Right Hemisphere Language Processing in Normal Right Handers

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ABSTRACT

Clinical neuropsychological research has generated conflicting views regarding the ability of the right cerebral hemisphere to process language. The present study consisted of four experiments designed to assess the verbal performance of the right hemisphere in right-handed individuals with normal intact brains. A manual reaction time (RT) technique was used to measure the relative efficiency of lateral stimulus-response pathways (e.g., left visual field-right hemisphere-left hand) in processing linguistic information.

Experiment 1 showed that the right hemisphere was unable to recognize abstract nouns in a word/nonword discrimination (lexical decision) task but that it was as efficient as the left hemisphere at recognizing concrete nouns. Experiments 2 and 3 demonstrated the right hemisphere's ability to detect semantic relationship between concrete nouns and their superordinate categories. Experiment 4 replicated the results of Experiment 1 and showed, in addition, that the right hemisphere could recognize concrete adjectives but not abstract adjectives or verbs.

These findings were discussed in terms of their consistency with data from split-brain research and their implications for models of the functional organization of language in the normal brain. It was proposed that the right hemisphere in the intact brain can play a role in processing language.

ABBREVIATIONS

LVF - left visual field

RT - reaction time

RVF - right visual field

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DEDICATION

This thesis is dedicated to the memory of the late Dr Terry Anders Prior to his sudden death in January, 1974, Terry demonstrated a deep concern for the welfare of graduate students and played a major role in encouraging faculty-student interactions His commitment to making graduate work a more flexible and meaningful experience encouraged and inspired me during those crucial early months of my graduate career

CHAPTER 1

INTRODUCTION

The problem of cortical localization of function has puzzled students of medicine, neurology, and psychology for centuries Throughout the middle ages it was thought that the human brain contained three ventricles each of which housed one or more different aspects of the soul including sensation, reasoning, and memory Although Galen eventually placed the site of mental activities in the substance of the brain, the notion of localized faculties and forces of the soul persisted in various forms well into the nineteenth century

It was not until the publication of Bouillaud's 1825 paper on the behavioral effects of cortical lesions that the groundwork was laid for the scientific study of cortical localization of higher functions Bouillaud devoted his attention to disorders of sensation, motion, and speech and reported that lesions of specific areas of the cortex were related to specific deficit syndromes Although Bouillaud expressed views on localization which were reasonably well substantiated by his lesion studies, he was not taken seriously by his contemporaries until 1861. It was in that year, at a series of meeting of the Societie d'Anthropologie, that Broca presented the autopsied brains of two aphasic patients revealing lesions of the anterior brain in the third frontal convolution of the left hemisphere. The localizationist school of brain function gained increasing respectability among neurologists as a result of Broca's demonstration. These early lesions studies heralded a new era in the study of brain function, and it was assumed that this approach would ultimately reveal the functional organization of the normal brain

However, several controversial issues soon surfaced and many of these problems have remained unresolved over the past century One issue concerns the extent to which the cortical control of language processes is localized in the two hemispheres of the brain This controversy arose originally from subtle differences in the interpretation of the effects of cortical lesions on language Two positions were taken The first, proposed by Broca (1965) and his followers, was that verbal functions are localized in a dominant hemisphere (the left hemisphere in right-handed people) This view was based on the fact that aphasias (language disorders) were almost always accompanied by left hemisphere lesions, except in left-handers. The second view was proposed by Hughlings Jackson (1874) who, although agreeing that the left hemisphere was dominant for language, held that the right hemisphere, too, supported some limited language functions This argument was based on the fact that residual language was observed in most aphasic syndromes.

Additional evidence has recently been brought to bear on this question from studies of other neurological preparations, most notably hemisphere disconnection Although studies of the human split-brain have largely supported the basic Jacksonian position, serious questions remain regarding the applicability of clinical findings to a model of normal brain organization for language. For this reason, there has been a growing emphasis on studying functional lateralization in the normal brain itself, a trend made possible by the development of behavioral and electrophysiological techniques for testing brain function in normal individuals.

The purpose of the present work was to assess the language performance of the right hemisphere in right-handed individuals with normal intact brains The description of this work and its implications for models of language lateralization in the normal brain will be prefaced by a review of the historical development and current status of the language lateralization problem

The Brain Lesion Studies

Broca and the strict localization school Broca's (1865) dictum, "On parle avec l'hemisphere gauche," set the stage for a view of cortical control of language that was to persist for over a century The initial impetus to the investigation of hemisphere differences in language came from Broca's original work (1861, 1865) in which he conducted autopsies on the brains of aphasic patients He concluded that disorders of articulated speech were caused by lesions of the brain lying anterior to the lower end of the left motor cortex Because language comprehension often remains intact in such cases, later investigators (e g , Geshwind, 1970) have regarded this area of the brain, commonly referred to as Broca's area, as important primarily in the control of established movement patterns of the speech organs

Subsequent research on aphasia extended Broca's findings to the point where it was commonly believed that the cortical control of many linguistic functions, not just speech, was localized in the left hemisphere. Not long after Broca's discovery Bastian (1869) and Schmidt (1871) reported cases of aphasia in which both speech and comprehension were affected Wernicke (1874) conducted post-mortem studies on such cases and found lesions of the posterior superior temporal area in the left hemisphere. Other specific language disorders have also been linked to left hemisphere damage In 1948 Goldstein described central or conduction aphasia, a disorder characterized by fluent speech but numerous errors in the choice of correct words, which results from lesions of the arcuate fasciculus, the region connecting Broca's and Wernicke's areas More recently, Milner (1967, 1971) reported that lesions or removal of the left temporal lobe produce selective and profound memory loss for verbal material. Thus, there is little doubt that many of the cortical areas in the left hemisphere are organized to serve language

Unilateral lesions of the right hemisphere, on the other hand, rarely disrupt language function, except in some left-handed people.[1] Instead, such lesions are usually related to deficits in nonverbal visual-spatial functions such as the ability to orient oneself in space (spatial agnosia), recognize nonverbal stimuli such as faces (prosopagnosia), or remember or reproduce melodies (amusia). That the right hemisphere may actually be dominant for these and similar nonverbal functions was first suggested in 1935 by Weisenberg and McBride who assessed the abilities of right- and left-lesioned patients with an extensive battery of performance tests They stated, "cases of right sided lesions are almost the reverse of the aphasic changes [in that they] involve the appreciation and manipulation of forms and spatial relationships" (Weisenberg & McBride, 1935, p 329). There

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[1]Levy (1974) recently reviewed reports published between 1952 and 1972 on the incidence of right and left hemisphere lesions in right- and left-handed aphasics and concluded that approximately 44% of left-handed and less than 1% of right-handed aphasics have right hemisphere lesions

have been occasional reports of language disturbances following right hemisphere lesions, but such disturbances do not seem to be aphasic in nature and are probably related to deficits in nonverbal information processing Weinstein (1964), in a review of early studies of language deficits following right hemisphere lesions, characterized these deficits as "existential" in that they involve the way a person talks about or interprets his nonverbal perceptions Some symptoms, such as difficulty naming objects, can be associated with damage to either side of the brain According to Weinstein and Keller (1963) right hemisphere damage produces a change in the person's perception of his environment (i e , an actual inability to recognize an object), whereas left hemisphere damage results in an inability to attach the correct phonetic or semantic reference to a recognized object. This evidence led to a school of thought that held that right-handed people had language functions represented exclusively in the left hemisphere and that the right hemisphere served no verbal functions

Jackson - Bilateral distribution of language. Although the strict localization view was originally proposed by Broca and achieved popularity among neurologists well before the turn of the century, it was challenged from the outset by Hughlings Jackson He wrote in 1874 that

> Both halves [of the brain] are alike in that each contains processes for words They are unlike in that the left alone is for the use of words in speech and right for other processes in which words serve. (p 130)

Jackson did not dispute Broca's evidence that the left hemisphere controlled speech, but he believed that the strict localization position was oversimplified Much of his writing was concerned with detailing the qualitative deficits and residual language functions associated with aphasic syndromes The main thrust of his argument was that the aphasic patient is seldom "wordless " He noted that in practically all diagnostic types of aphasia patients retained some ability to comprehend words or use words, even if inappropriately On the basis of these observations he concluded that a healthy left hemisphere is essential for forming and articulating "propositional" speech and that the right hemisphere contains words but cannot organize them in any usable (propositional) fashion Jackson also believed that the right hemisphere played a part in understanding language input, what he called the "automatic" use of words This position was supported many years later by Goldstein (1948) who noted that a gross defect in language comprehension usually required, in addition to a lesion of Wernicke's area in the left hemisphere, disconnection of the pathways connecting the right and left temporal lobes

The details of Jackson's arguments were often obscure and sometimes contradictory, and this may explain why his views were never seriously adopted by later neurologists (although see Head, 1926; and Nielson, 1946). Yet, the essence of his position was clear, and, despite its unpopularity with the strict localizationists, it was never really disproved The basic difference between the strict localization position and Jackson's modification of it stemmed from different assumptions about the cortical locus of residual language functions in aphasia The localizationists assumed that since damage to the right hemisphere did not affect language, any remaining language functions following left-sided lesions, as well as any recovery of function, must be attributable to remaining healthy left hemisphere tissue Jackson, on the other hand, assumed that the failure of left hemisphere lesions to obliterate language totally was a reflection of bilateral support of some language functions, primarily comprehension The fact that these two theoretical positions developed from the same basic data emphasizes the difficulty in developing a unified view of language lateralization on the basis of lesion studies alone

Recent studies of the effects of cortical lesions in infants and young children have shed some new light on the right hemisphere's potential for developing language Several authors have reported that damage to either side of the brain early in life can cause a transient disturbance or delay in the development of normal language skills (Basser, 1962, Krynauw, 1950, Lansdell, 1969) Recovery is typically rapid and complete, particularly if the damage occurs in the first few years of life These findings suggest that both hemispheres begin life with a potential for language[2] and that damage to one hemisphere can be compensated for by the opposite healthy hemisphere regardless of which one is damaged In the adult aphasic there is clearly not a complete takeover of language functions by the right hemisphere when the left hemisphere is damaged, suggesting that the left hemisphere's dominance for language is the result of a developmental process However, it is not clear whether this developmental process culminates in absolute left hemisphere control of language or not

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[2]This bilateral language potential does not necessarily reflect equipotentiality of the hemispheres. Recent electrophysiological (Molfese, Note 1), behavioral (Entus, Note 2), and anatomical (Witelson & Pallie, 1973) evidence suggests that the left hemisphere may be more specialized for language development than the right even at birth

Despite the fact that Jackson's position on the right hemisphere's role in language provided a reasonable alternative working hypothesis to the strict localization view, it was largely disregarded for almost 100 years The clear and profound verbal disturbances related to unilateral left hemisphere lesions, and the virtual absence of aphasic disorders in the presence of right hemisphere lesions, was evidence enough to stimulate most investigators to adopt the strict localization position as an article of faith (e.g , Brain, 1962)

Language and the Disconnected Right Hemisphere

As the preceding discussion indicates, it is difficult to localize the cortical control of functions solely on the basis of the behavioral effects of cortical damage without imposing additional assumptions It is true that lesion studies have revealed some general patterns of cerebral organization such as left hemisphere dominance for language processes and right hemisphere dominance for visual-spatial processes Yet, it has become increasingly apparent that the correlation of a deficiency syndrome with a neurological lesion is not sufficient for attributing a function to one specific region of the brain [3] Because of the exceedingly complex neural connections in the human central nervous system it is likely that a lesion in one part of the brain affects functioning in other areas of the brain as well and may well cause widespread neural disorganization.

For the above reasons, the lesioned brain provides a less than optimal preparation for studying the subtleties of hemisphere

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[3] For a detailed discussion of this problem, see Luria (1964, 1970, 1972)

localization of function. By constrast, hemisphere disconnection constitutes a much simpler preparation which requires fewer assumptions in the interpretation of its effects on behavior. Such a preparation became available about 15 years ago in the form of patients who had undergone cerebral commissurotomy This operation, which involves surgical separation of the forebrain commissures to halt the inter-hemispheric spread of epilepsy, isolates the left and right cerebral hemispheres from each other while leaving both intact and functioning independently This unique preparation provided the opportunity to test the right and left hemispheres separately and compare their performance on a variety of cognitive tasks within the same individual Thus, it became possible to conduct experiments on the language processing abilities of healthy hemispheres directly without having to make inferences about function on the basis of impairment alone.

An extensive series of studies on these patients has been carried out by Sperry, Gazzaniga, and Bogen and their associates Much of their work has been concerned with examining the relative language capacities of the two sides of the brain (e g., Gazzaniga & Sperry, 1967, Sperry, Gazzaniga, & Bogen, 1969). Their basic testing procedure utilized the fact that information exposed in the right or left visual half fields, for a period less than that required to change fixation (about 200 msec, according to Woodworth & Schlosberg, 1954), projects exclusively to the contralateral hemisphere. Thus, by directing verbal information only to the right hemisphere it was possible to test its ability to process language. In one variation of this procedure subjects had to identify a word or picture representing a common object projected tachistoscopically to the right hemisphere (Gazzaniga, 1970, Gazzaniga & Sperry, 1967, Sperry et al , 1969) Such right hemisphere presentations failed to elicit either spoken or written responses In fact, patients claimed that they had seen nothing By contrast, words presented to the left hemisphere via the right visual field were readily identified and described by the subjects.

Additional tests suggested that this failure of the right hemisphere to identify words reflected an inability to express itself verbally, rather than an inability to comprehend language. When nonverbal answers to the visually presented verbal information were required, the right hemisphere easily identified the words presented to it Comprehension of verbal information was tested by asking patients to pick out the correct object from a group of unseen objects behind a screen using the left hand, the coordination of which is controlled by the right hemisphere For example, when the word "pencil" was flashed to the right hemisphere they were able to pick out a pencil, using their left hand Furthermore, they were able to carry out simple commands using their left hand, such as retrieving an object from its verbal description (Nebes & Sperry, 1971), suggesting that the right hemisphere was capable of comprehending spoken language as well as written Additional evidence suggesting that the right hemisphere was carrying out these tasks on its own, without help from the left hemisphere, came from the observation that patients could not vocally identify an object correctly chosen by the left hand while the object was still out of view In other words, the left hemisphere, which contains the speech centers, had no knowledge of the visual information that had been directed to the right hemisphere or of what was in the left hand.

The disconnected right hemisphere's comprehension of language goes beyond the association of objects with their names or verbal descriptions as demonstrated by its ability to recognize some adjectives For example, when a picture of an object, such as a steaming cup of coffee, was flashed to the right hemisphere, the subjects could point to a card with "hot" written on it from among a series of cards (Gazzaniga, 1970) Comprehension of verbs, on the other hand, seemed to present a problem for the disconnected right hemisphere, at least in so far as translating the word into the action was concerned When single printed verbs were flashed to the right hemisphere the subjects could not initiate the action named (Gazzaniga, Bogen, & Sperry, 1967) Levy (Note 3) conducted a subsequent study to determine whether this failure was due to a lack of comprehension or a failure to act She flashed verbs to the right hemisphere and tested three different readouts (a) performing the act, (b) pointing to a picture of the act, and (c) tactually retrieving an object associated with the act Again, subjects were unable to perform the action, and they were only marginally successful at pointing to a picture of the act from among a group of pictures However, they were successful at retrieving an appropriate object associated with the act, thus suggesting that some right hemisphere comprehension of verbs was intact.

The recent development of a special contact lens which allows information in free vision to be restricted to one visual half field (Zaidel, 1975) has rendered the tachistoscopic procedure somewhat obsolete in testing split-brain subjects on unilateral visual tasks. With this device, information can be exposed for long periods of time, while being confined to one hemisphere, making it possible to administer standardized language tests to the right hemisphere Zaidel (1976) used this technique to administer a battery of picture vocabulary and word discrimination tests to two split-brain patients All of the tests involved pointing to one of several lateralized pictures or words in response to a single word spoken by the examiner. The results of these tests revealed the right hemisphere's command of a surprisingly good vocabulary On the Word Discrimination test of the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1972) the right hemisphere scored well on object nouns, action verbs, and geometric forms, although somewhat lower on color names and poorly on letters and numbers On the Peabody (Dunn, 1959) and Ammons Picture Vocabulary Tests (Ammons & Ammons, 1948), which consist primarily of matching a spoken word with a picture of an object noun or action verb, the mean vocabulary age of the disconnected right hemisphere was commensurate with that of the average 14 year old. As expected, left hemisphere scores exceeded the respective right hemisphere scores, however the picture-word recognition scores for both hemispheres followed a similar function of word frequency, suggesting that their lexicons are structured in a similar way

Although the above studies have shown that the disconnected right hemisphere demonstrates a remarkable ability to recognize and comprehend words (primarily concrete nouns, adjectives, and action verbs), further studies have shown that it is severely limited in other aspects of language processing Using the tachistoscopic procedure, Gazzaniga and Hillyard (1971) flashed in the left visual field pictures of scenes depicting some activity. They then read aloud two similar statements describing the activity, and the patient had to indicate the correct one by a simple nod of the head They found that the right hemisphere could not differentiate between the singular and plural, the active and passive voice, or the present and future tense Consequently, its knowledge of grammar was almost nonexistent.

Further deficiencies were reported by Zaidel (1977) who administered the Token Test (De Renzi & Vignolo, 1962) to the disconnected right hemisphere (using the contact lens device) to test its ability to follow a sequence of auditory instructions The Token Test is a standardized test in which the subject is presented with an array of 10 to 20 small plastic chips or "tokens" of various colors, sizes, and shapes, and asked to carry out oral instructions of varying complexity, by manipulating certain chips. The right hemisphere had no difficulty recognizing or matching chips on the basis of any single dimension, but it showed a marked deficiency in response to the more complex test instructions when compared to the left hemisphere The disconnected left hemisphere performed at the level of normal controls (equated for IQ), whereas the right hemisphere performed at the level of a four-year-old child

At first glance this apparent failure to decode fairly simple auditory messages is surprising in view of the right hemisphere's ability to comprehend instructions in a wide variety of experimental situations. However, the discourse in the typical test situation is normally redundant and context-dependent, in contrast to the Token Test instructions which are semantically nonredundant and refer to context-free visual information Zaidel (1977) suggests that the latter type of auditory processing is more taxing on short term verbal memory since the components of the reference phrases (size, color, shape) cannot be integrated into a single higher percept. Thus, the right hemisphere's poor performance on this task suggests a severe limitation on its ability to order sequential bits of unrelated verbal information in short term memory. This deficit is reminiscent of Jackson's (1874) early observation that only the left hemisphere is capable of utilizing words to form propositions. The response or output phase of the Token Test clearly requires prior formation or integration of the unrelated verbal information into a useful proposition.

