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Effects of Right Hemisphere Strokes

on

Psychomotor Performance

by

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Abstract

The performance on a subject-paced pursuit tracking task of ten subjects who had sustained right hemisphere strokes (RHS) was studied and compared with the performance of ten normal individuals matched for age and gender. The subjects were required to react to a series of target lights which provided variations in directional probability and the distance to be moved. Overall, the subjects performed a total of 12 trials which were divided into two testing sessions. In addition, the functional ability in activities of daily living of the stroke subjects, as measured by the Barthel Index, was compared to their performance on the pursuit task. The results indicated that the RHS group was able to learn the task, and their rate of learning did not vary from the controls. However, the RHS subjects were slower at executing motor responses and at correcting responses when they overshot the target. They did not respond to directional probability information in the same manner as the controls, rather they appeared to respond to each light in a sequential manner. The RHS group also demonstrated differences in performance between the left and right visual fields. Finally, no correlation was found between the Tracometer and Barthel Index measures.

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Chapter I

Introduction

Introduction to the Problem

In the last few decades right versus left brain functioning has gained much attention. The research findings have generally supported the view that the cerebral hemispheres in man exhibit specialization of function (Todor and Doane, 1978).

According to Ornstein (1977), the left hemisphere is predominantly involved in analytical, logical thinking, especially in verbal and mathematical functions in right-handed individuals. It's mode of operation is linear and it appears to process information serially (Cohen, 1973; Ornstein, 1977). In addition, the left hemisphere is generally regarded by investigators as the prime mediator of speech and language functions in most right-handed individuals (Ross and Mesulam, 1979; Searleman, 1977). Consequently, the left hemisphere has generally been designated as the "major" or "dominant" hemisphere (Ross and Mesulam, 1979). In terms of motor control, there is evidence which suggests that the left hemisphere is a critical part of a movement programming/selection system which operates bilaterally on the basic motor systems (Kimura, 1985; Kimura and Archibald, 1974).

On the other hand, the right hemisphere is said to be dominant for parallel information processing, and specialized for synthesis in right-handed individuals (Cohen, 1973; Todor and Doane, 1978). It is able to simultaneously process and integrate many inputs in order to capture the "Gestalt" or whole of a perception (Cohen, 1973; Ornstein, 1977). Some of the specific functions that the right hemisphere is said to be primarily responsible for are visual perception and memory (Kimura, 1963; Milner, 1968), perception of spatial relationships (Carmon and Benton, 1969), cerebral activation (Heilman and Van Den Abell, 1979) and constructional ability (Arrigoni and De Renzi, 1964; Benton, 1967; Piercy and Smyth, 1962). In terms of language function, the right hemisphere is thought to be responsible for affective language or prosody (the coloring, melody and cadence of speech) and nonverbal pragmatic language (gesture use and interpretation) (Pimental, 1986; Ross and Mesulam, 1979; Searleman, 1977).

Although the hemispheres are said to be specialized for different functions, it must be emphasized that it is not suggested that one hemisphere is silent while the other performs. What is proposed by several authors is that the hemispheres share the potential for many functions and both sides participate in many activities, but there are certain functions which are more efficiently performed by one hemisphere over the other (Stern, Oster and Newport, 1980; Ornstein, 1977).

In order to function, the brain requires an uninterrupted supply of glucose and oxygen and can survive only for a few minutes if they are reduced below a critical level (Brust, 1981). A sudden localized interruption of the blood supply to some part of the brain resulting in a disturbance of cerebral functioning lasting more than 24 hours, or leading to death, is known as a stroke or cerebrovascular accident (C.V.A.) (Wade, Langton Hewer, Skilbeck and David, 1985).

The neurological deficit resulting from a stroke usually reflects the size and site of the lesion, and the amount of collateral blood flow (Ryerson, 1985). Hence, stroke patients may demonstrate any of a wide variety of symptoms. One of the classic signs is hemiplegia, which is a type of paralysis that can affect both sensory input and motor output to the half of the body opposite to the hemisphere which has sustained the lesion. Thus, a stroke involving a lesion of the right hemisphere may result in a left hemiplegia. Other symptoms frequently encountered following a stroke include initial loss of consciousness, incontinence, visual loss, and loss of specific functions associated with the involved hemisphere, such as speech and language function or spatial perception, depending on the hemisphere involved (Brust, 1981; Wade et al., 1985).

Strokes are the third commonest cause of death in the Western world and are the single most common cause of serious physical disability, the care of which requires large financial resources (Mulley, 1985; Rose and Capideo, 1981).

To the patient, a stroke frequently means loss of income, decreased functional independence, and in some cases, long-term care in an institution.

Many investigations have been conducted in order to identify possible factors which may serve as predictors of functional outcome following a stroke. Studies examining the differential influence of side of cerebral lesion on various measures of outcome have had varying results (Wade, Langton Hewer and Wood, 1984). Generally, the results have shown that there is no significant difference in outcome between patients with left and right-sided strokes (Gowland, 1982; Mills and Digenio, 1983: and Wade et al., 1984), or the patients with right or non-dominant hemisphere involvement have less favorable functional outcomes (Denes, Semenza, Stoppa and Lis, 1982; Hurwitz and Adams, 1972; Lehmann, DeLateur, Fowler, Warren, Arnhold, Schertzer, Hurka, Whitmore, Masock, Chambers, 1975).

These findings are surprising, especially when one considers that patients with left or dominant hemisphere lesions, besides having motor impairment of the preferred hand, are frequently affected by language disturbances and/or apraxia, which is the inability to perform a familiar act, not caused by muscle paralysis (Kimura and Archibald, 1974). Consequently, the question arises as to whether there is some other non-language related factor involved in functional recovery which is more dependent on the non-dominant right hemisphere. Denes et al. (1982) noted that although generic factors such "perceptual and spatial deficits" are offered as a possible explanation, no systematic studies have been conducted to fully analyze the effects of such concomitant neuropsychological deficits.

Rationale

Past studies studying specific deficits associated with unilateral hemispheric lesions have examined the ability to perform specific perceptual motor skills, such as constructional ability, or have concentrated on the performance of the individual components of movement in simple motor tasks. However, the performance of functional activities of daily living and locomotion are dependent upon the individual's ability to perform complex motor skills. The control of skilled movements is a cognitive ability which involves decisions of where, when, how far, and how fast to move (Kerr and Blais, 1985). The ability to perceive external stimuli, make decisions about movement, as well as monitor and correct the outcome requires a considerable amount of information processing by the individual. Consequently, by examining how and when the motor performance of the right or "unaffected" upper limb of subjects who have had a right hemisphere stroke differs from that of healthy control subjects one may gain more insight into the nature of the problems leading to decreased functional ability. This understanding of some of the specific mechanisms behind functional problems may in time lead to the development of new treatment techniques and strategies which would enable right hemisphere stroke patients to overcome some of their specific disabilities.

Statement of the Problem

The basic purpose of this study was to investigate the effects of non-dominant right hemispheric lesions on psychomotor performance. The performance of the subjects with right hemisphere strokes was compared to normal subjects matched by age and gender.

All subjects were right hand dominant and performed 12 trials on a subject paced pursuit tracking task. All subjects used their right hand, which was the non-involved hand in the case of the subjects with right hemispheric lesions, in order to eliminate possible effects due to muscle paralysis in the affected side. It was felt that the deficits resulting from a right hemispheric lesion which are responsible for decreased functional outcome have some affect on both sides the body. This was in agreement with Ryerson (1985) who suggested that perhaps there is no such thing as an "uninvolved side" in stroke patients, and with Blackburn and Benton (1955) who suggested that hemispheric lesions may result in both specific and generalized neurological impairments. The National Research Council Tracometer (Buck, Leonardo and Hyde, 1981) was used to measure the psychomotor performance of the two groups. This task required the subject to move accurately across four movement distances within a choice reaction time paradigm. It provided measures of total response time, correct reaction time, non-overshoot movement time, overshoot movement time, error score and overshoot score.

In addition, the motor performance of the subjects with right hemispheric lesions was compared to their ability to perform activities of daily living as measured by a functional scale in order to examine a possible relationship between the two. The functional scale used was the Barthel Index (Appendix A) which is a weighted scale measuring performance in self-care (feeding, bathing, personal toilet, dressing, bowel and bladder care) and mobility (transfers and stair-climbing) and has been used in studies of outcomes of patient care in rehabilitation settings (Granger, Dewis, Peters, Sherwood and Barrett, 1979).

Hypotheses

The following hypotheses were tested in this study:

1) Subjects with right hemisphere strokes are slower than control subjects in total response time using the right hand.

