay, J. M. (1999). Limb activation and the rehabilitation of unilateral neglect: Evidence of task-specific effects. *Neurocase, 5*, 129-142.
10. Butler, B., Eskes, G., Harrison, E., & MacDonald, A. (1999). *Passive left limb movement improves visual scanning in hemispatial neglect.* Paper presented at the 60th Annual Convention of the Canadian Psychological Association, Halifax, N.S.
11. Butler, B. C., Eskes, G. A., & Vandorpe, R. A. (2004). Gradients of detection in neglect: Comparison of peripersonal and extrapersonal space. *Neuropsychologia, 42*(3), 346-358.
12. Callejas, A., Lupianez, J., & Tudela, P. (2004). The three attentional networks: On their independence and interactions. *Brain and Cognition, 54*, 225-227.
13. Cohen, J. D., MacWhinney, B., Flatt, M., & Provost, J. (1993). PsyScope: A new graphic interactive environment for designing psychology experiments. *Behavioral Research Methods, Instruments, and Computers, 25*(2), 257-271.
14. Collins, D. L., Zijdenbos, A. P., Kollokian, V., Sled, J. G., Kabani, N. J., Holmes, C. J., et al. (1998). Design and construction of a realistic digital brain phantom. *IEEE Trans Med Imaging, 17*(3), 463-468.

15. Corbetta, M. (1998). Frontoparietal cortical networks for directing attention and the eye to visual locations: Identical, independent, or overlapping neural systems? *Proceedings of the National Academy of Sciences, USA, 95*, 831-838.

16. Corbetta, M., Akbudak, E., Conturo, T. E., Snyder, A. Z., Ollinger, J. M., Drury, H. A., et al. (1998). A common network of functional areas for attention and eye movements. *Neuron, 21*(4), 761-773.

17. Corbetta, M., Kincade, J. M., Ollinger, J. M., McAvoy, M. P., & Shulman, G. L. (2000). Voluntary orienting is dissociated from target detection in human posterior parietal cortex. *Nature Neuroscience, 3*(3), 292-297.

18. Corbetta, M., Kincade, J. M., & Shulman, G. L. (2002). Neural systems for visual orienting and their relationships to spatial working memory. *Journal of Cognitive Neuroscience, 14*(3), 508-523.

19. Corbetta, M., Kincade, M. J., Lewis, C., Snyder, A. Z., & Sapir, A. (2005). Neural basis and recovery of spatial attention deficits in spatial neglect. *Nature Neuroscience, 8*(11), 1603-1610.

20. Corbetta, M., Miezin, F. M., Shulman, G. L., & Petersen, S. E. (1993). A PET study of visuospatial attention. *The Journal of Neuroscience, 13*(3), 1202-1226.

21. Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews: Neuroscience, 3*, 201-215.

22. Crawford, J. R., & Howell, D. C. (1998). Comparing an individual's test score against norms derived from small samples. *The Clinical Neuropsychologist, 12*(4), 482-486.

23. Cubelli, R., Paganelli, N., Achilli, D., & Pedrizzi, S. (1999). Is one hand always better than two? A replication study. *Neurocase, 5*, 143-151.

24. Damasio, A. R., Damasio, H., & Chang, C. H. (1980). Neglect following damage to frontal lobe or basal ganglia. *Neuropsychologia, 18*, 123-132.

25. Danziger, S., & Kingstone, A. (1999). Unmasking the inhibition of return phenomenon. *Perception & Psychophysics, 61*(6), 1024-1037.

26. D'Erme, P., Robertson, I. H., Bartolomeo, P., Daniele, A., & Gainotti, G. (1992). Early rightward orienting of attention on simple reaction time performance in patients with left-sided neglect. *Neuropsychologia, 30*(11), 989-1000.

27. Driver, J., & Mattingley, J. B. (1995). Selective attention in humans: Normality and pathology. *Current Opinion in Neurobiology, 5*, 191-197.

28. Eimer, M., Forster, B., Van Velzen, J., & Prabhu, G. (2005). Covert manual response preparation triggers attentional shifts: ERP evidence for the premotor theory of attention. *Neuropsychologia, 43*, 957-966.

29. Eskes, G. A., Butler, B., McDonald, A., Harrison, E. R., & Phillips, S. J. (2003). Limb activation effects in hemispatial neglect. *Archives of Physical Medicine and Rehabilitation, 84*, 323-328.

30. Fan, J., McCandliss, B. D., Fossella, J., Flombaum, J. I., & Posner, M. I. (2005). The activation of attentional networks. *NeuroImage, 26*, 471-479.

31. Faust, M. E., & Balota, D. A. (1997). Inhibition of return and visuospatial attention in healthy older adults and individuals with dementia of the Alzheimer type. *Neuropsychology, 11*(1), 13-29.

32. Fernandez-Duque, D., & Posner, M. I. (1997). Relating the mechanisms of orienting and alerting. *Neuropsychologia, 35*(4), 477-486.

33. Festa-Martino, E., Ott, B. R., & Heindel, W. C. (2004). Interactions between phasic alerting and spatial orienting: Effects of normal aging and Alzheimer's disease. *Neuropsychology, 18*(2), 258-268.

34. Frassinetti, F., Rossi, M., & Ladavas, E. (2001). Passive limb movements improve visual neglect. *Neuropsychologia, 39*, 725-733.

35. Friedrich, F. J., Egly, R., Rafal, R. D., & Beck, D. (1998). Spatial attention deficits in humans: A comparison of superior parietal and temporal-parietal junction lesions. *Neuropsychology, 12*(2), 193-207.

36. Fujii, N., Mushiake, H., & Tanji, J. (2000). Rostrocaudal distinction of the dorsal premotor area based on oculomotor involvement. *Journal of Neurophysiology, 83*, 1764-1769.

37. Gainotti, G., D'Erme, P., & Bartolomeo, P. (1991). Early orientation of attention toward the half space ipsilateral to the lesion in patients with unilateral brain damage. *Journal of Neurology, Neurosurgery, and Psychiatry, 54*, 1082-1089.

38. Gainotti, G., Perri, R., & Cappa, A. (2002). Left hand movements and right hemispheric activation in unilateral spatial neglect: A test of the interhemispheric imbalance hypothesis. *Neuropsychologia, 40*, 1350-1355.

39. Gitelman, D. R., Nobre, A. C., Parrish, T. B., LaBar, K. S., Kim, Y.-H., Meyer, J. R., et al. (1999). A large-scale distributed network for covert spatial attention: Further anatomical delineation based on stringent behavioural and cognitive controls. *Brain, 122*, 1093-1106.

40. Goldstein, G., & Shelley, C. (1981). Does the right hemisphere age more rapidly than the left? *Journal of Clinical Neuropsychology, 3*, 65-78.

41. Grady, C. L., Maisog, J. M., Horwitz, B., Ungerleider, L. G., Mentis, M. J., Salerno, J. A., et al. (1994). Age-related changes in cortical blood flow activation during visual processing of faces and location. *The Journal of Neuroscience, 14*(3), 1450-1462.

42. Greenwood, P. M., Parasuraman, R., & Haxby, J. V. (1993). Changes in visuospatial attention over the adult lifespan. *Neuropsychologia, 31*(5), 471-485.

43. Halligan, P. W., Burn, J. P., Marshall, J. C., & Wade, D. T. (1992). Visuo-spatial neglect: Qualitative differences and laterality of cerebral lesion. *Journal of Neurology, Neurosurgery, and Psychiatry, 55*, 1060-1068.

44. Halligan, P. W., Manning, L., & Marshall, J. C. (1991). Hemispheric activation vs spatio-motor cueing in visual neglect: A case study. *Neuropsychologia, 29*(2), 165-176.

45. Halligan, P. W., & Marshall, J. C. (1989a). Laterality of motor response in visuo-spatial neglect: A case study. *Neuropsychologia, 27*(10), 1301-1307.

46. Halligan, P. W., & Marshall, J. C. (1989b). Perceptual cueing and perceptuo-motor compatibility in visuo-spatial neglect: A single case study. *Cognitive Neuropsychology, 6*(4), 423-435.

47. Halligan, P. W., & Marshall, J. C. (1993). The history and clinical presentation of neglect. In I. H. Robertson & J. C. Marshall (Eds.), *Unilateral Neglect: Clinical and Experimental Studies* (pp. 3-25). Hove: Lawrence Erlbaum Associates Ltd.

48. Halligan, P. W., Marshall, J. C., & Wade, D. T. (1989). Visuospatial neglect: Underlying factors and test sensitivity. *The Lancet*(October 14), 908-910.

49. Hartley, A. A., & Kieley, J. M. (1995). Adult age differences in the inhibition of return of visual attention. *Psychology and Aging, 10*(4), 670-683.

50. Heilman, K. M., & Valenstein, E. (1979). Mechanisms underlying hemispatial neglect. *Annals of Neurology, 5*, 166-170.

51. Heilman, K. M., Watson, R. T., & Valenstein, E. (1993). Neglect and related disorders. In K. M. Heilman & E. Valenstein (Eds.), *Clinical Neuropsychology* (pp. 279-335). New York: Oxford University Press.

52. Joanette, Y., Brouchon, M., Gauthier, L., & Samson, M. (1986). Pointing with left vs right hand in left visual field neglect. *Neuropsychologia, 24*(3), 391-396.

53. Karnath, H. O., Ferber, S., & Himmelbach, M. (2001). Spatial awareness is a function of the temporal not the posterior parietal lobe. *Nature, 411*(6840), 950-953.

54. Karnath, H. O., Himmelbach, M., & Rorden, C. (2002). The subcortical anatomy of human spatial neglect: putamen, caudate nucleus and pulvinar. *Brain, 125*, 350-360.

55. Keller, P. E., Wascher, E., Prinz, W., Waszak, F., Koch, I., & Rosenbaum, D. A. (2006). Differences between intention-based and stimulus-based actions. *Journal of Psychophysiology, 20*(1), 9-20.

56. Kingstone, A., Klein, R., Morein-Zamir, S., Hunt, A., Fisk, J., & Maxner, C. (2002). Orienting attention in aging and Parkinson's diease: Distinguishing modes of control. *Journal of Clinical and Experimental Neuropsychology, 24*(7), 951-967.

57. Kinsbourne, M. (1987). Mechanisms of unilateral neglect. In M. Jeannerod (Ed.), *Neurophysiological and Neuropsychological Aspects of Spatial Neglect* (pp. 69-83). North-Holland: Elsevier Science Publishers B.V.

58. Kinsella, G., & Ford, B. (1985). Hemi-inattention and the recovery patterns of stroke patients. *International Rehabilitation Medicine, 7*, 102-106.

59. Klein, R., Kingstone, A., & Pontefract, A. (1992). Orienting of visual attention. In K. Rayner (Ed.), *Eye Movements and Visual Cognition: Scene Perception and Reading* (pp. 46-65). New York: Springer-Verlag.

60. Klein, R. M., & Taylor, T. L. (1994). Categories of cognitive inhibition with reference to attention. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory Processes in Attention, Memory, and Language* (pp. 113-150). New York: Academic Press.

61. Ladavas, E., Berti, A., Ruozzi, E., & Barboni, F. (1997). Neglect as a deficit determined by an imbalance between multiple spatial representations. *Experimental Brain Research, 116*, 493-500.

62. Ladavas, E., Carletti, M., & Gori, G. (1994). Automatic and voluntary orienting of attention in patients with visual neglect: Horizontal and vertical dimensions. *Neuropsychologia, 32*(10), 1195-1208.

63. Lebedev, M. A., & Wise, S. P. (2001). Tuning for the orientation of spatial attention in dorsal premotor cortex. *European Journal of Neuroscience, 13*, 1002-1008.

64. Leibovitch, F. S., Black, S. E., Caldwell, C. B., Ebert, P. L., Ehrlich, L. E., & Szalai, J. P. (1998). Brain-behavior correlations in hemispatial neglect using CT and SPECT: The Sunnybrook stroke study. *Neurology, 50*, 901-908.

65. Lezak, M. D. (1995). *Neuropsychological Assessment* (3rd ed.). New York: Oxford University Press, Inc.

66. Lorenzo-Lopez, L., Doallo, S., Vizoso, C., Amenedo, E., Rodriguez Holguin, S., & Cadaveira, F. (2002). Covert orienting of visuospatial attention in the early stages of aging. *NeuroReport, 13*, 1459-1462.

67. Losier, B. J. W., & Klein, R. M. (2001). A review of the evidence for a disengage deficit following parietal lobe damage. *Neuroscience and Biobehavioral Reviews, 25*, 1-13.

68. Lu, C.-H., & Proctor, R. W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin and Review, 2*, 174-207.

69. Luo, C. R., Anderson, J. M., & Caramazza, A. (1998). Impaired stimulus-driven orienting of attention and preserved goal-directed orienting of attention in unilateral visual neglect. *American Journal of Psychology, 111*(4), 487-507.

70. Lupianez, J., Milliken, B., Solano, C., Weaver, B., & Tipper, S. P. (2001). On the strategic modulation of the time course of facilitation and inhibition of return. *The Quarterly Journal of Experimental Psychology, 54A*(3), 753-773.

71. Marshall, J. C., & Halligan, P. W. (1989). Does the midsagittal plane play any priveleged role in "left" neglect? *Cognitive Neuropsychology, 6*(4), 403-422.

72. Masson, M. E. J., & Loftus, G. R. (2003). Using confidence intervals for graphically based data interpretation. *Canadian Journal of Experimental Psychology, 57*(3), 203-220.

73. Mattingley, J. B., Driver, J., Beschin, N., & Robertson, I. H. (1997). Attentional competition between modalities: Extinction between touch and vision after right hemisphere damage. *Neuropsychologia, 35*(6), 867-880.

74. Mattingley, J. B., Robertson, I. H., & Driver, J. (1998). Modulation of covert visual attention by hand movement: Evidence from parietal extinction after right-hemisphere damage. *Neurocase, 4*, 245-253.

75. Mesulam, M.-M. (1981). A cortical network for directed attention and unilateral neglect. *Annals of Neurology, 10*, 309-325.

76. Mima, T., Sadato, N., Yazawa, S., Hanakawa, T., Fukuyama, H., Yonekura, Y., et al. (1999). Brain structures related to active and passive finger movements in man. *Brain, 122*, 1989-1997.

77. Morrow, L. A., & Ratcliff, G. (1988). The disengagement of attention and the neglect syndrome. *Psychobiology, 16*(3), 261-169.

78. Mort, D. J., Malhotra, P., Mannan, S. K., Rorden, C., Pambakian, A., Kennard, C., et al. (2003). The anatomy of visual neglect. *Brain, 126*, 1986-1997.

79. Mysiw, W. J., Beegan, J. G., & Gatens, P. F. (1989). Prospective cognitive assessment of stroke patients before inpatient rehabilitation. The relationship of the Neurobehavioral Cognitive Status Examination to functional improvement. *American Journal of Physical Medicine and Rehabilitation, 68*(4), 168-171.

80. Osmon, D. C., Smet, I. C., Winegarden, B., & Gandhavadi, B. (1992). Neurobehavioral cognitive status examination: Its use with unilateral stroke patients in a rehabilitation setting. *Archives of Physical Medicine and Rehabilitation, 73*, 414-418.

81. Parasuraman, R. (1998). The attentive brain: Issues and prospects. In R. Parasuraman (Ed.), *The Attentive Brain* (pp. 3-15). Cambridage, Mass.: The MIT Press.

82. Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3-25.

83. Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and Performance* (Vol. X, pp. 531-556). Hove, UK: Lawrence Erlbaum Associates Ltd.

84. Posner, M. I., Cohen, Y., & Rafal, R. D. (1982). Neural systems control of spatial orienting. *Philosophical Transactions of the Royal Society of London B: Biological Sciences, 298*(1089), 187-198.