Before considering the implications of these split-brain studies for a model of language organization in the normal intact brain, it is worth noting some studies that point to basic differences in the disconnected hemispheres which may underlie the differences in their language abilities Many of the right hemisphere language deficits discussed so far suggest a deficiency at the phonetic-articulatory level of linguistic processing. The inability to articulate, the inability to integrate sequential, nonredundant, auditory-linguistic information in short term memory, and the poor performance on intermodal (auditory-visual) matching of single letters all suggest that the right hemisphere may be unable to decode phonetic feature information Levy and Trevarthen (cited in Levy, 1974) surmised that a deficiency in processing phonetic features of language would render the disconnected right hemisphere unable to perform a test of rhyming object names, even objects that it is typically able to recognize with no difficulty. They tachistoscopically presented split-brain subjects with chimeric (split-vision) stimuli composed of two pictures (e g., an eye and a bee), one in each visual field, and then gave a three-choice recognition test in which the subject had to point to the picture of an object that rhymed with what they saw (e g , a picture of a key, which rhymes with bee) Correct rhyming occurred 82% of the time to right visual field-left hemisphere stimuli and only 8% of the time to left visual field-right hemisphere stimuli (chance being 33%) To determine whether the right hemisphere's extremely low performance resulted from competition between the hemispheres, they tested the right hemisphere alone on the same task, using only left visual field presentations Performance rose only to absolute chance level

The right hemisphere's failure to make effective use of phonetic feature information was also demonstrated in recent dichotic listening studies by Zaidel (Note 4) and Springer and Gazzaniga (1975) When consonant-vowel syllables were presented dichotically, a different syllable in each ear, and subjects had to choose from a visual set of letters the sounds they had heard, a massive right ear advantage was obtained Left ear-right hemisphere speech sounds were recognized at or below chance level, even when subjects were instructed to attend the left ear (Springer & Gazzaniga, 1975) This failure to perceive left ear language stimuli during dichotic competition appears to be unique to nonmeaningful phonetic units, since it had previously been reported (Milner, Taylor, & Sperry, 1968) that object nouns presented to the left ear in a dichotic task were successfully retrieved by the left hand upon request

Thus, even though the disconnected right hemisphere can recognize a large number of words and decode redundant context-dependent speech, it appears to lack the mechanisms for processing basic phonetic feature information In view of the above evidence it has been suggested (Levy, 1974, Zaidel, Note 4) that the right hemisphere comprehends language by matching meaningful orthographic and phonological units of input with wholistic templates or gestalts in semantic memory

The Current Controversy

In view of the split-brain data reviewed in the previous section, it seems certain that the disconnected right hemisphere has the capacity to support some language functions However, whether the right hemisphere in the normal intact brain can perform the same functions is another question altogether The right hemisphere of the disconnected brain may be abnormal and not really reflect the true language capabilities of the normal right hemisphere, or alternatively, it may provide an accurate model for understanding the normal right hemisphere's language skills

The neural reorganization hypothesis Two main arguments can be advanced to support the notion that the split-brain is abnormal The first is the neural reorganization hypothesis, which is actually a corollary of the strict localization notion mentioned earlier This hypothesis states that the left hemisphere develops exclusive control over language, unless it is damaged early in life when the right hemisphere is capable of taking over language functions, and that the right hemisphere normally plays no role in language. It follows from this hypothesis that any language abilities demonstrated by the split-brain right hemisphere resulted from an abnormal redistribution of language functions due to early cerebral malfunction Since split-brain patients typically have a long history of intractable epilepsy, it is not unreasonable to assume that, as in cases where lesions occur in childhood, some language abilities were developed within the right hemisphere

However, there are several reasons for rejecting the neural reorganization hypothesis as an explanation of right hemisphere language. First, since the left hemisphere in split-brain patients demonstrates normal language capabilities, the need for postulating an early reorganization of language functions in these patients is questionable Secondly, there are numerous reports of other neurological patients demonstrating right hemisphere language which cannot be attributed to early damage to the left hemisphere For example, there are cases on record in which left hemispherectomy was performed in adulthood for late lesions leaving patients with only the healthy right hemicortex (Smith, 1966) Invariably, those patients who survived the operation demonstrated fairly good language comprehension, and some could even speak, though not fluently, despite the fact that their preoperative left hemisphere lesions had rendered them severely aphasic

Finally, additional evidence for right hemisphere language behavior in adults has come from observations of patients whose left hemispheres have been temporarily anesthetized by sodium amytal. Under these conditions of "functional hemispherectomy," the vast majority of right-handed individuals tested were able to comprehend what was being said to them, despite the fact that they could not speak (Milner, Branch, & Rasmussen, 1964, Rossi & Rossadini, 1967, Wada & Rasmussen, 1960) Thus there is ample evidence for the existence of right hemisphere language processing in cases where there is little reason to suspect early neural reorganization In view of this evidence, the notion that language develops exclusively in the left hemisphere in right-handed people (barring early neurological trauma) seems untenable.

The model of functional localization A second hypothesis has been advanced to account for the right hemisphere behavior of both split-brain and left hemispherectomy patients without postulating the existence of verbal behavior in the right hemisphere of the normal intact brain. This hypothesis, which Moscovitch (1973) has termed the model of functional localization, states that

> The verbal competence of the minor [right] hemisphere is the same in all right-handed people, including split-brains The extent to which the minor hemisphere's performance on verbal tasks reflects its limited underlying competence. depends on the degree to which the dominant hemisphere can control the verbal behavior of the minor hemisphere via the midline commissures and other pathways (p 114)

In other words, it is argued that in the intact brain the left hemisphere normally exerts an inhibitory control over right hemisphere verbal functions, and the right hemisphere cannot demonstrate its limited verbal abilities unless this inhibition is removed This postulated interhemispheric inhibitory control mechanism is a specific case of the more general concept of metacontrol, recently described by Levy and Trevarthen (1976) as "the neural mechanisms that determine which hemisphere will attempt to control cognitive operations" (p. 300)

The appeal of the model of functional localization lies in its ability to explain not only the display of language comprehension by the isolated right hemispheres of the split-brain and left hemispherectomy patients but also the loss of verbal comprehension in some aphasic syndromes In the case of the isolated right hemisphere, the sectioning of the cerebral commissures or removal of the left hemicortex serves to release the right hemisphere from the left hemisphere's inhibitory control and allows it to manifest its underlying language competence In aphasic cases where left hemisphere lesions have produced severe comprehension deficits, such as in global aphasias and pure alexias, it is assumed that critical sections of the healthy neural tissue remaining in the left hemisphere maintain the normal inhibitory control over the right hemisphere.

In support of this model of functional localization, Moscovitch (1973) notes that different neurological syndromes manifest different levels of right hemisphere language performance which are consistent with the release of function notion He notes, for example, that the language behavior of left hemispherectomy patients seems to be superior to that of the disconnected right hemisphere This, he argues, implies that the left hemisphere in commissurotomy patients can maintain some measure of control over the right hemisphere's verbal behavior by way of extra-commissural (subcortical) pathways, and that the right hemisphere's true verbal capacity is not released unless the entire left hemisphere is removed Moreover, Moscovitch argues that the language performance of aphasics is often worse than that of the split-brain right hemisphere because right hemisphere language remains largely suppressed in such cases

Even though the model of functional localization provides a convenient theoretical framework for explaining a variety of neurological phenomena, alternative interpretations are possible For one thing, profound loss of comprehension in left damaged aphasics with normal right hemispheres may not reflect continued left hemisphere suppression of the verbal activity of the right but rather a widespread effect of the lesion itself (Sperry et al , 1969) Secondly, the model of functional localization assumes that the residual language in many cases of aphasia is mediated not by the right hemisphere but by remaining healthy left hemisphere centers Yet, Kinsbourne (1971) has reported that sodium amytal testing on three aphasics revealed that their residual language was controlled by the right hemisphere, not the left

Finally, the model depends heavily for its support on the notion that there are differences between the language behavior of aphasics, left hemidecorticates, and split-brain right hemispheres Zaidel (1976) has recently questioned these alleged differences, suggesting that they may be more apparent than real He compared the right hemisphere scores of two split-brain patients and a left hemidecorticate with the scores of several diagnostic groups of aphasia on the Token Test and picture vocabulary tests mentioned earlier. The right hemisphere scores were roughly comparable to the aphasic scores on all of the tests, with all of the patients demonstrating a fairly good auditory vocabulary but poor performance on the Token Test of extra-lexical auditory comprehension The left hemidecorticate actually scored lower than the split-brain right hemisphere on auditory vocabulary, and the mean aphasic score was slightly higher than that of the split-brain right hemisphere Zaidel (1976) concluded that, since there is basically no real discrepancy between the auditory comprehension of aphasics and the split-brain right hemisphere, "there is no need to argue that left hemisphere control or inhibition masks right hemisphere language comprehension ability in either the intact brain or the left damaged brain" (p 15) However, one could argue that comparing the "average aphasic" to the split-brain right hemisphere serves to mask the differences that do exist The fact that half of the aphasics scored lower than the split-brain right hemisphere on the language tests could be viewed as support for the notion that, in many cases, the left hemisphere continues to inhibit right hemisphere language as long as the commissures are intact.

Summary This section began with the question of whether the limited language skills displayed by the split-brain right hemisphere actually reflect the language performance of the normal intact right hemisphere This is tantamount to asking whether the split-brain right hemisphere's demonstration of language is normal or abnormal. Two alternatives to a split-brain model of right hemisphere language have been considered The evidence reviewed in this section has argued against a neural reorganization explanation of right hemisphere language which maintains that language functions are localized exclusively in the dominant left hemisphere unless early damage to that hemisphere causes the lateralization of these functions to the right hemisphere The model of functional localization provides a different account of the neurological evidence for right hemisphere language and, despite some limitations, presents an interesting alternative to a split-brain model of normal right hemisphere verbal behavior This model, which is essentially a restatement of the strict localization view in functional terms, draws a distinction between right hemisphere verbal competence and verbal performance The critical question that distinguishes the split-brain model from the functional localization model is not whether the right hemisphere possesses the capacity (competence) to process language, but whether this capacity is demonstrable (performance) in the normal brain, the split-brain model claims that it is (Zaidel, 1976), and the model of functional localization claims that it is not (Moscovitch, 1973) A true test of the predictive value of these two models must ultimately rely on an assessment of the right hemisphere's language performance in the normal intact brain itself. The next chapter reviews some relevant data from studies of language lateralization in the normal brain

CHAPTER 2

BEHAVIORAL MEASURES OF FUNCTIONAL ASYMMETRIES IN THE INTACT BRAIN

The neurological evidence reviewed in the previous chapter leaves little doubt that the mechanisms underlying some aspects of language processing are distributed bilaterally in the brain. It is also clear that the language capacity of the minor, right hemisphere is operational at least under some rather unique neurological circumstances (hemisphere disconnection, hemidecortication, and perhaps even following left cortical damage in adults) The question that must now be considered is whether the demonstration of right hemisphere language in these cases is abnormal (model of functional localization) or whether it is an accurate reflection of functional language skills in the right hemisphere of the normal intact brain (split-brain model).

For the past 15 years or so, behavioral and electrophysiological techniques have been used in attempts to assess the nature and degree of lateralization of cognitive functions in normals Attempts to assess the lateralization of language processes in the intact brain typically rely on having subjects perform a verbal task Then, by a variety of methods, differences in the performance or activation of the two halves of the brain are measured Broadly speaking, there are two behavioral measures used to detect functional asymmetries in the intact brain One approach is to present verbal information to either the left or right hemisphere by way of lateralized visual or auditory sensory-cortical pathways and measure the relative accuracy of recognition of the stimuli direction to the two hemispheres (Kimura, 1967; White, 1969) The second approach uses similar procedures, but the response measure is reaction time (RT) (Moscovitch, 1973) The rationale behind both approaches is that performance differences occurring as a function of the hemisphere receiving the initial input are a reflection of differential efficiency of the two hemispheres for processing language.

The purpose of this chapter is to provide a critical review of the behavioral methods used to assess hemisphere performance in the intact brain Some typical findings will be discussed which illustrate the problems encountered when applying these methods to an assessment of right hemisphere language skills. The chapter will conclude with a summary of the various methodological and procedural factors which must be considered in a test of the central question of this thesis Can the right hemisphere in the intact brain perform in accordance with the language skills demonstrated by the disconnected right hemisphere?

Asymmetries in Identification of Lateralized Verbal Stimuli

Dichotic listening studies The dichotic listening technique was originally introduced by Broadbent (1954) and involves playing two different auditory messages simultaneously, one to each ear In 1961, Kimura discovered that the technique could be used to detect differences between the two ears in reporting messages She reported that serial digits were recalled better when presented to the right ear, whereas the left ear was superior for identifying nonverbal auditory material such as melodies (Kimura, 1964) Since it had previously been shown that the primary auditory pathways project from the ear to the auditory cortex in the contralateral hemisphere (Hall & Goldstein, 1968; Rosenzweig, 1951), Kimura (1961) claimed that these performance differences were due to the functional differences between the two hemispheres for processing verbal and nonverbal information The basic finding of a right ear advantage (REA) for recall and recognition of verbal information has been replicated many times using digits (Bryden, 1962, 1965, Zurif & Bryden, 1969), words (Dee, 1971), nonsense words (Curry, 1967, Kimura, 1967), letters (Weiss & House, 1970), consonant-vowel syllables (Shankweiler & Studdert-Kennedy, 1967, Studdert-Kennedy & Shankweiler, 1970), and even backward speech (Kimura & Folb, 1968) and morse code signals (Papcun, Krashen, Terbeek, Remington, & Harshman, 1974),

Although the REA probably reflects a left hemisphere superiority for processing verbal input, the implication of the phenomenon for the question of right hemisphere language processing is not entirely clear The right hemisphere is clearly inferior to the left at processing auditory verbal information for verbal report, but just how inferior and at what stage(s) in the process the right hemisphere is deficient cannot be determined from the REA alone One problem is that dichotic listening studies have typically required subjects to use a vocal response when recalling stimuli Such a procedure may well bias performance in favor of the left hemisphere solely on the basis of its control over speech output. In other words, the use of vocal responses does not permit the right hemisphere to express itself directly, and information presented to the right hemisphere may have the disadvantage of being somewhat degraged in transcallosal crossing to the left hemisphere for a vocal response to be initiated.

However, this left hemisphere output bias cannot be the only factor responsible for the REA since the extent of the left hemisphere's superiority (as reflected in the size of the REA) is also dependent on the nature of the speech input being processed For example, Shankweiler and Studdert-Kennedy (1967) showed that the REA was greater for the identification of stop consonants than for vowels in dichotically presented consonant-vowel syllables Similarly, Cutting (1974) and Darwin (1971) found that speech stimuli containing formant transitions (i.e , rapid changes in frequency) produced significant REAs, whereas speech stimuli without transitions yielded no ear advantage These results suggest that the REA may depend on a left hemisphere speech mechanism that is specialized for analyzing phonetic features and, furthermore, that the acoustic properties of speech, such as frequency (steady-state vowels), may be processed by either hemisphere. This conclusion is consistent with the neurologically derived notion described earlier that phonetic feature processing is a left hemisphere process (Levy, 1974, Zaidel, Note 4)

But what of the right hemisphere's ability to process meaningful linguistic units? The few dichotic listening studies that have used meaningful words as stimuli (e.g , Kimura, 1961, Dee, 1971) have reported REAs, but the implication of this finding for right hemisphere lexical processing is not clear There are at least two reasons for not ruling out right hemisphere processing of meaningful speech on the basis of the REA for recalling words. One is that the dichotic listening task, as it is typically employed, places a heavy load on verbal short term memory (STM) and verbal expressive mechanisms, thus bringing into play phonetic and articulatory processes Since the recall of words, as well as nonmeaningful speech, is likely to depend on these processes in the dichotic listening task, the REA for words may not be a reflection of hemisphere differences in lexical competence per se, but rather of the lateralization of phonetic-articulatory processing in the left hemisphere

A second reason for not ruling out right hemisphere word processing, or even phonetic processing for that matter, is that it is not clear whether the REA is a measure of relative differences between the two hemispheres or of absolute dominance of the left hemisphere For example, it is possible that verbal stimuli presented to the left ear-right hemisphere are reported less efficiently because the right hemisphere is merely less efficient than the left at processing verbal information Alternatively, it may be that only the left hemisphere processes verbal information, and the stimuli presented to the right hemisphere must cross the corpus callosum to the left hemisphere before they can be analyzed at all and thus suffer some degradation as a function of transmission time and distance.

For the above reasons, the REA has questionable bearing on the issue of the right hemisphere's verbal behavior. The only justifiable conclusion that can be reached on the basis of the existing dichotic listening data is that, in the intact brain, the processing of phonetic features of language is lateralized, to an undetermined extent, in the left hemisphere.

Visual field studies. Just as auditory stimuli can be projected via lateralized auditory pathways to the left and right hemispheres, so too can visual stimuli be projected laterally Due to the laws of physiological optics and the nature of retinocerebral neural projections, information in the left half of the visual field falls on the right halves of the retinae and is projected to the right hemisphere Similarly, information in the right half of the visual field falls on the left halves of the retinae and is projected to the left hemisphere Thus, if a subject fixates on a central fixation point and a stimulus is presented in one half of his visual field, with an exposure duration brief enough to prohibit foveation (<200 msec), the visual information is restricted to the contralateral neural pathways and is received by the contralateral hemisphere

This technique has been used extensively in attempts to confirm the dominance of the left hemisphere on verbal tasks. Several investigators have reported that when words are presented unilaterally and randomly in the two visual fields, those presented to the right visual field-left hemisphere are identified with greater accuracy (Harcum & Finkel, 1963, Harcum & Jones, 1962; Mishkin & Forgays, 1952, Terrace, 1959) Taken at face value (although see below), this right visual field advantage is analogous to the REA in dichotic listening and, as such, is subject to the same limitations when it comes to assessing the right hemisphere's verbal performance the apparent left hemisphere advantage could be due to subjects' use of a vocal identification response and not to any inherent left hemisphere superiority for identifying words.

However, some investigators have attempted to determine whether different visual field accuracy asymmetries exist for different classes of words. The assumption here is that a smaller right visual field-left hemisphere advantage for a particular class of words would indicate some ability on the part of the right hemisphere to recognize such words Ellis and Shepherd (1974) presented concrete and abstract nouns bilaterally (simultaneously in the right and left visual fields) and found that words projected to the right visual field-left hemisphere were identified more accurately than words projected to the left visual field-right hemisphere, but they also reported a larger visual field asymmetry for abstract nouns than for concrete nouns They interpreted this difference in visual field asymmetry to mean that at least some concrete words must be recognized by the right hemisphere However, attempts to replicate this finding have produced inconsistent results Hines (1976) obtained the same results as Ellis and Shepherd (1974), using both bilateral and unilateral displays of concrete and abstract nouns and found, moreover, that the effect was limited to familiar words By contrast, Orenstein and Meighan (1976) were unable to replicate the effect using Ellis and Shepherd's exact procedure and word source In fact, they found a left visual field superiority for both classes of nouns

Orenstein and Meighan's (1976) failure to replicate Ellis and Shepherd's (1974) results calls into question the adequacy of visual field recognition accuracy as a measure of hemisphere dominance This issue has been discussed at length in reviews by White (1969, 1973) who has noted that superior identification of left visual field words is the rule rather than the exception when words are displayed bilaterally This is in contrast to better identification of right visual field words when random unilateral presentations are used This discrepancy has prompted some authors to argue that visual field accuracy differences actually reflect a learned tendency to scan verbal information in a rightward direction, rather than functional differences between the hemispheres (Bryden, 1967, Harcum, 1972, Heron, 1957, White, 1973) Since words are typically read in a left-to-right fashion it is logical that the readout from a post-exposural trace of bilaterally presented words would begin in the left visual field and proceed rightward In the case of unilateral presentations, the subject does not know on any given trial which half-field will contain a word, and attention is not likely to be biased in any one direction Thus post-exposural scanning would begin at central fixation, and in this case the right visual field information would benefit from the tendency to scan to the right This directional scanning explanation of visual field accuracy differences has been supported by data showing that native Hebrew readers recognize unilaterally presented words better in the left visual field (Mishkin & Forgays, 1953, Orbach, 1953, 1967) Moreover, Harcum (1966) and Harcum and Finkel (1963) have shown that whereas unilaterally presented English words are better recognized in the right visual field, their mirror-images are better recognized in the left visual field, suggesting that stimulus directionality also has an affect on visual field accuracy

In an attempt to overcome this scanning problem and produce a useful visual field recognition paradigm for testing functional hemisphere differences, McKeever (1971, McKeever & Huling, 1971a, 1971b) introduced a modification of the bilateral presentation procedure which requires the subject to focus attention on the central fixation area and not on the left visual field. His method requires the subject to read out a centrally displayed digit before reporting any of the bilaterally presented information. Unlike studies that have not used this "fixation control" procedure, McKeever's method typically results in a right visual field advantage and is explained in terms of left hemisphere dominance for word recognition (McKeever, 1973).