2) Subjects with right hemisphere strokes have longer reaction times than control subjects using the right hand.

3) Subjects with right hemisphere strokes do not differ from

control subjects in non-overshoot movement time using the right hand.

4) Subjects with right hemisphere strokes have longer overshoot movement times than control subjects using the right hand.

5) Subjects with right hemisphere strokes have a higher error score than control subjects using the right hand.

6) Subjects with right hemisphere strokes have a higher overshoot score than control subjects using the right hand.

7) Subjects within the right hemisphere stroke group demonstrate differences in performance between targets in the left and right visual fields.

8) There is a relationship between the motor performance of the patients with right hemispheric lesions on the pursuit tracking task and their functional ability to perform activities of daily living as measured by the Barthel Index.

Definition of Terms

Apraxia: An inability to perform a familiar act which is not caused by the paralysis of muscles.

Cerebrovascular Accident (C.V.A.): A sudden localized interruption of the blood supply to part of the brain resulting in a disturbance of cerebral functioning and lasting more than 24 hours or leading to death.

Correct Reaction Time: The time interval between the presentation of the target light and the initiation of the response executed in the correct direction.

Error Score: The percentage of movements initiated in the wrong direction.

Hemiplegia: A type of paralysis that can affect both sensory input and motor output to the half of the body opposite to the cerebral hemisphere which has sustained the lesion.

Non-overshoot Movement Time: The time interval between the initiation of the response and the beginning of a successful alignment of the pointer with the target, without overshooting the target light.

Overshoot Movement Time: The time interval between the initiation of the response and the beginning of a successful alignment of the pointer with the target in all movements where the subjects went beyond the target before a correct alignment was achieved.

Overshoot Score: The percentage of movements which overshoot the target light before correct alignment.

Stroke: See Cerebrovascular Accident.

Total Response Time: The total time on average to complete a single response.

Chapter II

Review of Literature

Studies examining the differential influence of side of lesion in stroke patients on various measures of outcome have shown that there is no significant difference between the two groups, or, the patients with non-dominant right hemisphere involvement have less favorable outcomes. As mentioned previously these findings are surprising considering patients with left or dominant hemisphere lesions, besides having motor impairment of the preferred hand, are frequently affected by language disorders and disturbances in the motor programming selection system.

One common finding described by several authors is that it appears that the presence of perceptual deficits, such as visuo-spatial disorders, rather than side of lesion affects functional recovery following stroke (Denes et al, 1982; Gowland, 1982). It is noted that while not exclusively confined to patients with lesions of the right hemisphere, the incidence of perceptual deficits is higher in this group. An interesting point was raised by Denes et al (1982) suggesting that unilateral neglect may be a symptom merely coincident with other factors which have a detrimental effect on recovery. The following review of literature describes some of the specific deficits related to psychomotor performance that occur as a result of right hemispheric lesions and which may possibly affect the functional recovery in these individuals.

Information in the area of hemispheric specialization of function has been obtained from a variety of types of studies which have involved both neurological patients and normal subjects. However, since the literature on cerebral laterality is voluminous, for the purposes of this paper the following review will focus primarily on studies examining various aspects of psychomotor performance in patients who have sustained unilateral cerebral lesions.

It is important to note that in examining the psychomotor aspects of movement, one is not just concerned with observable behavior, but also concerned with those central controlling processes that both guide and produce that behavior (Kerr, 1982). Consequently, this discussion of the literature will be organized using an information-processing model approach. According to Welford (1977) the three main features of this model include the sense organs, the central mechanisms and the effectors (muscular system). The sense organs provide the sensory input from both internal and external sources, while the effectors produce motor output. Between these two are three central components identified as the central mechanisms which may be distinguished from one another by function. In the first of these central mechanisms, the perceptual mechanism, the data from the sensory receptors is thought to be analyzed, co-ordinated and supplemented by data from memory stores. In the second central mechanism, the decision or translation mechanism, it is felt that the translation of perception to action in the form of choice of response occurs. In the third, the effector control mechanism, the programming of the sequence of muscular actions involved occurs. Various feedback loops provide the system with information about the success of the movement, thus allowing corrections to be made. According to Marteniuk (1976), using this model one can conceive of the individual as a communication system, which receives information from the environment and acts on it such that what results is a message being sent to the muscles in order that movement can occur. He concludes that if the system has been efficient and accurate in processing the information input, what should result is an output or movement that is co-ordinated to the demands of the environment.

In the context of the present study, the patient with a right hemispheric lesion may have deficits at various stages of information processing and these could be responsible for their lack of functional recovery. Thus, the following review of literature pertaining to psychomotor deficits associated with right hemispheric lesions is broken down into three sections according to the three main features of the information-processing model, namely, sensory input, central processing and motor output.

i) Sensory Input

The analysis of information involved in motor control begins at the sensory receptor level. According to Wade et al (1985) there is good evidence that an intact sensory system is vital for normal motor control. Sensory receptors are important for acquiring the information necessary to produce a motor response as well as providing feedback regarding the success of the movement. However, despite the important role of sensation, the measurement of sensory disability is very difficult. According to Wade et al (1985) one of the major problems in testing sensation is in developing objective measures for an essentially subjective phenomena. They also note that sensory assessment is further complicated in stroke patients by language deficits, the phenomenon of neglect and denial, and the large number of sensory functions that can be measured. Some of the sensory deficits which have been noted in the contralateral, as well as ipsilateral, side of the body following a right hemisphere stroke are discussed in the following two subsections, followed by a summary.

a) Contralateral sensory deficits

In addition to hemiparesis, a right hemisphere stroke frequently results in sensory deficits of the contralateral or left side of the body. According to Bobath (1978) some of the most frequently encountered sensory disturbances are those connected with touch, proprioception, and vision. She noted that a great variety and degree of sensory deficits can be found. Ryerson (1985) stated that in terms of tactile and proprioceptive sensations, the majority of stroke patients experience partial impairment which usually affects the higher discriminatory sensations. Consequently, in the affected limbs, a patient may feel touch but be unable to localize it, or may sense hot and cold but be unable to distinguish variations in temperature.

One common sensory complication following a stroke is homonymous hemianopsia which is the loss of sight in the same half of both visual fields resulting in a lack of awareness of anything in the visual field opposite to the side of the hemispheric lesion (Adams, 1966). Homonymous hemianopsia occurs as a result of damage to the optic tracts leading to the visual cortex, or damage to the visual cortex itself which is located posteriorly in the occipital lobe (Smith, 1971; Brust, 1981). This deficit may be temporary or persistent, with varying degrees of improvement and may contribute to partial neglect or complete denial of the affected side (Bobath, 1978).

b) Ipsilateral sensory deficits

Sensory deficits described thus far have been those which are present in the "affected side" of the body, which is the side contralateral to the hemispheric lesion. Sensory disturbances which affect the limbs ipsilateral to the lesion are not as well described as they have traditionally been thought of as the "unaffected side". However, there is some evidence that sensory deficits may occur in the ipsilateral as well as the contralateral side to the hemispheric lesion. Two such studies will now be discussed.

Birch, Proctor and Bortner (1961) conducted a study which examined the ability of stroke patients to identify the localization of touched parts on the body surface. Their study involved a total of 45 patients in three groups: right C.V.A.'s, left C.V.A.'s, and a control group. The task involved localization of touched points on the body surface. The findings indicated that when points to be located were on the affected limb, the hemiplegic patients made significantly fewer correct responses than did the non-hemiplegic subjects. Findings were similar for conditions involving stimulation of the unaffected limb except the group differences obtained were significant only to the .07 level of confidence. There appeared to be no significant differences between the groups of left and right C.V.A.'s. These findings suggest that patients who have unilateral hemispheric lesions not only demonstrate sensory disturbances in their contralateral limbs, but in their ipsilateral limbs as well.