85. Posner, M. I., & DiGirolamo, G. J. (1998). Executive attention: Conflict, target detection, and cognitive control. In R. Parasuraman (Ed.), *The Attentive Brain* (pp. 401-423). Cambridge, Mass.: The MIT Press.

86. Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13*, 25-42.

87. Posner, M. I., Petersen, S. E., Fox, P. T., & Raichle, M. E. (1988). Localization of cognitive operations in the human brain. *Science, 240*(4859), 1627-1631.

88. Posner, M. I., Rafal, R. D., Choate, L. S., & Vaughan, J. (1985). Inhibition of return: Neural basis and function. *Cognitive Neuropsychology, 2*, 211-228.

89. Posner, M. I., Snyder, C. R. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General, 109*(2), 160-174.

90. Posner, M. I., Walker, J. A., Friedrich, F. A., & Rafal, R. D. (1987). How do the parietal lobes direct covert attention? *Neuropsychologia, 25*(1A), 135-145.

91. Posner, M. I., Walker, J. A., Friedrich, F. J., & Rafal, R. D. (1984). Effects of parietal injury on covert orienting of attention. *The Journal of Neuroscience, 4*(7), 1863-1874.

92. Pratt, J., & Fischer, M. H. (2002). Examining the role of the fixation cue in inhibition of return. *Canadian Journal of Experimental Psychology, 56*(4), 294-301.

93. Rafal, R. D. (1994). Neglect. *Current Opinion in Neurobiology, 4*, 231-236.

94. Rafal, R. D. (1998). Neglect. In R. Parasuraman (Ed.), *The Attentive Brain* (pp. 489-526). Cambridge, Mass.: The MIT Press.

95. Rafal, R. D., & Posner, M. I. (1987). Deficits in human visual spatial attention following thalamic lesions. *Proceedings of the National Academy of Sciences, USA, 84*(20), 7349-7353.

96. Reuter-Lorenz, P. A., Stanczak, L., & Miller, A. C. (1999). Neural recruitment and cognitive aging: Two hemispheres are better than one, especially as you age. *Psychological Science, 10*(6), 494-500.

97. Riddoch, M. J., & Humphreys, G. W. (1994). Towards an understanding of neglect. In M. J. Riddoch & G. W. Humphreys (Eds.), *Cognitive Neuropsychology and Cognitive Rehabilitation* (pp. 125-149): Lawrence Erlbaum Associates Ltd.

98. Rizzolatti, G., & Camarda, R. (1987). Neural circuits for spatial attention and unilateral neglect. In M. Jeannerod (Ed.), *Neurophysiological and Neuropsychological Aspects of Spatial Neglect* (pp. 289-313). North-Holland: Elsevier Science Publishers B.V.

99. Rizzolatti, G., & Gallese, V. (1988). Mechanisms and theories of spatial neglect. In F. Boller & J. Grafman (Eds.), *Handbook of Neuropsychology* (Vol. 1, pp. 223-246): Elsevier Science Publishers B.V.

100. Robertson, I. H. (1991). Use of left vs right hand in responding to lateralized stimuli in unilateral neglect. *Neuropsychologia, 29*(11), 1129-1135.

101. Robertson, I. H. (1993). The relationship between lateralized and non-lateralized attentional deficits in unilateral neglect. In I. H. Robertson & J. C. Marshall

(Eds.), *Unilateral Neglect: Clinical and Experimental Studies* (pp. 257-275). Hove: Lawrence Erlbaum Associates.

102. Robertson, I. H., & Halligan, P. W. (1999). *Spatial neglect. A clinical handbook for diagnosis and treatment*: Psychology Press.

103. Robertson, I. H., & Hawkins, K. (1999). Limb activation and unilateral neglect. *Neurocase, 5*, 153-160.

104. Robertson, I. H., Hogg, K., & McMillan, T. M. (1998). Rehabilitation of unilateral neglect: Improving function by contralateral limb activation. *Neuropsychological Rehabilitation, 8*(1), 19-29.

105. Robertson, I. H., McMillan, T. M., MacLeod, E., Edgeworth, J., & Brock, D. (2002). Rehabilitation by limb activation training reduces left-sided motor impairment in unilateral neglect patients: A single-blind randomised control trial. *Neuropsychological Rehabilitation, 12*(5), 439-454.

106. Robertson, I. H., & North, N. T. (1992). Spatio-motor cueing in unilateral left neglect: The role of hemispace, hand and motor activation. *Neuropsychologia, 30*(6), 553-563.

107. Robertson, I. H., & North, N. T. (1993). Active and passive activation of left limbs: Influence on visual and sensory neglect. *Neuropsychologia, 31*(3), 293-300.

108. Robertson, I. H., & North, N. T. (1994). One hand is better than two: Motor extinction of left hand advantage in unilateral neglect. *Neuropsychologia, 32*(1), 1-11.

109. Robertson, I. H., North, N. T., & Geggie, C. (1992). Spatio-motor cueing in unilateral left neglect: Three case studies of its therapeutic effects. *Journal of Neurology, Neurosurgery, and Psychiatry, 55*, 799-805.

110. Robertson, I. H., Tegner, R., Goodrich, S. J., & Wilson, C. (1994). Walking trajectory and hand movements in unilateral left neglect: A vestibular hypothesis. *Neuropsychologia, 32*(12), 1495-1502.

111. Robertson, I. H., Ward, T., Ridgeway, V., & Nimmo-Smith, I. (1994). The Test of Everyday Attention - manual. Bury St. Edmunds, England: Thames Valley Test Company.

112. Rosen, A. C., Rao, S. M., Caffarra, P., Scaglioni, A., Bobholz, J. A., Woodley, S. J., et al. (1999). Neural basis of endogenous and exogenous spatial orienting: A functional MRI study. *Journal of Cognitive Neuroscience, 11*(2), 135-152.

113. Sapir, A., Hayes, A., Henik, A., Danziger, S., & Rafal, R. (2004). Parietal lobe lesions disrupt saccadic remapping of inhibitory location tagging. *Journal of Cognitive Neuroscience, 16*(4), 503-509.

114. Simon, S. R., Meunier, M., Piettre, L., Berardi, A. M., Segebarth, C. M., & Boussaoud, D. (2002). Spatial attention and memory versus motor preparation: premotor cortex involvement as revealed by fMRI. *Journal of Neurophysiology, 88*, 2047-2057.

115. Small, M., Cowey, A., & Ellis, S. (1994). How lateralised is visuospatial neglect? *Neuropsychologia, 32*(4), 449-464.

116. Spalek, T. M., & Hammad, S. (2004). Supporting the attentional momentum view of IOR: Is attention biased to go right? *Perception & Psychophysics, 66*(2), 219-233.

117. Stone, S. P., Halligan, P. W., Greenwood, R. J., & Marshall, J. C. (1991). Performance of age-matched controls on a battery of visuo-spatial neglect tests. *Journal of Neurology, Neurosurgery, and Psychiatry, 54*(4), 341-344.

118. Stone, S. P., Wilson, B., Halligan, P. W., Lange, L. S., Marshall, J. C., & Greenwood, R. J. (1991). Assessment of visuo-spatial neglect after acute stroke. *Journal of Neurology, Neurosurgery, and Psychiatry, 54*(4), 345-350.

119. Tabachnick, B. G., & Fidell, L. S. (2001). *Using multivariate statistics* (4th ed.). Boston: Allyn & Bacon.

120. Taylor, T. L., & Klein, R. M. (1998). On the causes and effects of inhibition of return. *Psychonomic Bulletin and Review, 5*(4), 625-643.

121. Taylor, T. L., & Klein, R. M. (2000). Visual and motor effects in inhibition of return. *Journal of Experimental Psychology: Human Perception and Performance, 26*(5), 1639-1656.

122. Tzourio-Mazoyer, N., Landeau, B., Papathanassiou, D., Crivello, F., Etard, O., Delcroix, N., et al. (2002). Automated anatomical labeling of activations in SPM using a macroscopic anatomical parcellation of the MNI MRI single-subject brain. *NeuroImage, 15*, 273-289.

123. Vallar, G. (2001). Extrapersonal visual unilateral spatial neglect and its neuroanatomy. *NeuroImage, 14*, S52-S58.

124. Vallar, G., & Perani, D. (1986). The anatomy of unilateral neglect after right-hemisphere stroke lesions. A clinical/CT-scan correlation study in man. *Neuropsychologia, 24*(5), 609-622.

125. Vecera, S. P., & Rizzo, M. (2003). Spatial attention: normal processes and their breakdown. *Neurologic Clinics, 21*(3).

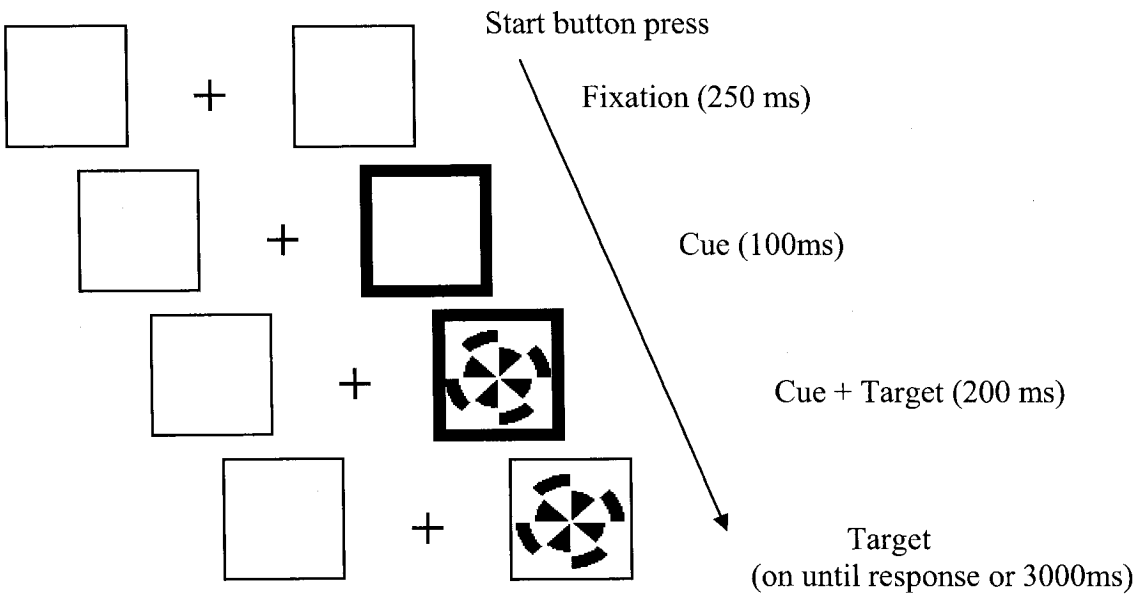
126. Weiller, C., Juptner, M., Fellows, S., Rijntjes, M., Leonhardt, G., Kiebel, S., et al. (1996). Brain representation of active and passive movements. *NeuroImage, 4*, 105-110.

127. Wise, S. P., Boussaoud, D., Johnson, P. B., & Caminiti, R. (1997). Premotor and parietal cortex: Corticocortical connectivity and combinatorial computations. *Annual Reviews in Neuroscience, 20*, 25-42.

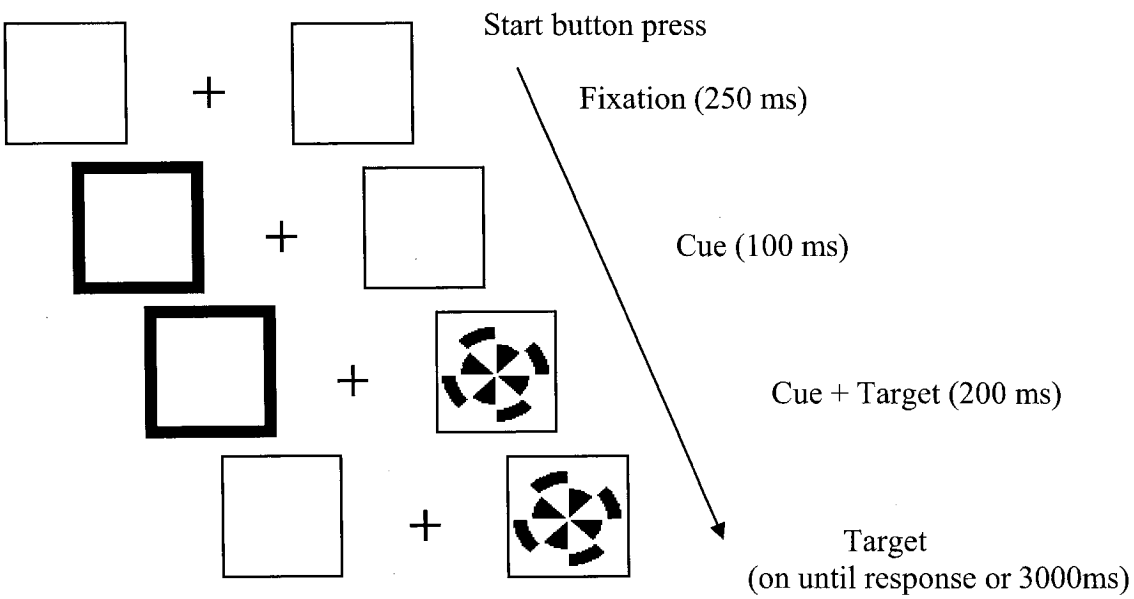
128. Zachary, R. A. (1986). *Shipley Institue of Living Scale. Revised manual.* Los Angeles: Western Psychological Services.