Yet, as Orenstein (1976) and Kaufer, Morais, and Bertelson (1975) have noted, McKeever's results are quite compatible with an explanation based on learned scanning or reading habits Since the subject must first report a central digit, the next most likely item to report, consistent with a highly overlearned reading response, would be the one to the right of fixation, hence, the right visual field recognition superiority

Despite the problems inherent in the visual field recognition method, it may be that under certain circumstances visual field accuracy differences do reflect functional differences between the hemispheres For example, Barton, Goodglass, and Shai (1965) presented Hebrew words unilaterally, but in a vertical orientation, and found better right visual field recall, contrary to what would be expected on the basis of learned scanning habits Furthermore, McKeever and Gill (1972), using the fixation control paradigm, found a right visual field advantage for bilaterally presented vertical words, but they noted that the visual field asymmetry was much smaller than that found for horizontal words under the same circumstances. It may be that the right visual field advantage for horizontally displayed words consists of both a left hemisphere superiority for processing words and a further right visual field advantage due to directional scanning (Fudin & Masterson, 1976). The smaller right visual field advantage for vertical words may be due to the elimination of the scanning component and reflect primarily the left hemisphere dominance factor,

In view of the above considerations, it is clear that the evidence for visual field differences in word recognition accuracy has generated more questions than it has answered The findings of studies that did not use vertical word presentation are ambiguous because of the possible contribution of scanning tendencies to the visual field effect However, even under conditions which control for scanning, the right visual field advantage must be interpreted with caution As mentioned earlier, the apparent left hemisphere superiority for identifying words may simply reflect a greater stimulus-trace degradation of left visual field-right hemisphere words during interhemispheric transfer to the left hemisphere for initiation of a vocal response, rather than a right hemisphere deficiency or inability to identify words Furthermore, even if the visual field asymmetry does represent superior left hemisphere processing of verbal input as well as output, there is no way of determining whether the right hemisphere is merely less efficient or totally deficient at recognizing words In other words, a simple comparison of visual field accuracy scores will not indicate whether words presented to the right hemisphere must be transferred to the left to be recognized. Because of these problems of interpretation, investigators interested in right hemisphere verbal behavior have turned to a manual reaction time measure to assess hemisphere function.

The Use of Reaction Time (RT) to Assess Hemisphere Function

The reaction time (RT) approach to studying hemisphere performance is similar to the recognition accuracy approach in that stimuli are projected via lateralized sensory pathways to the left and right hemispheres, but the speed, rather than the accuracy, of the response is the major dependent measure. The RT measure has proved to be a powerful tool for detecting functional differences between the hemispheres on a variety of cognitive tasks For example, RTs to stimuli requiring phonetic analysis, as in tasks which require matching letters on the basis of whether they sound alike, have consistently favored right visual field-left hemisphere presentations, whereas stimuli requiring only visual-spatial analysis typically favor the left visual field-right hemisphere (Cohen, 1972, Geffen, Bradshaw, & Nettleton, 1972, Geffen, Bradshaw, & Wallace, 1971, Gross, 1972, Moscovitch, 1973, Rizzolatti, Umilta, & Berlucchi, 1971) Moreover, in contrast to the accuracy measure, a right visual field RT superiority for verbal processing is obtained regardless of stimulus directional characteristics (Isseroff, Carmon, & Nachshon, 1974) or native reading habits (Carmon, Nachshon, Isseroff, & Kleiner, 1972), suggesting that the RT measure of hemisphere differences transcends scanning tendencies

Furthermore, the use of manual responses permits one to control or manipulate the hemisphere emitting the response and thus eliminate the possible bias in favor of left hemisphere performance inherent in vocal responding Filby and Gazzaniga (1969), in fact, used RT to illustrate that a vocal response can produce what appears to be a left hemisphere superiority on a simple task which both hemispheres actually perform equally well They required subjects to detect the presence or absence of a dot flashed randomly in the right and left visual fields. When a vocal response was used, RTs favored the right visual field-left hemisphere by 30 to 40 msec, but when a whole-hand motor response (which can be controlled by either the ipsilateral or contralateral motor cortex) was employed there was no visual field RT difference

Although manual RTs to lateralized verbal stimuli typically favor the right visual field by 10 to 50 msec (Cohen, 1972, 1975, Geffen et al., 1972, Geffen et al , 1971, Gross, 1972, Isseroff et al , 1974, Moscovitch, 1973, Rizzolatti et al , 1971), the visual field RT difference does not in itself provide sufficient information to determine the level of the right hemisphere's verbal performance Because there is no way to restrict the sensory information to the right hemisphere once it has entered the central nervous system, the visual field RT difference is ambiguous It could reflect either slower right hemisphere analysis of verbal information or the extra time required for the transfer of the stimulus from a functionally nonverbal right hemisphere to the verbal left hemisphere for analysis

However, Moscovitch (1973) has described a RT technique for determining whether or not verbal information presented to the right hemisphere does in fact travel to the left hemisphere for analysis The technique involves varying orthogonally the hemisphere receiving the verbal input (via the lateralized visual pathways) and the hemisphere emitting the response (via movements of distal finger muscles controlled exclusively by the contralateral motor cortex) This permits a comparison of the efficiency (in terms of speed of response) of the different sensory-cortico-motor pathways. Figure 1 shows a simplified drawing of the brain with its visual and motor projections. According to this diagram, stimuli presented to the hemisphere emitting the response should be responded to faster than stimuli presented to the opposite hemisphere, and the difference in response times should reflect the amount of time required for information to travel from one hemisphere to the other. Several investigators have recorded times required to detect simple, lateralized auditory and visual stimuli and have reported results which are consistent with this model (Berlucchi, Heron, Hyman, Rizzolatti, & Umilta, 1971; Bertera, Callan, Parsons, & Pishkin, 1975; Bradshaw & Perriment, 1970).

A simple extension of this technique to tasks which require verbal processing has made it possible to test the verbal performance of the right hemisphere. Moscovitch (1973) had subjects perform a letter matching task in which a single letter (memory letter) was presented auditorily, and two seconds later a second letter (test letter) was presented briefly in either the right or left visual field. The subjects had to indicate, by pressing a button with either the right or left hand, whether the test letter had the same terminal phoneme as the memory letter. For example, if the memory letter was B, the subject indicated "yes" if the test letter was V or "no" if the test letter was M. Moscovitch (1973) found that the time required to make phoneme matches was shorter when the test letter was presented to the right visual field-left hemisphere than to the left visual field-right hemisphere. In addition to confirming the results of earlier studies showing that verbal tasks are performed faster by the left hemisphere,

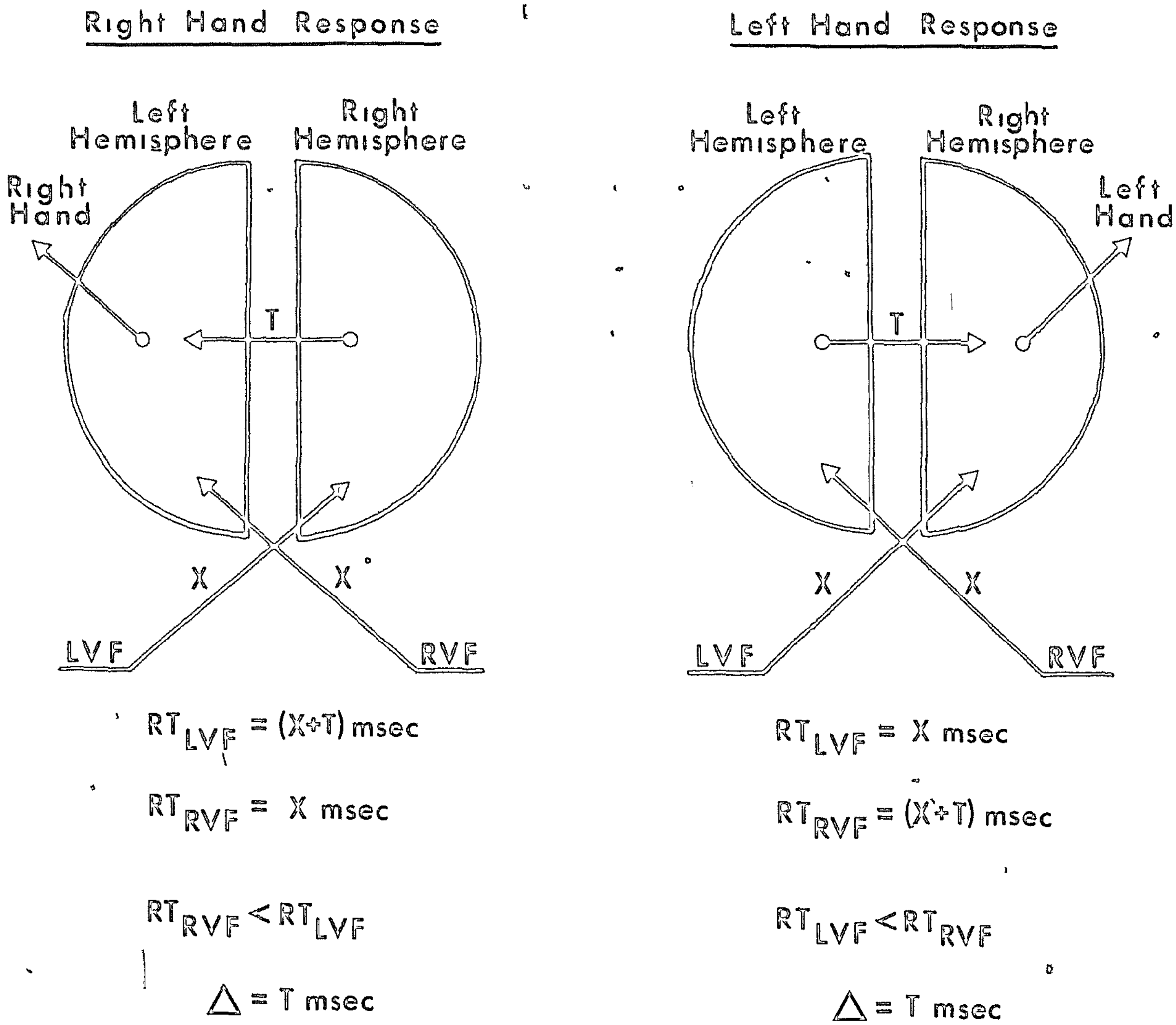


Figure 1. Pathway along which information from a visual stimulus presented to either the right or left visual field must travel before it evokes a manual response. T is the interhemispheric transmission time (msec), X is the transmission time from visual field to hemisphere, LVF and RVF are the left and right visual fields. (Modified from Moscovitch, 1973)

a further analysis of the RT data made it possible to determine if the right hemisphere was displaying any verbal skills in this task.

Figures 2 and 3 show schematic diagrams of the two alternative interpretations of the right visual field-left hemisphere superiority on this task If the right hemisphere was failing to perform the phonemic matching task (Figure 2), then RTs should favor the right visual field by equal amounts regardless of the hand used to respond, since visual field RT differences with both hands should reflect the stimulus crossing time (T_s) from the right to the left hemisphere Alternatively, if the right hemisphere was performing the task, but less efficiently than the left, then the visual field RT difference should be different for the left and right responding hands Figure 3 illustrates this prediction by showing that visual field RT differences for the left hand responses should be smaller than for right hand responses When the left hand is responding, the right hemisphere has the advantage of T_r msec (interhemispheric delay) over the left hemisphere by virtue of its direct initiation of the left hand response, but it also suffers the disadvantage of Y msec additional (less efficient) processing time Thus, the hemisphere RT difference can be characterized as $Y-T_r$ msec for left hand responding However, for the right hand, the left hemisphere has the advantage of both T_r and Y msec over the right hemisphere, so the hemisphere RT difference is $Y+T_r$ for right hand responding In other words, if the right hemisphere does display some (even though less efficient) verbal skills, then a visual field by hand interaction should be obtained

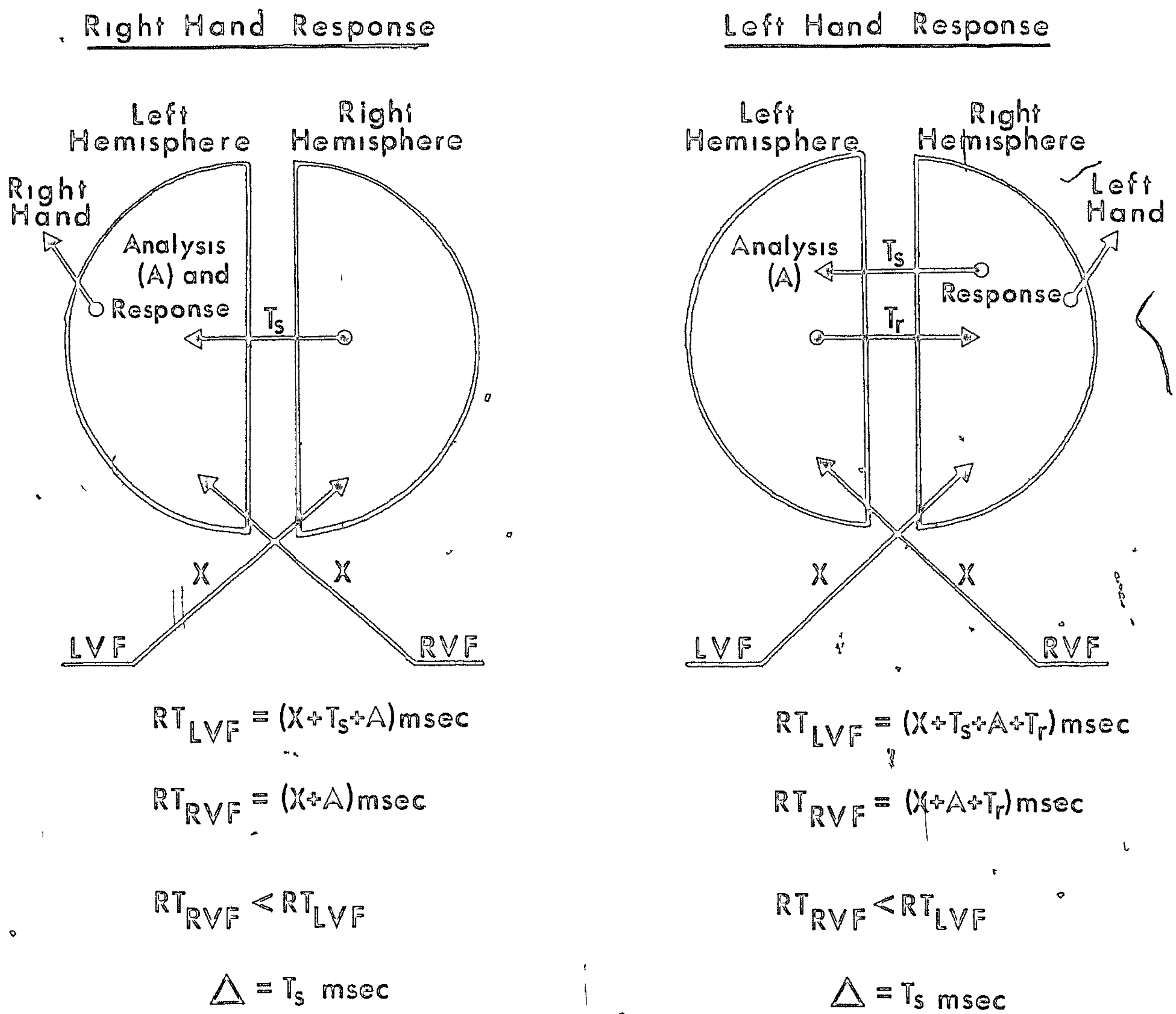
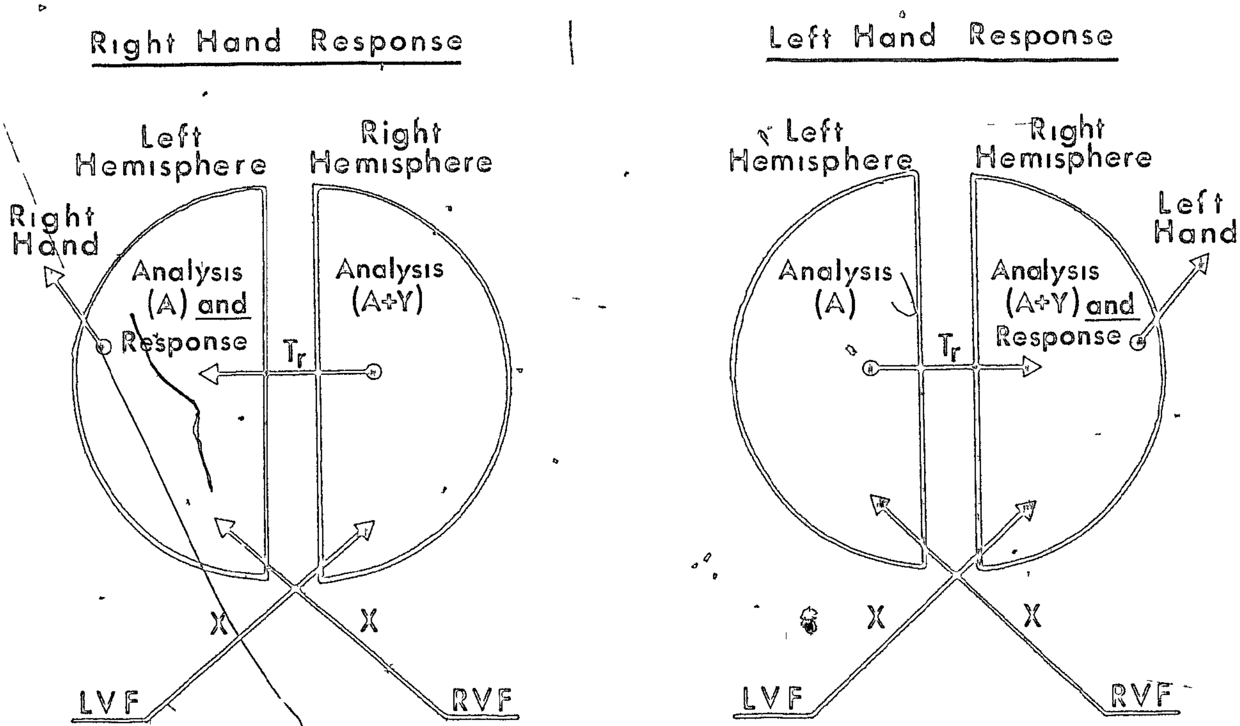


Figure 2 Neural-cognitive diagram of the phoneme matching task when only the left hemisphere performs the phonemic analysis T_s is the interhemispheric transmission time of the stimulus information (msec), T_r is the transmission time of the response information (msec); X is the transmission time from visual field to hemisphere, LVF and RVF are the left and right visual fields. (Modified from Moscovitch, 1973)



$RT_{LVF} = (X+A+Y+T_r)$ msec

$RT_{RVF} = (X+A)$ msec

$RT_{RVF} < RT_{LVF}$

$\Delta = (Y+T_r)$ msec

$RT_{LVF} = (X+A+Y)$ msec

$RT_{RVF} = (X+A+T_r)$ msec

$RT_{RVF} < RT_{LVF}$

$\Delta = (Y-T_r)$ msec

Figure 3. Neural-cognitive diagram of the phoneme matching task when both hemispheres perform the phonemic analysis, but the right hemisphere is slower. T_r is the interhemispheric transmission time (msec); X is the transmission time from visual field to hemisphere; Y is the additional processing time required for phonemic analysis in the right hemisphere; LVF and RVF are the left and right visual fields. (Modified from Moscovitch, 1973)

The results of Moscovitch's (1973) phoneme matching experiment showed that the right visual field RT superiority was identical for both right and left hand responding This lack of a visual field by hand interaction suggested, then, that only the left hemisphere was actively processing the phonetic information, a conclusion consistent with both the split-brain and functional localization models of language lateralization

This RT method of assessing hemisphere performance has been validated in a number of other experiments For example, when lateralized information can only be processed on the basis of visual-spatial cues or features, such as in discriminating subtle differences in faces (Rizzolatti et al , 1971, Moscovitch, Scullion, & Christie, 1976), RTs favor the left visual field-right hemisphere by a constant amount regardless of the hand used to respond, suggesting that this information is processed only by the right hemisphere On the other hand, when task requirements are such that stimuli can be analyzed on the basis of either visual-spatial or verbal features, or on the basis of lower order precategorical visual information, a visual field by hand interaction is typically obtained (Moscovitch, 1973, Moscovitch et al., 1976), suggesting that both hemispheres are able to perform the task Other studies have also confirmed Moscovitch's (1973) finding of exclusive left hemisphere analysis of phonetic information. For example, Rizzolatti et al. (1971) and Umilta, Frost, and Hyman (1972) found that subjects recognized target (memory) letters faster in a go-no go verbal STM task when test letters were presented in the right visual field In both experiments the right visual field advantage was of the same magnitude regardless of the hand used to respond. Springer (1971) tested subjects on detection of a target spoken syllable by having them press a button when they heard the target among dichotically presented test syllables She found that responses were faster and more often correct when the syllable was heard in the right ear as opposed to the left ear, and again there was no ear by hand interaction Levy and Bowers (1974) replicated Springer's results using spoken digits in a similar dichotic listening task The evidence from all of these RT studies has clearly demonstrated that the right hemisphere in the intact brain is not actively involved in performing tasks which require the analysis of phonetic information from speech sounds and visual letters. This conclusion is consistent with what both the split-brain and functional localization models predict about language lateralization in the intact brain. However, it does not answer the essential question that really distinguishes the two models, i e , can the right hemisphere in the intact brain process meaningful verbal information despite an inability to analyze phonetic feature information?