A study conducted by Vaughan and Costa (1962) also gives some indication of sensory deficits in the limb ipsilateral to the hemispheric lesion. As well, it addresses the question as to whether bilateral somatosensory impairments occur more frequently in patients with lesions of the left hemisphere than in those with right hemispheric damage. Vaughan and Costa (1962) stated that previous investigations had suggested a difference in organization between the hemispheres with regard to both somesthetic and motor functions. They noted that in the somesthetic sphere, it is proposed that the functions tested may be more discretely organized within the left hemisphere than within the right, and that lesions of the left hemisphere are more prone to produce ipsilateral deficits than are lesions of the right hemisphere. Their study involved 53 subjects in three distinct groups: patients with left hemispheric lesions, patients with right hemispheric lesions and control subjects. They studied performance on a total of four sensory, motor and sensorimotor tasks. The subjects were tested on both of their hands for pressure threshold and two-point discrimination. The results indicated that in all tests involving the hand contralateral to the lesion the performance of subjects with right lesions was poorer than that of control subjects and subjects with left hemispheric lesions. Subjects with left lesions produced contralateral deficits as compared to the control subjects in the two-point discrimination task only. Both groups demonstrated ipsimanual deficits in the sensory tests. Interestingly, despite the fact that there were fewer overall deficits associated with left cerebral lesions, the proportion of ipsimanual deficits in this group was significantly higher than in the group with right sided lesions. This second finding supported the original hypothesis of the study which predicted that while ipsilateral deficits may occur following damage to either hemisphere, they are more prone to occur following left hemisphere damage.

c) Summary

It appears that unilateral hemispheric lesions are usually accompanied by sensory deficits in the limb contralateral to the side of the lesion. Some of the most frequently encountered sensory disturbances are those connected with touch, proprioception and vision. However, there is some evidence that sensory deficits may also occur in the side ipsilateral to the side of the lesion and it is suggested that ipsilateral deficits may be more prone to occur following left hemispheric lesions (Vaughan and Costa, 1962). When considering sensory deficits following unilateral cerebral lesions, it is also interesting to note that Ryerson (1985) suggests that perhaps there is no such thing as an "uninvolved side" following a stroke since sensory loss of the affected side leaves the two sides of the body with different sensory messages, thus providing the brain with different forms of sensory feedback. She feels that this disturbed sensory feedback may then result in disturbances of movement in the "good" side of the body. Consequently, one may suspect that sensory deficits accompanying a right hemispheric lesion may have some effect on the psychomotor performance of the ipsilateral right upper limb, although the magnitude of this effect is unknown and difficult to ascertain.

ii) Central Processing

As mentioned earlier, the first of the central mechanisms in information processing is known as the perceptual mechanism (Welford, 1977). Kerr (1982) defined perception as the active process of the brain which involves the interpretation of the sensory stimuli through the conscious organization of incoming information. It is the perceptual mechanism which is thought to analyze, coordinate and supplement from memory stores the data received from the sensory receptors. According to Newcombe and Ratcliffe (1979) the perceptual deficits that follow damage to the brain are poorly understood. They stated that it is not always clear whether the perceptual deficits reported in the literature are only symptoms of acute brain damage, or whether they persist into the chronic phase. However, it was noted earlier that studies examining factors which influence recovery following stroke have indicated that perceptual deficits appear to negatively affect outcome. The following three subsections will concentrate on three types of perceptual deficits frequently described in patients with right hemispheric lesions which could affect their ability to perform motor skills. The three types of perceptual deficits discussed are: a) disorders in visual perception, b) disorders in the perception of spatial relationships, and c) visual-spatial neglect.

The second central mechanism, the decision or translation mechanism, is thought to be where the translation of perception to action in the form of choice of response occurs (Welford, 1977). According to Kerr (1982) the actual time it takes to complete this decisional phase is usually referred to as reaction time. Reaction time can be broken down into central (time taken to select the response) and peripheral (time taken to initiate the response) components. However, since the peripheral component has been found to be relatively constant for any given response, reaction time is regarded as a function of how efficiently information is processed by the central mechanisms (Kerr, 1982). Thus, the fourth subsection dealing with deficits in central processing discusses reaction time studies involving patients with right cerebral lesions.

The third central mechanism, according to Welford (1977) is the effector control mechanism. Here the programming of the sequence of motor actions is thought to occur. A review of the literature indicated that there was little evidence linking deficits in motor sequencing to right hemispheric lesions. However, since the effector mechanism is thought to produce motor output, deficits in this area resulting from right hemisphere lesions may contribute to those described in the final section of this review which deals with motor output.

a) Disorders in visual perception

According to Newcombe and Ratcliffe (1979) it is quite clear from clinical and experimental evidence that visual perceptual deficits, when they can not be explained by some underlying sensory change, are predominantly associated with damage to the right hemisphere. Three types of visual perceptual impairments that have been identified as occurring in association with right hemispheric lesions are visual recognition, visual memory and visual neglect. Two of these visual perceptual impairments, visual recognition and visual memory, will briefly be described in this subsection. The third, visual neglect, will be described in the subsection dealing with visual-spatial neglect.

In terms of visual recognition, the general indication is that the right hemisphere has relative dominance for the perception of unfamiliar visual material and visual tasks which require discriminating and comparing sense data (Kimura, 1963; DeRenzi and Spinnler, 1966). Alternately, it appears that the left hemisphere is involved in the higher cognitive function of identification of meanings of visually presented information (DeRenzi, Scotti and Spinnler, 1969).

In terms of visual memory, it appears that patients with right hemispheric lesions were significantly inferior to patients with left hemispheric lesions in tasks involving recognition of previously seen abstract material and photographs of faces (Milner, 1968).

In the case of visual memory for position, DeRenzi, Faglioni and Scotti (1969) observed that the presence of visual field defects rather than the side of lesion was related to poor performance. The task used for this study required the subjects to locate by memory the correct position of six geometrical designs, arranged in two rows. The authors suggested that the observed lack of difference between patients with right and left lesions may be due to the fact that this type of task involved both spatial and language components. DeRenzi et al (1969) indicated that the apparent relationship between visual field deficits and visual deficits may not one of cause and effect, but rather the two are coincidental symptoms indicative of damage of the posterior regions of the hemispheres, especially the right hemisphere.

It has been stated previously that the left hemisphere is primarily involved in language functions, while the right hemisphere plays an important role in the perception of spatial relationships. The following subsection discusses studies examining the role of the right hemisphere in the processing of spatial information.

b) <u>Disorders in spatial perception</u>

According to Newcombe and Ratcliff (1979) it appears that patients with right hemispheric lesions have particular difficulty with the analysis of spatial aspects of stimuli. They noted that it has been difficult to characterize the specific deficit since the label "spatial" has been applied to various tasks. However, they suggested that the deficit appears to consist of an inability to appreciate the relative positions of stimuli or stimulus elements and organize them into a coherent spatial framework. The following section will discuss some of the studies which have examined the performance of patients with hemispheric lesions on various "spatial" tasks.

Semmes, Weinstein, Ghent and Teuber (1955) conducted an early study concerned with examining the nature of spatial disorientation following brain injury. The subjects involved were service men who had sustained penetrating injuries to the brain. The task utilized required the subjects to walk through a given path based on information presented on maps which were perceived under two separate conditions, visually and tactually. The results failed to demonstrate any differences between right and left hemispheric involvement.

Milner (1965) noted that the findings of Semmes et al (1955) were inconsistent with many clinical observations which had found that patients with right hemispheric lesions were more impaired than patients with left lesions in tasks involving spatial orientation (e.g. Paterson and Zangwill, 1944; McFie, Piercy and Zangwill, 1950). The following studies have demonstrated differences in performance on various tasks involving the perception of spatial relationships related to side of hemispheric lesion, thus supporting the earlier clinical observations.

Milner (1965) conducted a study which involved visually-guided maze learning in order to investigate the effects of various cerebral lesions on the learning ability of a spatial task. Maze learning was chosen as a task as it was not dependent on verbal skills and permitted the use of massed trials. The subjects consisted of 79 patients with unilateral cortical excisions carried out for relief of focal epilepsy and 11 normal control subjects. The task involved was a stylus maze which consisted of bolt heads mounted on a board, spaced one inch apart in a ten by ten array. The subjects were required to discover and remember the one correct path leading from the lower left hand corner to the upper right hand corner. The subjects had to proceed one step at a time from bolt head to bolt head with the loud click of an electronic error-counter informing them whenever they left the correct path. At the end of each trial subjects were told how many errors they had made and were required to continue until a criterion of three successive errorless runs had been attained. Training was carried out in blocks of 25 trials, twice daily, until the criterion was reached. The results indicated that on this maze learning task the right temporal group required significantly more trials and made significantly more errors than the left temporal group.

Interestingly, despite some verbal limitations, the maze learning scores of the left temporal group did not differ from those of normal control subjects.