Appendix A
Orienting Stimulus Display

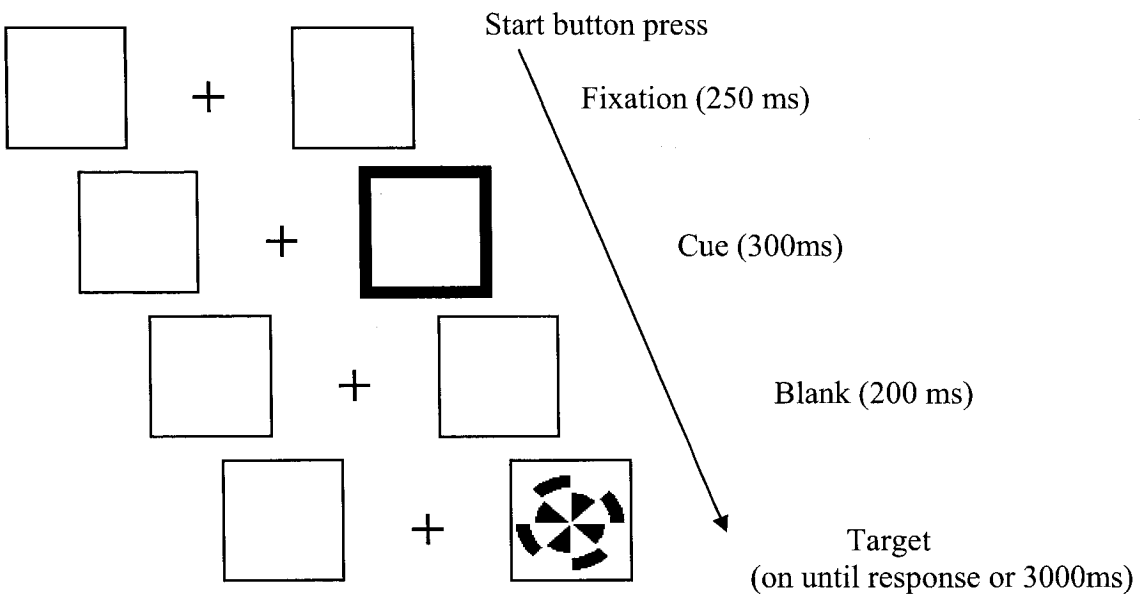
Valid Cue Condition (e.g. right cue-right target, 100ms SOA)



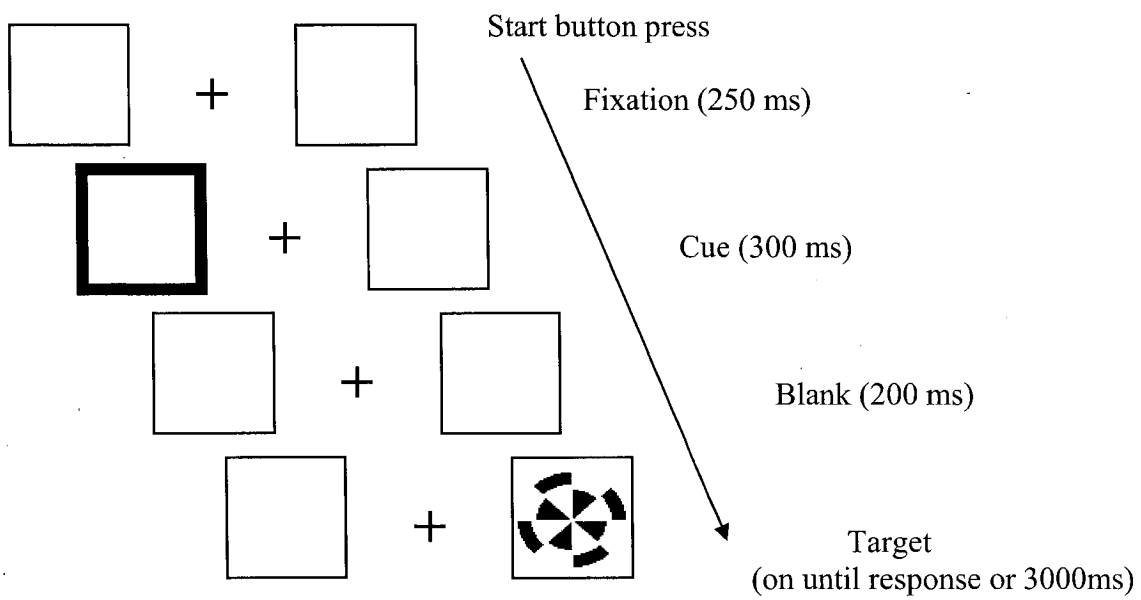
Invalid Cue Condition (e.g. left cue-right target, 100ms SOA)



Valid Cue Condition (e.g. right cue-right target, 500ms SOA)



Invalid Cue Condition (e.g. left cue-right target, 500ms SOA)



APPENDIX B

Lesion Localization Checklist

Study:_____ **Checked by:**_____

Subject Code:_____ **Circle one:** **CT** **MRI**

			Right	Left	Notes
Etiology	Superficial Infarct				
	Deep Infarct				
	Superficial & Deep Infarct				
	Lacunar				
	ICA occlusion				
	Intracerebral Hemorrhage				
	Subarachnoid Hemorrhage				
	AVM				
	Aneurysm				
	Other (includes subdural)				
Vascular Territory		**Brodmann's**			
	ACA territory				
	MCA territory				
	PCA territory				
	Frontal Lobe				
Lateral	Sup. Frontal Gyrus: ant.	8,9			
	Middle Frontal Gyrus: ant.	10			
	Dorsolateral Frontal	9,46			
	Inf. Frontal Gyri	44,45,47			
	Premotor Cortex: superior	6			
	Premotor Cortex: inferior	6			
	Precentral Gyrus (M1): superior	4			
	Precentral Gyrus (M1): inferior	4			
Medial	Sup. Frontal Gyrus: ant.	8,9			
	Middle Frontal Gyrus: ant.	10			
	Supplementary Motor Area	6			
	Anterior Paracentral (M1)	4			
	Medial Frontal	32			
Inferior	Orbital gyri	11,12			
	Parietal Lobe				
Lateral	Parieto-Frontal	43			
	Postcentral Gyrus: Sup	1,2,3			
	Postcentral Gyrus: Inf	1,2,3			
	Inf. Parietal (SMG)	40			
	Inf. Parietal (AG)	39			
	Superior parietal	5,7			
Medial	Paracentral Lobule	1,2,3			
	Superior parietal	5,7			

		Right	Left	Notes
Temporal Lobe				
Lateral Sup. Temporal Gyrus: ant.	22			
Sup. Temporal Gyrus: post.	22,41,42			
Mid. Temporal Gyrus	21			
Inf. Temporal Gyrus	20			
Temporal Pole	38			
Occipitotemporal	37			
Insular Cortex	48			
Medial/Inferior Amygdala				
Hippocampus				
Occipitotemporal	37			
Fourth Temporal gyrus	35,36			
Occipital Lobe				
Lateral Lateral Occipital Gyri	18,19			
Medial/Inferior Cuneus	18,19			
Primary visual cortex	17			
Lingual (& Fusiform) Gyri	18,19			
Limbic Lobe				
Ant. Cingulate Gyrus	24,33			
Post. Cingulate Gyrus	23,31			
Parahippocampal Gyrus	27,28			
Deep Structures				
Basal Ganglia				
Caudate Nucleus: head				
Caudate Nucleus: tail				
Centrum Semiovale				
Corona Radiata				
Internal Capsule Ant.				
Post.				
External Capsule				
Thalamus anterior				
posterior				
medial				
lateral				
Brain Stem				
Cerebellum				
Other				
Volume (cc's)				
Diameter (mm's)				

APPENDIX C1
Raw Reaction Time Data

Table C1.2 Raw reaction time data (ms) in the no movement condition for the young healthy control group (YHC, n=20), older healthy control group (OHC, n=20), Right-hemisphere stroke 'no disengage deficit' group (RHS/DD-, n=11) and the five individual stroke participants with a disengage deficit score larger than the mean of the older healthy control group (RHS/DD+,RHS/DD++).

	No Limb Movement (NM)															
	100ms SOA								500ms SOA							
	LEFT ARM				RIGHT ARM				LEFT ARM				RIGHT ARM			
	RT (ms) Left targets		RT (ms) Right targets		RT (ms) Left targets		RT (ms) Right targets		RT (ms) Left targets		RT (ms) Right targets		RT (ms) Left targets		RT (ms) Right targets	
	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue
YHC (n=20)	415	428	416	425	421	440	421	435	362	341	351	341	362	344	359	345
OHC (n=20)	451	486	441	489	444	478	447	484	430	410	428	417	445	410	435	431
RHS/DD- (n=11)	528	577	504	552	545	590	519	563	514	507	493	489	517	518	497	502
RHS/DD++ (1022)	595	924	608	587	612	911	521	581	479	808	558	627	440	770	514	557
RHS/DD++ (1045)	1122	1162	379	412	747	981	384	416	777	819	419	460	574	932	424	416
RHS/DD+ (1385)	852	904	692	782	910	1075	602	705	654	856	568	638	686	956	566	620
RHS/DD+ (1379)	665	771	705	775	690	801	788	741	627	669	698	649	671	663	696	666
RHS/DD+ (1380)	733	790	676	753	600	695	690	744	671	708	680	673	691	717	715	632

Table C1.2 Raw reaction time data (ms) in the passive movement condition for the young healthy control group (YHC, n=20), older healthy control group (OHC, n=20), Right-hemisphere stroke 'no disengage deficit' group (RHS/DD-, n=11) and the five individual stroke participants with a disengage deficit score larger than the mean of the older healthy control group (RHS/DD+,RHS/DD++).

	Passive Limb Movement (PM)															
	100ms SOA								500ms SOA							
	LEFT ARM				RIGHT ARM				LEFT ARM				RIGHT ARM			
	RT (ms) Left targets		RT (ms) Right targets		RT (ms) Left targets		RT (ms) Right targets		RT (ms) Left targets		RT (ms) Right targets		RT (ms) Left targets		RT (ms) Right targets	
	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue
YHC (n=20)	437	450	413	446	415	436	410	426	371	341	353	341	349	343	353	333
OHC (n=20)	483	507	473	499	473	496	464	513	445	420	434	429	442	422	435	426
RHS/DD- (n=11)	542	589	515	572	544	591	547	586	506	503	491	499	533	499	499	474
RHS/DD++ (1022)	530	883	454	532	702	969	610	661	444	735	516	524	651	656	613	593
RHS/DD++ (1045)	1019	1106	464	491	729	966	482	499	705	657	399	447	611	674	421	442
RHS/DD+ (1385)	803	1158	641	680	926	916	592	669	519	701	483	475	504	881	531	542
RHS/DD+ (1379)	701	745	677	794	679	699	651	647	740	584	627	615	597	579	564	544
RHS/DD+ (1380)	872	836	926	789	945	855	825	906	839	859	746	817	852	858	740	815

Table C1.3 Raw reaction time data (ms) in the active movement condition for the young healthy control group (YHC, n=20), older healthy control group (OHC, n=20), Right-hemisphere stroke 'no disengage deficit' group (RHS/DD-, n=11) and the five individual stroke participants with a disengage deficit score larger than the mean of the older healthy control group (RHS/DD+,RHS/DD++).

	Active Limb Movement (AM)															
	100ms SOA								500ms SOA							
	LEFT ARM				RIGHT ARM				LEFT ARM				RIGHT ARM			
	RT (ms) Left targets		RT (ms) Right targets		RT (ms) Left targets		RT (ms) Right targets		RT (ms) Left targets		RT (ms) Right targets		RT (ms) Left targets		RT (ms) Right targets	
	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue	Valid cue	Inv cue
YHC (n=20)	444	461	428	452	435	455	431	441	354	335	346	335	357	337	339	334
OHC (n=20)	502	526	520	527	492	528	507	517	438	427	440	425	457	419	446	438
RHS/DD- (n=11)	598	594	553	608	575	614	570	580	544	481	490	496	534	488	479	481
RHS/DD++ (1022)	607	683	463	645	673	1048	603	661	496	572	517	604	555	836	570	568
RHS/DD++ (1045)	1093	1192	430	443	938	772	407	369	967	920	380	396	697	658	383	303
RHS/DD+ (1385)	678	841	687	680	875	927	656	625	591	805	488	499	596	617	573	580
RHS/DD+ (1379)	867	819	792	815	771	732	854	757	626	670	624	584	591	574	600	563
RHS/DD+ (1380)	911	855	829	867	836	867	697	761	802	738	751	737	696	723	686	757

APPENDIX C2
Cueing Effects and Disengage Deficit Scores

Table C2.1 Cueing effects and disengage deficit scores (ms) in the no movement condition for the young healthy control group (YHC, n=20), older healthy control group (OHC, n=20), Right-hemisphere stroke 'no disengage deficit' group (RHS/DD-, n=11) and the five stroke participants with a large disengage deficit score (RHS/DD+,RHS/DD++).

	No Limb Movement (NM)											
	100ms SOA						500ms SOA					
	LEFT ARM			RIGHT ARM			LEFT ARM			RIGHT ARM		
	Left Cuing effect (ms)	Right Cuing Effect (ms)	DDS (ms)	Left Cuing effect (ms)	Right Cuing Effect (ms)	DDS (ms)	Left Cuing Effect (ms)	Right Cuing Effect (ms)	DDS (ms)	Left Cuing effect (ms)	Right Cuing Effect (ms)	DDS (ms)
	(Inv L – Val L)	(Inv R – Val R)	(CE_L - CE_R)	(Inv L – Val L)	(Inv R – Val R)	(CE_L - CE_R)	(Inv L – Val L)	(Inv R – Val R)	(CE_L - CE_R)	(Inv L – Val L)	(Inv R – Val R)	(CE_L - CE_R)
YHC (n=20)	13	9	4	19	14	5	-21	-10	-11	-18	-14	-4
OHC (n=20)	35	48	-13	34	37	-3	-20	-11	-9	-35	-4	-31
RHS/DD- (n=11)	49	48	1	45	44	1	-7	-4	-3	1	5	-4
RHS/DD++ (1022)	329	-21	350	299	60	239	329	69	260	330	43	287
RHS/DD++ (1045)	40	33	7.0	234	32	202	42	41	1	358	-8	366
RHS/DD+ (1385)	52	90	-38	165	103	62	202	70	132	270	54	216
RHS/DD+ (1379)	106	70	36	111	-47	158	42	-49	91	-8	-30	22
RHS/DD+ (1380)	57	77	-20	95	54	41	37	-7	44	26	-83	109

DDS = Disengage Deficit Score

Table C2.2 Cueing effects and disengage deficit scores (ms) in the passive movement condition for the young healthy control group (YHC, n=20), older healthy control group (OHC, n=20), Right-hemisphere stroke 'no disengage deficit' group (RHS/DD-, n=11) and the five stroke participants with a large disengage deficit score (RHS/DD+,RHS/DD++).

	Passive Limb Movement (PM)											
	100ms SOA						500ms SOA					
	LEFT ARM			RIGHT ARM			LEFT ARM			RIGHT ARM		
	Left Cuing effect (ms)	Right Cuing Effect (ms)	DDS (ms)	Left Cuing effect (ms)	Right Cuing Effect (ms)	DDS (ms)	Left Cuing Effect (ms)	Right Cuing Effect (ms)	DDS (ms)	Left Cuing effect (ms)	Right Cuing Effect (ms)	DDS (ms)
	(Inv L – Val L)	(Inv R – Val R)	(CE_L - CE_R)	(Inv L – Val L)	(Inv R – Val R)	(CE_L - CE_R)	(Inv L – Val L)	(Inv R – Val R)	(CE_L - CE_R)	(Inv L – Val L)	(Inv R – Val R)	(CE_L - CE_R)
YHC (n=20)	13	33	-20	21	16	5	-30	-12	-18	-6	-20	14
OHC (n=20)	24	26	-2	23	49	-26	-25	-5	-20	-20	-9	-11
RHS/DD- (n=11)	47	57	-10	47	39	8	-3	8	-11	-34	-25	-9
RHS/DD++ (1022)	353	78	275	267	51	216	291	8	283	5	-20	25
RHS/DD++ (1045)	87	27	60	237	17	220	-48	48	-96	63	21	42
RHS/DD+ (1385)	355	39	316	-10	77	-87	182	-8	190	377	11	366
RHS/DD+ (1379)	44	117	-73	20	-4	24	-156	-12	-144	-18	-20	2
RHS/DD+ (1380)	-36	-137	101	-90	81	-171	20	71	-51	6	75	-69

DDS = Disengage Deficit Score

Table C2.3 Cueing effects and disengage deficit scores (ms) in the active movement condition for the young healthy control group (YHC, n=20), older healthy control group (OHC, n=20), Right-hemisphere stroke 'no disengage deficit' group (RHS/DD-, n=11) and the five stroke participants with a large disengage deficit score (RHS/DD+,RHS/DD++).