A few recent studies have looked at hemisphere RT differences in word identification, but the results have been inconclusive with regard to determining the right hemisphere's level of lexical competence Cohen (1975) and Isseroff et al (1974) measured the time to identify words in the right and left visual fields and found a right visual field-left hemisphere advantage of 23 to 40 msec. However, their subjects used a vocal response, and, as mentioned earlier, Filby and Gazzaniga (1969) showed that a vocal response can produce a 30 to 40 msec right visual field advantage even when both hemispheres are, in fact, equally efficient at performing a task. Isseroff et al (1974) also tested the speed of word recognition using a manual response Subjects performed a go-no go memory task in which they were first given a target word to remember then a list of test words presented one at a time and randomly in the right and left visual fields Target words presented in the right visual field during the test phase were detected approximately 34 msec faster than target words in the left visual field, and the visual field RT difference was the same for both right and responding hands. As previously discussed, this pattern of RT performance suggests that only the left hemisphere was actively engaged in the task However, this finding may only reflect the right hemisphere's failure to maintain verbal information in STM and should not be taken to mean that the right hemisphere does not recognize words at all

Thus, even though the RT studies reported to date have demonstrated fairly conclusively that the right hemisphere in the intact brain, like the split-brain, is functionally unable to utilize phonetic feature information, there has been no adequate test of the normal right hemisphere's ability to process meaningful verbal information at a lexico-semantic level All attempts to compare right and left hemisphere word processing have been confounded by the presence of phonetic and/or articulatory task demands that are likely to bias performance in favor of the left hemisphere, since the left hemisphere contains special processors for such information.

Statement of the Problem

In evaluating several different methodological and procedural approaches to studying hemisphere differences, the present chapter has placed heavy emphasis on the interaction of task-related and stimulus-related factors. Any visually presented verbal stimulus, for example, can be processed on the basis of several different feature dimensions depending on the demands of the task A good illustration of the way in which the interaction of task demands and stimulus features affects relative hemisphere performance can be seen in studies by Cohen (1972) and Geffen et al. (1972) These authors showed that when a subject's task was to judge the "sameness" of two letters on the basis of visual-spatial features (e g , AA or aa), RTs favored the left visual field-right hemisphere. When the task changed to judging "sameness" on the basis of name or phonetic identity (e g , Aa or aA), RTs favored the right visual field-left hemisphere

Words are also represented by different features, including orthographic patterns, strings of phonetic transitions, and meaningful representations stored in an internal lexicon Thus, it should be possible to examine hemisphere differences in dealing with words at these different levels of representation Yet, because the studies reviewed in this chapter have used tasks which rely heavily on a phonetic-articulatory level of coding verbal input, they have not been adequate to assess the right hemisphere's lexical competence, i.e , its ability to recognize words.

A consideration of the methodological and procedural problems discussed above suggests that an adequate assessment of the right hemisphere's ability to process lexical information must meet certain criteria (a) The task should require that lexical information be accessed, yet it should not required that information be maintained in verbal (phonetic-articulatory) STM. (b) A manual RT measure should be used to eliminate the left hemisphere vocal bias and allow for an assessment of interhemispheric transfer of information (c) Word stimuli should be presented in a vertical orientation and randomly in the right and left visual fields to control for the potential effects of scanning habits on visual field performance

A task requiring subjects to make instantaneous lexical decisions on the basis of briefly presented vertical words would maximize the possibility of meeting these criteria Accordingly, the first experiment of the present series was designed to test the lexical competence of the intact right hemisphere by having subjects perform a simple word-nonword discrimination task. In this type of task, subjects are typically presented strings of letters and asked to decide whether the string is a word or not, and RT to make this decision is recorded The RT presumably reflects the time required to access a lexical entry in long-term lexical memory (Rubenstein, Garfield, & Millikan, 1970)

CHAPTER 3

EXPERIMENT 1

The purpose of Experiment 1 was to test the split-brain model of right hemisphere lexical competence by asking two questions The first question was whether the right hemisphere can discriminate words from nonwords To answer this question a lexical decision task was designed in which words and nonwords were presented randomly and unilaterally in the right and left visual fields, and RTs to judge stimuli as words were recorded. The rationale behind the experiment is simple If words are recognized faster when presented in the right visual field, and this right visual field superiority is the same regardless of the hand used to respond, then lexical entries are accessible only in the left hemisphere (model of functional localization) On the other hand, if no difference is found between the visual fields, or if an interaction between visual field and responding hand is obtained with a smaller visual field difference for the left hand, then it can be concluded that lexical entries are accessible in the right hemisphere as well as in the left (split-brain model)

The second question was whether the right hemisphere's ability to recognize words is a function of word concreteness This issue has not been addressed explicitly in experiments on the disconnected right hemisphere Zaidel (1976) has noted that because of the types of word recognition tests administered to the disconnected right hemisphere (matching words with object or picture referents), most of the data on the right hemisphere's lexical competence concerns only its ability to recognize fairly concrete words Also, as previously mentioned, recent studies investigating visual field effects in vocal identification of concrete and abstract words in normals have produced inconsistent results (Ellis & Shepherd, 1974, Hines, 1976, Orenstein & Merghan, 1976). For these reasons, the present experiment examined lexical decision performance on two types of words, concrete nouns and abstract nouns, to determine whether the right hemisphere's lexical vocabulary is limited to words with concrete referents

Method

Subjects Fourteen right-handed Dalhousie University students (eight male and six female), ranging in age from 19 to 26 years, participated in the experiment. All subjects were prescreened for handedness on the Edinburgh Inventory (Oldfield, 1971), and only those with a laterality quotient of 80 or higher were selected (see Appendix A) In addition, only subjects with right-handed parents and siblings were selected All subjects reported having 20 20 vision or vision corrected to 20.20 by lenses.

Stimuli. The words used in this experiment were 32 concrete and 32 abstract nouns (i.e , above 6.10 and below 4.20, respectively, on the 7-point scale of concreteness published by Paivio, Yuille, and Madigan, 1968). The concrete and abstract nouns (see Appendix B) were matched for length (four or five letters) and Thorndike-Lorge (Thorndike, 1944) frequency counts (at least 50 occurrences per million). In addition, 64 nonsense or nonwords were constructed by altering a single letter in each of the words in such a way that the resulting letter strings were easily pronounceable and maintained a conformity to the rules of English orthography For example, PIPE was changed to

PIFE, DRESS to GRESS, and so forth (see Appendix B).

The stimuli were constructed from black 12 pt Futura Medium Letraset capital letters and mounted on 35 mm glass slides in a vertical orientation to control for a possible left-to-right reading bias. Two slides of each stimulus were made, one with the letters positioned 9 mm to the right of center and the other with the letters the same distance to the left of center, so that when the slides were projected on a rear projection screen the words and nonwords appeared 2.5 cm to the right or left of a central point on the screen. The vertically-oriented stimuli subtended visual angles of 3.2^{o} (four letter words) and 4.2^{o} (five letter words) vertical and approximately 0.6^{o} horizontal, and the distance between the inner edge of each stimulus and the central fixation point subtended a visual angle of 1.5^{o} at a viewing distance of 85 cm. Thirty-two practice stimuli were constructed in the same manner as the test items.

Two series of 128 stimuli each were constructed. Within a series the order of the first 64 items were determined by a randomization of eight concrete nouns on the left, eight different concrete nouns on the right; eight abstract nouns on the left, eight different abstract nouns on the right, and 16 nonwords on the left and 16 nonwords on the right. The remaining 64 items in the series were composed of a randomized order of the same items on the opposite side from their positions in the first half of the series. The second series was constructed in the same way as the first using the remaining 64 stimuli. The two series were matched for concreteness, word length, and word frequency (see Appendix B). Within a series, then, each stimulus appeared once in the right visual field and once in the left. In addition, the 32 nonwords in the first series were created by altering the 32 words in the second series, and vice versa, thereby avoiding obvious similarities between words and nonwords within a series. Once the stimulus order within a series was determined the slides were arranged appropriately in four carousels of 64 slides each. Thus, the order of stimuli within a block of 64 trials remained fixed across subjects.

Apparatus. The subject sat at one end of a table 153 cm long and 64.5 cm wide. A rear projection screen (28.5 cm high by 24 cm wide), mounted in a wooden frame, was positioned 85 cm from the subject's end of the table with the center of the screen equidistant from the sides of the table and 25 cm above the table top. The stimuli were projected on the screen by a slide projector (Kodak Carousel, Model 800) with an electronic shutter (Ralph Gerbrands, Model G1166) mounted on the lens. The viewing distance was held constant for all subjects by having them position their head in a chin-head rest. A PDP-12 digital computer was programmed to control the rate of stimulus presentation and the exposure duration of each stimulus through a set of relays to the slide projector and shutter. Centered on the table immediately in front of the subject was a single response button consisting of a microswitch housed in a custom-made metal box 10 cm long, 5.5 cm wide, and 5.5 cm high. Subjects were instructed to keep their arm resting on the table during the experiment with their index finger resting on the button in preparation for responding. At the onset of the shutter activation (i.e., stimulus onset), the computer activated a msec clock which was stopped by closure of the microswitch or after 2.0 seconds if no response occurred.

Procedure. Each subject was told that he would see a series of slides displayed on the screen in front of him and that each slide would contain a vertically oriented string of four or five letters appearing either to the left or right of the central fixation point. The subject was instructed to fix his gaze on the center of the screen when he heard the warning click of the projector advance One second later the stimulus was displayed for 100 msec, and the subject's task was to press the button in front of him with his index finger if the stimulus was a word but to refrain from pressing the button if it was not a word.[4] If the subject did not respond to a word within two seconds, an error was recorded The inter-trial-interval (ITI) was always two seconds

Subjects were tested on both series in a single session for a total of 256 test trials. The session was divided into four blocks of 64 trials with a break of approximately two minutes between blocks. The first two blocks were performed with one hand and the last two with the other hand. Hand order and series order were counterbalanced across subjects Each subject was given 16 practice trials at the beginning of the session and 16 more when switching from one hand to the other The instructions emphasized both speed and accuracy, and both RTs and errors were recorded.

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[4]The single finger go-no go response was used to insure that only one hemisphere was primed to respond during a block of trials Of course, a choice RT procedure using two fingers on the same hand would have achieved the same purpose, but the intent here was to use as simple and straightforward a response as possible.

Individual RTs were clocked (in msec) by the computer and stored on magnetic tape together with a preprogrammed code for each trial designating the visual field of presentation and whether the item was a concrete word, abstract word, or nonword The computer was also programmed to match a response, or the absence of a response, with the code for words and nonwords on each trial and record errors appropriately (both false positives and false negatives)

Results

The RT and error data are summarized in Table 1. Median RTs of correct responses were calculated for each subject as a function of noun type, visual field of presentation, and responding hand (see Appendix B for individual subjects' data). Separate 2 (Visual Field) x 2 (Hand) x 14 (Subject) analyses of variance were conducted for abstract and concrete nouns.[5]

Abstract nouns The analysis of RTs to abstract nouns (see Appendix B) revealed a significant main effect of Visual Field, $F\ (1, 13) = 15.37$, $p <\ .005$, RTs favoring the right visual field by 35 msec, and a significant effect of Hand, $F\ (1, 13) = 5.88$, $p < .05$, RTs favoring the right hand by 61 msec The Visual Field by Hand interaction was not significant A subsequent 2 (Visual Field) x 2

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[5]Since the purpose of this experiment was to determine the relative effects of visual fields and hands on RT performance within each noun class, and not to assess absolute differences in RTs to concrete and abstract nouns, the two noun classes were analyzed separately. However, similar results were obtained with an overall analysis that included concreteness as a factor, i.e., an interaction between Visual Field and Concreteness, $F\ (1, 13) = 13.65$, $p < .005$. A supplemental t-test showed a significant visual field RT difference for abstract nouns, two-tailed $t\ (13) = 3.88$, $p < .01$

Table 1

Mean Reaction Times (in msec) to Concrete and Abstract Nouns in Experiment 1

		Concrete			Abstract		
Hand	n	LVF	RVF	L-R[a]	LVF	RVF	L-R[a]
Left	14	692 (152)	700 (.160)	-8	735 (143)	699 (143)	+36
Right	14	664 (174)	660 (.143)	+4	672 (165)	639 (170)	+33
Overall	14	678 (.163)	680 (157)	-2	704 (.154)	669 (157)	+35

Note Numbers in parentheses indicate error percentages

[a] L-R = left visual field (LVF) minus right visual field (RVF).

Hand) x 32 (Word) analysis of variance was performed on the median RTs for words, calculated across subjects, to determine whether the right visual field superiority held across words as well as subjects (see Appendix B) Reaction times favored the right visual field by 39 msec (LVF = 725 msec, RVF = 686 msec), F (1, 31) = 4 99, $p < .05$ This significant difference suggests that the results can be generalized across abstract nouns An analysis of errors (see Table 1 and Appendix B), i e., failures to recognize abstract nouns as words, showed no differences between Visual Fields or Hands and no Visual Field by Hand interaction The overall rate of failure to recognize abstract nouns was 15.5%

Concrete nouns. The analysis of RTs to concrete nouns (see Appendix B) revealed no significant effects of either Visual Field or Hand. Although there was a tendency for RTs to favor the visual field ipsilateral to the responding hand, the Visual Field by Hand interaction was not significant. The overall rate of failure to recognize concrete nouns was 15 7%, and an analysis of these errors (see Table 1 and Appendix B) showed that the error rate did not differ across any of the Visual Field-Hand conditions.

False positive responses The proportion of responses to nonwords (false positives) was tabulated for each subject as a function of visual field and responding hand (see Appendix B for individual subjects' scores). A 2 (Visual Field) X 2 (Hand) x 14 (Subject) analysis of variance was performed on these scores (see Appendix B) to determine whether the Visual Field effect reported above was due to a response bias. For example, the right visual field advantage could have been due to more indiscriminate responding to stimuli in the right visual field than in the left visual field, i e , responding quickly without actually making the lexical decision In the event of such a speed-accuracy tradeoff, more false positives would be expected in the right visual field condition However, since the analysis revealed no differences in the percentage of false positive responses to nonwords in the right (25.0%) and left (24 2%) visual fields, it is unlikely that a speed-accuracy tradeoff was occurring in this experiment

Discussion

The RT data indicate a right visual field superiority for the speed of response to abstract nouns but no difference between the left and right visual fields for the speed of response to concrete nouns. The fact that the right visual field RT superiority for abstract nouns was of the same magnitude for both hands (right hand, 33 msec; left hand, 36 msec) suggests that abstract nouns presented to the left visual field-right hemisphere had to cross to the left hemisphere before a lexical decision could be made. The visual field RT difference of approximately 35 msec provides an estimate of the time involved in transmitting and recoding the words across the interhemispheric pathways. This estimated interhemispheric delay is consistent with electrophysiological studies showing that excitation originating in one hemisphere requires from 10 msec (primary positive wave) to 35 msec (secondary negative wave) to cross the corpus callosum to the other side of the brain (Grafstein, 1959; Bremer, 1958, Teitelbaum, Sharpless, & Byck, 1968).

The lack of visual field difference in the case of RTs to concrete nouns suggests that lexical decisions about these words were made equally efficiently in both hemispheres. However, according to the neural pathway RT model described in Figure 1, stimuli presented to the hemisphere emitting the response should be responded to faster than stimuli presented to the other hemisphere when both hemispheres are able to perform the task. This expected hemisphere (visual field) by hand interaction did not achieve significance, although the visual field RT differences were in the correct directions for both hands (left visual field 8 msec faster with left hand responding and right visual field 4 msec faster with right hand responding). An examination of the individual subjects' RT scores revealed no consistent visual field advantage for either hand. For left hand responding only 8 of 14 subjects showed the expected left visual field advantage, and for right hand responding only 6 of 14 showed a right visual field advantage. One possible explanation of the lack of consistent visual field differences for concrete nouns is that, since both hemispheres are able to recognize these words, the information received by one hemisphere may be transmitted to be "rechecked" by the other on some trials. If this were so, it would have the effect of producing exceptionally long RTs on some trials, for example, where the left hand is responding to left visual field information (by adding two extra callosal crossings), thereby partially cancelling out the RT superiority which should obtain for that condition. The net result would then be essentially no visual field RT advantage for either hand. Admittedly, this explanation is highly speculative, and perhaps impossible to test, but it cannot be ruled out on the basis of existing evidence. Of course, it is also possible that each hemisphere may have some ipsilateral control over simple finger flexion movements. However, despite the failure of the Visual Field by Hand interaction to attain significance, the lack of a visual field RT difference suggests that the two hemispheres recognized concrete nouns equally well.

The results of this experiment, then, can be interpreted as reflecting differences between the two hemispheres in the retrieval of lexical information. The findings suggest that lexical entries for abstract nouns are accessible only in the left hemisphere, whereas lexical entries representing concrete nouns are accessible in both hemispheres. Thus, with regard to the issues that motivated this experiment, it can be concluded (a) that the right hemisphere in the intact brain does have an accessible lexical vocabulary and (b) that its ability to recognize nouns depends on their concreteness.

CHAPTER 4

EXPERIMENT 2

The right hemisphere's performance on the lexical decision task in Experiment 1 depended on its having a lexical memory for concrete nouns. This conclusion is consistent with the split-brain findings which have shown that the disconnected right hemisphere has a relatively sophisticated lexical vocabulary consisting of at least concrete object-nouns (Gazzaniga, 1970, Zaidel, 1976) There is also evidence from split-brain studies which suggests that the right hemisphere has the ability to recognize semantic associations between object-nouns and to use this information to perform simple tasks. For example, when commissurotomized patients are given the command to "retrieve the fruit monkeys like best" they are able to use their left hand to pull out a banana from a grab bag full of plastic fruit (Gazzaniga, 1967), indicating that the right hemisphere knows that "banana" is a specific instance of the category "fruit" and that it is associated with "monkeys "

The question naturally arises as to whether the right hemisphere in the intact brain can demonstrate a knowledge of semantic associations between the words that it knows. Experiment 2 was designed to answer this question by measuring the speed at which nouns presented in the left and right visual fields are recognized as instances of specific semantic categories If both the right and left hemispheres are able to recognize category-noun associations, then the time required to recognize test nouns as instances of categories should be the same for right and left visual field presentations. If, on the other hand, the right hemisphere is unable to detect relationships between nouns and their superordinate categories, then those nouns presented to the left visual field-right hemisphere should have to travel to the left hemisphere before a category decision could be made. In this event, an interhemispheric transfer delay similar to that found for abstract nouns in Experiment 1 should be obtained.

Method

Subjects Sixteen Dalhousie University students (eight male and eight female) participated in the experiment. The criteria for subject selection were the same as in Experiment 1.

Stimuli. The stimuli were 64 pairs of nouns Each pair consisted of a superordinate category word and either a positive or negative instance of the category (e g., animal-horse, animal-rock). Four positive and four negative instances were paired with each of eight different categories. Half of the categories were concrete and half were abstract (see Appendix C), and all of the category instances were high frequency words (at least 50 occurrences per million, Thorndike, 1944). The two words of each pair were printed on separate slides so that categories and instances could be presented successively. The words representing positive and negative instances were oriented vertically, as in Experiment 1, and two slides of each word were constructed, one for right visual field and one for left visual field presentation. This resulted in a total of 16 pairings in each category for a total of 128 test pairs. The superordinate category words were printed on slides in a horizontal orientation centered for foveal presentation.