Corkin (1965) conducted a follow-up study to the previous work using a tactually guided maze in which visual guidance is completely excluded in order to test the generality of the findings of Milner (1965). The subjects involved in the study by Corkin (1965) were 53 of the 79 patients with unilateral cortical excisions and the 11 normal control subjects used in the study by Milner (1965). The task involved a stylus maze placed inside of a wooden frame which was open on the experimenter's side but was covered by a black curtain on the subjects's side thus preventing the subject from viewing the maze. The subjects were required to find the correct path from start to finish using a stylus held in the preferred hand. The training was carried out on two consecutive days in blocks of 10 trials until a criterion of three consecutive errorless runs or 50 trials had been completed. No more than 30 and no less than 20 trials were given in one day. An analysis of variance performed on the error scores indicated that the performance of patients with right hemispheric lesions was inferior to patients with left lesions. In addition, the proportion of right temporal lobe subjects who reached the criterion in 50 trials or less was significantly less than the combined proportion of left temporal lobe patients and normal control subjects. There was a high positive correlation between the results of this study and those of Milner (1965) which Corkin (1965) stated supported the idea that spatial abilities are not organized along modality-specific lines. However, her findings that right hemispheric lesions appeared to impair performance more than left lesions differed from those of Semmes et al (1955).

Carmon and Benton (1969) conducted a study which investigated the perception of the direction and number of tactile stimuli applied to the palms of the hands in patients with unilateral cerebral lesions. They assumed that the basic sensory information derived from tactile stimulation of one or the other side of the body is primarily conveyed to the contralateral cerebral hemisphere. They suggested that the question then arises concerning the role of each hemisphere in the processing of this information to achieve perception or recognition. They predicted that, based on the presumed specialized role of the right hemisphere in mediating the spatial aspects of behavior, patients with lesions of the right hemisphere would demonstrate more bilateral defects in the tactile perception of direction of stimuli than would patients with lesions of the left hemisphere. On the other hand, they noted there was no such basis for predicting that there would be differences between groups for the tactile perception of number of stimuli.

The study conducted by Carmon and Benton (1969) involved a total of 60 subjects, 30 with left hemispheric lesions and

30 with right lesions. Aphasic patients were excluded from the study. The experiment consisted of stimulating the palms of each hand with one to three small tactile stimuli presented in nine different combinations of direction and number. Subjects were required to identify each tactile stimulus by pointing to the appropriate pattern presented on a visual display. The instrument used to present the tactile stimuli was an electromechanical stimulator. Two types of errors were scored: 1) responses involving the incorrect identification of number; and 2) responses involving the incorrect identification of the direction of the stimulus. The results indicated that the two groups of patients showed no significant difference in performance with respect to the tactile perception of number; there was approximately equally severe deficits on the contralateral hand in each group and performance on the ipsilateral hand was not significantly different from normal. In contrast, the two groups showed a significant difference in the pattern of performance with respect to the tactile perception of direction of stimuli. Although there were equally severe deficits in the contralateral hands in the two groups (which may be explained by sensory deficits) the patients with right hemispheric lesions showed a high incidence of defective performance on the ipsilateral hand, while patients with lesions of the left hemisphere were basically not impaired in this regard. Carmon and Benton (1969) noted that these findings supported

those of Corkin (1965) that right hemispheric lesions lead to a particularly severe impairment in tactile performances involving a spatial component. They concluded that this provided further evidence that the right hemisphere plays a more important role than the left in the mediation of behavior requiring the appreciation of spatial relations.

Fontenot and Benton (1971) conducted an investigation which was a modification and extension of the previous work by Carmon and Benton (1969). They stated that two considerations led them to undertake this second investigation. The first was based on the fact that in the earlier study the subjects were required to report both the direction and number of the stimuli. Hence, the possibility existed that the observed impairment in patients with lesions of the right hemisphere may have been due, wholly or in part, to a general defect in the processing of dissimilar information, rather than to a specific deficit in the tactile perception of direction. The second limitation was that aphasic patients were excluded from the earlier study, thus creating a possible bias in favor of a higher performance level on the part of patients with left hemisphere lesions. These two limitations were overcome in the present investigation by: 1) using a simplified task requiring only the tactile perception of direction; and 2) studying both aphasic and non-aphasic patients. Otherwise, the procedure was the same as that in the earlier study except that a control group of subjects was tested in addition to the two groups of patients with hemispheric lesions. The results indicated that for the contralateral hand a significant difference was found between the mean number of errors made by each of the brain damaged groups and that of the control group. For the ipsilateral hand the mean number of errors made by the left hemispheric damaged group was not different from that of the control group. However, the mean error score for the ipsilateral hand of the right hemisphere damaged group was higher than the mean scores of both the control and left hemispheric group. These findings confirmed those of Carmon and Benton (1969) that damage to the right hemisphere results in bilateral impairment in the perception of direction of tactile stimulation applied to the skin surface. The possibility that these findings were due to limitations in the capacity to process dissimilar information or the exclusion of aphasic patients was rejected.

Based on these findings it appears that the right hemisphere plays a distinctively important role in the mediation of spatial information. It has been noted that, in studies involving both visually and tactually-guided stylus mazes and in studies involving the perception of direction of tactual stimuli, the performance of patients with damage to the right hemisphere is more impaired than that of patients with left hemispheric lesions. However, the early study by Semmes et al (1955) failed to find any difference in performance on a route-finding task between subjects with right and those with left hemispheric lesions. Milner (1965) suggested that these differences in findings may be due to the nature of the task used by Semmes et al (1955).

A possible clue to the mechanism of hemispheric specialization in tasks involving spatial functioning was presented by Semmes (1968). She noted that studies of sensory and motor capacities of the hands in brain-injured subjects had indicated that these capacities are present but represented differently in the two hemispheres, tending to be focally represented in the left hemisphere, but diffusely represented in the right hemisphere. She suggested that the diffuse organization of functions within the right hemisphere may actually produce an advantage in this hemisphere for spatial abilities. She proposed that the proximity of unlike functional elements in a diffusely organized hemisphere would lead to a different type of integration of input from that which would occur in a focally-organized hemisphere. In the diffusely-organized hemisphere unlike units would more frequently converge resulting in a heteromodal integration of stimuli to a greater extent than that possible in a focally-organized hemisphere. Hence she concluded:

> In contrast to functions which may depend on a high degree of convergence of <u>like</u> elements, spatial function may depend instead on convergence of <u>unlike</u> elements - visual, kinesthetic, vestibular, and perhaps others

combining in such a way as to create through experience a single supramodal space. (Semmes, 1968, p. 24)

Even though the majority of the previously described studies appear to indicate that the right hemisphere plays a key role in visuospatial processing, it must be noted that one recently published paper provides some indication that the left hemisphere is also involved in this type of processing. Mehta, Newcombe and Damasio (1987) conducted a study involving subjects who had sustained a penetrating missile wound during World War II to either the right or the left side of the brain and a control group matched for age, ability and socioeconomic status. The subjects were administered two visuoperceptual (closure and face recognition) and two visuospatial (line orientation and shape rotation) tasks. The results indicated a predominantly right hemisphere deficit on the visuoperceptual tasks, and a relatively greater left than right hemisphere deficit on the spatial tasks. The authors noted that the discrepancy between their findings and other studies which have emphasized the almost exclusive role of the right hemisphere in spatial processing needs to be further studied in relation to several important variables, such as etiology of lesion, and different patterns of recovery from injuries sustained in young adulthood compared to cerebrovascular disease in later life.

The previous subsection described deficits in the perception of spatial information associated with right hemispheric lesions. The following subsection describes another deficit related to spatial perception, that of visual-spatial neglect.

c) Visual-spatial neglect

Visual-spatial neglect is a well recognized complication of brain injury and is defined as a neglect of visual stimuli over a part of extrapersonal space (Lawson, 1962). "Spatial agnosia" and "hemi-spatial inattention" are two other terms used in the literature to describe this type of syndrome involving neglect of, or inattention to, one-half of extra-personal space. Lawson (1962) noted that patients with visual-spatial neglect exhibit an additional deficit towards visual space which differs from that demonstrated by patients with simple hemianopsia. He observed that the patient with simple hemianopsia is able to use the intact parts of the visual fields to scan to the affected side, whereas the patient with visual-spatial neglect fails to do so.

According to Wade et al (1985) visual-spatial neglect complicates physical rehabilitation and can have profound effects on a patient's everyday behavior. For example, a patient with left visual-spatial neglect will be unable to find objects situated in the left visual space and so will be unaware of any food, drink, or toilet articles placed on that side. Both Lawson (1962) and Wade et al (1985) commented that the particularly striking feature of visual-spatial neglect is the disturbance in reading. The patient will fail to return his attention to the left hand margin of print when starting a new line and so will miss out a number of words to the left of the midline. The patient will be unaware of what he is doing, although he may note that the text he is reading does not make sense.