	Active Limb Movement (AM)											
	100ms SOA						500ms SOA					
	LEFT ARM			RIGHT ARM			LEFT ARM			RIGHT ARM		
	Left Cuing effect (ms)	Right Cuing Effect (ms)	DDS (ms)	Left Cuing effect (ms)	Right Cuing Effect (ms)	DDS (ms)	Left Cuing Effect (ms)	Right Cuing Effect (ms)	DDS (ms)	Left Cuing effect (ms)	Right Cuing Effect (ms)	DDS (ms)
	(Inv L – Val L)	(Inv R – Val R)	(CE_L - CE_R)	(Inv L – Val L)	(Inv R – Val R)	(CE_L - CE_R)	(Inv L – Val L)	(Inv R – Val R)	(CE_L - CE_R)	(Inv L – Val L)	(Inv R – Val R)	(CE_L - CE_R)
YHC (n=20)	17	24	-7	20	10	10	-19	-11	-8	-20	-5	-15
OHC (n=20)	24	7	17	36	10	26	-11	-15	4	-38	-8	-30
RHS/DD- (n=11)	-4	55	-59	39	10	29	-63	6	-69	-46	2	-48
RHS/DD++ (1022)	76	182	-106	375	58	317	76	87	-11	281	-2	283
RHS/DD++ (1045)	99	13	86	-166	-38	-128	-47	16	-63	-39	-80	41
RHS/DD+ (1385)	163	-7	170	52	-31	83	214	11	203	21	7	14
RHS/DD+ (1379)	-48	23	-71	-39	-97	58	44	-40	84	-17	-37	20
RHS/DD+ (1380)	-56	38	-94	31	64	-33	-64	-14	-50	27	71	-44

DDS = Disengage Deficit Score

APPENDIX C3

Percent Error and Eye Movement Data from Covert Orienting Task

Table C3.1. Younger healthy control group (YHC, n=20): percent error data for all within-subjects experimental conditions collapsed across error type (miss, RT < 100ms, RT > 2000ms).

SOA	Arm used	Cue Validity	Target Side	Movement Condition		
				NM	PM	AM
100ms	Left	Invalid	Left	1.00	1.50	1.25
			Right	0.75	0.75	1.25
		Valid	Left	2.00	1.50	1.00
			Right	1.25	1.50	0.50
	Right	Invalid	Left	1.00	2.00	2.00
			Right	0.75	2.75	2.25
		Valid	Left	1.25	3.00	1.00
			Right	1.75	1.25	2.50
500ms	Left	Invalid	Left	3.00	1.50	2.75
			Right	2.50	1.00	1.50
		Valid	Left	2.00	1.50	2.50
			Right	3.25	2.00	2.75
	Right	Invalid	Left	2.00	2.50	3.50
			Right	2.75	2.25	4.00
		Valid	Left	1.50	4.00	2.25
			Right	2.00	2.00	3.00

Table C3.2. Older healthy control group (OHC, n=20): percent error data for all within-subjects experimental conditions collapsed across error type (miss, RT < 100ms, RT > 2000ms).

SOA	Arm used	Cue Validity	Target Side	Movement Condition		
				NM	PM	AM
100ms	Left	Invalid	Left	1.00	1.50	1.25
			Right	1.00	0.75	1.75
		Valid	Left	1.75	1.25	2.00
			Right	1.00	1.00	1.00
	Right	Invalid	Left	1.50	1.50	1.00
			Right	2.00	1.00	2.00
		Valid	Left	2.25	1.50	2.00
			Right	1.25	1.25	1.50
500ms	Left	Invalid	Left	2.50	1.50	3.75
			Right	0.50	1.50	2.00
		Valid	Left	2.50	2.25	2.75
			Right	2.25	1.50	3.00
	Right	Invalid	Left	2.50	1.75	5.75
			Right	1.25	1.25	3.50
		Valid	Left	0.50	1.75	2.25
			Right	1.00	1.50	4.50

Table C3.3. Right-hemisphere stroke group (RHS, n=16): percent error data for all within-subjects experimental conditions collapsed across error type (miss, RT < 100ms, RT > 2000ms).

SOA	Arm used	Cue Validity	Target Side	Movement Condition		
				NM	PM	AM
100ms	Left	Invalid	Left	6.25	6.56	3.75
			Right	8.13	3.13	2.81
		Valid	Left	6.56	3.44	3.13
			Right	5.31	3.75	2.19
	Right	Invalid	Left	5.31	7.81	5.00
			Right	4.06	5.00	2.81
		Valid	Left	4.06	5.31	2.50
			Right	5.00	3.44	3.13
500ms	Left	Invalid	Left	6.56	6.56	6.25
			Right	5.31	4.06	5.00
		Valid	Left	5.63	5.94	3.13
			Right	5.94	5.63	3.44
	Right	Invalid	Left	6.25	9.69	3.13
			Right	7.81	5.31	3.75
		Valid	Left	6.25	4.06	4.38
			Right	5.94	4.06	5.31

Table C3.4. Younger healthy control group (YHC, n=20): percent of trials removed as a result of eye movements for all within-subjects experimental conditions.

SOA	Arm used	Cue Validity	Target Side	Movement Condition		
				NM	PM	AM
100ms	Left	Invalid	Left	0.75	0.25	0.75
			Right	0.25	0.25	0.00
		Valid	Left	0.50	1.50	0.00
			Right	0.25	0.75	0.00
	Right	Invalid	Left	1.00	0.25	0.25
			Right	0.75	0.00	0.00
		Valid	Left	1.50	0.25	0.50
			Right	0.50	0.50	0.00
500ms	Left	Invalid	Left	0.75	0.50	0.25
			Right	0.50	0.25	1.00
		Valid	Left	0.75	0.50	0.75
			Right	0.75	0.25	0.50
	Right	Invalid	Left	1.75	1.50	0.25
			Right	1.50	0.50	1.00
		Valid	Left	0.50	0.50	0.25
			Right	1.25	0.25	0.25

Table C3.5. Older healthy control group (OHC, n=20): percent of trials removed as a result of eye movements for all within-subjects experimental conditions.

SOA	Arm used	Cue Validity	Target Side	Movement Condition		
				NM	PM	AM
100ms	Left	Invalid	Left	2.50	2.25	1.50
			Right	2.25	1.00	2.50
		Valid	Left	1.25	0.50	0.25
			Right	0.25	0.75	1.75
	Right	Invalid	Left	1.00	2.25	0.75
			Right	0.50	0.75	0.50
		Valid	Left	1.25	1.25	0.75
			Right	1.25	1.75	1.25
500ms	Left	Invalid	Left	1.00	1.75	3.75
			Right	1.50	2.75	2.00
		Valid	Left	1.50	1.50	2.00
			Right	2.00	2.75	3.00
	Right	Invalid	Left	2.50	2.00	3.75
			Right	2.50	1.75	2.75
		Valid	Left	1.25	2.25	2.75
			Right	2.25	2.00	6.25

Table C3.6. Right-hemisphere stroke group (RHS, n=16): percent of trials removed as a result of eye movements for all within-subjects experimental conditions.

SOA	Arm used	Cue Validity	Target Side	Movement Condition		
				NM	PM	AM
100ms	Left	Invalid	Left	6.88	6.88	9.38
			Right	3.75	5.63	5.31
		Valid	Left	3.44	0.94	5.00
			Right	0.94	4.06	3.75
	Right	Invalid	Left	5.94	5.31	10.00
			Right	4.69	1.88	3.44
		Valid	Left	1.88	0.94	3.75
			Right	0.94	0.94	2.50
500ms	Left	Invalid	Left	9.38	6.56	11.56
			Right	9.06	11.88	12.50
		Valid	Left	5.94	5.63	9.38
			Right	7.81	5.31	8.44
	Right	Invalid	Left	9.06	8.44	10.31
			Right	8.44	10.31	10.31
		Valid	Left	7.19	5.31	7.50
			Right	4.38	4.69	7.19

APPENDIX C4
Lesion Localization for each RHS/DD- Participant

Table C4. Percentage of right-hemisphere stroke participants in the 'no disengage deficit' group (RHS/DD-; n=11) with damage in right-hemisphere neuroanatomical regions of interest and number of 1mm^3 voxels of damage in each of these eleven participants.

Right-hemisphere Neuroanatomical region	% RHS/DD- lesioned	RHS/DD- participants Number of 1mm^3 voxels damaged				
		1386	**1047**	**1382**	**1387**	**1375**
FRONTAL						
Rolandic operculum[a]	55	5064	9880			
Inf. Frontal operculum[a]	73	2822	7682		292	113
Precentral Gyrus[a]	64	1348	5166		44	113
Middle Frontal Gyrus	45		1808		7	55
Superior Frontal Gyrus[b]	27		453			9
Suppl. Motor Area	9		9			
Med. Sup. Frontal Gyr.	0					
Ant. Cingulate Gyrus	9		3			
TEMPORAL						
Mid. Temporal Gyrus[a]	45	144	13077			
Insular Cortex[a]	91	2830	11882	432	546	314
Sup. Temporal Gyrus[a]	45	4731	17624			
Fusiform Gyrus	18		505			
PARIETAL						
Supramarginal Gyrus[a]	45	1772	6045			
Precuneus	27		122			
Superior Parietal Lobe[b]	27		2068			
Inferior Parietal Lobe	36		4839			
Angular Gyrus	27		10182			
SUBCORTICAL						
Globus Pallidus	36		143	227		
Putamen	82		3425	969	199	483
Caudate Nucleus	36		148	3		
Thalamus	9					
NON-CORTICAL	100	1922	45922	1475	4054	2960
TOTAL LESION SIZE		26402	168731	3107	5259	4047

Data from automated anatomical labeling template (Tzourio-Mazoyer et al., 2002) in MRIcro (http://www.sph.sc.edu/comd/ rorden/mricro.html).

[a] – ventral orienting network

[b] – dorsal spatial attention network

Table C4 (cont.). Percentage of right-hemisphere stroke participants in the 'no disengage deficit' group (RHS/DD-; n=11) with damage in right-hemisphere neuroanatomical regions of interest and number of 1mm^3 voxels of damage in each of these eleven participants.

Right-hemisphere Neuroanatomical region	RHS/DD- participants Number of 1mm^3 voxels damaged					
	1384	**1378**	**1381**	**1034**	**1376**	**1388**
FRONTAL						
Rolandic operculum[a]	101			2438	2165	8249
Inf. Frontal operculum[a]	17			1871	410	3556
Precentral Gyrus[a]				1071	330	11696
Middle Frontal Gyrus				1444		900
Superior Frontal Gyrus[b]						27
Suppl. Motor Area						
Med. Sup. Frontal Gyr.						
Ant. Cingulate Gyrus						
TEMPORAL						
Mid. Temporal Gyrus[a]				9640	155	5629
Insular Cortex[a]	3153	24	28	1311		4425
Sup. Temporal Gyrus[a]				10150	3634	16069
Fusiform Gyrus				836		
PARIETAL						
Supramarginal Gyrus[a]				8663	1678	14163
Precuneus				5903		10
Superior Parietal Lobe[b]				5909		1494
Inferior Parietal Lobe				6596	8	7908
Angular Gyrus				8256		8565
SUBCORTICAL						
Globus Pallidus	15		186			
Putamen	2751	1084	205	52		397
Caudate Nucleus				293		145
Thalamus				3128		
NON-CORTICAL	3691	1755	425	59130	204	25670
TOTAL LESION SIZE	9728	4524	863	154584	13076	133261

Data from automated anatomical labeling template (Tzourio-Mazoyer et al., 2002) in MRIcro (http://www.sph.sc.edu/comd/ rorden/mricro.html).