Apparatus and procedure. The apparatus was identical to that used in the previous experiment. The procedure was also similar in that it involved a positive-negative discrimination on each trial and a go-no go response format with an emphasis on both speed and accuracy The procedure differed from Experiment 1 in that the subject saw two successive stimuli on each trial The first stimulus was always a foveally presented superordinate category word displayed for one second. This was followed by a one second interval and then a 100 msec presentation of either a positive or negative category instance The subject's task was to respond as quickly as possible only when the second word was a positive instance of the category Two seconds were allowed for a response, and trials were separated by a two second ITI. Eight of the subjects responded with the right hand throughout the experiment, and the other eight responded with the left hand [6].

Subjects were tested in a single session consisting of 16 practice trials and 128 test trials The test trials were presented in four blocks of 32 trials with a two minute interval between blocks Each block consisted of a randomization of four positive and four negative concrete category matches and an equal number of abstract category

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[6] Individual subjects were not tested with both hands because this procedure would have required either a) doubling the number of category pairs or b) displaying category pairs twice in each visual field, in order to obtain a sufficient number of trials per hand. Doubling the number of pairs was impossible (at least for abstract pairs) given the constraints imposed on the selection of test stimuli, i e., high frequency words with a reasonably small number of letters per word. Displaying test words twice in each visual field was avoided in an effort to control for an additional familiarity effect that might conceivably have a different influence on right and left hemisphere performance.

matches in each visual field. All pairs were tested in one visual field or the other before any given pair was tested in the opposite visual field

Results

The RT and error data are summarized in Table 2 Median correct RTs were calculated for each right and left hand responding subject as a function of category type (concrete and abstract) and visual field of presentation of the test words (see Appendix C for individual subjects' data). Separate 2 (Visual Field) x 2 (Hand) x 8 (Subject) analyses of variance were conducted for abstract and concrete categories

Abstract categories. The analysis of RTs to make abstract category decisions (see Appendix C) revealed only a significant main effect of Visual Field, $F(1, 14) = 13.44$, $p < .005$, RTs favoring the right visual field by 36 msec The Visual Field by Hand interaction was not significant A second 2 (Visual Field) x 2 (Hand) x 16 (Word) analysis of variance, performed on median correct RTs for abstract word pairs calculated across subjects (see Appendix C), also yielded a significant effect of Visual Field, $F(1, 15) = 5.46$, $p < .05$, RTs favoring the right visual field by 45 msec (LVF = 590 msec, RVF = 545 msec) The results of this analysis suggest that the right visual field advantage can be generalized across abstract category pairs as well as subjects. Errors occurred on only 2.7% of the positive abstract category trials, and a 2 (Visual Field) x 2 (Hand) x 8 (Subject) analysis of variance showed no difference in errors across any of the Visual Field-Hand conditions (see Appendix C).

Table 2

Mean Reaction Times (in msec) to Identify Concrete and Abstract Nouns as Instances of Semantic Categories in Experiment 2

		Concrete			Abstract		
Hand	n	LVF	RVF	L-R[a]	LVF	RVF	L-R[a]
Left	8	581 (047)	594 (.031)	-13	574 (.047)	543 (.024)	+31
Right	8	585 (.039)	574 (031)	+11	572 (024)	532 (016)	+40
Overall	16	583 (043)	584 (031)	-1	573 (.036)	538 (020)	+35

Note · Numbers in parentheses indicate error percentages.

[a] L-R = left visual field (LVF) minus right visual field (RVF).

Concrete categories. The analysis of RTs to make concrete category matches (see Appendix C) revealed no significant main effects. Although there was a tendency toward a Visual Field by Hand interaction, with RTs favoring the visual field ipsilateral to the responding hand, the interaction was not significant Errors occurred on only 3.7% of the positive concrete category trials, and an analysis showed no difference in errors between any of the Visual Field-Hand conditions.

False positive responses The proportion of responses to negative abstract and concrete category matches was tabulated for each subject as a function of visual field and responding hand (see Appendix C for individual subjects' data). False positive responses occurred on 7 6% of the negative abstract category trials and 10 1% of the negative concrete category trials Separate 2 (Visual Field) x 2 (Hand) x 8 (Subject) analyses of variance were conducted for concrete and abstract categories, and neither analysis revealed differences in errors as a function of Visual Field or Hand (see Appendix C), suggesting that the RT results were not due to a tradeoff between speed and accuracy of responding.

Discussion

The results show that abstract nouns are recognized faster as instances of categories when they are presented in the right visual field. The fact that the visual field RT difference favoring the right visual field is not significantly different for right and left hand responses suggests that abstract test words presented to the left visual field-right hemisphere had to cross to the left hemisphere for analysis. This is not surprising since Experiment 1 suggested that the right hemisphere does not recognize abstract nouns and therefore should not be able to make category decisions about them It is also interesting to note that Experiments 1 and 2 provide virtually identical estimates of the interhemispheric delay involved in processing abstract nouns from the left visual field (Experiment 1, 35 msec, Experiment 2, 36 msec).

With respect to concrete category matches, the lack of a visual field RT difference suggests that the recognition of concrete nouns as instances of previously presented categories is accomplished with equal speed regardless of the hemisphere receiving the test noun. This finding suggests that the right hemisphere may be able to recognize word associations However, this interpretation cannot be stated unequivocally on the basis of the present data. The possibility remains that associative processing may in fact be mediated solely by the left hemisphere. The foveal presentation of a superordinate category word in the present task may cause the dominant left hemisphere to prime or activate semantic associates of the category word, prior to the test stimulus, not only within the left hemisphere's lexicon but in the right hemisphere's lexicon as well by way of interhemispheric pathways Thus, although the lack of a visual field RT difference clearly suggests that the right hemisphere's lexical vocabulary is activated in the performance of the category matching task, it is not clear whether the associative process is mediated independently in the left and right hemispheres or only in the left. The following experiment was designed to distinguish between these two interpretations of the right hemisphere's performance on the category matching task

CHAPTER 5

EXPERIMENT 3

In Experiment 3 the category and test words were presented simultaneously. By eliminating the one second inter-stimulus-interval used in Experiment 2, the possibility was ruled out that the right hemisphere could be primed by the left hemisphere prior to the presentation of the test word It was hypothesized that if the right hemisphere is able to recognize associations between concrete nouns based on category membership, then the results of Experiment 2 would be replicated. In other words, RTs to recognize laterally presented nouns as instances of foveally presented categories should be the same for the left and right visual fields If, however, the normal right hemisphere does not have a functional associative network, then nouns presented to the right hemisphere will have to travel to the left hemisphere for associative analysis, thus producing slower RTs to left visual field-right hemisphere stimuli

Method

Subjects Sixteen Dalhousie University students (eight male and eight female) participated in the experiment The criteria for subject selection were the same as in the previous experiments

Stimuli As in the previous experiment, the stimuli were 32 positive and 32 negative category-noun pairs The concrete categories were animals, food, and metals, and the abstract categories were feelings, months, and time (units) There were five positive and five negative instances of each category except for feelings and food which were assigned six positive and negative instances each (see Appendix D). Both words of a pair were printed on the same slide for simultaneous presentation. The category word was oriented along the vertical midline of the visual field for foveal presentation, and the positive or negative instance was positioned to the right or left of center as in the previous experiment

Apparatus and procedure. The apparatus and procedure were identical to those used in Experiment 2 with the following exceptions (a) The category and instance words were displayed simultaneously on each trial, and the subject's task was to decide whether the lateralized word was an instance of the centrally displayed category. (b) The exposure time was increased from 100 to 150 msec because pilot work showed that most subjects were unable to recognize the lateralized word while fixating on the centrally displayed category word at the shorter exposure duration

Results

The RT and error data are summarized in Table 3 Median RTs of correct responses were calculated for each right and left hand responding subject as a function of category type (concrete and abstract) and visual field of presentation of the test words (see Appendix D for individual subjects' data) Separate 2 (Visual Field) x 2 (Hand) x 8 (Subject) analyses of variance were conducted for concrete and abstract categories

Abstract categories. The analysis of RTs to make abstract category decisions (see Appendix D) revealed only a significant main effect of visual field, F (1, 14) = 8.54, $p < .025$, RTs favoring the right visual

Table 3

Mean Reaction Times (in msec) to Identify Concrete and Abstract Nouns as Instances of Semantic Categories in Experiment 3

		Concrete			Abstract		
Hand	n	LVF	RVF	L-R[a]	LVF	RVF	L-R[a]
Left	8	890 (.226)	890 (.195)	0	889 (.210)	860 (.180)	+29
Right	8	929 (.343)	908 (.305)	+21	880 (.218)	849 (.164)	+31
Overall	16	910 (.285)	899 (.250)	+11	885 (.214)	855 (.172)	+30

Note. Numbers in parentheses indicate error percentages

[a] L-R = left visual field (LVF) minus right visual field (RVF).

field by 30 msec The Visual Field by Hand interaction was not significant Another 2 (Visual Field) x 2 (Hand) x 16 (Word) analysis of variance was also performed on median correct RTs for abstract word pairs, calculated across subjects, to determine if the Visual Field effect could be generalized across category pairs as well as subjects Mean RTs for left and right visual field category decisions were 916 msec and 868 msec, respectively The 48 msec visual field RT difference was significant, F (1, 15) = 4 70, $p <$ 05, and thus offered support for the generality of the right visual field superiority across abstract category pairs Errors occurred on 19 3% of the positive abstract category trials, and an analysis of variance (Subjects X Visual Field X Hand) revealed no differences in the rate of errors across any of the Visual Field-Hand conditions (see Appendix D)

Concrete categories The analysis of RTs to make concrete category matches revealed no significant main effects of (Visual Field or Hand (see Appendix D) Although a 21 msec right visual field advantage occurred for right hand responding, in contrast to no visual field RT difference for left hand responding, the Visual Field by Hand interaction was not significant. Errors occurred on 26 8% of the positive concrete category trials, and a 2 (Visual Field) x 2 (Hand) x 8 (Subject) analysis of variance revealed no differences in errors across any of the Visual Field-Hand conditions (see Appendix D)

False positive responses. The rate of responding to negative abstract and concrete category matches was tabulated for each subject as a function of visual field and responding hand (see Appendix D for individual subjects' scores). False positive responses occurred on 8.2%

of the negative abstract category trials and 6 1% of the negative concrete trials Separate 2 (Visual Field) x 2 (Hand) x 8 (Subject) analyses of variance were conducted on concrete and abstract false positives, and neither analysis revealed any differences in errors as a function of Visual Field or Hand (see Appendix D) suggesting that the RT results were not due to a tradeoff between the speed and accuracy of responding

Discussion

The results show that RTs for matching laterally presented concrete nouns with centrally presented categories do not differ as a function of the visual field of presentation This indicates that the right hemisphere was as efficient as the left at performing this particular linguistic task and thus suggests that the right hemisphere recognized semantic associations between concrete nouns at the level of categorical membership. The results also show that abstract nouns are recognized faster as instances of specific categories when presented in the right visual field. This finding, together with the lack of a difference in the right visual field RT advantage between the left and right responding hands, is consistent with the results of Experiment 2 in suggesting that abstract nouns presented to the left visual field-right hemisphere must be transmitted to the left hemisphere for analysis The visual field RT difference (30 msec) was roughly the same as in the previous experiments

The only noteworthy difference between the results of this experiment and Experiment 2 is the overall performance decrement in the present experiment. The simultaneous presentation of category and instance words (Experiment 3) led to both slower RTs and higher error rates than the sequential presentation procedure (Experiment 2). This difference probably reflects not only the benefit derived from priming the appropriate lexical subset in Experiment 2, but also the fact that Experiment 3 required the subject to extract more information from the presumably rapidly decaying visual trace

The apparent equivalence of the two hemispheres for processing concrete category information in this task runs contrary to the results of a study by Gross (1972). Her subjects performed a manual RT task which required them to decide whether two concrete nouns presented simultaneously in one visual half-field belonged to the same category. Gross found a right visual field-left hemisphere RT advantage of 35 msec and no visual field by hand interaction, suggesting that the task was being performed exclusively by the left hemisphere. Although there are several minor procedural differences between Gross' study and the present one, there is a critical difference in the nature of the manual response which may account for the discrepant results. Gross' subjects used a lever push-or-pull response which is likely to involve the use of more proximal muscles than the finger press response used in the present study. One consequence of using such a whole-hand movement, which can be controlled by either the contralateral or ipsilateral hemisphere, is that the dominant (left) hemisphere may take control of responding regardless of the hand used to respond. Given the left hemisphere's predominance for language, this "metacontrol" (Levy & Trevarthan, 1976) may occur in a situation where either hemisphere has the opportunity to control responding. By contrast, the present study precluded such an eventuality by forcing the right hemisphere to respond half of the time, thus establishing optimal conditions for the right hemisphere to demonstrate any functional verbal processing abilities that it might possess by responding to verbal input

CHAPTER 6

EXPERIMENT 4

The first three experiments demonstrated that the right hemisphere in the intact brain has an accessible, organized, lexical vocabulary consisting of at least common concrete nouns. The purpose of the present experiment was to further assess the breadth of the right hemisphere's vocabulary. As mentioned earlier, studies of split-brain patients have shown that the disconnected right hemisphere is able to recognize some adjectives (Gazzaniga, 1970, Zaidel, 1976) and verbs (Levy, Note 3, Zaidel, 1976, although see also Gazzaniga, Bogen, & Sperry, 1967, and Gazzaniga, 1970). One of the questions asked in the present experiment, then, was whether the right hemisphere in the intact brain can also demonstrate the ability to recognize such words. In addition, since the concreteness of the referent seems to be a critical factor in the right hemisphere's recognition of nouns, this factor was also investigated with respect to adjectives and verbs. If the right hemisphere's recognition of a word is in fact contingent on the extent to which the word's referent can be experienced by the senses (concreteness), then the recognition of adjectives and verbs differing along this dimension should parallel the results obtained for nouns (Experiment 1). To test this question, subjects were tested on a lateralized lexical decision task involving words rated high and low on the extent to which they can be experienced by the senses. Six different types of words were used: high and low concrete nouns (replication of Experiment 1), high and low concrete adjectives, and verbs rated high and low in enactive imagery.[7]

Method

Subjects. Twenty-four Dalhousie University students (12 male and 12 female) were selected as subjects using the same criteria as in the previous experiments.

Stimuli. Six classes of words were used in this experiment. concrete and abstract nouns, concrete and abstract adjectives, and concrete and abstract verbs (see Appendix E) Sixteen words of each type were selected from three different sets of norms The nouns were selected from the concreteness norms of Paivio et al. (1968). Concrete nouns were rated above 6.52 and abstract nouns below 4 18 on their 7-point scale. The adjectives were selected from a set of adjective concreteness norms generated for the purpose of this experiment Twelve individuals were asked to rate 163 four and five letter adjectives for concreteness on a 7-point scale using Paivio's et al. (1968) instructions for rating noun concreteness but modified for rating adjectives. The 16 high and 16 low concrete adjectives chosen from these norms were rated above 6 00 and below 3.83, respectively. The concrete and abstract verbs were selected from Lippmann's (1974) norms of enactive imagery and were rated above 5.32 and below 4 33 on this 7-point scale of imagery

Within each word class (e g., noun) the words in the two subclasses (concrete and abstract) were matched for length (four and five letters)

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[7]The terms concrete and abstract will be used from here on to refer to these high and low imagery verbs. Because word concreteness and word imagery are so highly correlated (Paivio et al., 1968), the terms will be considered operationally interchangeable for our purposes.

and Kucera-Francis (1967) word frequency counts. No attempt was made to equate for word frequency precisely between nouns, adjectives, and verbs, although all of the words were fairly common in the English language with Kucera-Francis ratings of 15 or above (see Appendix E). Ninety-six nonwords were also constructed as in the first experiment by altering a single letter in each of the 96 words

Six series of 64 words and nonwords were constructed. The series were designated Noun-1, Noun-2, Adjective-1, and so forth, and each series served as a block of trials A series consisted of, for example in the case of nouns, a randomization of 8 concrete, 8 abstract, and 16 nonwords in one visual field and an equal number of different concrete, abstract, and nonwords in the other visual field. Noun-1 and Noun-2 series consisted of the same randomized items, but visual field of presentation was reversed The same system was used for constructing the adjective and verb series. In addition, the nonwords in each series were created by altering the words in one of the other series to avoid obvious similarities between words and nonwords within a block of trials (see Appendix E)

Apparatus and procedure The apparatus and procedure were identical to those employed in Experiment 1 with the following exceptions Each subject was tested on six blocks of trials with word class order counter-balanced across subjects. For example, four of the subjects were tested on an N, A, V, N, A, V sequence of blocks, four on an N, V, A, N, V, A sequence, four on an A, V, N, A, V, N sequence, etc. For each different sequence, half of the subjects responded with the left hand index finger and half with the right index finger throughout the experiment. Thus, there were 12 left hand and 12 right hand responding subjects. Finally, the stimulus exposure duration was increased from 100 to 125 msec in an attempt to reduce the high rate of errors found in Experiment 1

Results

The RT and error data are summarized in Table 4 Median RTs of correct responses were calculated for each right and left hand responding subject as a function of word class, concreteness, and visual field of presentation (see Appendix E for individual subjects' data) Separate 2 (Visual Field) x 3 (Word Class) x 2 (Hand) x 12 (Subject) were conducted for concrete and abstract words

Abstract words. The analysis of variance of RTs to abstract words (see Appendix E) revealed a significant main effect of Visual Field, $F\ (1, 22) = 16.68$, $p < .001$, RTs favoring the right visual field by 41 msec. There were no other significant main effects and no significant interactions. A further 2 (Visual Field) x 3 (Word Class) x 2 (Hand) x 16 (Word) analysis of variance was performed on median RTs to words with subjects as a fixed effect to determine whether this Visual Field effect held across words as well as subjects (see Appendix E) The mean left visual field RT was 677 msec, and the mean right visual field RT was 637 msec, $F\ (1, 45) = 13.40$, $p < .001$ This 40 msec visual field RT difference offered strong support for generalizing the visual field effect across abstract words.

The overall rate of failure to recognize abstract words was 18.3% (see Table 4a). A 2 (Visual Field) x 3 (Word Class) x 2 (Hand) x 12 (Subject) analysis of these errors (see Appendix E) showed only a significant main effect of Word Class, $F\ (2, 44) = 4.69$, $p < .025$.

Table 4 (a)

Mean Reaction Times (in msec) to Abstract

Words in Experiment 4

		Nouns			Adjectives			Verbs		
Hand	n	LVF	RVF	L-R[a]	LVF	RVF	L-R[a]	LVF	RVF	L-R[a]
Left	12	656 (.188)	631 (.198)	+25	660 (.255)	607 (.286)	+53	679 (.229)	631 (118)	+48
Right	12	666 (.177)	629 (.078)	+37	673 (161)	616 (.161)	+57	690 (.161)	667 (109)	+23
Overall	24	661 (.182)	630 (.137)	+31	667 (.208)	612 (.223)	+55	685 (195)	649 (149)	+36

Note Numbers in parentheses indicate error percentages.

[a]L-R = left visual field (LVF) minus right visual field (RVF)

Table 4 (b)

Mean Reaction Times (in msec) to Concrete

Words in Experiment 4

		Nouns			Adjectives			Verbs		
Hand	n	LVF	RVF	L-R[a]	LVF	RVF	L-R[a]	LVF	RVF	L-R[a]
Left	12	643 (.182)	649 (.161)	-6	636 (.167)	624 (.161)	+12	647 (.145)	622 (.135)	+25
Right	12	645 (.125)	642 (.089)	+3	647 (.109)	660 (.068)	-1[illegible]	641 (.120)	617 (.083)	+24
Overall	24	644 (.153)	646 (.125)	-2	642 (.138)	642 (.115)	0	644 (.138)	619 (.109)	+25

Note. Numbers in parentheses indicate error percentages.

[a] L-R = left visual field (LVF) minus right visual field (RVF)

Supplementary t-tests revealed more errors in the adjective condition (21 6%) than in the noun condition (16.0%), t (23) = 2 23, p < 05 or the verb condition (17.2%), t (23) = 2 21, p < .05, which in turn did not differ from each other Within each word class the error rate did not differ significantly across any of the Visual Field-Hand conditions .