In a report which provides a good illustration of the nature of this disorder Lawson (1962) described the results of his attempts to retrain reading skills in two patients with visual-spatial neglect following right hemispheric brain lesions. Initially the patients were trained to use the edge of the book as a guiding line to the fingers and then, presumably from proprioceptive awareness of where the fingers were, the patients were able to learn to direct their vision onto them. In time, the patients became so fluent in their reading they were able to scan appropriately without the conscious use of the fingers as a guide. However, the defect remained since on other tasks the patients unconsciously regressed to visual neglect. Lawson (1962) felt that there was evidence which suggested that the visual-spatial neglect of these patients was a perceptual disorder since: 1) it was dependent on linear continuity and enclosure; 2) it gave way to the primary employment of other senses in situations where vision is normally dominant; and, 3) at least initially, it required a conscious and deliberate effort to overcome.

The preceding has provided a description of the nature of the deficits demonstrated by patients with visual-spatial neglect. The following describes studies which have examined visual-spatial neglect following unilateral brain lesions and discusses possible hypotheses that have been proposed to explain this behavioral abnormality.

Battersby, Bender, Pollack and Kahn (1956) noted that previous studies describing spatial agnosia had suggested that the right parietal lobe has some special function in relation to visuospatial cognition. They conducted a study which attempted to determine the relative importance of location of cerebral lesion and neurological defect for the occurrence of unilateral spatial agnosia. Their study involved a total of 164 patients in three groups: control patients with neurological involvement confined to the spinal cord, patients with space occupying cerebral lesions, and patients with non-localizable cerebral lesions. The two experimental groups of patients were assessed and classified according to the presence or absence of somatosensory, motor, mental and visual defects. All of the subjects were tested on a battery of perceptual tests designed to reveal the presence of unilateral spatial deficits. The results indicated that the relative incidence of unilateral spatial deficit is much higher in cases of non-dominant (80 per cent) as compared to dominant lesions (20 per cent). However, the authors noted that fewer cases with lesions of the dominant hemisphere were tested due to the presence of aphasia and when these cases were included in the totals, the relative incidence of spatial deficits in dominant and non-dominant lesions more closely approximated each other (40 and 48 per cent respectively). In terms of location of the lesion within each hemisphere, the results indicated that symptoms of unilateral spatial neglect were almost always associated with damage in the posterior portion of the cerebrum, although the symptoms were also present after lesions of the parietal, temporal or occipital areas of either hemisphere. In terms of neurological status, patients with positive signs of unilateral spatial neglect had a higher incidence of visual, somatosensory, motor and mental symptoms than did subjects without signs of neglect. The authors noted an especially high incidence of hemianopsia and disorientation for time, place and person in the patients with positive signs of unilateral neglect. They also noted that there was no disorientation for time, place or person among the hemianopic patients who did not manifest signs of unilateral spatial neglect. In other words, patients without neglect did not show this combination of symptoms. Based on these results, the authors advanced the hypothesis that unilateral spatial neglect is due to defective sensory input, primarily visual, superimposed on a background of altered mental functioning. However, it should be noted that this study did not involve the use of statistical procedures for the analyses of data.

DeRenzi, Faglioni and Scotti (1970) suggested that the appreciation of spatial relationships among or within objects implies the adequate exploration of extrapersonal space. They noted that when this exploration is carried out through the visual modality, as is usually the case, it involves the interplay of perceptual, motor and mental mechanisms such as searching movements of the eyes, attention to stimuli peripheral to the fixation point and the conceptual representation of the space to be explored. They suggested that impairment of any of these mechanisms following brain damage may derange a patient's exploratory behavior and manifest itself in different ways, including unilateral visual-spatial neglect.

In order to examine this hypothesis, DeRenzi et al (1970) conducted a study designed to investigate the relationship between unilateral brain damage and performance on two tasks requiring space exploration through both the visual and tactile modalities. In addition to the hemisphere involved, the presence or absence of visual field defects was also taken into consideration as a factor possibly affecting the performance. The subjects included 30 normal control subjects and 121 experimental patients with unilateral hemispheric damage. The testing procedures involved a visual searching test in which the subject was required to find a number on a display board, and a tactile searching test which required the subject to find a marble in a board maze using the hand ipsilateral to the side of the lesion. A total of eight trials were performed on each task and each trial was scored in terms of time spent searching up to a maximum time limit of 90 seconds. The results indicated that on the visual test both brain damaged groups were significantly slower than the controls and patients with visual field defects were slower than patients without. On the tactile searching task, the overall performance of the brain-damaged group was not significantly impaired in comparison to the controls. However, within the brain-damaged group, patients with visual field deficits were significantly worse than patients without. The authors noted that in the visual tests the sensory defect could be assumed to be the direct cause of the impairment associated with visual field defects. They reasoned that hemianopsia would slow down the performance by preventing the automatic quick re-orientation of visual attention towards stimuli in the blind field and by requiring the patient to make voluntary eye and head movements in order to compensate for his sensory deficit. However, no such explanation could be advanced for the similar findings for the tactually guided task which was carried out without the aid of vision by the hand ruled by the supposedly intact hemisphere. The authors suggested that the impairment on the tactile test in patients with visual field defects is an indication that the posterior areas of the hemispheres involved in vision are also crucial for mental operations involved in the representation of space.

In both the visual and tactile tests patients tended to be slower in searching when the object was located in the contralateral field. According to DeRenzi et al (1970), this finding supports the assumption that injury in one hemisphere mainly impairs exploration of the contralateral field. On the basis of searching time, damage to the right hemisphere did not appear to have more of a detrimental effect than damage to the left hemisphere. However, the authors noted that this lack of difference may be accounted for by a ceiling effect due to the 90 second limit place on searching time. When performance was scored again in terms of failure in finding the marble within the 90 second limit, the group of right hemisphere patients with visual field defects was significantly more impaired than any other brain-damaged subgroup. The authors concluded that the unawareness of space may not be linked to blocking information or impaired scanning mechanisms, but may be dependent on a cognitive deficit which may be viewed as a mutilated representation of space. They did not elaborate further on the nature of this cognitive deficit.

Oxbury, Campbell and Oxbury (1974) noted that although thirty years had elapsed since the early descriptions of visual-spatial neglect, a number of important questions remained unanswered . For instance, it was still not clear whether spatial neglect was one of many consequences of a cerebral lesions which produced general intellectual deterioration, or whether it primarily resulted from damage in the posterior part of the right hemisphere. They felt that if the latter was true, then there was some question as to whether impaired spatial analysis and visual perception are associated in some way with unilateral visual-spatial neglect in patients with right hemisphere damage. They conducted a study involving 39 acute stroke patients who were examined for the presence of unilateral visual-spatial neglect and impairments of spatial analysis and visual perception. The patients were divided into three groups according to the site of the lesion: brain stem, left hemisphere, or right hemisphere. Only the results for the latter two groups will be discussed here. Patients initially had a neurological examination which included testing of limb weakness and visual field defects. Within three to four weeks after the onset of the stoke the patients underwent a neuropsychological examination which included tests of copying and drawing, paragraph recall, digit span, picture naming and visual recognition tests. Patients were identified as demonstrating unilateral visual-spatial neglect if they failed to complete either the left or the right side of their pictures in the tests of copying and drawing. The results indicated that no signs of unilateral neglect were found amongst any of the patients with left hemisphere damage. However, 41 per cent of the right hemispheric patients were identified as having left visual-spatial neglect and these patients performed worse than the other right hemisphere patients on all tests of visual perception and spatial analysis. They felt this difference could not be attributed to general intellectual deterioration because the patients with neglect were not impaired on other cognitive tasks. The authors noted that the presence of visual and spatial deficits alone could not be responsible for visual-spatial neglect since some of the patients with right hemispheric damage demonstrated evidence of these deficits in the absence of neglect. In conclusion, the authors suggested that left visual-spatial neglect may be one important factor responsible for impairments of spatial analysis and visual perception arising from right hemisphere damage.

Campbell and Oxbury (1976) conducted a follow-up study involving the same patients six months post stroke in order to examine changes in visual-spatial neglect in relation to time since onset. They used essentially the same battery of tests to determine the presence of neglect as well as deficits in spatial analysis and visual perception. The results indicated that of the six patients with right hemispheric damage who had demonstrated neglect at three to four weeks post stroke, only two of these patients continued to demonstrate neglect as measured by the test of copying and drawing. However, this same group of patients still performed significantly worse than the others on all the tests of visual and spatial analysis even though most of them now made drawings that were complete. The authors noted that superficially these findings provided evidence against a persisting association or causal relationship between impairments of visual and spatial analysis and visual-spatial neglect. However, they noted that the resolution of the basic disorder may be more apparent than real since on the visual recognition test the original group with left-sided neglect continued to demonstrate a strong preference for right-sided responses which was as marked six months post stroke as it had been at three to four weeks. Thus, the authors concluded the resolution of neglect in drawing may have simply reflected the development of strategies to overcome an obvious disability of which the patient had become aware through much practice, rather than recovery from the underlying disorder.