[a] – ventral orienting network

[b] – dorsal spatial attention network

APPENDIX D
STATISTICAL ANALYSES TABLES

Table D1. Omnibus mixed analysis of variance of reaction time data of young controls (YHC), older controls (OHC), and right-hemisphere stroke participants (RHS). Design = Group (YHC, OHC, RHS) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Between subjects		
Group	2	17.67**	0.000
Within-group Error	53	(447083)	
	Within subjects		
Movement (M)	1.7	3.10	0.057
Movement X Group	3.5	0.81	0.509
Error (M)	91.5	(19805)	
Arm (A)	1	0.17	0.680
Arm X Group	2	0.07	0.931
Error (A)	53	(7998)	
Cue (C)	1	11.98**	0.001
Cue X Group	2	5.55**	0.006
Error (C)	53	(7788)	
Target (T)	1	6.95*	0.011
Target X Group	2	5.12**	0.009
Error (T)	53	(49997)	
SOA	1	170.96**	0.000
SOA X Group	2	2.23	0.117
Error (SOA)	53	(21282)	
Movement X Arm	2	1.03	0.360
Movement X Arm X Group	4	0.88	0.476
Error (M x A)	106	(4086)	
Movement X Cue	2	12.80**	0.000
Movement X Cue X Group	4	7.31**	0.000
Error (M x C)	106	(875)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D1 (cont.) Group (YHC, OHC, RHS) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Arm X Cue	1	0.28	0.598
Arm X Cue X Group	2	0.64	0.533
Error (A x C)	53	(456)	
Movement X Arm X Cue	1.7	0.39	0.646
Movement X Arm X Cue X Group	3.5	1.63	0.180
Error (M x A x C)	91.6	(1063)	
Movement X Target	1.7	0.16	0.825
Movement X Target X Group	3.5	0.80	0.510
Error (M x T)	91.6	(1506)	
Arm X Target	1	0.64	0.429
Arm X Target X Group	2	0.02	0.981
Error (A x T)	53	(2469)	
Movement X Arm X Target	2	0.87	0.421
Movement X Arm X Target X Group	4	0.13	0.973
Error (M x A x T)	106	(754)	
Cue X Target	1	0.04	0.844
Cue X Target X Group	2	1.81	0.173
Error (C x T)	53	(4281)	
Movement X Cue X Target	2	2.95	0.057
Movement X Cue X Target X Group	4	7.76**	0.000
Error (M x C x T)	106	(763)	
Arm X Cue X Target	1	5.19	0.027
Arm X Cue X Target X Group	2	5.10**	0.009
Error (A x C x T)	53	(782)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D1 (cont.) Group (YHC, OHC, RHS) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Movement X Arm X Cue X Target	2	0.27	0.766
Movement X Arm X Cue X Target X Group	4	1.61	0.177
Error (M x A x C x T)	106	(1186)	
Movement X SOA	2	20.87**	0.000
Movement X SOA X Group	4	0.64	0.638
Error (M x SOA)	106	(3778)	
Arm X SOA	1	1.95	0.168
Arm X SOA X Group	2	1.40	0.255
Error (A x SOA)	53	(1361)	
Movement X Arm X SOA	2	0.03	0.969
Movement X Arm X SOA X Group	4	0.99	0.415
Error (M x A x SOA)	106	(1134)	
Cue X SOA	1	85.18**	0.000
Cue X SOA X Group	2	0.82	0.444
Error (C x SOA)	53	(3182)	
Movement X Cue X SOA	2	1.51	0.227
Movement X Cue X SOA X Group	4	1.30	0.275
Error (M x C x SOA)	106	(889)	
Arm X Cue X SOA	1	0.01	0.925
Arm X Cue X SOA X Group	2	1.13	0.329
Error (A x C x SOA)	53	(846)	
Movement X Arm X Cue X SOA	2	0.02	0.978
Movement X Arm X Cue X SOA X Group	4	0.80	0.527
Error (M x A x C x SOA)	106	(745)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D1 (cont.) Group (YHC, OHC, RHS) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Within subjects (cont.)		
Target X SOA	1	3.10	0.084
Target X SOA X Group	2	2.10	0.133
Error (T x SOA)	53	(3958)	
Movement X Target X SOA	2	0.69	0.505
Movement X Target X SOA X Group	4	0.62	0.647
Error (M x T x SOA)	106	(651)	
Arm X Target X SOA	1	0.72	0.399
Arm X Target X SOA X Group	2	0.20	0.816
Error (A x T x SOA)	53	(1145)	
Movement X Arm X Target X SOA	2	2.75	0.068
Movement X Arm X Target X SOA X Group	4	1.71	0.154
Error (M x A x T x SOA)	106	(775)	
Cue X Target X SOA	1	2.60	0.113
Cue X Target X SOA X Group	2	0.22	0.807
Error (C x T x SOA)	53	(1766)	
Movement X Cue X Target X SOA	1.7	2.69	0.083
Movement X Cue X Target X SOA X Group	3.3	1.29	0.281
Error (M x C x T x SOA)	88.0	(810)	
Arm X Cue X Target X SOA	1	1.09	0.301
Arm X Cue X Target X SOA X Group	2	0.18	0.837
Error (A x C x T x SOA)	53	(636)	
Movement X Arm X Cue X Target X SOA	1.6	4.07	0.028
Movement X Arm X Cue X Target X SOA X Group	3.2	0.58	0.639
Error (M x A x C x T x SOA)	85.0	(1122)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D2. Analysis of variance of error data collapsed over type of error (miss, RT < 100ms, RT > 200ms) for young controls (YHC) and older controls (OHC).
Design = Group (YHC, OHC) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Between subjects		
Group	1	0.06	0.807
Within-group Error	38	(135.2)	
	Within subjects		
Movement (M)	2	2.68	0.075
Movement X Group	2	1.04	0.360
Error (M)	76	(32.3)	
Arm (A)	1	2.32	0.136
Arm X Group	1	0.44	0.510
Error (A)	38	(28.3)	
Cue (C)	1	0.00	0.964
Cue X Group	1	0.05	0.821
Error (C)	38	(6.28)	
Target (T)	1	1.44	0.238
Target X Group	1	0.82	0.371
Error (T)	38	(15.3)	
SOA	1	25.70**	0.000
SOA X Group	1	0.11	0.740
Error (SOA)	38	(14.1)	
Movement X Arm	2	2.71	0.073
Movement X Arm X Group	2	1.27	0.287
Error (M x A)	76	(14.3)	
Movement X Cue	1.6	1.71	0.194
Movement X Cue X Group	1.6	0.13	0.835
Error (M x C)	60.3	(7.5)	
Arm X Cue	1	2.43	0.127
Arm X Cue X Group	1	0.05	0.825
Error (A x C)	38	(12.9)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D2 (cont.) Error data: Group (YHC, OHC) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Movement X Arm X Cue	1	0.55	0.579
Movement X Arm X Cue X Group	1	0.56	0.572
Error (M x A x C)	38	(7.1)	
Movement X Target	2	1.05	0.356
Movement X Target X Group	2	0.78	0.462
Error (M x T)	76	(7.9)	
Arm X Target	1	2.56	0.118
Arm X Target X Group	1	0.02	0.885
Error (A x T)	38	(5.5)	
Movement X Arm X Target	2	1.09	0.341
Movement X Arm X Target X Group	2	0.29	0.753
Error (M x A x T)	76	(12.5)	
Cue X Target	1	0.95	0.337
Cue X Target X Group	1	0.22	0.642
Error (C x T)	38	(10.0)	
Movement X Cue X Target	2	1.08	0.347
Movement X Cue X Target X Group	2	0.16	0.850
Error (M x C x T)	76	(10.1)	
Arm X Cue X Target	1	0.46	0.503
Arm X Cue X Target X Group	1	2.49	0.123
Error (A x C x T)	38	(6.4)	
Movement X Arm X Cue X Target	1.6	1.09	0.330
Movement X Arm X Cue X Target X Group	1.6	0.77	0.442
Error (M x A x C x T)	61.8	(9.7)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D2 (cont.) Error data: Group (YHC, OHC) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Movement X SOA	2	6.19**	0.003
Movement X SOA X Group	2	2.40	0.098
Error (M x SOA)	76	(10.7)	
Arm X SOA	1	0.40	0.529
Arm X SOA X Group	1	0.00	0.966
Error (A x SOA)	38	(7.3)	
Movement X Arm X SOA	2	2.18	0.120
Movement X Arm X SOA X Group	2	1.21	0.303
Error (M x A x SOA)	76	(8.1)	
Cue X SOA	1	0.56	0.460
Cue X SOA X Group	1	0.06	0.805
Error (C x SOA)	38	(10.3)	
Movement X Cue X SOA	2	0.84	0.436
Movement X Cue X SOA X Group	2	0.52	0.594
Error (M x C x SOA)	76	(13.0)	
Arm X Cue X SOA	1	2.31	0.137
Arm X Cue X SOA X Group	1	0.44	0.512
Error (A x C x SOA)	38	(8.6)	
Movement X Arm X Cue X SOA	1.4	0.82	0.405
Movement X Arm X Cue X SOA X Group	1.4	0.17	0.761
Error (M x A x C x SOA)	51.7	(10.4)	
Target X SOA	1	0.09	0.767
Target X SOA X Group	1	0.53	0.473
Error (T x SOA)	38	(7.2)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D2 (cont.) Error data: Group (YHC, OHC) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Movement X Target X SOA	2	0.29	0.748
Movement X Target X SOA X Group	2	0.70	0.501
Error (M x T x SOA)	76	(6.7)	
Arm X Target X SOA	1	0.03	0.871
Arm X Target X SOA X Group	1	3.76	0.581
Error (A x T x SOA)	38	(12.2)	
Movement X Arm X Target X SOA	2	0.13	0.875
Movement X Arm X Target X SOA X Group	2	0.03	0.966
Error (M x A x T x SOA)	76	(11.8)	
Cue X Target X SOA	1	4.29	0.045
Cue X Target X SOA X Group	1	1.67	0.204
Error (C x T x SOA)	38	(14.4)	
Movement X Cue X Target X SOA	2	2.49	0.090
Movement X Cue X Target X SOA X Group	2	2.45	0.093
Error (M x C x T x SOA)	76	(7.5)	
Arm X Cue X Target X SOA	1	0.04	0.841
Arm X Cue X Target X SOA X Group	1	2.75	0.105
Error (A x C x T x SOA)	38	(8.0)	
Movement X Arm X Cue X Target X SOA	2	0.26	0.770
Movement X Arm X Cue X Target X SOA X Group	2	0.34	0.712
Error (M x A x C x T x SOA)	76	(10.8)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D3. Analysis of variance of reaction time data of young controls (YHC) and older controls (OHC).
Design = Group (YHC, OHC) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Between subjects		
Group	1	6.35	0.016
Within-group Error	38	(375385)	
	Within subjects		
Movement (M)	2	3.08	0.052
Movement X Group	2	1.58	0.213
Error (M)	76	(16168)	
Arm (A)	1	0.20	0.654
Arm X Group	1	0.29	0.591
Error (A)	38	(3768)	
Cue (C)	1	2.63	0.113
Cue X Group	1	1.48	0.231
Error (C)	38	(2433)	
Target (T)	1	1.85	0.182
Target X Group	1	4.25	0.046
Error (T)	38	(1821)	
SOA	1	127.63**	0.000
SOA X Group	1	4.62	0.038
Error (SOA)	38	(19495)	
Movement X Arm	2	1.71	0.189
Movement X Arm X Group	2	0.45	0.639
Error (M x A)	76	(2989)	
Movement X Cue	2	1.20	0.306
Movement X Cue X Group	2	3.05	0.053
Error (M x C)	76	(546)	
Arm X Cue	1	0.08	0.781
Arm X Cue X Group	1	0.10	0.754
Error (A x C)	38	(316)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D3 (cont.) Group (YHC, OHC) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Movement X Arm X Cue	2	0.86	0.428
Movement X Arm X Cue X Group	2	0.79	0.456
Error (M x A x C)	76	(403)	
Movement X Target	2	1.75	0.181
Movement X Target X Group	2	1.34	0.267
Error (M x T)	76	(540)	
Arm X Target	1	1.73	0.196
Arm X Target X Group	1	0.11	0.741
Error (A x T)	38	(509)	
Movement X Arm X Target	2	2.16	0.122
Movement X Arm X Target X Group	2	0.32	0.725
Error (M x A x T)	76	(286)	
Cue X Target	1	5.21	0.028
Cue X Target X Group	1	0.78	0.382
Error (C x T)	38	(814)	
Movement X Cue X Target	2	2.45	0.093
Movement X Cue X Target X Group	2	3.32	0.041
Error (M x C x T)	76	(412)	
Arm X Cue X Target	1	0.39	0.537
Arm X Cue X Target X Group	1	9.09**	0.005
Error (A x C x T)	38	(375)	
Movement X Arm X Cue X Target	2	0.96	0.389
Movement X Arm X Cue X Target X Group	2	0.69	0.506
Error (M x A x C x T)	76	(555)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D3 (cont.) Group (YHC, OHC) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Movement X SOA	2	13.69**	0.000
Movement X SOA X Group	2	0.60	0.549
Error (M x SOA)	76	(3288)	
Arm X SOA	1	4.69	0.037
Arm X SOA X Group	1	1.58	0.216
Error (A x SOA)	38	(1108)	
Movement X Arm X SOA	2	0.48	0.624
Movement X Arm X SOA X Group	2	1.36	0.264
Error (M x A x SOA)	76	(976)	
Cue X SOA	1	100.56**	0.000
Cue X SOA X Group	1	2.71	0.108
Error (C x SOA)	38	(1877)	
Movement X Cue X SOA	2	1.41	0.251
Movement X Cue X SOA X Group	2	2.55	0.085
Error (M x C x SOA)	76	(547)	
Arm X Cue X SOA	1	0.15	0.701
Arm X Cue X SOA X Group	1	2.09	0.156
Error (A x C x SOA)	38	(719)	
Movement X Arm X Cue X SOA	2	0.18	0.840
Movement X Arm X Cue X SOA X Group	2	2.08	0.131
Error (M x A x C x SOA)	76	(409)	
Target X SOA	1	0.34	0.563
Target X SOA X Group	1	0.15	0.704
Error (T x SOA)	38	(573)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D3 (cont.) Group (YHC, OHC) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Movement X Target X SOA	2	0.32	0.730
Movement X Target X SOA X Group	2	1.09	0.342
Error (M x T x SOA)	76	(344)	
Arm X Target X SOA	1	0.26	0.611
Arm X Target X SOA X Group	1	0.82	0.966
Error (A x T x SOA)	38	(455)	
Movement X Arm X Target X SOA	2	0.52	0.599
Movement X Arm X Target X SOA X Group	2	2.28	0.109
Error (M x A x T x SOA)	76	(410)	
Cue X Target X SOA	1	4.53	0.040
Cue X Target X SOA X Group	1	0.85	0.363
Error (C x T x SOA)	38	(845)	
Movement X Cue X Target X SOA	2	4.01	0.022
Movement X Cue X Target X SOA X Group	2	0.83	0.440
Error (M x C x T x SOA)	76	(431)	
Arm X Cue X Target X SOA	1	2.12	0.154
Arm X Cue X Target X SOA X Group	1	0.68	0.413
Error (A x C x T x SOA)	38	(302)	
Movement X Arm X Cue X Target X SOA	1.4	2.64	0.100
Movement X Arm X Cue X Target X SOA X Group	1.4	0.99	0.349
Error (M x A x C x T x SOA)	51.4	(1061)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D4.1. Analysis of variance of reaction time data for the no movement (NM) condition in healthy controls.
Design = Group (YHC, OHC) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Between subjects		
Group	1	5.52	0.024
Within-group Error	38	(95641)	
	Within subjects		
Arm (A)	1	1.37	0.249
Arm X Group	1	0.12	0.731
Error (A)	38	(2459)	
Cue (C)	1	3.08	0.087
Cue X Group	1	4.29	0.045
Error (C)	38	(1227)	
Target (T)	1	0.00	0.950
Target X Group	1	1.13	0.294
Error (T)	38	(835)	
SOA	1	95.92**	0.000
SOA X Group	1	9.37**	0.004
Error (SOA)	38	(5384)	
Arm X Cue	1	0.24	0.630
Arm X Cue X Group	1	1.76	0.193
Error (A x C)	38	(298)	
Arm X Target	1	1.04	0.314
Arm X Target X Group	1	0.61	0.439
Error (A x T)	38	(384)	
Cue X Target	1	5.80	0.021
Cue X Target X Group	1	3.89	0.056
Error (C x T)	38	(391)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D4.1 (cont.) No movement: Group (YHC, OHC) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Within subjects (cont.)			
Arm X Cue X Target	1	0.00	0.963
Arm X Cue X Target X Group	1	0.63	0.434
Error (A x C x T)	38	(493)	
Arm X SOA	1	1.13	0.295
Arm X SOA X Group	1	5.50	0.031
Error (A x SOA)	38	(583)	
Cue X SOA	1	105.92**	0.000
Cue X SOA X Group	1	10.20**	0.003
Error (C x SOA)	38	(696)	
Arm X Cue X SOA	1	0.06	0.816
Arm X Cue X SOA X Group	1	0.32	0.573
Error (A x C x SOA)	38	(393)	
Target X SOA	1	0.09	0.764
Target X SOA X Group	1	0.61	0.441
Error (T x SOA)	38	(403)	
Arm X Target X SOA	1	0.00	0.959
Arm X Target X SOA X Group	1	1.03	0.318
Error (A x T x SOA)	38	(250)	
Cue X Target X SOA	1	3.33	0.076
Cue X Target X SOA X Group	1	0.00	0.959
Error (C x T x SOA)	38	(456)	
Arm X Cue X Target X SOA	1	2.19	0.147
Arm X Cue X Target X SOA X Group	1	3.90	0.056
Error (A x C x T x SOA)	38	(227)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D4.2. Analysis of variance of reaction time data of the younger healthy control group comparing cueing effects at each SOA.
Design = Cue (Valid, Invalid) x SOA (100ms, 500ms)

Source	df	F	p
	Within subjects		
Cue	1	0.11	0.750
Error (C)	19	(146)	
SOA	1	85.01**	0.000
Error SOA	19	(1308)	
Cue X SOA	1	36.33**	0.000
Error (C x SOA)	19	(121)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D4.3. Analysis of variance of reaction time data of the older healthy control group comparing cueing effects at each SOA.
Design = Cue (Valid, Invalid) x SOA (100ms, 500ms)

Source	df	F	p
	Within subjects		
Cue	1	4.80	0.041
Error (C)	19	(467)	
SOA	1	22.05**	0.000
Error SOA	19	(1384)	
Cue X SOA	1	69.59**	0.000
Error (C x SOA)	19	(227)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D5.1. Analysis of variance of reaction time data to determine limb movement effects at the 100ms SOA.
Design = Group (YHC, OHC) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R)

Source	df	F	p
	Between subjects		
Group	1	3.05	0.089
Within-group Error	38	(253787)	
	Within subjects		
Movement (M)	2	6.70**	0.002
Movement X Group	2	1.44	0.242
Error (M)	76	(14118)	
Arm (A)	1	1.57	0.218
Arm X Group	1	0.01	0.915
Error (A)	38	(3178)	
Cue (C)	1	112.74**	0.000
Cue X Group	1	7.35**	0.010
Error (C)	38	(1174)	
Target (T)	1	1.62	0.211
Target X Group	1	2.95	0.094
Error (T)	38	(1601)	
Movement X Arm	2	1.18	0.312
Movement X Arm X Group	2	0.99	0.377
Error (M x A)	76	(2667)	
Movement X Cue	2	2.67	0.076
Movement X Cue X Group	2	5.26**	0.007
Error (M x C)	76	(531)	
Arm X Cue	1	0.18	0.670
Arm X Cue X Group	1	0.86	0.360
Error (A x C)	38	(640)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D5.1 (cont.) 100ms SOA: Group (YHC, OHC) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R)