Concrete words The analysis of RTs to concrete words (see Appendix E) showed no significant main effects of Visual Field, Word Class or Hand and no significant interactions Despite the lack of a Visual Field by Word Class interaction, the visual field RT difference appeared to be much larger in the verb condition, 25 msec in favor of the right visual field, than in the noun and adjective conditions where there were virtually no visual field RT differences (see Table 4b) A supplementary analysis was performed to determine whether the 25 msec difference was significant. A 2 (Visual Field) x 2 (Hand) x 12 (Subject) analysis of variance on RTs to concrete verbs (see Appendix E) did, in fact, reveal a significant main effect of Visual Field, F (1, 22) = 7.29, p < 025 An additional 2 (Visual Field) x 2 (Hand) x 16 (Word) analysis of variance (see Appendix E) performed on RTs to words calculated across subjects showed that the Visual Field effect also held across words, F (1, 15) = 5 85, p < 05, RTs favoring the right visual field by 39 msec (LVF = 643 msec, RVF = 604 msec) Finally, an analysis was performed to determine whether the visual field RT difference for concrete verbs differed significantly from the visual field RT differences in the abstract noun, adjective, and verb conditions. A 2 (Visual Field) x 4 (Word Class) x 2 (Hand) x 12 (Subject) analysis of variance (see

Appendix E) revealed a significant main effect of Visual Field, F (1, 22) = 18.01, $p <$ .001, but no Visual Field by Word Class interaction, suggesting that the Visual Field effect in the concrete verb condition was not significantly different from the Visual Field effect in the three abstract conditions

The overall rate of failure to recognize concrete words was 12.9% (see Table 4b) A 2 (Visual Field) x 3 (Word Class) x 2 (Hand) x 12 (Subject) analysis of these errors (see Appendix E) revealed a significant main effect of Visual Field, F (1, 22) = 4 57, $p <$ .05 (LVF = 14 1%, RVF = 11.6%), but no other main effects or interactions

False positive responses False positive responses occurred on 7.9% of the left visual field nonword trials and 6 9% of the right visual field nonword trials (see Appendix E for individual subjects' scores) A 2 (Visual Field) x 3 (Word Class) x 2 (Hand) x 12 (Subject) analysis of variance yielded no significant main effects or interactions (see Appendix E) The lack of a Visual Field effect suggests that the response criterion was the same for stimuli in both visual fields and argues against a speed-accuracy tradeoff interpretation of the RT data.

Discussion

The RT results show that abstract nouns, abstract adjectives, and both concrete and abstract verbs were recognized faster in the right visual field-left hemisphere than in the left visual field-right hemisphere The mean visual field RT difference of 37 msec across these four word classes was almost identical to that found for abstract nouns alone in the previous lexical decision experiment (35 msec-Experiment 1). Furthermore, there was no evidence for a Visual Field by Hand interaction, suggesting that the right visual field-left hemisphere RT superiority reflected exclusive left hemisphere processing of these words

The results also show that both concrete nouns and concrete adjectives were recognized equally fast in the left and right visual fields This lack of a visual field RT difference suggests that these words were recognized equally efficiently by both hemispheres, although the error data show that the left hemisphere recognized slightly more concrete words than the right hemisphere This difference in the number of words recognized may reflect a more extensive concrete lexical vocabulary in the left hemisphere than in the right

CHAPTER 7

GENERAL DISCUSSION

The present series of experiments began with the question "Can the normal right hemisphere perform in accordance with the linguistic skills demonstrated by the disconnected right hemisphere?" The main conclusion emerging from the four experiments reported is that the normal right hemisphere can indeed display limited word processing skills which are similar to those displayed by the split-brain right hemisphere Moreover, the present results, together with previous observations on split-brain patients, suggest that qualitative as well as quantitative differences exist between right and left hemisphere language representation. The following discussion will elaborate on these conclusions

The present data suggest that the processing of laterally presented concrete nouns and adjectives for lexical search (Experiments 1 and 4) and the recognition of concrete noun-category associations (Experiments 2 and 3) can be accomplished with equal facility by either hemisphere At the same time, the results show that abstract nouns and adjectives, as well as verbs in general, are processed more slowly when presented to the right hemisphere than when presented to the left hemisphere. There are at least two possible interpretations of the RT difference. One is that the right hemisphere is less efficient than the left at processing the abstract words and verbs. The other is that these words are analyzed exclusively by the left hemisphere, with the visual field RT difference resulting from the differential efficiency of the direct (contralateral) and indirect (ipsilateral) sensory-cortico pathways to the left hemisphere. The latter interpretation is supported by the fact that the visual field RT difference is constant regardless of the hemisphere initiating the motor response (see Figure 2) If the right hemisphere were simply slower than the left at analyzing the linguistic information, then a left hand (right hemisphere) response would shorten the overall RT to left visual field worlds. This would produce a smaller visual field RT difference for the left hand than for the right hand, i.e., a visual field by hand interaction (see Figure 3).[8]

Other hypotheses have been advanced to account for perceptual asymmetries such as those found in the present experiments (Harcum, 1972; White, 1973, Kinsbourne, 1970, 1973) These interpretations tend to deemphasize the interhemispheric communication process and focus on strategic and attentional factors. For example, the directional scanning hypothesis, mentioned earlier (Harcum, 1972, White, 1973), argues that superior recognition of verbal material presented in the right visual field is due to a learned tendency to scan the post-exposural trace of the stimulus in a rightward direction and not necessarily to inherent functional differences between the hemispheres. Kinsbourne's (1970, 1973) interpretation of perceptual asymmetries, on the other hand, includes the notion of functional cerebral asymmetries but rejects the notion that the right visual field advantage results

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[8]Although the present data minimize the importance of this efficiency interpretation, it is still possible that the right hemisphere recognizes abstract words but is so slow that a left hemisphere decision initiates either a right or left hand response before a signal to respond can be generated by the right hemisphere. Even granting this possibility, it must be concluded that the right hemisphere is not actively contributing to the execution of the task

from faster access, i e , a shorter neural route, of right visual field material to the left hemisphere. According to Kinsbourne, engaging in a verbal task selectively activates the language dominant left hemisphere which in turn automatically directs the subject's attention to the contralateral sensory field. Thus, for Kinsbourne, the right visual field advantage is a function of this rightward attentional shift and is not necessarily related to the relative efficiency of the direct and indirect pathways to the left hemisphere. However, neither the directional scanning nor the activation-attention hypothesis can account for the present data since both predict that a right visual field advantage should have been obtained for all words, including the concrete nouns and adjectives for which no visual field difference was found In the absence of any reasonable alternative explanation, then, it must be concluded that the present visual field RT differences reflect the relative ease of access of the left and right visual field information to the left hemisphere.

The present results for concrete nouns and adjectives stand in contrast to most of the RT data on hemisphere differences in word recognition (Cohen, 1975; Gross, 1972; Isseroff et al , 1974). Yet, as previously mentioned, these other studies have consistently provided less than favorable conditions for the right hemisphere to demonstrate its verbal skills. By contrast, the present experiments were designed to create optimal task conditions for the expression of the right hemisphere's language potential by (a) using tasks which the split-brain right hemisphere was able to perform (i.e , an emphasis on lexico-semantic processes rather than phonetic-articulatory processes) and (b) by forcing the right hemisphere to respond, through the left hand, thus preventing the left hemisphere from dominating the task

Before discussing the implications of the present findings for models of language organization in the normal brain, a few additional comments on the data are necessary The first concerns the problem of individual differences in the direction of the visual field RT advantage. In all four of the experiments there were a minority of subjects who deviated from the norm by showing a left visual field RT advantage for abstract nouns, abstract adjectives, and verbs. Of the 70 subjects tested in the four experiments 10 (14%) showed this reversed visual field advantage The factor(s) contributing to this left visual field advantage are not entirely clear. It is possible, though unlikely, that these reversers were actually right hemisphere language dominant Estimates of right hemisphere language dominance in right-handers, based on the incidence of aphasia resulting from unilateral right hemisphere damage, typically range around 1% (see footnote 1) and are nowhere near the 14% reversed visual field advantage found here Levy (1974, Levy & Reid, 1976) has recently suggested that hemisphere specialization for language may be reflected in the hand posture adopted in writing She has shown that, in left-handers where cerebral dominance for language varies considerably more than in right-handers, "inverted" and "normal" hand postures correspond with left and right hemisphere language control, respectively. Similarly, inverted writing posture in right-handers (a rare phenomenon) may reflect right hemisphere (ipsilateral) control of verbal expression (writing) and language processes in general. Follow up observations on five of the 10 reversers from the present experiments (the other five were unavailable) revealed no cases of inverted writing posture While this certainly does not rule out the possibility that inverted hand posture can be used as an index of ipsilateral language dominance in right-handers, it does show that an atypical visual field advantage is not necessarily accompanied by an atypical writing posture

Another possible explanation of the reversed visual field advantage in the present experiments is that some subjects were "less lateralized" than others. A breakdown of the reversers by sex revealed that eight of the 10 were females This is consistent with recent reports in both the normal and clinical literature that females, as a group, are more likely than males to have bilateral language representation (for a review of sex differences in lateralization see Harshman & Remington, Note 5)

The unusual relationship between word type and task also deserves some comment In the lexical decision task (Experiments 1 and 4), overall RTs to concrete and abstract words were roughly equal (concrete, 660 msec, abstract, 669 msec), whereas with the category matching task (Experiments 2 and 3), abstract nouns were categorized about 30 msec faster than concrete nouns While unusual, the former result is not without precedent (Rubenstein et al , 1970). The latter finding, however, is very puzzling since most previous studies have obtained more efficient processing of concrete words (cf , Paivio, 1971). Since frequency and word length were carefully equated, these variables cannot account for any differences between abstract and concrete words. However, one factor that was not explicitly controlled in these experiments was category size It is well known that the time to decide whether a stimulus belongs to a particular category is a positive function of category size. An examination of the categories used in the present experiments revealed that the concrete categories (e.g., animals and food) were, in fact, much larger than the abstract categories (e g , months and directions) and should therefore involve longer decision times. Since there is no reason to expect that category size would affect processing time in the lexical decision task (Experiments 1 and 4), the apparent interaction between word type and task may be explained by this factor

Implications for Models of Language Organization

The present investigation of right hemisphere language skills was motivated by the lack of conclusive evidence for either the split-brain or functional localization models of language organization in the normal brain The present results, in combination with other studies of the normal brain, suggest that the language skills, and deficits, displayed by the normal right hemisphere provide a fairly accurate reflection of the split-brain right hemisphere's language performance. As mentioned in Chapter 2, previous studies have shown that the right hemisphere in normal persons, like the split-brain right hemisphere, is unable to process the phonetic features of language (e.g., Moscovitch, 1973, Springer, 1971), thus demonstrating a common language deficit in both populations. The present results reveal further similarities between these groups by confirming the right hemisphere's ability to process concrete nouns and adjectives

The present findings also supplement the split-brain data by suggesting that meaningful language stimuli devoid of concrete referents may be processed exclusively by the left hemisphere, thus defining an additional right hemisphere deficit The picture with respect to verbs is less clear As mentioned in the introduction, the split-brain findings on right hemisphere recognition of verbs have been inconsistent with some studies showing fairly good comprehension of verbs (Levy, Note 3, Zaidel, 1976) and others reporting an apparent lack of comprehension (Gazzaniga, 1970, Gazzaniga et al , 1967) The present results suggest that even highly imageable verbs may be processed exclusively by the left hemisphere in the intact brain

Despite the ambiguity with respect to the right hemisphere's recognition of verbs, the present findings provide reasonable support for the notion that the disconnected brain can serve as a model for language organization in the intact brain The present data suggest, then, contrary to the model of functional localization, that the presence of intact forebrain commissures in the normal brain is not sufficient to prohibit the right hemisphere from demonstrating its limited language capacity Under appropriate experimental conditions the right hemisphere is capable of processing some linguistic stimuli regardless of the physical integrity of the callosal fibers Thus, the notion that the normal and split brain hemispheres are "functionally" different is called into question.

Actually, this notion was based on a rather tenuous assumption in the first place According to Moscovitch (1976), the model of functional lozalization was originally proposed to account for a presumed inconsistency between the functional language skills of the disconnected and intact right hemispheres, i e , the split-brain right hemisphere's success at comprehending words and the normal right hemisphere's failure to decode nonmeaningful phonetic units.[9] This notion of an inconsistency rests, of course, on the assumption that word comprehension cannot proceed without phonemic analysis Recent evidence demonstrates that this assumption is false (e g , Baron, 1973, Bower, 1970, Frederiksen & Kroll, 1976, Kolers, 1970)[10] Furthermore, the data from normal and split-brain experiments are consistent in demonstrating that the right hemisphere can process words despite its failure to translate linguistic units into a phonemic code Thus, there is ample evidence to suggest that the mechanisms used to process word meanings can operate independently from those used to analyze the internal phonemic structure of words

While the distinction between language organization in the intact brain and split-brain appears to be an artificial one, the model of functional localization may not be entirely wrong in concluding that language processes are normally controlled by the left hemisphere The

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[9] Moscovitch (1976) also claims that the normal right hemisphere is unable to decode semantic information. To support this claim he cites evidence which suggests that in the intact brain the left hemisphere decides whether two letters have the same semantic referent, e.g., the name "A" (Cohen, 1972, Geffen et al., 1972). Even if we accept the rather unlikely premise that letter name matches are semantic rather than phonetic, it is clear that the present results do not support Moscovitch's position

[10] A clinical syndrome which dramatically illustrates this point is phonemic dyslexia, a language disorder in which left hemisphere damage selectively impairs the phonemic encoding process while leaving word comprehension intact (Marshall & Newcombe, 1966, Saffran & Marin, Note 6, Shallice & Warrington, 1975).

fact that the right hemisphere can process semantic information does not necessarily imply that it normally does so in the intact brain or, for that matter, in the split-brain. In fact, evidence from split-brain experiments suggests that the left hemisphere typically controls language behavior in the disconnected brain, except in some experimental situations where optimal conditions exist for eliciting right hemisphere language performance For example, Levy and Trevarthen (1976) tested split-brain subjects in a free response situation, where either hemisphere could take control of responding, and found that the left hemisphere dominated (through right hand responding) on tasks that required matching objects on the basis of conceptual (semantic) categories The failure of the disconnected right hemisphere to perform conceptual category matches in this "competitive" situation occurred despite ample evidence suggesting that it is quite capable of performing similar tasks when only a left hand response is permitted (i e , when left hemisphere dominance is precluded)

Levy and Trevarthen (1976) explain the split-brain left hemisphere's dominance during processing and responding to verbal information as a form of metacontrol in which competition between the two hemispheres for a single intentional mechanism usually results in the selective unilateral activation of the hemisphere more specialized for the task at hand They also note that this metacontrol mechanism must have a subcortical locus since hemisphere disconnection precludes callosal mediation between the two hemispheres One might well assume, then, that the same mechanism operates in the intact brain and that the procedure used in the present experiments in some way disrupted an habitual bias toward left hemisphere activation during language tasks. It is possible that the activation of the right hemisphere in preparation for a left hand finger response produced a "functional release" from left hemisphere control over verbal processing. Indeed, the elicitation of right hemisphere language skills in both the intact and split-brain, by forcing the right hemisphere to respond through the left hand, might be thought of as the logical result of a procedure that interferes with or overrides the normal operation of a metacontrol mechanism In this respect, it is noteworthy that the "release" of the right hemisphere, enabling it to demonstrate its verbal skills, does not require the actual physical disconnection of, or damage to, the commissural pathways previously suggested by Moscovitch (1973, 1976)

We should note, however, that one aspect of the present data is not consistent with the above explanation. If activation of either hemisphere by priming it to respond is sufficient to bias performance in favor of that hemisphere on concrete tasks, then RT performance should favor the visual field ipsilateral to the responding hand It will be recalled that this prediction was not born out in the present experiments Particularly interesting in this regard is the fact that right hand responding did not produce the expected right visual field RT superiority, suggesting that the left hemisphere was no more efficient than the right even when it was in control of responding. Odd as it may seem, this would suggest that the equivalent RTs to left and right visual field concrete words represent not only an equivalence of the two hemispheres in terms of ability to recognize concrete words, but also a lack of lateral dominance on such a task Thus, we may be forced to entertain the possibility that both hemispheres in the intact brain play a functional role in processing concrete verbal information

If the normal right hemisphere does, in fact, play an active role in processing some language, then we must also conclude that there is a functional difference between the normal and split-brain right hemisphere but that it is exactly the opposite of that postulated by the model of functional localization (Moscovitch, 1973, 1976) In other words, while there is evidence to suggest that the split-brain right hemisphere's language skills are normally rendered inactive by a metacontrol process (Levy & Trevarthen, 1976), there is no evidence for such an inhibition in the intact brain This difference might be explained as follows There may be a basic subcortical metacontrol mechanism which operates in both the split-brain and the intact brain to regulate competition and control conflict between the hemispheres However, in the intact brain, there may also be a cortical mechanism operating via the midline commissures which can supercede this subcortical control and permit direct communication and cooperation between the hemispheres We might think of the subcortical mechanism as serving the fairly conservative function of simultaneously activating one hemisphere and inhibiting the other By contrast, the cortical mechanism may permit a wider range of options like simultaneous activation (or suppression) and direct cooperation between the hemispheres.

One troublesome point remains How can the notion of a right hemisphere that processes concrete verbal information be reconciled with the existence of aphasic cases where focal lesions of the left hemisphere produce profound loss of comprehension? Such cases are typically cited to support the notion that the right hemisphere must be functionally nonverbal. However, it may be just as reasonable to assume, as Sperry et al (1969) suggested, that certain types of pathology in the left hemisphere may cause widespread neural disorganization resulting in a disturbance of right hemisphere language performance as well In any event, we might recall Jackson's observation, made over a century ago, that the aphasic is seldom "wordless " Typically some comprehension remains. In this regard it is interesting to note Shallice and Warrington's (1975) recent report of a left hemisphere damaged patient who showed a marked deficiency in reading abstract words while retaining the ability to read concrete words

The Nature of Right Hemisphere Language

Given that some words are recognized by the right hemisphere, some consideration must be given to the question of how these words are represented in memory Although both hemispheres are capable of processing meaningful linguistic symbols, it seems likely that the internal representations of these symbols may be different in the two sides of the brain The left hemisphere has been characterized by many writers as propositional, analytical, temporally-oriented, linear, and abstract, whereas the right hemisphere is considered to be wholistic, concrete, and spatially-oriented (Bogen, 1969, Ornstein, 1972). Though these descriptive phrases are rather vague, the experimental findings to date are generally consistent with these notions.

Levy (1974) and Zaidel (Note 4) have both suggested, on the basis of split-brain experiments, that the right hemisphere, because it is unable to decode units smaller than words, must match meaningful linguistic symbols with wholistic entries or gestalts in memory While this notion is certainly consistent with the results of the present investigation, the present findings suggest a qualification only words whose referents are concrete, i.e , readily imageable, are stored in the right hemisphere On the basis of this evidence, we might assume that word meanings are represented in the right hemisphere as "images " A memory system for words based on imagery would obviously preclude the effective processing of linguistic material which is low in imagery-generating properties By contrast, it is likely that the left hemisphere, which is clearly able to process both concrete and abstract words, encodes meanings in a form that is compatible with both types of words, e g , as propositions

This conclusion is reminiscent of Paivio's (1969, 1971) hypothesis that concrete words are amenable to dual pictoral (imaginal)-verbal (propositional) encoding in memory, but it carries the further implication that these codes are hemisphere-specific A study by Seamon and Gazzaniga (1973) offers additional evidence to support this view They had subjects match visually lateralized pictures of objects with words held in memory under two different sets of instructions When subjects were told to rehearse the memory words in sentences, test pictures presented to the right visual field-left hemisphere were matched faster; but when they were told to generate images of the objects represented by the words, the right hemisphere performed the matches faster Thus, the evidence suggests that word meanings may be represented in fundamentally different ways in the two sides of the brain

If the right hemisphere is, in fact, limited to associating language symbols with meaningful "internal images" of objects, can we then speak of right hemisphere "language" in the true sense of the word? Perhaps we cannot, if we think of language in terms of analytic thought and expression flowing from the temporal integration of phonology, grammar, syntax, and symbolic meaning. However, if we accept that the ability to translate arbitrary linguistic symbols into meaningful internal representations (regardless of the form of such representations) is a demonstration of a basic linguistic skill, then we must conclude that the right hemisphere does engage in a form of language behavior

Conclusion

The contribution of the present work toward an understanding of the way language is organized in the normal brain is three-fold First, it supports the generality of the basic split-brain model by showing that the normal right hemisphere can effectively process certain kinds of meaningful linguistic information Second, the present results supplement the split-brain data by suggesting that the right hemisphere's ability to deal with language may be restricted to fairly concrete nominal and descriptive information Third, the data suggest, contrary to the model of functional localization, that the right hemisphere in the intact brain may normally play a functional role in processing concrete verbal information In addition, the present findings lend support to the notion that word processing can occur in the absence of a phonetic code.