In an effort to ascertain the mechanisms underlying hemispatial neglect, Heilman and Valenstein, (1979) advanced three possible hypotheses to explain this behavioral abnormality. The first hypothesis they referred to as "deafferentation" and simply suggested that hemispatial neglect occurs as a result of the presence of visual field defects or hemianopsia. This hypothesis is partly supported by the findings of Battersby et al (1956) which indicated an especially high incidence of hemianopsia in the patients with unilateral neglect. However, the same authors noted that patients with hemianopsia without disorientation to time, place and person, did not display signs of unilateral spatial neglect. DeRenzi et al (1970) also reported a relationship between presence of visual field defects and unilateral neglect. However, they felt that this relationship was an indication that the posterior areas of the brain involved in vision are also important for mental operations involved in the representation of space.

The second hypothesis advanced by Heilman and Valenstein (1979) proposed that hemispatial neglect occurs as a result of sensory inattention or inattention to various forms of sensory input. This hypothesis is supported by the findings of DeRenzi et al (1970) who found that hemispatial neglect was not limited to the visual modality but also occurred in a task requiring the exploration of space using the tactile modality. However, the results of Oxbury, Campbell and Oxbury (1974) which indicated that visual and spatial deficits were observed in patients who did not display evidence of visual-spatial neglect contradict this second hypothesis.

The third hypothesis proposed by Heilman and Valenstein (1979) suggested that hemispatial neglect occurs as a result of hemispatial hypokinesia which they described as a difficulty in performing any act which must occur in the neglected hemispatial field or the space to one side of the midline of the body.

In order to test this third hypothesis Heilman and Valenstein (1979) conducted an investigation involving six patients with evidence of left hemispatial neglect who were required to perform a modified line bisecting task. Prior to bisecting a line, the patients were asked to read a letter at either the right or the left end of the line in order to ensure that they had observed how far the line extended. The task was performed alternately with the lines placed at either the right, the center, or the left of the body midline of the patients. For half of the trials the patients were required to read the letter to the left before bisecting the line, while for the other half they were required to read the letter to the right. Trials were scored by measuring the distance between the actual midline and the patient's intersection of the line. The results indicated that performance in trials when the patients were required to look to the left before bisecting a line did not differ significantly from when they were required to look right. However, performance was found to be significantly better when the lines were placed to the right side of the body rather than the left even when the patient was required to read the letter to the left before bisecting the line. The authors felt that this observation was inconsistent with the hypothesis that the line is incorrectly bisected because it is not seen. They suggested that these findings seemed to indicate that patients with hemispatial neglect demonstrated a hemispatial hypokinesia or inability to perform movements in the neglected hemispatial field.

In their discussion of these findings, Heilman and Valenstein (1979) noted that observations in normal subjects had supported the hypothesis that each hemisphere is important for mediating behavior in the contralateral spatial field. They suggested that lesions which produce unilateral neglect also produce an asymmetrical reduction of arousal and the hyperaroused hemisphere is unable to prepare for action and consequently is hypokinetic. They noted that some of the previous investigations had found that hemispatial neglect occurred more frequently after right hemispheric lesions. Hence, they proposed that if neglect is caused by a defect in arousal, then the apparently higher incidence of neglect following right hemispheric lesions implies that there is a hemispheric asymmetry in arousal mechanisms.

A recent study conducted by Weintraub and Mesulam (1987) reported findings which appear to support the third hypothesis suggested by Heilman and Valenstein (1979). This study examined the performance of patients with unilateral brain damage and normal control subjects on two tasks, one which required visual exploration, and the other which required manual exploration. The results confirmed previous observations that contralateral neglect is markedly more severe following right hemisphere injury, independent of the modality of sensory input or motor output. Neglect was evident even in the absence of hemianopia, hemisensory loss, and hemiparesis. Interestingly, the patients with right hemisphere injury in this study also showed multimodal neglect for targets in the hemisphere ipsilateral to the brain lesion.

In their discussion, the authors agreed that the motor components of neglect described by Heilman and Valenstein (1979) as hemispatial hypokinesia are very important in neglect behaviour. However, they stated that they preferred to describe this aspect of neglect in terms of exploratory motor deficits, thus indicating that the difficulty is occurring at the level of active scanning within the extrapersonal space and not at the level of more elementary motor organization. They proposed that the emergence of both contralateral and ipsilateral neglect observed in their subjects with right hemispheric lesions strongly supports a model of right hemispheric dominance for the distribution of attention within the extrapersonal space. They suggested that the left hemisphere may contain neural units for directing attention only to the contralateral right hemispace, while the right hemisphere may contain neural units for directing attention to the contralateral left hemispace and to a lesser extent, the ipsilateral right hemispace.

This hypothesis indicating a defect in attention/arousal mechanisms in patients with right hemispheric lesions and studies examining this question are discussed in more detail in the next subsection dealing with reaction time.

d) <u>Effect on reaction time</u>

Reaction time is generally defined as the time from onset of a stimulus to the beginning of a response and can be considered an indicator of the efficiency of the sensory mechanisms and central control mechanisms involved in planning movement. In one of the early studies examining the reaction time characteristics of patients with cerebral disease Blackburn and Benton (1955) reported that brain-injured patients were significantly slower than controls in both simple and choice reaction time tasks using the right hand. Later, Dee and Van Allen (1971) noted that reaction time was a topic of considerable interest since it had the potential to be a simple yet efficient tool for the identification of cerebral disease and its hemispheric locus. This section primarily discusses studies which have examined the performance of patients with unilateral hemispheric lesions on simple reaction time tasks. The focus is on simple reaction time since it has been demonstrated that choice reaction time tasks do not provide a more discriminative index of cerebral disease than do simple reaction time tasks (Blackburn and Benton, 1955; Dee and Van Allen, 1971).

Benton and Joynt (1958) conducted an investigation to determine whether the reaction time slowing reported earlier by Blackburn and Benton (1955) was present in the ipsilateral as well as the contralateral side in patients with unilateral hemispheric lesions. The study involved a total of 60 subjects in three groups: patients with right lesions, patients with left lesions, and controls. All of the patients with lesions had normal use of their upper extremities and sufficient vision to see two lights at once. The reaction time apparatus involved the presentation of a visual stimulus in the form of a light which was preceded by a two second ready signal. The subjects performed a simple reaction time task using the index finger of their right hand and a choice reaction time task using the index fingers of both hands. The results indicated that in the simple reaction time task the patients with hemispheric lesions were slower than the controls. In the choice reaction time task, the groups of patients with lesions had slower reaction times in the ipsilateral as well as the contralateral hand compared to the control group. However, for both groups with hemispheric lesions, the hand contralateral to the lesion was significantly slower than the ipsilateral hand. The authors suggested that the unilateral focal lesions appeared to impair the individual's readiness to react. They also noted that the hemispheric lesions appeared to have both general bilateral and specific unilateral effects on reaction time.

DeRenzi and Faglioni (1965) agreed with Blackburn and Benton (1955) that hemispheric lesions may result in both specific and generalized neurological impairments. They suggested that specific impairments such as paralysis, anaesthesia, aphasia and apraxia were caused by lesions to localized anatomical structures. Alternately, they felt that generalized impairments were expressed essentially as a decreased level of mental efficiency and were caused by widespread cerebral dysfunction. They noted that it is difficult to compare degrees of generalized impairment in patients with differently localized lesions because there is the risk of handicapping some of the patients depending on the task chosen and the specific impairment present. For example, it would be inappropriate to evaluate general mental efficiency in patients with unilateral brain damage using a verbal intelligence task since patients with left hemispheric lesions may be at a disadvantage. Hence, they stated that in order to assess general mental efficiency, a test was required which would be sensitive to cerebral damage but not affected specifically by the side of the lesion. They suggested that vigilance tasks would meet these criteria since they required prolonged maintenance of high levels of attention and the rapid activation of perceptual and motor structures.