Source	df	F	p
Within subjects (cont.)			
Movement X Arm X Cue	2	0.18	0.839
Movement X Arm X Cue X Group	2	2.16	0.122
Error (M x A x C)	76	(496)	
Movement X Target	2	1.42	0.248
Movement X Target X Group	2	2.00	0.143
Error (M x T)	76	(504)	
Arm X Target	1	1.09	0.304
Arm X Target X Group	1	0.05	0.830
Error (A x T)	38	(762)	
Movement X Arm X Target	2	1.94	0.151
Movement X Arm X Target X Group	2	1.57	0.215
Error (M x A x T)	76	(383)	
Cue X Target	1	0.00	0.947
Cue X Target X Group	1	0.00	0.975
Error (C x T)	38	(1205)	
Movement X Cue X Target	2	4.74*	0.011
Movement X Cue X Target X Group	2	2.80	0.067
Error (M x C x T)	76	(551)	
Arm X Cue X Target	1	1.73	0.196
Arm X Cue X Target X Group	1	2.41	0.129
Error (A x C x T)	38	(403)	
Movement X Arm X Cue X Target	1.6	0.29	0.704
Movement X Arm X Cue X Target X Group	1.6	1.38	0.258
Error (M x A x C x T)	60.9	(967)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D5.2. Analysis of variance of reaction time data of the younger healthy control group (YHC) to determine limb movement effects at the 100ms SOA.
Design = Movement (NM, PM, AM) x Cue (Valid, Invalid)

Source	df	F	p
	Within subjects		
Movement (M)	2	1.14	0.329
Error (M)	38	(3256)	
Cue (C)	1	42.15**	0.000
Error (C)	19	(218)	
Movement X Cue	2	1.16	0.324
Error (M x C)	38	(98)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D5.3. Analysis of variance of reaction time data of the older healthy control group (OHC) to determine limb movement effects at the 100ms SOA.
Design = Movement (NM, PM, AM) x Cue (Valid, Invalid)

Source	df	F	p
	Within subjects		
Movement (M)	2	6.58**	0.004
Error (M)	38	(3803)	
Cue (C)	1	70.59**	0.000
Error (C)	19	(369)	
Movement X Cue	2	5.59**	0.007
Error (M x C)	38	(168)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D6.1. Analysis of variance of reaction time data to determine limb movement effects at the 500ms SOA.
Design = Group (YHC, OHC) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R)

Source	df	F	p
	Between subjects		
Group	1	12.05**	0.001
Within-group Error	38	(141094)	
	Within subjects		
Movement (M)	2	0.03	0.967
Movement X Group	2	1.34	0.269
Error (M)	76	(5338)	
Arm (A)	1	0.58	0.451
Arm X Group	1	1.66	0.205
Error (A)	38	(1699)	
Cue (C)	1	20.03**	0.000
Cue X Group	1	0.02	0.888
Error (C)	38	(3136)	
Target (T)	1	1.22	0.276
Target X Group	1	3.91	0.055
Error (T)	38	(794)	
Movement X Arm	2	1.86	0.163
Movement X Arm X Group	2	0.03	0.973
Error (M x A)	76	(1298)	
Movement X Cue	2	0.02	0.981
Movement X Cue X Group	2	0.47	0.629
Error (M x C)	76	(562)	
Arm X Cue	1	0.04	0.849
Arm X Cue X Group	1	2.50	0.122
Error (A x C)	38	(394)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D6.1 (cont.) 500ms SOA: Group (YHC, OHC) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R)

Source	df	F	p
Within subjects (cont.)			
Movement X Arm X Cue	2	1.04	0.358
Movement X Arm X Cue X Group	2	0.32	0.727
Error (M x A x C)	76	(317)	
Movement X Target	1.6	0.88	0.400
Movement X Target X Group	1.6	0.25	0.735
Error (M x T)	62.5	(462)	
Arm X Target	1	0.87	0.358
Arm X Target X Group	1	0.11	0.744
Error (A x T)	38	(203)	
Movement X Arm X Target	2	0.28	0.758
Movement X Arm X Target X Group	2	1.36	0.264
Error (M x A x T)	76	(312)	
Cue X Target	1	17.79**	0.000
Cue X Target X Group	1	2.98	0.093
Error (C x T)	38	(454)	
Movement X Cue X Target	2	0.43	0.652
Movement X Cue X Target X Group	2	0.64	0.532
Error (M x C x T)	76	(292)	
Arm X Cue X Target	1	0.32	0.576
Arm X Cue X Target X Group	1	9.66**	0.004
Error (A x C x T)	38	(274)	
Movement X Arm X Cue X Target	2	4.43	0.015
Movement X Arm X Cue X Target X Group	2	0.05	0.950
Error (M x A x C x T)	76	(497)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D6.2. Analysis of variance of reaction time data to determine limb movement effects for the younger controls (YHC) at the 500ms SOA.
Design = Arm (L, R) x Cue (Valid, Invalid) x Target (L, R), averaged across movement condition (NM,PM,AM)

Source	df	F	p
	Within subjects		
Arm (A)	1	0.18	0.677
Error (A)	19	(439)	
Cue (C)	1	31.20**	0.000
Error (C)	19	(315)	
Target (T)	1	7.58*	0.013
Error (T)	19	(166)	
Arm X Cue	1	1.65	0.214
Error (A x C)	19	(77)	
Arm X Target	1	0.26	0.618
Error (A x T)	19	(48)	
Cue X Target	1	3.23	0.088
Error (C x T)	19	(145)	
Arm X Cue X Target	1	3.33	0.084
Error (A x C x T)	19	(89)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D6.3. Analysis of variance of reaction time data to determine limb movement effects for the older controls (OHC) at the 500ms SOA.
Design = Arm (L, R) x Cue (Valid, Invalid) x Target (L, R), averaged across movement condition (NM,PM,AM)

Source	df	F	p
	Within subjects		
Arm (A)	1	1.72	0.206
Error (A)	19	(693)	
Cue (C)	1	6.28	0.022
Error (C)	19	(1776)	
Target (T)	1	0.28	0.605
Error (T)	19	(364)	
Arm X Cue	1	1.11	0.306
Error (A x C)	19	(186)	
Arm X Target	1	0.61	0.443
Error (A x T)	19	(88)	
Cue X Target	1	17.01**	0.001
Error (C x T)	19	(157)	
Arm X Cue X Target	1	6.56	0.019
Error (A x C x T)	19	(94)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D7.1. Omnibus analysis of variance of error data collapsed over type of error (miss, RT < 100ms, RT > 200ms).
Design = Group (OHC, RHS) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Between subjects		
Group	1	6.14	0.018
Within-group Error	34	(686.1)	
	Within subjects		
Movement (M)	1.2	0.37	0.586
Movement X Group	1.2	2.73	0.099
Error (M)	41.3	(237.4)	
Arm (A)	1	0.05	0.824
Arm X Group	1	0.02	0.884
Error (A)	34	(108.4)	
Cue (C)	1	4.72	0.037
Cue X Group	1	4.32	0.045
Error (C)	34	(21.3)	
Target (T)	1	5.99	0.020
Target X Group	1	0.80	0.378
Error (T)	34	(19.6)	
SOA	1	8.29**	0.007
SOA X Group	1	0.07	0.798
Error (SOA)	34	(33.0)	
Movement X Arm	2	0.65	0.527
Movement X Arm X Group	2	0.52	0.597
Error (M x A)	68	(34.6)	
Movement X Cue	2	0.45	0.641
Movement X Cue X Group	2	1.34	0.268
Error (M x C)	68	(12.6)	
Arm X Cue	1	1.08	0.306
Arm X Cue X Group	1	0.30	0.589
Error (A x C)	34	(14.4)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

TableD7.1 (cont.) Error data: Group (OHC, RHS) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Movement X Arm X Cue	1	1.88	0.161
Movement X Arm X Cue X Group	1	3.10	0.052
Error (M x A x C)	34	(15.8)	
Movement X Target	2	2.87	0.063
Movement X Target X Group	2	2.41	0.097
Error (M x T)	68	(14.3)	
Arm X Target	1	0.66	0.424
Arm X Target X Group	1	0.33	0.570
Error (A x T)	34	(11.7)	
Movement X Arm X Target	2	0.66	0.522
Movement X Arm X Target X Group	2	0.08	0.922
Error (M x A x T)	68	(17.7)	
Cue X Target	1	3.57	0.067
Cue X Target X Group	1	0.74	0.396
Error (C x T)	34	(21.1)	
Movement X Cue X Target	2	0.87	0.422
Movement X Cue X Target X Group	2	1.31	0.277
Error (M x C x T)	68	(21.5)	
Arm X Cue X Target	1	0.22	0.641
Arm X Cue X Target X Group	1	0.05	0.824
Error (A x C x T)	34	(12.2)	
Movement X Arm X Cue X Target	2	0.12	0.891
Movement X Arm X Cue X Target X Group	2	0.23	0.799
Error (M x A x C x T)	68	(15.1)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D7.1 (cont.) Error data: Group (OHC, RHS) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Movement X SOA	2	2.86	0.064
Movement X SOA X Group	2	1.09	0.341
Error (M x SOA)	68	(18.0)	
Arm X SOA	1	0.09	0.764
Arm X SOA X Group	1	0.25	0.619
Error (A x SOA)	34	(18.9)	
Movement X Arm X SOA	2	0.91	0.407
Movement X Arm X SOA X Group	2	6.45**	0.003
Error (M x A x SOA)	68	(12.7)	
Cue X SOA	1	0.00	0.981
Cue X SOA X Group	1	0.57	0.457
Error (C x SOA)	34	(11.0)	
Movement X Cue X SOA	2	0.10	0.910
Movement X Cue X SOA X Group	2	0.20	0.816
Error (M x C x SOA)	68	(16.7)	
Arm X Cue X SOA	1	1.18	0.285
Arm X Cue X SOA X Group	1	0.51	0.482
Error (A x C x SOA)	34	(12.9)	
Movement X Arm X Cue X SOA	1.5	2.36	0.119
Movement X Arm X Cue X SOA X Group	1.5	2.87	0.081
Error (M x A x C x SOA)	49.8	(18.3)	
Target X SOA	1	0.12	0.732
Target X SOA X Group	1	1.29	0.265
Error (T x SOA)	34	(7.4)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D7.1 (cont.) Error data: Group (OHC, RHS) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Movement X Target X SOA	2	0.18	0.838
Movement X Target X SOA X Group	2	0.42	0.657
Error (M x T x SOA)	68	(12.4)	
Arm X Target X SOA	1	0.38	0.540
Arm X Target X SOA X Group	1	0.18	0.675
Error (A x T x SOA)	34	(19.3)	
Movement X Arm X Target X SOA	2	0.25	0.779
Movement X Arm X Target X SOA X Group	2	0.04	0.957
Error (M x A x T x SOA)	68	(13.6)	
Cue X Target X SOA	1	2.39	0.131
Cue X Target X SOA X Group	1	1.62	0.212
Error (C x T x SOA)	34	(23.9)	
Movement X Cue X Target X SOA	2	0.58	0.565
Movement X Cue X Target X SOA X Group	2	1.55	0.219
Error (M x C x T x SOA)	68	(16.5)	
Arm X Cue X Target X SOA	1	0.25	0.620
Arm X Cue X Target X SOA X Group	1	1.73	0.198
Error (A x C x T x SOA)	34	(13.7)	
Movement X Arm X Cue X Target X SOA	2	2.01	0.142
Movement X Arm X Cue X Target X SOA X Group	2	2.27	0.111
Error (M x A x C x T x SOA)	68	(12.8)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D7.2. Older Healthy Control group (OHC, n=20). Analysis of variance of error data, collapsed over type of error (miss, RT < 100ms, RT > 200ms).
Design = Movement (NM, PM, AM) x Arm (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Within subjects		
Movement (M)	1.4	3.71	0.052
Error (M)	26.7	(10.5)	
Arm (A)	1	0.72	0.406
Error (A)	19	(2.9)	
SOA	1	13.98**	0.001
Error (SOA)	19	(2.3)	
Movement X Arm	2	0.78	0.467
Error (M x A)	38	(3.2)	
Movement X SOA	1.4	7.11**	0.007
Error (M x SOA)	26.6	(3.8)	
Arm X SOA	1	0.08	0.786
Error (A x SOA)	19	(1.4)	
Move X Arm X SOA	2	2.40	0.104
Error (M x A x SOA)	38	(2.5)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D7.3. Right-hemisphere Stroke group (RHS, n=16). Analysis of variance of error data, collapsed over type of error (miss, RT < 100ms, RT > 200ms).
Design = Movement (NM, PM, AM) x Arm (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Within subjects		
Movement (M)	1.2	1.09	0.323
Error (M)	17.9	(121.6)	
Arm (A)	1	0.00	0.972
Error (A)	15	(57.7)	
SOA	1	2.31	0.149
Error (SOA)	15	(15.8)	
Movement X Arm	2	0.46	0.638
Error (M x A)	30	(15.5)	
Movement X SOA	2	0.15	0.861
Error (M x SOA)	30	(6.9)	
Arm X SOA	1	0.15	0.701
Error (A x SOA)	15	(9.0)	
Move X Arm X SOA	2	4.05	0.028
Error (M x A x SOA)	30	(4.0)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D8. Omnibus analysis of variance of reaction time data of the older healthy control group (OHC) versus the right-hemisphere stroke group (RHS).
Design = Group (OHC, RHS) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Between subjects		
Group	1	13.92**	0.001
Within-group Error	34	(449766)	
	Within subjects		
Movement (M)	2	3.33	0.042
Movement X Group	2	0.72	0.488
Error (M)	68	(18193)	
Arm (A)	1	0.02	0.880
Arm X Group	1	0.04	0.841
Error (A)	34	(10985)	
Cue (C)	1	10.98**	0.002
Cue X Group	1	4.37	0.044
Error (C)	34	(11649)	
Target (T)	1	5.28	0.028
Target X Group	1	5.76	0.022
Error (T)	34	(77448)	
SOA	1	107.98**	0.000
SOA X Group	1	2.25	0.143
Error (SOA)	34	(18342)	
Movement X Arm	2	0.58	0.563
Movement X Arm X Group	2	0.64	0.530
Error (M x A)	68	(5056)	
Movement X Cue	2	14.96**	0.000
Movement X Cue X Group	2	4.49	0.015
Error (M x C)	68	(1216)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D8 (cont.) Group (OHC, RHS) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Arm X Cue	1	0.65	0.425
Arm X Cue X Group	1	0.61	0.440
Error (A x C)	34	(532)	
Movement X Arm X Cue	2	0.37	0.692
Movement X Arm X Cue X Group	2	2.30	0.108
Error (M x A x C)	68	(1251)	
Movement X Target	2	0.01	0.989
Movement X Target X Group	2	0.69	0.503
Error (M x T)	68	(1922)	
Arm X Target	1	0.38	0.543
Arm X Target X Group	1	0.00	0.973
Error (A x T)	34	(3652)	
Movement X Arm X Target	2	0.32	0.725
Movement X Arm X Target X Group	2	0.15	0.858
Error (M x A x T)	68	(1031)	
Cue X Target	1	0.18	0.672
Cue X Target X Group	1	2.21	0.146
Error (C x T)	34	(6464)	
Movement X Cue X Target	2	2.54	0.086
Movement X Cue X Target X Group	2	11.05**	0.000
Error (M x C x T)	68	(1044)	
Arm X Cue X Target	1	1.73	0.198
Arm X Cue X Target X Group	1	6.96	0.012
Error (A x C x T)	34	(1088)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D8 (cont.) Group (OHC, RHS) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Movement X Arm X Cue X Target	2	0.88	0.422
Movement X Arm X Cue X Target X Group	2	1.28	0.286
Error (M x A x C x T)	68	(1603)	
Movement X SOA	2	14.92**	0.000
Movement X SOA X Group	2	0.15	0.858
Error (M x SOA)	68	(4431)	
Arm X SOA	1	1.31	0.260
Arm X SOA X Group	1	2.07	0.160
Error (A x SOA)	34	(1730)	
Movement X Arm X SOA	2	0.44	0.649
Movement X Arm X SOA X Group	2	0.70	0.499
Error (M x A x SOA)	68	(1254)	
Cue X SOA	1	46.54**	0.000
Cue X SOA X Group	1	0.11	0.740
Error (C x SOA)	34	(4439)	
Movement X Cue X SOA	2	1.12	0.333
Movement X Cue X SOA X Group	2	1.50	0.231
Error (M x C x SOA)	68	(1201)	
Arm X Cue X SOA	1	0.09	0.773
Arm X Cue X SOA X Group	1	1.09	0.303
Error (A x C x SOA)	34	(1204)	
Movement X Arm X Cue X SOA	2	0.30	0.745
Movement X Arm X Cue X SOA X Group	2	0.50	0.612
Error (M x A x C x SOA)	68	(964)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D8 (cont.) Group (OHC, RHS) x Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Within subjects (cont.)		
Target X SOA	1	2.50	0.123
Target X SOA X Group	1	2.32	0.137
Error (T x SOA)	34	(5980)	
Movement X Target X SOA	2	1.05	0.356
Movement X Target X SOA X Group	2	0.10	0.909
Error (M x T x SOA)	68	(905)	
Arm X Target X SOA	1	0.55	0.464
Arm X Target X SOA X Group	1	0.21	0.647
Error (A x T x SOA)	34	(1624)	
Movement X Arm X Target X SOA	2	3.79	0.027
Movement X Arm X Target X SOA X Group	2	0.52	0.595
Error (M x A x T x SOA)	68	(1025)	
Cue X Target X SOA	1	1.64	0.209
Cue X Target X SOA X Group	1	0.14	0.715
Error (C x T x SOA)	34	(2563)	
Movement X Cue X Target X SOA	1.6	2.28	0.123
Movement X Cue X Target X SOA X Group	1.6	1.02	0.353
Error (M x C x T x SOA)	53.9	(1144)	
Arm X Cue X Target X SOA	1	0.81	0.375
Arm X Cue X Target X SOA X Group	1	0.14	0.716
Error (A x C x T x SOA)	34	(872)	
Movement X Arm X Cue X Target X SOA	1.6	3.29	0.055
Movement X Arm X Cue X Target X SOA X Group	1.6	0.35	0.660
Error (M x A x C x T x SOA)	54.2	(1446)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D9. Analysis of variance of reaction time data for the no movement (NM) condition for the healthy older control group (OHC) versus the right-hemisphere stroke group (RHS). Design = Group (RHS, OHC) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Between subjects		
Group	1	17.78**	0.000
Within-group Error	34	(137575)	
	Within subjects		
Arm (A)	1	0.17	0.686
Arm X Group	1	0.04	0.835
Error (A)	34	(3898)	
Cue (C)	1	19.59**	0.000
Cue X Group	1	7.35**	0.010
Error (C)	34	(5426)	
Target (T)	1	4.61	0.039
Target X Group	1	5.30	0.028
Error (T)	34	(30437)	
SOA	1	55.76**	0.000
SOA X Group	1	1.39	0.246
Error (SOA)	34	(5488)	
Arm X Cue	1	0.15	0.701
Arm X Cue X Group	1	2.11	0.156
Error (A x C)	34	(768)	
Arm X Target	1	0.21	0.646
Arm X Target X Group	1	0.08	0.778
Error (A x T)	34	(1983)	
Cue X Target	1	1.82	0.186
Cue X Target X Group	1	7.91**	0.008
Error (C x T)	34	(3123)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D9 (cont.) Group (RHS, OHC) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Within subjects (cont.)		
Arm X Cue X Target	1	0.70	0.410
Arm X Cue X Target X Group	1	1.78	0.192
Error (A x C x T)	34	(1238)	
Arm X SOA	1	2.65	0.113
Arm X SOA X Group	1	0.59	0.450
Error (A x SOA)	34	(992)	
Cue X SOA	1	45.90**	0.000
Cue X SOA X Group	1	2.14	0.153
Error (C x SOA)	34	(1658)	
Arm X Cue X SOA	1	0.25	0.618
Arm X Cue X SOA X Group	1	0.06	0.816
Error (A x C x SOA)	34	(538)	
Target X SOA	1	3.57	0.067
Target X SOA X Group	1	2.24	0.144
Error (T x SOA)	34	(2731)	
Arm X Target X SOA	1	0.59	0.449
Arm X Target X SOA X Group	1	0.08	0.773
Error (A x T x SOA)	34	(1115)	
Cue X Target X SOA	1	0.00	0.969
Cue X Target X SOA X Group	1	1.28	0.266
Error (C x T x SOA)	34	(1071)	
Arm X Cue X Target X SOA	1	0.93	0.342
Arm X Cue X target X SOA X Group	1	1.96	0.171
Error (A x C x T x SOA)	34	(432)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D10.1. Analysis of variance of reaction time data at the 100ms SOA for the older healthy control group (OHC) and the right-hemisphere stroke group (RHS) in the no movement (NM) condition averaged across arm used.
Design = Group (OHC, RHS) x Cue (Valid, Invalid) x Target (L, R)