The accumulated evidence suggests, then, that right hemisphere language differs from left hemisphere language both quantitatively and qualitatively. More research is needed, though, to determine the full range of the right hemisphere's functional language skills and to establish more precisely the basis of the constraints on these skills. Such questions can hopefully be answered through the use of improved techniques for studying the disconnected hemispheres in isolation (Zaidel, 1975) and by attempts to teach symbolic language to aphasics (Gazzaniga, 1972), as well as through the use of reaction time techniques for studying the flow of information in the normal brain

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APPENDIX A

Handedness Questionnaire

Instructions Please indicate your preference in the use of hands in the following activities by putting a "+" in the appropriate column Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put "++" If in any case you are really indifferent, put a "+" in both columns

Some of the activities require both hands In these cases the part of the task, or object for which hand preference is wanted is indicated in parentheses.

Please try to answer all the questions, and only leave a blank if you have no experience at all with the object or task

		LEFT	RIGHT
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife		
7	Spoon		
8	Broom (upper hand)		
9	Striking Match (match)		
10	Opening box (lid)		
A	Which foot do you prefer to kick with?		
B	Which eye do you use when using only one? (For example, looking through a telescope)		

Are either of your parents or any of your brothers or sisters left-handed or ambidextrous? If so, please state their relationship to you (For example: father--left-handed.)

APPENDIX B-1

Ratings of Nouns for Concreteness and Thorndike-Lorge Frequency Counts List 1

Concrete Nouns			Abstract Nouns		
Word	Concreteness	T-L Frequency	Word	Concreteness	T-L Frequency
SKIN	6.96	AA	COST	3.41	AA
SEAT	6.79	AA	HOUR	2.93	AA
IRON	6.87	AA	DUTY	2.32	AA
HOME	6.25	AA	MIND	2.60	AA
GIRL	6.83	AA	FACT	3.31	AA
HALL	6.72	AA	LORD	4.18	AA
ARMY	6.55	AA	DEED	4.19	A
NAIL	6.96	A	DREAM	3.03	AA
WOMAN	6.63	AA	MONTH	3.20	AA
BLOOD	6.82	AA	HONOR	1.75	AA
BRAIN	6.63	A	ANGER	1.70	A
FLOOD	6.62	A	GLORY	1.77	A
CLOCK	6.94	A	SHAME	1.70	A
HOTEL	6.80	A	FAULT	2.87	A
SLAVE	6.38	A	CRIME	3.81	A
CABIN	6.96	A	PRIDE	1.49	A
	$\overline{X}$ = 6.73			$\overline{X}$ = 2.77	

APPENDIX B-2

Ratings of Nouns for Concreteness and Thorndike-Lorge Frequency Counts: List 2

Concrete Nouns			Abstract Nouns		
Word	Concreteness	T-L Frequency	Word	Concreteness	T-L Frequency
BODY	6 58	AA	LIFE	2 97	AA
GOLD	6 76	AA	IDEA	1 42	AA
TREE	7 00	AA	SOUL	1 87	AA
WIFE	6 48	AA	FORM	4 08	AA
ROCK	6 96	AA	TIME	2 47	AA
KISS	6.68	AA	HOPE	1 18	AA
PIPE	6.90	A	LOVE	1 80	AA
DRESS	6 93	AA	FATE	1.46	A
MONEY	6 63	AA	TRUTH	1 69	AA
HOUSE	6 93	AA	DEATH	2 97	AA
BEAST	6 51	A	DEVIL	2 13	A
TOWER	6.96	A	CHARM	2 17	A
COAST	6.59	A	MORAL	1 39	A
METAL	6 76	A	STYLE	3 18	A
FLESH	6.90	A	SHOCK	3 97	A
PUPIL	6 63	A	EVENT	3 72	A
	$\overline{X}$ = 6.73			$\overline{X}$ = 2.40	

APPENDIX B-3

Nonwords

List 1		List 2	
TOMAN	MORTH	GRESS	CRUTH
BLORD	HOZOR	MOXEY	DEACH
KRAIN	ANPER	HONSE	DEVIP
FLOND	GLOJY	BELST	CHARB
SLOCK	SCAME	TOFER	MOXAL
HOXEL	DAULT	CONST	STYGE
SLUVE	CRILE	MEPAL	SHECK
TABIN	PRILE	FLESP	EKENT
NAIK	DREAF	PUVIL	FOTE
SKIR	NOST	BOFY	LAFE
SEAB	HOUG	GOLK	IDEG
CRON	DUKY	TREP	SPUL
JOME	MUND	BIFE	FOOM
GIRN	FAXT	RORK	TIFE
ZALL	LORF	RISS	HOJE
ARKY	DERD	PIFE	LOKE

APPENDIX B-4

Median RTs and Error Percentages for Individual Subjects (n=14) in Experiment 1

	Concrete				Abstract			
	Left Hand		Right Hand		Left Hand		Right Hand	
Subject	LVF	RVF	LVF	RVF	LVF	RVF	LVF	RVF
1	604	585	591	578	597	557	606	582
	125	125	063	063	000	125	125	188
2	702	753	674	714	722	702	653	631
	188	188	125	188	313	188	188	188
3	624	591	585	619	596	584	598	576
	000	063	063	000	125	.000	125	000
4	477	496	475	502	529	469	520	443
	125	063	313	313	.125	125	250	188
5	764	875	614	604	788	772	658	595
	125	125	063	063	000	000	.125	188
6	617	538	577	544	600	513	680	552
	188	063	063	125	188	063	.250	125
7	576	565	548	587	559	608	554	528
	063	125	250	063	063	063	063	.063
8	574	608	684	623	624	547	565	604
	250	313	188	125	188	125	.125	250
9	808	830	873	730	837	842	939	774
	063	188	250	125	000	125	.000	125
10	704	763	755	760	740	745	712	736
	125	125	063	125	188	250	125	.063
11	852	809	870	897	985	1058	838	734
	250	125	188	000	125	125	188	125
12	1009	862	666	697	1055	942	726	751
	250	125	188	188	313	313	188	313
13	783	810	794	805	921	842	791	823
	.250	.250	500	375	063	125	375	188
14	596	718	584	581	741	600	568	628
	.125	.375	125	250	313	375	188	375
$\overline{X}$	692	700	664	660	735	699	672	639
	152	160	174	143	.143	.143	165	170

APPENDIX B-5

Analyses of Variance
for RTs to Abstract Nouns

Source of Variance	Sum of Squares	df	Mean Square	F
S	922950 50	13	70996 19	
VF	16940 64	1	16940 64	15 37**
VF X S	14329 36	13	1102.26	
H	52828 57	1	52828.57	5 88*
H X S	116808 43	13	8985 26	
VF X H	48 29	1	48 29	< 1 00
VF X H X S	38980 71	13	2998 52	
Total	1162886 50	55		

S=subjects VF=visual field. H=hand. **p< 005 *p< 05

Source of Variance	Sum of Squares	df	Mean Square	F
W	627205 62	31	20232 44	
VF	53015 82	1	53015 82	4 99*
VF X W	329386 43	31	10625 37	
H	129222.57	1	129222 57	15 98***
H X W	250446 68	31	8078 93	
VF X H	4740.95	1	4740 95	< 1 00
VF X H X W	327140 30	31	10552 91	
Total	1721158 40	127		

W=words VF=visual field H=hand ***p< 001 p<.05

APPENDIX B-6

Analysis of Variance for Abstract Noun Errors

Source of Variance	Sum of Squares	df	Mean Square	F
S	3212.19	13	247.09	
VF	0.70	1	0.70	< 1.00
VF X S	868.44	13	66.80	
H	84.40	1	84.40	1.08
H X S	1019.11	13	78.39	
VF X H	0.70	1	0.70	< 1.00
VF X H X S	438.76	13	33.75	
Total	5624.30	55		

S=subjects VF=visual field H=hand

APPENDIX B-7

Analysis of Variance for RTs to Concrete Nouns

Source of Variance	Sum of Squares	df	Mean Square	F
S	670565 50	13	51581 96	
VF	73 14	1	73 14	< 1 00
VF X S	20860 36	13	1604 64	
H	16525 79	1	16525.79	2 01
H X S	107011 71	13	8231 67	
VF X H	468 64	1	468 64	< 1 00
VF X H X S	28430 86	13	2186 99	
Total	843936 00	55		

S=subjects VF=visual field H=hand

APPENDIX B-8

Analysis of Variance for Concrete Noun Errors

Source of Variance	Sum of Squares	df	Mean Square	F
S	3016.88	13	232 07	
VF	17 44	1	17.44	< 1 00
VF X S	734 51	13	56 50	
H	0.70	1	0 70	< 1 00
H X S	1298 13	13	99 86	
VF X H	56 50	1	56 50	1 27
VF X H X S	578 26	13	44 48	
Total	5702 43	55		

S=subjects VF=visual field H=hand

APPENDIX B-9

Mean False Positive Percentage for Individual Subjects (n=14)

	Left Hand		Right Hand	
Subject	LVF	RVF	LVF	RVF
1	125	156	125	156
2	219	219	156	281
3	156	063	063	094
4	125	.281	281	281
5	125	094	219	250
6	500	500	313	344
7	156	156	094	094
8	281	469	406	375
9	375	406	500	250
10	281	156	250	125
11	094	125	125	125
12	.313	281	219	188
13	500	469	438	500
14	250	188	313	125
$\bar{X}$	250	255	250	228

APPENDIX B-10

Analysis of Variance for False Positives

Source of Variance	Sum of Squares	df	Mean Square	F
S	9685.32	13	745.02	
VF	14.19	1	14.19	< 1.00
VF X S	774.95	13	59.61	
H	38.89	1	38.89	< 1.00
H X S	973.61	13	74.89	
VF X H	21.00	1	21.00	< 1.00
VF X H X S	737.82	13	56.76	
Total	12245.79	55		

S=subjects VF=visual field H=hand

APPENDIX C-1

Category-Noun Pairs

Concrete Categories			Abstract Categories		
Category	Positive Match	Negative Match	Category	Positive Match	Negative Match
ANIMAL	BEAR	HALL	FEELING	LOVE	COST
ANIMAL	BIRD	ROCK	FEELING	HATE	FORM
ANIMAL	HORSE	MONEY	FEELING	PRIDE	EVENT
ANIMAL	SHEEP	METAL	FEELING	SHAME	CRIME
FURNITURE	DESK	ARMY	MONTH	JUNE	FATE
FURNITURE	LAMP	KISS	MONTH	JULY	DUTY
FURNITURE	CHAIR	WOMAN	MONTH	MARCH	ANGER
FURNITURE	TABLE	BLOOD	MONTH	APRIL	DEATH
CLOTHING	COAT	TREE	DIRECTION	EAST	SOUL
CLOTHING	SUIT	IRON	DIRECTION	WEST	LIFE
CLOTHING	DRESS	CABIN	DIRECTION	SOUTH	DEVIL
CLOTHING	SKIRT	HOUSE	DIRECTION	NORTH	CHARM
FOOD	MEAT	NAIL	TIME	HOUR	FACT
FOOD	MILK	SEAT	TIME	WEEK	HOPE
FOOD	BREAD	CLOCK	TIME	YEAR	GLORY
FOOD	APPLE	HOTEL	TIME	MONTH	TRUTH

APPENDIX C-2

Median RTs and Error Percentages for Individual Subjects (n=16) in Experiment 2

	Left Hand					Right Hand			
	Concrete		Abstract			Concrete		Abstract	
Subject	LVF	RVF	LVF	RVF	Subject	LVF	RVF	LVF	RVF
1	521	546	533	475	9	577	533	541	498
	000	000	000	000		063	000	000	000
2	598	666	625	568	10	656	640	697	643
	000	000	063	000		000	000	000	000
3	525	537	493	449	11	515	481	474	454
	063	063	000	000		000	125	.063	063
4	575	557	507	479	12	649	597	636	549
	125	063	000	000		125	063	063	063
5	596	614	539	584	13	590	587	603	545
	000	.000	.125	000		063	063	000	000
6	702	724	718	666	14	618	575	549	534
	063	000	000	063		000	000	000	000
7	566	551	622	527	15	534	571	505	502
	063	063	063	063		.063	.000	063	000
8	570	562	558	594	16	544	610	572	530
	063	063	125	063		000	000	000	000
$\overline{X}$	581	594	574	543	$\overline{X}$	585	574	572	532
	047	031	047	024		.039	031	024	.016

APPENDIX C-3

Analyses of Variance for RTs to Abstract Category Matches

Source of Variance	Sum of Squares	df	Mean Square	F
H	344 53	1	344 53	< 1.00
H X S	124132 44	14	8866.60	
VF	10332 03	1	10332 03	13 44 **
VF X H	148.78	1	148.78	< 1 00
VF X H X S	10758 69	14	768 48	
Total	145716 47	31		

H=hand S=subjects VF=visual field $^{**}p < .005$

Source of Variance	Sum of Squares	df	Mean Square	F
W	299506 86	15	19967 12	
VF	32265 14	1	32265.14	5 46 *
VF X W	88542 11	15	5902 81	
H	17 02	1	17.02	< 1 00
H X W	30583 23	15	2038 88	
VF X H	185 64	1	185 64	< 1 00
VF X H X W	23203.61	15	1546.91	
Total	474303.61	63		

W=words VF=visual field H=hand. $^{*}p < .05$

APPENDIX C-4

Analysis of Variance for
Errors on Abstract Category Matches

Source of Variance	Sum of Squares	df	Mean Square	F
H	19 53	1	19 53	< 1.00
H X S	288 09	14	20 58	
VF	19 53	1	19 53	2 07
VF X H	4 88	1	4 88	< 1 00
VF X H X S	131 48	14	9.42	
Total	463 87	31		

H=hand S=subjects VF=visual field.

APPENDIX C-5

Analysis of Variance for
RTs to Concrete Category Matches

Source of Variance	Sum of Squares	df	Mean Square	F
H	552 78	1	552 78	< 1 00
H X S	81667 69	14	5834 12	
VF	7.03	1	7.03	< 1.00
VF X H	1164 0[illegible]	1	1164 03	1 80
VF X H X S	9053.44	14	646.67	
Total	92454 97	31		

H=hand. S=subjects VF=visual field

APPENDIX C-6

Analysis of Variance for
Errors on Concrete Category Matches

Source of Variance	Sum of Squares	df	Mean Square	F
H	1 22	1	1 22	< 1 00
H X S	358.89	14	25 63	
VF	10 99	1	10 99	< 1 00
VF X H	1 22	1	1 22	< 1 00
VF X H X S	163 57	14	11 68	
Total	535 89	31		

H=hand S=subjects. VF=visual field

APPENDIX C-7

Mean False Positive Percentage
for Individual Subjects (n=16)

	Left Hand					Right Hand			
	Concrete		Abstract			Concrete		Abstract	
Subject	LVF	RVF	LVF	RVF	Subject	LVF	RVF	LVF	RVF
1	.063	000	000	000	9	063	000	.000	063
2	063	188	.063	063	10	000	000	.000	.000
3	438	250	.500	.188	11	.313	250	.188	313
4	.063	.000	063	000	12	188	.250	.125	.313
5	000	063	.000	063	13	063	125	063	063
6	.000	000	000	000	14	.063	000	.000	063
7	.125	.000	.000	000	15	.000	.125	.000	.000
8	125	313	125	125	16	.063	063	.063	.000
$\overline{X}$	110	102	.094	055	$\overline{X}$	.094	.102	055	.102

APPENDIX C-8

Analysis of Variance for False Positive Errors on Abstract Category Matches

Source of Variance	Sum of Squares	df	Mean Square	F
H	1 22	1	1.22	< 1 00
H X S	3278 81	14	234 20	
VF	1 22	1	1.22	< 1 00
VF X H	206 30	1	206 30	4 57
VF X H X S	632 32	14	45 17	
Total	4119 87	31		

H=hands S=subjects, VF=visual field

APPENDIX C-9

Analysis of Variance for False Positive Errors on Concrete Category Matches

Source of Variance	Sum of Squares	df	Mean Square	F
H	43 95	1	43.95	< 1.00
H X S	3334 96	14	238.21	
VF	0 00	1	0 00	0.00
VF X H	4.88	1	4.88	< 1 00
VF X H X S	737.30	14	52 66	
Total	4121.09	31		

H=hand S=subjects. VF=visual field.

APPENDIX D-1

Category-Noun Pairs

Concrete Categories			Abstract Categories		
Category	Positive Match	Negative Match	Category	Positive Match	Negative Match
ANIMAL	HORSE	PAPER	MONTH	APRIL	CHARM
ANIMAL	SHEEP	HOTEL	MONTH	MARCH	GLORY
ANIMAL	BEAR	MONEY	MONTH	JUNE	FATE
ANIMAL	BIRD	ROCK	MONTH	JULY	DUTY
ANIMAL	LION	HALL	MONTH	AUGUST	DEATH
FOOD	BREAD	STONE	FEELING	ANGER	CRIME
FOOD	FRUIT	CHAIR	FEELING	PRIDE	DEVIL
FOOD	GRAIN	BOOK	FEELING	SHAME	EVENT
FOOD	MEAT	NAIL	FEELING	LOVE	EAST
FOOD	MILK	KISS	FEELING	HATE	COST
FOOD	EGGS	BALL	FEELING	HOPE	SOUTH
METAL	SILVER	CABIN	TIME	MINUTE	TRUTH
METAL	STEEL	BLOOD	TIME	MONTH	NORTH
METAL	BRASS	HOUSE	TIME	WEEK	DEED
METAL	IRON	TREE	TIME	YEAR	MIND
METAL	GOLD	FISH	TIME	HOUR	FACT

APPENDIX D-2

Median RTs and Error Percentages for Individual Subjects (n=16) in Experiment 3

	Left Hand					Right Hand			
	Concrete		Abstract			Concrete		Abstract	
Subject	LVF	RVF	LVF	RVF	Subject	LVF	RVF	LVF	RVF
1	837	801	857	822	9	996	950	969	968
	.125	250	000	000		188	125	188	000
2	787	832	727	694	10	866	786	950	823
	188	.125	250	063		063	.063	063	000
3	865	858	964	959	11	953	920	916	849
	250	125	250	063		313	313	.188	125
4	904	876	942	920	12	1210	1151	1090	1050
	500	375	250	250		500	438	500	500
5	1131	1094	1085	1060	13	848	837	738	727
	125	188	.313	313		500	438	250	313
6	809	896	874	842	14	863	791	736	791
	375	313	188	313		125	188	063	000
7	814	889	777	731	15	891	914	916	865
	000	000	.063	000		438	438	125	125
8	973	871	882	859	16	809	911	721	723
	250	188	375	375		500	438	375	250
$\bar{X}$	890	890	889	861	$\bar{X}$	930	908	880	849
	234	195	215	178		328	305	225	164

APPENDIX D-3

Analysis of Variance for
RTs to Abstract Category Matches

Source of Variance	Sum of Squares	df	Mean Square	F
H	830 28	1	830 28	< 1 00
H X S	390711.94	14	27908 00	
VF	6641 28	1	6641 28	8 54 *
VF X H	11 28	1	11 28	< 1 00
VF X H X S	10890.94	14	777 92	
Total	409805 72	31		

H=hand S=subjects VF=visual field $p < .025$

Source of Variance	Sum of Squares	df	Mean Square	F
W	673976 36	15	44931 76	
VF	37781 64	1	37781 64	4 70 *
VF X W	120454 61	15	8030 30	
H	27348 89	1	27348 89	3 96
H X W	103541 36	15	6902 76	
VF X H	206 64	1	206 64	< 1.00
VF X H X W	79329 61	15	5288 64	
Total	1042639.10	63		

W=words VF=visual field. H=hand $p < .05$

APPENDIX D-4

Analysis of Variance for
Errors on Abstract Category Matches

Source of Variance	Sum of Squares	df	Mean Square	F
H	1 22	1	1.22	< 1.00
H X S	6162 01	14	433 00	
VF	147 71	1	147 71	3.94
VF X H	10 99	1	10 99	< 1 00
VF X H X S	524 90	14	37.49	
Total	6746 83	31		

H=hand S=subjects VF=visual field.