Consequently, DeRenzi and Faglioni (1965) conducted an investigation to determine if vigilance tasks, in the form of visual reaction time and continuous choice reaction time, would adequately reflect the general functional level of the of the brain. The investigation was carried out of 166 patients with either left or right hemispheric damage, and 139 control patients. For the visual reaction time task the brain-damaged patients used the hand ipsilateral to the lesion. For the continuous choice reaction time task the patients were required to watch a screen and press a button each time a specified combination of geometric figures appeared. In addition, all of the subjects were given the Raven's Progressive Matrices intelligence test. The results indicated that the two vigilance tests showed greater efficiency in discriminating between normal and pathological subjects than did the intelligence tests. In the continuous choice reaction time task no difference was found between the two hemispheric groups. In the visual reaction time task the patients with right hemispheric damage were significantly slower than patients with left-sided lesions. The authors interpreted this result as reflecting the presence of a more severe degree of cerebral damage in the right-sided group. Based on this, they advanced the hypothesis that reaction time may be regarded as a measure of the severity of a hemispheric lesion, unbiased by its location.

In order to test the hypotheses proposed by DeRenzi and Faglioni (1965), Boller, Howes and Patten (1970) conducted a study which correlated reaction time and lesion size in patients with unilateral brain damage. The patients included 43 patients with either left or right hemispheric lesions.

All patients had a brain scan and were tested for both visual and auditory reaction time using the hand ipsilateral to the lesion. The results indicated that reaction time appeared to be related to the extent of brain damage as indicated by the scan for lesions of the right hemisphere, but not for lesions of the left. Based on these findings they concluded that the use of reaction time as a measure of the size of a hemispheric lesion was invalid. They suggested that another interpretation of the finding of significantly slower reaction times in patients with right brain damage reported by DeRenzi and Faglioni (1965) and also by Benson and Barton (1970) may be that reaction time is primarily a right hemispheric function. They indicated that further research was required in this area.

Howes and Boller (1975) conducted an investigation to further examine the possibility that the non-dominant (right) hemisphere is in some way dominant for simple reaction time. Their study involved 49 patients with unilateral brain disease and 32 control subjects who were tested on a simple auditory reaction time task. Subjects were required to press a telegraph key using the index finger of the hand ipsilateral to the hemispheric lesion in response to a loud click from a loudspeaker. The experimental series consisted of 100 clicks which occurred at intervals of varying duration, ranging from four to fifteen seconds. Brain scans were performed on all patients to estimate the relative size of the lesions for the two groups. The estimates of lesion size indicated that the dominant hemisphere lesions were slightly larger on average, but this difference was not statistically significant. The results of the reaction time task supported the findings of DeRenzi and Faglioni (1965) that: 1) unilateral cerebral lesions produce an increase in simple reaction time even when the subject responds with the hand ipsilateral to the lesion, and 2) the effect is asymmetrical with lesions of the non-dominant hemisphere producing greater impairments than those of the dominant hemisphere. According to the authors, these group differences could not be attributed to asymmetries in either the size or type of lesion.

In addition, Howes and Boller (1975) noted that there was greater variability within the group with non-dominant lesions than there was within either of the other two groups. They felt that this pointed to the fact that there may be focal regions in the non-dominant hemisphere which are critical for reaction time. Examination of the maps of the brainscans for the patients with the highest reaction times indicated that structures in or near the basal ganglia, and the posterior parietal region of the non-dominant hemisphere were damaged in these patients. According to Howes and Boller (1975) both of these implicated regions were known to perform functions relevant to simple reaction time. The basal ganglia are the coordinating centres of the extrapyramidal motor system and play an important role in sensory motor coordination. Hypokinesia is a common finding associated with disease of these structures. Why the observed focal effect on reaction time is restricted to lesions of the non-dominant hemisphere was unclear. The functions of the other implicated area, the posterior parietal region of the non-dominant hemisphere, are poorly understood but it appears to play an important role in the integration of sensory information from different modalities, especially with regard to spatial functions. However, the authors stressed that these comments regarding the localization of reaction time deficits were speculative in nature since the method upon which they were premised was novel, and the number of cases small.

Studies involving electromyogram (EMG) recordings have enabled researchers to divide reaction times into two separate measures: 1) the premotor time, which is measured from the stimulus until the beginning of the EMG activity of the prime mover muscles, and 2) the motor time, which is the time between EMG onset and mechanical response. Nakamura and Taniguchi (1977) conducted a study to investigate which of these components was most responsible for the increase in reaction time which they stated was known to occur in patients with hemiparesis due to cerebrovascular accidents. Their study involved 10 patients with left hemisphere lesion, 12 with right-sided lesions, and 10 control subjects . All of the patients could move each finger separately of the affected hand, but had some residual impairments of motor function as identified by a grip test. The subjects were required to perform a finger lifting task in response to an auditory stimulus. Ten trials were performed consecutively with one hand followed by ten trials with the other hand. The EMG measures were taken from the finger extensor muscles with surface electrodes. The results indicated that a significant delay in motor time was observed in the affected limbs of both groups with hemispheric lesions, as compared to the controls. However, measures of premotor time indicated that patients with right hemispheric lesions demonstrated a significant bilateral deficit while those with left hemispheric lesions had slowing in their affected hand only. The authors pointed out that the longer premotor time associated with right hemispheric lesions could not be related to impairments of the sensory or motor output systems since it was equally observed in both hands. They proposed that the slowing of premotor time may be due to delays in the processing of sensory stimulation. Thus, they suggested that the right hemisphere may play a dominant role in the processing of sensory stimulation during a reaction time task.

Heilman and Van Den Abell (1979) conducted a study designed to investigate further the question of why lesions of the right hemisphere produce slower reaction times. They postulated that the right hemisphere may dominate in mediating cerebral activation which they defined as the physiological readiness to respond to environmental stimuli. They noted that it had been shown that warning stimuli may prepare an organism for action and thereby reduce reaction times. Thus, they proposed that if, as postulated, the right hemisphere dominates mediation of activation, a warning signal projected to the right hemisphere of normal subjects would reduce reaction time of the right hand more than a warning stimuli projected to the left hemisphere would reduce reaction time of the left hand. Their study involved 24 normal college students who performed 90 reaction time trials in response to a centrally located green light which was preceded by a red light presented in either the left or the right visual field. All subjects performed half of the trials with their right hand, and the other half with their left hand. The results indicated that warning stimuli presented to the right cerebral hemisphere (left warning stimulus) reduced reaction times of the right hand more than warning stimuli presented to the left hemisphere (right warning stimulus) reduced left hand reaction times. In addition, warning stimuli projected to the right cerebral hemisphere reduced the reaction time of the right hand more than the warning stimuli projected directly to the left hemisphere. All of these comparisons were significant. The authors stated that these results supported the hypothesis that the right hemisphere dominates activation. They proposed that each hemisphere can mediate its own activation, but the right hemisphere can activate for the left hemisphere more than the left hemisphere can activate the right hemisphere.

In their discussion, Heilman and Van Den Abell (1979) suggested that the proposed role of the right hemisphere in cerebral activation may be linked to the hemispatial neglect syndrome associated with right hemispheric lesions which had been described in the paper by Heilman and Valenstein (1979). They explained that left hemispheric lesions produced less neglect than right hemispheric lesions because the right hemisphere would be capable of activating the left hemisphere. Alternately, right hemispheric lesions would produce a bilateral (although asymmetrical) defect since the left hemisphere would be less capable of activating the right hemisphere and since left hemisphere arousal would also be reduced because of the right hemispheric damage. This hypothesis is in agreement with that of Weintraub and Mesulam (1987) who suggested that the right hemisphere is dominant for distribution of attention in both the left and right extrapersonal hemispace.

Recently, many studies have been conducted to further examine the relationship between the role of the right hemisphere in cerebral activation and hemispatial hypokinesia described by Heilman and Van Den Abell (1979). Two key articles examining this area will now be discussed.

Heilman, Bowers, Coslett, Whelan and Watson (1985) postulated that hemispatial neglect induced by right hemisphere lesions may be associated with a directional hypokinesia, ie., initiation of movements toward the hemispace contralateral to the lesion is affected more than movements toward the lesion. Their study involved six patients with hemispatial neglect caused by right hemisphere damage, seven with left hemisphere damage and no neglect, and twelve controls. The subjects were required to use the hand ipsilateral to their lesion to move a wooden handle along a fixed linear pathway in the horizontal plane. They were instructed to move as quickly as possible at the sound of a tone. The subjects were tested on a total of 60 movements to the left and 60 to the right over two consecutive days. The two dependent variables were reaction time and movement time.