Source	df	F	p
	Between subjects		
Group	1	17.52**	0.000
Within-group Error	34	(38916)	
Cue (C)	1	107.97**	0.000
Cue X Group	1	5.86	0.021
Error (C)	34	(839)	
Target (T)	1	4.65	0.038
Target X Group	1	4.78	0.036
Error (T)	34	(12049)	
Cue X Target	1	1.36	0.252
Cue X Target X Group	1	3.55	0.068
Error (C x T)	34	(1015)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D10.2. Analysis of variance of reaction time data at the 500ms SOA for the older healthy control group (OHC) and the right-hemisphere stroke group (RHS) in the no movement (NM) condition averaged across arm used.
Design = Group (OHC, RHS) x Cue (Valid, Invalid) x Target (L, R)

Source	df	F	p
	Between subjects		
Group	1	16.71**	0.000
Within-group Error	34	(32615)	
Cue (C)	1	0.23	0.633
Cue X Group	1	6.22	0.018
Error (C)	34	(2703)	
Target (T)	1	4.19	0.048
Target X Group	1	5.77	0.022
Error (T)	34	(4534)	
Cue X Target	1	1.36	0.251
Cue X Target X Group	1	8.71**	0.006
Error (C x T)	34	(1082)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D10.3. Analysis of variance of reaction time data at the 500ms SOA averaged across arm used for the older healthy control participants (OHC) in the no movement (NM) condition.
Design = Cue (Valid, Invalid) x Target (L, R)

Source	df	F	p
	Within subjects		
Cue (C)	1	7.03	0.016
Error (C)	1	(874)	
Target (T)	1	1.31	0.267
Error (T)	19	(245)	
Cue X Target	1	10.29**	0.005
Error (C x T)	19	(188)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D10.4. Analysis of variance of reaction time data at the 500ms SOA averaged across arm used for the right-hemisphere stroke participants (RHS) in the no movement (NM) condition.
Design = Cue (Valid, Invalid) x Target (L, R)

Source	df	F	p
	Within subjects		
Cue (C)	1	2.15	0.164
Error (C)	19	(5020)	
Target (T)	1	4.06	0.062
Error (T)	19	(9967)	
Cue X Target	1	3.73	0.073
Error (C x T)	19	(2214)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D11. Analysis of variance of disengage deficit scores (DDS) of right-hemisphere stroke participants (RHS) versus older healthy controls (OHC).
Design = Group (RHS, OHC) x Movement (NM, PM, AM) x Arm (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Between subjects		
Group	1	2.21	0.146
Within-group Error	34	(25855)	
	Within subjects		
Movement (M)	2	2.54	0.086
Movement X Group	2	11.05**	0.000
Error (M)	68	(4175)	
Arm (A)	1	1.73	0.198
Arm X Group	1	6.96*	0.012
Error (A)	34	(4353)	
SOA	1	1.64	0.209
SOA X Group	1	0.14	0.715
Error (SOA)	34	(10254)	
Movement X Arm	2	0.88	0.422
Movement X Arm X Group	2	1.28	0.286
Error (M x A)	68	(6414)	
Movement X SOA	1.6	2.28	0.123
Movement X SOA X Group	1.6	1.02	0.353
Error (M x SOA)	53.9	(4577)	
Arm X SOA	1	0.81	0.375
Arm X SOA X Group	1	0.14	0.716
Error (A x SOA)	34	(3489)	
Movement X Arm X SOA	1.6	3.29	0.055
Movement X Arm X SOA X Group	1.6	0.35	0.660
Error (M x A x SOA)	54.2	(5785)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D12. Results of cue-by-target analyses of variance and paired t-tests of reaction time data in the No Movement condition (averaged over arm used and SOA) for the older healthy control group (OHC) and individual right-hemisphere stroke participants.

	Cue x Target F (1, 19)	P value	Inv LT vs. Inv RT t_{19}	P value	Inv LT vs. Val LT t_{19}	P value
OHC (n=20)	6.64	0.019	-1.61	0.123	0.67	0.510
RHS/DD++						
1022	23.62**	0.000	5.02**	0.000	6.26**	0.000
1045	9.18**	0.007	13.11**	0.000	3.84**	0.001
RHS/DD+						
1385	3.92	0.062	5.87**	0.000	4.11**	0.000
1379	4.60*	0.045	1.25	0.227	2.44*	0.025
1380	3.19	0.090	2.22*	0.039	3.98**	0.001
RHS/DD-						
1047	1.15	0.298	4.15**	0.001	2.62*	0.017
1386	0.71	0.410	1.66	0.113	2.50*	0.022
1382	0.17	0.689	1.82	0.084	2.69*	0.014
1387	0.00	0.980	-0.16	0.876	0.59	0.560
1375	0.00	0.983	1.67	0.111	-1.42	0.171
1384	0.01	0.947	-0.26	0.799	1.48	0.157
1378	0.01	0.945	1.83	0.083	1.81	0.086
1381	0.02	0.899	-0.02	0.987	1.36	0.190
1034	0.30	0.588	-3.97	0.001	0.70	0.491
1376	0.68	0.420	-1.39	0.180	2.08	0.052
1388	0.41	0.529	5.69**	0.000	-0.38	0.709
DD- group (n=11)	0.11	0.745	1.40	0.191	3.37**	0.007

* - $p < 0.05$, ** - $p < 0.01$. Inv LT – invalidly-cued left target, Inv RT – invalidly-cued right target, Val LT – validly-cued left target. RHS/DD++ severe disengage deficit, RHS/DD+ mild-moderate disengage deficit, RHS/DD- no disengage deficit.

Table D13. Analysis of variance of limb movement effects on disengage deficit scores (DDS) comparing the RHS/DD- group (n=11), RHS/DD+ group (n=5) and older healthy control group (OHC, n=20).
Design = Movement (NM, PM, AM) x Arm (L, R)

Source	df	F	p
	Between subjects		
Group	2	13.62**	0.000
Within-group Error	33	(7771)	
	Within subjects		
Movement (M)	2	8.50**	0.001
Movement X Group	4	7.53**	0.000
Error (M)	66	(1957)	
Arm (A)	1	4.41	0.044
Arm X Group	2	2.91	0.038
Error (A)	33	(2214)	
Movement X Arm	1.6	1.96	0.159
Movement X Arm X Group	3.2	1.81	0.155
Error (M x A)	52.6	(3880)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D14.1. RHS/DD++ participant #1022. Analysis of variance of limb movement effects on disengage deficit scores (DDS).
Design = Movement (NM, PM, AM) x Arm (L, R)

Source	df	F	p
	Within subjects		
Movement (M)	2	3.09	0.057
Error (M)	38	(86044)	
Arm (A)	1	0.79	0.384
Error (A)	19	(103936)	
Movement X Arm	2	5.55**	0.000
Error (M x A)	38	(47162)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D14.2. RHS/DD++ participant #1022. Analysis of variance of reaction time data. Design = Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Within subjects		
Movement (M)	2	0.01	0.993
Error (M)	38	(37906)	
Arm (A)	1	22.28**	0.000
Error (A)	19	(41118)	
Cue (C)	1	121.13**	0.000
Error (C)	19	(44652)	
Target	1	76.36**	0.000
Error (T)	19	(45577)	
SOA	1	36.66**	0.000
Error (SOA)	19	(39299)	
Movement X Arm	2	15.37**	0.000
Error (M x A)	38	(36792)	
Movement X Cue	2	1.60	0.214
Error (M x C)	38	(35104)	
Arm X Cue	1	0.09	0.765
Error (A x C)	19	(54173)	
Movement X Arm X Cue	2	5.36**	0.009
Error (M x A x C)	38	(30689)	
Movement X Target	2	0.45	0.644
Error (M x T)	38	(38101)	
Arm X Target	1	5.52	0.030
Error (A x T)	19	(31780)	
Movement X Arm X Target	2	5.96**	0.006
Error (M x A x T)	38	(22674)	
Cue X Target	1	50.76**	0.000
Error (C x T)	19	(48005)	
Movement X Cue X Target	2	3.09	0.057
Error (M x C x T)	38	(43022)	
Arm X Cue X Target	1	0.79	0.384
Error (A x C x T)	19	(51968)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D14.2 (cont.) RHS/DD++ participant #1022. Design: Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Within subjects (cont.)		
Movement X Arm X Cue X Target	2	15.55**	0.000
Error (M x A x C x T)	38	(23581)	
Movement X SOA	2	0.05	0.948
Error (M x SOA)	38	(38740)	
Arm X SOA	1	6.15	0.023
Error (A x SOA)	19	(24059)	
Move X Arm X SOA	2	0.25	0.784
Error (M x A x SOA)	38	(36098)	
Cue X SOA	1	8.16**	0.010
Error (C x SOA)	19	(19273)	
Movement X Cue X SOA	2	2.59	0.088
Error (M x C x SOA)	38	(40068)	
Arm X Cue X SOA	1	1.17	0.293
Error (A x C x SOA)	19	(39728)	
Movement X Arm X Cue X SOA	2	0.58	0.567
Error (M x A x C x SOA)	38	(13612)	
Target X SOA	1	28.39**	0.000
Error (T x SOA)	19	(34324)	
Movement X Target X SOA	2	0.19	0.824
Error (M x T x SOA)	38	(35597)	
Arm X Target X SOA	1	0.01	0.927
Error (A x T x SOA)	19	(34590)	
Movement X Arm X Target X SOA	2	0.10	0.906
Error (M x A x T x SOA)	38	(26532)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D14.2 (cont.) RHS/DD++ participant #1022. Design: Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Within subjects (cont.)		
Cue X Target X SOA	1	0.42	0.524
Error (C x T x SOA)	19	(26685)	
Movement X Cue X Target X SOA	2	0.56	0.577
Error (M x C x T x SOA)	38	(33688)	
Arm X Cue X Target X SOA	1	0.35	0.561
Error (A x C x T x SOA)	19	(41171)	
Movement X Arm X Cue X Target X SOA	2	2.08	0.139
Error (M x A x C x T x SOA)	38	(19164)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D14.3. RHS/DD++ participant #1022. Analysis of variance of right limb movement effects on reaction times (averaged over SOA).
Design = Movement (NM, PM, AM) x Cue (Valid, Invalid) x Target (L, R)

Source	df	F	p
	Within subjects		
Movement (M)	2	5.93**	0.006
Error (M)	38	(23639)	
Cue (C)	1	38.78**	0.000
Error (C)	19	(32786)	
Target	1	56.76**	0.000
Error (T)	19	(22982)	
Movement X Cue	2	4.81*	0.014
Error (M x C)	38	(15250)	
Movement X Target	2	0.72	0.491
Error (M x T)	38	(19505)	
Cue X Target	1	29.10**	0.000
Error (C x T)	19	(26735)	
Movement X Cue X Target	2	2.11	0.136
Error (M x C x T)	38	(21331)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D14.4. RHS/DD++ participant #1022. Analysis of variance of left limb movement effects on reaction times (averaged over SOA).
Design = Movement (NM, PM, AM) x Cue (Valid, Invalid) x Target (L, R)