APPENDIX D-5

Analysis of Variance for
RTs to Concrete Category Matches

Source of Variance	Sum of Squares	df	Mean Square	F
H	6583 78	1	6583 78	< 1.00
H X S	328145 94	14	23439.00	
VF	1001.28	1	1001.28	< 1.00
VF X H	935.28	1	935 28	< 1.00
VF X H X S	27285 94	14	1949 00	
Total	363952 22	31		

H=hand. S=subjects VF=visual field

APPENDIX D-6

Analysis of Variance for Errors on Concrete Category Matches

Source of Variance	Sum of Squares	df	Mean Square	F
H	1026 61	1	1026 61	2 09
H X S	6862 79	14	490 20	
VF	98.88	1	98.88	2.97
VF X H	1 22	1	1.22	< 1 00
VF X H X S	466 31	14	33 31	
Total	8455 81	31		

H=hand. S=subjects VF=visual field

APPENDIX D-7

Mean False Positive Percentage for Individual Subjects (n=16)

	Left Hand					Right Hand			
	Concrete		Abstract			Concrete		Abstract	
Subject	LVF	RVF	LVF	RVF	Subject	LVF	RVF	LVF	RVF
1	.000	000	125	000	9	063	.063	.188	188
2	.063	063	000	.000	10	000	.000	.000	000
3	125	.063	125	.125	11	063	000	000	125
4	125	.000	.000	000	12	063	.000	000	.063
5	000	.063	.063	000	13	063	.063	.125	.063
6	125	.188	.313	063	14	000	063	.000	063
7	.000	.000	.000	.063	15	.188	250	.250	.313
8	063	.125	125	250	16	.000	.063	.000	.000
$\overline{X}$	063	063	094	.063	$\overline{X}$	.055	063	070	102

APPENDIX D-8

Analysis of Variance for False Positive Errors on Abstract Category Matches

Source of Variance	Sum of Squares	df	Mean Square	F
H	4 88	1	4 88	< 1 00
H X S	2255.86	14	161.13	
VF	0 00	1	0.00	0 00
VF X H	78.13	1	78 13	1 87
VF X H X S	585 94	14	41 85	
Total	2924.80	31		

H=hand. S=subjects VF=visual field.

APPENDIX D-9

Analysis of Variance for False Positive Errors on Concrete Category Matches

Source of Variance	Sum of Squares	df	Mean Square	F
H	1.22	1	1 22	< 1 00
H X S	1032 71	14	73.77	
VF	1.22	1	1 22	< 1 00
VF X H	1 22	1	1 22	< 1 00
VF X H X S	251 46	14	17 96	
Total	1287.84	31		

H=hand. S=subjects. VF=visual field

APPENDIX E-1

Ratings of Nouns for Concreteness and Kucera-Francis Frequency Counts

Concrete Nouns			Abstract Nouns		
Word	Concreteness	K-F Frequency	Word	Concreteness	K-F Frequency
BODY	6.58	276	DEATH	2.97	277
MONEY	6.63	265	LOVE	1.80	232
WIFE	6.52	228	IDEA	1.42	195
HALL	6.72	152	HOPE	1.18	178
ARMY	6.55	132	HOUR	2.93	144
HOTEL	6.80	126	MONTH	3.20	130
BLOOD	6.82	121	TRUTH	1.69	126
HORSE	6.94	117	STYLE	3.18	98
ROCK	6.96	75	LORD	4.18	93
DRESS	6.93	67	EVENT	3.72	64
METAL	6.76	61	DREAM	3.03	64
SEAT	6.79	54	DUTY	2.32	61
SKIN	6.96	47	ANGER	1.70	48
BRAIN	6.63	45	SOUL	1.87	47
PIPE	6.90	20	FATE	1.46	33
CLOCK	6.94	20	SHAME	1.70	21
	$\overline{X}$ = 6.78	Mdn = 96		$\overline{X}$ = 2.40	Mdn = 96

APPENDIX E-2

Ratings of Adjectives for Concreteness and Kucera-Francis Frequency Counts

Concrete Adjectives

Word	Concreteness	K-F Frequency
FULL	6 00	230
SHORT	6 33	212
DARK	6.58	185
BROWN	6 92	176
BLUE	6 67	143
GREEN	6 92	116
HEAVY	6 18	110
THIN	6 08	92
ROUND	6.58	81
GRAY	6.83	80
THICK	6 25	67
TALL	6 58	55
PINK	6.50	48
ROUGH	6 50	41
NAKED	6.50	32
LOUD	6 00	20
	$\overline{X}$ = 6.52	Mdn = 87

Abstract Adjectives

Word	Concreteness	K-F Frequency
LEAST	2.92	343
TRUE	1 82	231
LATE	3 00	179
BASIC	1 92	171
FINAL	2 83	156
EASY	2 92	125
POOR	3 83	113
HAPPY	3.08	98
NICE	2 83	75
LEGAL	3 50	72
PURE	3 67	56
PROUD	3 00	50
HOLY	2 00	49
FUNNY	3.00	41
WISE	2 00	36
FALSE	2 50	29
	$\overline{X}$ = 2 84	Mdn = 87

Appendix E-3

Ratings of Verbs for Enactive Imagery and Kucera-Francis Frequency Counts

High Enactive Imagery Verbs

Word	Enactive Imagery	K-F Frequency
PLAY	5.37	200
TALK	5.67	154
WRITE	5.35	106
REACH	5.39	106
DRIVE	5.40	105
BREAK	6.00	88
TOUCH	5.79	87
KILL	6.08	63
COOK	5.62	47
THROW	5.90	42
WASH	5.50	37
LAUGH	6.45	28
JUMP	6.25	24
SWING	5.98	24
RUSH	5.32	20
KICK	6.32	16
	$\overline{X}$ = 5.73	Mdn = 55

Low Enactive Imagery Verbs

Word	Enactive Imagery	K-F Frequency
THINK	4.33	433
KEEP	2.79	264
WISH	3.77	110
SERVE	3.89	107
WAIT	3.94	94
BEGIN	3.33	84
SEND	3.64	74
SAVE	3.10	62
RAISE	3.93	52
SELL	4.23	41
SHIFT	3.80	41
FAIL	4.08	37
YIELD	3.71	35
DELAY	2.48	21
URGE	3.60	21
QUIT	3.60	15
	$\overline{X}$ = 3.74	Mdn = 57

APPENDIX E-4

Nonwords

Noun-1 Series and Adjective-2 Series		Noun-2 Series and Verb-1 Series		Adjective-1 Series and Verb-2 Series	
BERVE	PLAP	MEGAL	LOOR	GONTH	BOUR
TAISE	VILL	RASIC	DRUE	DREAK	IDEN
HEACH	KUMP	KINAL	PASY	FEATH	MORD
KRIVE	HEND	VAPPY	TOLY	CRUTH	NOVE
FOUCH	LAIL	MEAST	VATE	ENGER	JATE
NELAY	MEEP	DUNNY	PIFE	SHYLE	FUTY
GLINK	MOOK	CALSE	BISE	EGENT	TOPE
CHIFT	RAIT	TROUD	HURE	CHAME	SOUD
TRING	LISH	NEAVY	VULL	LOTEL	RALL
NAUGH	JICK	THORT	FOUD	BRAIT	ARKY
SEGIN	URTE	COUND	TRIN	PLOOD	SIFE
THROG	TASH	FREEN	DRAY	METAR	NODY
ALOID	RUIT	NAKEL	HINK	DORSE	LEAT
DREAK	DUSH	PLICK	TARK	GONEY	VOCK
CIELD	RALK	MOUGH	NALL	PLOCK	SKIR
CRITE	SELP	TROWN	BLUG	GRESS	LIPE

APPENDIX E-5

Median RTs and Error Percentages for Individual Subjects (n=24) in Abstract Word Conditions of Experiment 4

	Left Hand							Right Hand					
	Noun		Adjective		Verb			Noun		Adjective		Verb	
Subject	LVF	RVF	LVF	RVF	LVF	RVF	Subject	LVF	RVF	LVF	RVF	LVF	RVF
1	580	608	624	606	648	597	13	744	702	755	719	983	826
	.250	625	.563	563	313	375		125	000	.250	250	250	063
2	643	608	648	618	776	634	14	873	652	793	572	673	649
	313	.063	500	188	313	250		188	000	188	125	188	000
3	647	621	694	606	746	715	15	559	558	572	521	569	564
	063	.063	313	.438	188	188		000	000	000	000	000	000
4	848	742	787	635	765	632	16	603	595	617	611	673	618
	.438	500	.500	.688	375	438		000	000	000	063	063	000
5	614	586	601	578	744	596	17	742	736	614	625	679	667
	.063	.125	063	125	.125	.063		125	125	063	.125	000	125
6	605	603	614	572	623	580	18	464	465	481	500	482	476
	.125	.063	.125	125	250	188		000	.000	000	000	.063	000
7	486	529	582	537	553	521	19	618	573	704	567	627	651
	.063	.063	063	.188	.063	.000		313	125	375	313	375	.250
8	933	809	785	763	790	714	20	560	592	551	584	625	661
	188	.125	.313	125	250	188		000	125	.063	000	000	250
9	616	612	585	605	652	627	21	700	695	728	663	701	667
	438	.313	438	688	500	.500		188	125	063	188	063	063
10	577	597	644	541	639	653	22	825	727	756	713	738	786
	.188	125	063	125	063	063		438	125	.188	250	250	188
11	642	559	693	611	596	597	23	611	585	894	687	834	691
	063	188	063	125	125	000		500	188	313	188	500	250
12	677	700	668	606	623	709	24	694	667	617	635	693	747
	.063	125	063	063	188	000		250	125	438	438	188	125
$\bar{X}$	656	631	660	607	679	631	$\bar{X}$	666	629	673	616	690	667
	188	198	.255	.286	229	.188		177	078	161	161	161	.109

APPENDIX E-6

Analyses of Variance for RTs to Abstract Words

Source of Variance	Sum of Squares	df	Mean Square	F
H	5929 00	1	5929 00	< 1.00
H X S	811462 89	22	36884 68	
VF	59454 69	1	59454 69	16 68***
VF X H	96 69	1	96.69	< 1 00
VF X H X S	78436 61	22	3565.30	
WCL	20178 18	2	10089 09	2 46
WCL X H	2152 79	2	1076 40	< 1 00
WCL X H X S	180236 03	44	4096 27	
VF X WCL	4135 43	2	2067 71	1 36
VF X WCL X H	2357 60	2	1178.80	< 1 00
VF X WCL X H X S	66827 97	44	1518 82	
Total	1231267.90	143		

H=hand. S=subjects. VF=visual field. WCL=word class ***$p<.001$

APPENDIX E-6

Source of Variance	Sum of Squares	df	Mean Square	F
WCL	46732.63	2	23366.31	1.35
WCL X W	778526.58	45	17300.59	
VF	76121.51	1	76121.51	13.40*
VF X WCL	12.54	2	6.27	< 1.00
VF X WCL X W	255550.70	45	5678.90	
H	484.51	1	484.51	< 1.00
H X WCL	1161.17	2	580.58	< 1.00
H X WCL X W	254534.08	45	5656.31	
VF X H	338.67	1	338.67	< 1.00
VF X H X WCL	625.50	2	312.75	< 1.00
VF X H X WCL X W	168186.58	45	3737.48	
Total	1582274.50	191		

WCL=word class W=words VF=visual field H=hand * $p < .001$

APPENDIX E-7

Analysis of Variance for Abstract Word Errors

Source of Variance	Sum of Squares	df	Mean Square	F
H	2448 19	1	2448.19	2 11
H X S	25533 31	22	1160 61	
VF	228 14	1	228 14	1 72
VF X H	228 14	1	228 14	1 72
VF X H X S	2922 63	22	132 85	
WCL	837 13	2	418 57	4 69
WCL X H	134.01	2	67.00	< 1 00
WCL H X H S	3924 70	44	89 20	
VF X WCL	300 02	2	150 01	2 91
VF X WCL X H	163 30	2	81 65	1.58
VF X WCL X H X S	2271 05	44	51 61	
Total	38990 61	143		

H=hand. S=subjects VF=visual field WCL=word class *p*< 025

APPENDIX E-8

Median RTs and Error Percentages for Individual Subjects (n=24) in Concrete Word Conditions of Experiment 4

	Left Hand					
	Noun		Adjective		Verb	
Subject	LVF	RVF	LVF	RVF	LVF	RVF
1	630	617	624	670	602	574
	.250	313	.375	250	250	188
2	598	693	588	604	670	573
	375	188	188	.188	250	188
3	600	632	628	558	679	646
	.125	063	.063	.063	188	125
4	739	692	795	813	678	628
	313	375	250	375	313	250
5	634	626	641	592	688	725
	188	063	.125	063	063	.063
6	627	651	612	617	621	679
	.000	063	125	063	188	.250
7	517	599	537	513	545	509
	000	000	063	.188	000	063
8	909	772	775	712	892	768
	.063	.125	125	063	063	125
9	598	594	640	602	600	611
	375	.313	500	.563	.313	188
10	593	636	580	535	571	556
	125	125	.000	000	.000	063
11	621	556	577	582	568	561
	.188	.188	125	000	.000	000
12	648	620	638	691	644	639
	188	125	063	125	125	125
$\overline{X}$	643	649	636	624	647	622
	182	161	167	161	.145	135

	Right Hand					
	Noun		Adjective		Verb	
Subject	LVF	RVF	LVF	RVF	LVF	RVF
13	828	768	787	864	835	762
	188	125	063	.063	125	063
14	672	572	689	616	635	584
	125	000	063	000	063	000
15	537	499	571	572	532	512
	000	000	000	000	063	000
16	620	634	654	639	596	579
	.063	000	000	125	000	000
17	633	613	605	575	586	595
	125	125	188	.000	063	125
18	466	475	475	485	488	490
	.000	000	000	000	000	000
19	686	650	624	678	588	542
	313	250	188	125	313	188
20	588	617	564	602	603	563
	000	063	000	063	000	000
21	702	748	694	792	708	647
	.000	.063	000	063	.063	125
22	691	734	708	704	737	705
	188	063	.188	188	188	.250
23	684	776	703	615	789	777
	375	188	313	125	.250	125
24	629	623	693	775	591	644
	125	188	313	063	313	.125
$\overline{X}$	645	642	647	660	641	617
	125	089	109	.068	.120	.083

APPENDIX E-9

Analysis of Variance for RTs to Concrete Words

Source of Variance	Sum of Squares	df	Mean Square	F
H	925 17	1	925 17	< 1 00
H X S	850081 49	22	38640 07	
VF	1928 67	1	1928 67	1 20
VF X H	269.51	1	268 51	< 1 00
VF X H X S	35472 65	22	1612 39	
WCL	4585.10	2	2292 55	< 1 00
WCL X H	6076 01	2	3038 01	1 13
WCL X H X S	118778.22	44	2699 51	
VF X WCL	5051 76	2	2525 88	1.99
VF X WCL X H	1764 18	2	882.09	< 1 00
VF X WCL X H X S	55768 72	44	1267 47	
Total	1080701.50	143		

H=hand S=subjects VF=visual field WCL=word class.

APPENDIX E-10

Analyses of Variance for RTs to Concrete Verbs

Source of Variance	Sum of Squares	df	Mean Square	F
H	402.52	1	402.52	< 1.00
H X S	347456.79	22	15793.49	
VF	6936.02	1	6936.02	7.29*
VF X H	0.21	1	0.21	< 1.00
VF X H X S	20926.46	22	951.20	
Total	375721.81	47		

H=hand. S=subjects VF=visual field * $p < .025$

Source of Variance	Sum of Squares	df	Mean Square	F
W	175122.36	15	11674.82	
VF	24375.02	1	24375.02	5.85*
VF X W	62511.73	15	4167.45	
H	1269.14	1	1269.14	< 1.00
H X W	51591.61	15	3439.44	
VF X H	365.77	1	365.77	< 1.00
VF X H X W	58160.98	15	3877.40	
Total	373396.61	63		

W=words VF=visual field H=hand *$p < .05$

APPENDIX E-11

Analysis of Variance for RTs
to Abstract Words and Concrete Verbs

Source of Variance	Sum of Squares	df	Mean Square	F
H	3209 51	1	3209 51	< 1 00
H X S	1090769.60	22	49580 44	
VF	63911 51	1	63911 51	18 01**
VF X H	73 76	1	73 76	< 1 00
VF X H X S	78065 12	22	3548 41	
WCL	33126 72	3	11042 24	2 93
WCL X H	5274 81	3	1758 27	< 1 00
WCL X H X S	248386 09	66	3763 43	
VF X WCL	6614 64	3	2204.88	1 65
VF X WCL X H	2380 56	3	793 52	< 1 00
VF X WCL X H X S	88125 93	66	1335.24	
Total	1619938 20	191		

H=hand. S=subjects VF=visual field WCL=word class **p<.001

APPENDIX E-12

Analysis of Variance
for Concrete Word Errors

Source of Variance	Sum of Squares	df	Mean Square	F
H	1290.01	1	1290.01	2.23
H X S	12752.03	22	579.64	
VF	227.51	1	227.51	4.57*
VF X H	61.36	1	67.36	1.23
VF X H X S	1095.78	22	49.81	
WCL	84.11	2	42.05	< 1.00
WCL X H	84.50	2	42.25	< 1.00
WCL X H X S	2732.44	44	62.10	
VF X WCL	2.08	2	1.04	< 1.00
VF X WCL X H	6.38	2	3.19	< 1.00
VF X WCL X H X S	1356.14	44	30.82	
Total	19692.35	143		

H=hand S=subjects VF=visual field WCL=word-class *$p < .05$

APPENDIX E-13

Mean False Positive Errors (percentage) for
Individual Subjects (n=24) in Noun, Adjective, and Verb Blocks of Trials

	Left Hand							Right Hand					
	Noun		Adjective		Verb			Noun		Adjective		Verb	
Subject	LVF	RVF	LVF	RVF	LVF	RVF	Subject	LVF	RVF	LVF	RVF	LVF	RVF
1	.031	000	063	000	000	031	13	031	094	.031	031	063	000
2	094	250	000	.156	188	281	14	.031	094	.000	031	.063	031
3	125	.094	250	.125	063	125	15	031	125	188	.125	.125	125
4	156	.094	188	156	219	219	16	000	.063	.000	000	031	.000
5	.313	156	188	125	188	.125	17	156	094	219	.063	156	125
6	.063	000	156	031	063	000	18	031	031	031	.031	094	.000
7	063	094	000	094	156	094	19	156	031	094	.125	094	125
8	031	000	063	094	031	.094	20	063	000	.063	000	000	094
9	094	000	000	000	031	125	21	.063	000	031	063	063	031
10	063	000	094	031	031	031	22	000	000	031	000	000	000
11	000	000	000	.000	031	.000	23	125	219	125	125	094	063
12	094	063	094	094	063	000	24	063	031	031	.000	031	.000
$\bar{X}$	094	063	091	076	.086	094	$\bar{X}$	063	063	070	.049	068	073

APPENDIX E-14

Analysis of Variance for False Positives

Source of Variance	Sum of Squares	df	Mean Square	F
H	143 24	1	143 24	< 1 00
H X S	3945 00	22	179 32	
VF	32 79	1	32.79	< 1.00
VF X H	6 81	1	6.81	< 1 00
VF X H X S	797 24	22	36 24	
WCL	31 02	2	15.51	< 1 00
WCL X H	3 79	2	1.90	< 1.00
WCL X H X S	1274 89	44	28.97	
VF X WCL	39 69	2	19 85	< 1 00
VF X WCL X H	23 32	2	11 66	< 1 00
VF X WCL X H X S	985 75	44	22 40	
Total	7283 55	143		

H=hand S=subjects VF=visual field WCL=word class