Source	df	F	p
	Within subjects		
Movement (M)	2	10.37**	0.000
Error (M)	38	(13710)	
Cue (C)	1	86.33**	0.000
Error (C)	19	(16626)	
Target (T)	1	33.34**	0.000
Error (T)	19	(15696)	
Movement X Cue	2	2.10	0.136
Error (M x C)	38	(17646)	
Movement X Target	2	5.69**	0.007
Error (M x T)	38	(10882)	
Cue X Target	1	19.83**	0.000
Error (C x T)	19	(23251)	
Movement X Cue X Target	2	17.11**	0.000
Error (M x C x T)	38	(11971)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D15.1. RHS/DD++ participant #1045. Analysis of variance of limb movement effects on disengage deficit scores (DDS).
Design = Movement (NM, PM, AM) x Arm (L, R)

Source	df	F	p
	Within subjects		
Movement (M)	2	3.00	0.062
Error (M)	38	(85161)	
Arm (A)	1	5.05	0.037
Error (A)	19	(92189)	
Movement X Arm	2	2.54	0.092
Error (M x A)	38	(111846)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D15.2. RHS/DD++ participant #1045. Analysis of variance of reaction time data. Design = Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Within subjects		
Movement (M)	2	0.36	0.703
Error (M)	38	(92215)	
Arm (A)	1	35.90**	0.000
Error (A)	19	(63687)	
Cue (C)	1	12.17**	0.002
Error (C)	19	(33151)	
Target	1	681.32**	0.000
Error (T)	19	(70670)	
SOA	1	97.53**	0.000
Error (SOA)	19	(41623)	
Movement X Arm	1.2	3.94	0.054
Error (M x A)	22.5	(100691)	
Movement X Cue	2	7.89**	0.001
Error (M x C)	38	(42550)	
Arm X Cue	1	0.48	0.496
Error (A x C)	19	(68523)	
Movement X Arm X Cue	2	4.45	0.018
Error (M x A x C)	38	(56075)	
Movement X Target	2	7.15**	0.002
Error (M x T)	38	(80515)	
Arm X Target	1	25.27**	0.000
Error (A x T)	19	(71928)	
Movement X Arm X Target	1.2	1.07	0.326
Error (M x A x T)	22.8	(75634)	
Cue X Target	1	7.04	0.016
Error (C x T)	19	(32564)	
Movement X Cue X Target	2	3.00	0.062
Error (M x C x T)	38	(42580)	
Arm X Cue X Target	1	5.05	0.037
Error (A x C x T)	19	(46095)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D15.2 (cont.) RHS/DD++ participant #1045. Design: Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Movement X Arm X Cue X Target	2	2.54	0.092
Error (M x A x C x T)	38	(55923)	
Movement X SOA	2	2.94	0.065
Error (M x SOA)	38	(43945)	
Arm X SOA	1	3.72	0.069
Error (A x SOA)	19	(74242)	
Move X Arm X SOA	2	0.66	0.523
Error (M x A x SOA)	38	(72158)	
Cue X SOA	1	0.40	0.533
Error (C x SOA)	19	(62319)	
Movement X Cue X SOA	2	0.88	0.424
Error (M x C x SOA)	38	(51556)	
Arm X Cue X SOA	1	0.48	0.497
Error (A x C x SOA)	19	(50984)	
Movement X Arm X Cue X SOA	2	0.44	0.645
Error (M x A x C x SOA)	38	(57192)	
Target X SOA	1	6.14**	0.000
Error (T x SOA)	19	(41072)	
Movement X Target X SOA	2	1.34	0.273
Error (M x T x SOA)	38	(57888)	
Arm X Target X SOA	1	6.97	0.016
Error (A x T x SOA)	19	(49622)	
Movement X Arm X Target X SOA	2	0.94	0.398
Error (M x A x T x SOA)	38	(78792)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D15.2 (cont.) RHS/DD++ participant #1045. Design: Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Cue X Target X SOA	1	0.11	0.741
Error (C x T x SOA)	19	(89519)	
Movement X Cue X Target X SOA	2	1.58	0.219
Error (M x C x T x SOA)	38	(51741)	
Arm X Cue X Target X SOA	1	1.67	0.212
Error (A x C x T x SOA)	19	(54065)	
Movement X Arm X Cue X Target X SOA	2	0.64	0.533
Error (M x A x C x T x SOA)	38	(56563)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p \leq 0.015$ (marginally significant)

Table D16.1. RHS/DD+ participant #1385. Analysis of variance of limb movement effects on disengage deficit scores (DDS).
Design = Movement (NM, PM, AM) x Arm (L, R)

Source	df	F	p
	Within subjects		
Movement (M)	2	1.60	0.215
Error (M)	38	(69857)	
Arm (A)	1	0.56	0.462
Error (A)	19	(127284)	
Movement X Arm	2	1.89	0.165
Error (M x A)	38	(79667)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p \leq 0.015$ (marginally significant)

Table D16.2. RHS/DD++ participant #1385. Analysis of variance of reaction time data. Design = Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Within subjects		
Movement (M)	2	16.34**	0.000
Error (M)	38	(39546)	
Arm (A)	1	0.93	0.346
Error (A)	19	(80917)	
Cue (C)	1	59.10**	0.000
Error (C)	19	(43486)	
Target	1	157.59**	0.000
Error (T)	19	(56725)	
SOA	1	184.92**	0.000
Error (SOA)	19	(35593)	
Movement X Arm	2	0.04	0.962
Error (M x A)	38	(49824)	
Movement X Cue	2	2.09	0.138
Error (M x C)	38	(61795)	
Arm X Cue	1	0.55	0.466
Error (A x C)	19	(43939)	
Movement X Arm X Cue	2	1.36	0.270
Error (M x A x C)	38	(54139)	
Movement X Target	2	2.79	0.074
Error (M x T)	38	(62274)	
Arm X Target	1	2.30	0.146
Error (A x T)	19	(51447)	
Movement X Arm X Target	2	2.56	0.090
Error (M x A x T)	38	(50047)	
Cue X Target	1	21.57**	0.000
Error (C x T)	19	(52794)	
Movement X Cue X Target	2	1.60	0.215
Error (M x C x T)	38	(34928)	
Arm X Cue X Target	1	0.56	0.462
Error (A x C x T)	19	(63642)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D16.2 (cont.) RHS/DD++ participant #1385. Design: Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Movement X Arm X Cue X Target	2	1.89	0.165
Error (M x A x C x T)	38	(39833)	
Movement X SOA	2	7.75**	0.002
Error (M x SOA)	38	(24611)	
Arm X SOA	1	0.89	0.358
Error (A x SOA)	19	(34457)	
Move X Arm X SOA	2	4.23	0.022
Error (M x A x SOA)	38	(36454)	
Cue X SOA	1	1.42	0.248
Error (C x SOA)	19	(44742)	
Movement X Cue X SOA	2	0.06	0.946
Error (M x C x SOA)	38	(53192)	
Arm X Cue X SOA	1	2.01	0.173
Error (A x C x SOA)	19	(38540)	
Movement X Arm X Cue X SOA	2	2.06	0.141
Error (M x A x C x SOA)	38	(71487)	
Target X SOA	1	5.48	0.030
Error (T x SOA)	19	(87843)	
Movement X Target X SOA	2	2.49	0.096
Error (M x T x SOA)	38	(31229)	
Arm X Target X SOA	1	11.88**	0.003
Error (A x T x SOA)	19	(27281)	
Movement X Arm X Target X SOA	2	3.97	0.027
Error (M x A x T x SOA)	38	(58068)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D16.2 (cont.) RHS/DD++ participant #1385. Design: Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Cue X Target X SOA	1	3.88	0.064
Error (C x T x SOA)	19	(44142)	
Movement X Cue X Target X SOA	2	0.82	0.447
Error (M x C x T x SOA)	38	(57582)	
Arm X Cue X Target X SOA	1	2.58	0.125
Error (A x C x T x SOA)	19	(38341)	
Movement X Arm X Cue X Target X SOA	2	2.04	0.145
Error (M x A x C x T x SOA)	38	(80304)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p \leq 0.015$ (marginally significant)

Table D17.1. RHS/DD+ participant #1379. Analysis of variance of limb movement effects on disengage deficit scores (DDS).
Design = Movement (NM, PM, AM) x Arm (L, R)

Source	df	F	p
	Within subjects		
Movement (M)	2	3.34	0.046
Error (M)	38	(42124)	
Arm (A)	1	3.15	0.092
Error (A)	19	(34932)	
Movement X Arm	2	1.34	0.275
Error (M x A)	38	(20885)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p \leq 0.015$ (marginally significant)

Table D17.2. RHS/DD++ participant #1379. Analysis of variance of reaction time data. Design = Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Within subjects		
Movement (M)	2	19.32**	0.000
Error (M)	38	(14261)	
Arm (A)	1	13.43**	0.002
Error (A)	19	(16093)	
Cue (C)	1	0.11	0.746
Error (C)	19	(7843)	
Target	1	0.43	0.519
Error (T)	19	(10521)	
SOA	1	281.09**	0.000
Error (SOA)	19	(12582)	
Movement X Arm	2	7.07**	0.002
Error (M x A)	38	(22055)	
Movement X Cue	2	2.92	0.066
Error (M x C)	38	(17637)	
Arm X Cue	1	6.15	0.023
Error (A x C)	19	(7302)	
Movement X Arm X Cue	2	0.30	0.743
Error (M x A x C)	38	(28994)	
Movement X Target	2	1.99	0.151
Error (M x T)	38	(21272)	
Arm X Target	1	0.27	0.607
Error (A x T)	19	(36048)	
Movement X Arm X Target	2	1.92	0.161
Error (M x A x T)	38	(24894)	
Cue X Target	1	1.02	0.325
Error (C x T)	19	(17380)	
Movement X Cue X Target	2	3.34	0.046
Error (M x C x T)	38	(23062)	
Arm X Cue X Target	1	3.15	0.092
Error (A x C x T)	19	(17466)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D17.2 (cont.) RHS/DD++ participant #1379. Design: Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Movement X Arm X Cue X Target	2	1.34	0.275
Error (M x A x C x T)	38	(10442)	
Movement X SOA	2	13.29**	0.000
Error (M x SOA)	38	(26184)	
Arm X SOA	1	0.16	0.694
Error (A x SOA)	19	(20640)	
Move X Arm X SOA	2	0.05	0.955
Error (M x A x SOA)	38	(24042)	
Cue X SOA	1	5.25	0.034
Error (C x SOA)	19	(24517)	
Movement X Cue X SOA	2	4.53	0.017
Error (M x C x SOA)	38	(18693)	
Arm X Cue X SOA	1	4.73	0.042
Error (A x C x SOA)	19	(14739)	
Movement X Arm X Cue X SOA	2	0.92	0.407
Error (M x A x C x SOA)	38	(19734)	
Target X SOA	1	0.93	0.347
Error (T x SOA)	19	(21510)	
Movement X Target X SOA	2	0.27	0.764
Error (M x T x SOA)	38	(16727)	
Arm X Target X SOA	1	0.00	0.997
Error (A x T x SOA)	19	(17041)	
Movement X Arm X Target X SOA	2	0.86	0.432
Error (M x A x T x SOA)	38	(18173)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D17.2 (cont.) RHS/DD++ participant #1379. Design: Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Within subjects (cont.)		
Cue X Target X SOA	1	0.08	0.780
Error (C x T x SOA)	19	(15784)	
Movement X Cue X Target X SOA	2	1.56	0.223
Error (M x C x T x SOA)	38	(10955)	
Arm X Cue X Target X SOA	1	2.09	0.164
Error (A x C x T x SOA)	19	(22186)	
Movement X Arm X Cue X Target X SOA	2	1.78	0.182
Error (M x A x C x T x SOA)	38	(13504)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p \leq 0.015$ (marginally significant)

Table D18.1. RHS/DD+ participant #1380. Analysis of variance of limb movement effects on disengage deficit scores (DDS).
Design = Movement (NM, PM, AM) x Arm (L, R)

Source	df	F	p
	Within subjects		
Movement (M)	2	3.07	0.058
Error (M)	38	(38852)	
Arm (A)	1	0.13	0.772
Error (A)	19	(61084)	
Movement X Arm	2	3.31	0.047
Error (M x A)	38	(38052)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p \leq 0.015$ (marginally significant)

Table D18.2. RHS/DD++ participant #1380. Analysis of variance of reaction time data. Design = Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
	Within subjects		
Movement (M)	2	60.20**	0.000
Error (M)	38	(27976)	
Arm (A)	1	4.61	0.045
Error (A)	19	(27821)	
Cue (C)	1	1.52	0.232
Error (C)	19	(32015)	
Target	1	18.75**	0.000
Error (T)	19	(11971)	
SOA	1	32.71**	0.000
Error (SOA)	19	(23351)	
Movement X Arm	2	2.91	0.067
Error (M x A)	38	(36121)	
Movement X Cue	2	0.81	0.453
Error (M x C)	38	(27177)	
Arm X Cue	1	1.94	0.180
Error (A x C)	19	(29707)	
Movement X Arm X Cue	2	2.09	0.138
Error (M x A x C)	38	(20096)	
Movement X Target	2	1.67	0.201
Error (M x T)	38	(23183)	
Arm X Target	1	0.00	0.978
Error (A x T)	19	(27713)	
Movement X Arm X Target	2	1.32	0.279
Error (M x A x T)	38	(27611)	
Cue X Target	1	1.37	0.257
Error (C x T)	19	(17472)	
Movement X Cue X Target	2	3.07	0.058
Error (M x C x T)	38	(19426)	
Arm X Cue X Target	1	0.13	0.722
Error (A x C x T)	19	(30542)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D18.2 (cont.) RHS/DD++ participant #1380. Design: Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Movement X Arm X Cue X Target	2	3.31	0.047
Error (M x A x C x T)	38	(19026)	
Movement X SOA	1.4	4.48	0.033
Error (M x SOA)	26.3	(29103)	
Arm X SOA	1	2.38	0.139
Error (A x SOA)	19	(13464)	
Move X Arm X SOA	2	1.39	0.261
Error (M x A x SOA)	38	(28388)	
Cue X SOA	1	0.00	0.957
Error (C x SOA)	19	(32851)	
Movement X Cue X SOA	1.4	8.99**	0.003
Error (M x C x SOA)	27.2	(21664)	
Arm X Cue X SOA	1	1.58	0.223
Error (A x C x SOA)	19	(11634)	
Movement X Arm X Cue X SOA	2	0.94	0.399
Error (M x A x C x SOA)	38	(19852)	
Target X SOA	1	0.18	0.676
Error (T x SOA)	19	(12783)	
Movement X Target X SOA	2	5.92**	0.006
Error (M x T x SOA)	38	(15908)	
Arm X Target X SOA	1	0.02	0.897
Error (A x T x SOA)	19	(44051)	
Movement X Arm X Target X SOA	2	3.34	0.046
Error (M x A x T x SOA)	38	(25673)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p < 0.015$ (marginally significant)

Table D18.2 (cont.) RHS/DD++ participant #1380. Design: Movement (NM, PM, AM) x Arm (L, R) x Cue (Valid, Invalid) x Target (L, R) x SOA (100ms, 500ms)

Source	df	F	p
Within subjects (cont.)			
Cue X Target X SOA	1	0.38	0.545
Error (C x T x SOA)	19	(14073)	
Movement X Cue X Target X SOA	2	0.39	0.682
Error (M x C x T x SOA)	38	(27070)	
Arm X Cue X Target X SOA	1	0.65	0.432
Error (A x C x T x SOA)	19	(25873)	
Movement X Arm X Cue X Target X SOA	2	1.61	0.213
Error (M x A x C x T x SOA)	38	(21004)	

Note. Values enclosed in parentheses represent mean square errors.
** $p \leq 0.01$, * $p \leq 0.015$ (marginally significant)