The results indicated that, independent of movement direction, the reaction times of patients with neglect after right hemispheric lesions were slower than patients with left hemisphere lesions. In addition, in patients with right hemisphere lesions reaction times of the right hand directed toward the neglected hemispatial field were slower than those directed away from the neglected field. In terms of movement time data, the right hemisphere group were slower than the controls, but they did not show evidence of directional or hemispatial bradykinesia, (ie., there was no difference in movement time to the right or left). In their discussion, Heilman et al (1985) noted that unlike line bisection and cancellation tasks used to assess hemispatial neglect, in this study no stimulus had to be seen or attended to in the left hemispace. Therefore, the asymmetrically slowed reaction time could not be attributed to sensory loss or inattention. They suggested that the explanation for the observed directional hypokinesia was that the left hemisphere activates the areas responsible for producing movements toward the contralateral hemispace while the right hemisphere can activate the areas responsible for inducing movements into either hemispace.

The second recent study examining the role of right hemisphere in cerebral activation as described by Heilman and Van Den Abell (1979) was conducted by Verfaellie, Bowers, and Heilman (1988) and was concerned with the specific nature of this activation. Verfaillie et al (1988) noted that the manner in which incoming information is processed in the brain is modulated by a number of processes, including selective attention and intention. They defined selective attention as the mechanism by which one decides what information to process and how far to process it. Alternatively, they described intention as the mechanisms of motor preparation by which one selectively prepares for action. They questioned whether the role of the right hemisphere in mediating activation reflects a role in selective attention, intention, or both. Their study involved 16 normal subjects who were tested on a choice reaction time task in which they were given preliminary warning stimuli which indicated either where the target stimulus would occur (attentional warning), or which hand they would have to use for responding (intentional warning). The results did not indicate any asymmetry in the processing of attentional information. In contrast, asymmetries were found for the processing of intentional information. That is, on trials with valid intentional information, reaction times were faster with the left hand than with the right hand, while no differences between the hands were found on trials without intentional information. The authors suggested that this observed left hand advantage was due to the intentional manipulation and thus implies a right hemisphere superiority for intention.

Thus, to summarize the reaction time literature it has been demonstrated by several authors that right hemispheric lesions resulted in a slowing of reaction times (DeRenzi and Faglioni, 1965; Benson and Barton, 1970; Howes and Boller, 1975). This reported slowing does not appear to be related to either the size or type of lesion (Boller et al, 1970; Howes and Boller, 1975). Reaction times have been shown to be asymmetrical in nature, in that in patients with right hemisphere lesions reaction times by the right hand directed toward the neglected hemispatial field were slower than those directed away from the neglected field (Heilman et al, 1985). Several theories have been proposed to explain the slowing of reaction times in patients with right hemispheric lesions. Howes and Boller (1975) suggested that there may be focal regions in the non-dominant hemisphere which are critical for reaction time. Nakamura and Taniguchi (1977) proposed that the right hemisphere may play a dominant role in the processing of sensory stimulation in a reaction time task. Heilman and Van Den Abell (1979) postulated that the right hemisphere may be dominant in mediating cerebral activation and suggested this proposed role may be linked to the hemispatial neglect syndromes associated with right hemispheric damage. Finally, Verfaillie et al (1988) suggested that the role of the right hemisphere in cerebral activation is that of mediating intention, which they described as the mechanisms by which one selectively prepares for motor action.

e) Summary

The previous four subsections have examined deficits in central processing associated with right hemispheric lesions. Specific disorders have been described in visual perception, perception of spatial information as well as visual-spatial neglect associated with right hemispheric lesions. In addition, right hemispheric lesions appear to be related to a slowing in reaction times. It has been suggested that the right hemisphere is dominant in mediating cerebral activation and consequently, lesions of the right hemisphere may reduce the readiness to respond to environmental stimuli.

In summary, it would appear that these central processing deficits may negatively affect the psychomotor performance and consequently the ability to perform functional activities of daily living in patients with right hemispheric lesions. In addition, the motor performance of these patients may also be affected by specific deficits in motor output and kinesthetic feedback which are described in the following section.

iii) Motor Output

As stated previously in the description of the information processing approach described by Welford (1977), motor output is the third main feature of the model. According to Martenuik (1976), once the appropriate plan of action has been chosen, a sequence of commands is passed to the effector mechanism which then organizes the response and sends the appropriate motor commands to the muscular system with the net result being motor output. He noted that feedback plays an important role in movement execution since information about the movement can be fed back into the effector mechanism and thus allow, if time permits, corrections to be made in motor output while the movement is still proceeding.

The following section on motor output is divided into five subsections. The first subsection examines whether deficits in motor performance occur in the ipsilateral as well as the contralateral hand following unilateral hemispheric lesions. The second considers the effects of hemispheric lesions on specific parameters of motor performance, such as speed and accuracy. The third deals with the ability of patients with hemispheric lesions to learn a motor task. The fourth discusses the utilization of kinesthetic feedback in patients with hemispheric lesions. The final subsection summarizes the literature on motor output and discusses the suitability of the Tracometer as a measure of psychomotor performance in patients with right hemisphere strokes.

a) Ipsilateral deficits in motor output

According to Haaland, Cleeland and Carr (1977) several investigators have offered evidence that the left hemisphere is more critical than the right in mediating bilateral motor behavior in right handed individuals. Based on this premise, left hemispheric lesions should produce bilateral motor deficits, while right hemispheric lesions should result in motor deficits only in the limb contralateral to the lesion. Studies which have examined this question will now be discussed.

Thomas, Spangler, Izutsu and Peszczynski (1961) noted that in some psychologic functions patients with right and left hemispheric lesions are undifferentiated while in other areas patients with left-sided lesions were given a better prognoses for successful rehabilitation. They conducted an investigation to analyze the possibility of differential performance between patients with right and left C.V.A.'s and a control group on a variety of psychomotor skills using the "uninvolved" or "good" upper extremity. The sample was composed of 20 right C.V.A. patients, 20 left C.V.A. patients and 20 control subjects. The hand functions tested included such tasks as pegboard, tying, hammering, stapling, cutting, hand sewing, and using a screwdriver. The results indicated that overall the various tests used did not discriminate one group from another. Tasks with qualities that tended to favor the dominant hand or two handed function did distinguish subjects with left lesions from the controls and to a lesser extent, patients with right lesions from the controls. The authors concluded that their results did not support the contention that patients with dominant hemisphere involvement have a greater probability for successful vocational rehabilitation than patients with non-dominant or right hemisphere lesions. Based on the findings of this study it does not appear that the motor performance of the uninvolved upper extremity in patients with right and left hemispheric lesions was significantly affected relative to the controls. However, it should be noted that the tasks used in this study were relatively simple and familiar and this may have influenced the results.

Haaland et al (1977) conducted an investigation designed to compare deficits in motor behavior resulting from right or left brain damage to a group of control subjects. Unlike Thomas et al (1961) they noted the importance of using motor tasks that were not dependent on verbal mediation, that could clearly be performed by one hand alone, and were unfamiliar to the subjects. The groups with right or left hemispheric lesions were selected from about 150 patients with a tumor and were matched for age, education and full-scale IQ (WAIS). The six motor tasks used were given in order of degree of complexity and included grip strength, finger tapping speed, static steadiness, vertical groove steadiness, maze coordination and grooved pegboard. In order to assess whether motor deficits were unilateral or bilateral, subjects performed the tasks with each hand individually. The results indicated that group differences were significant only for the two most complex tasks of maze coordination and grooved pegboard. On these tasks the group with left hemisphere damage demonstrated bilateral impairment relative to the control group. Alternately, the right hemisphere group was significantly impaired relative to the control group only with the hand contralateral to the lesion site. The authors concluded that these findings supported the idea that the left hemisphere has a unique contribution to manual control, but this uniqueness is only evident at a certain point in task complexity.

More recently, Haaland and Delaney (1981) conducted an investigation designed to assess intertask differences in two etiological groups by studying the motor performance of stroke and tumor patients with left or right hemisphere damage. The subjects included 26 patients with left C.V.A.'s, 17 patients with right C.V.A.'s, 14 patients with tumors of the left hemisphere, 15 patients with tumors of the right hemisphere, and 40 control subjects. The motor tasks administered were the same as those used by Haaland et al (1977) and subjects were tested for both right and left hand motor performance. Two sets of results are of relevance here. First, while ipsilateral hand motor performance was comparable across the two etiological groups, stroke patients, particularly those with left hemispheric damage manifested greater contralateral impairment than tumour patients. Secondly, ipsilateral hand deficits relative to controls were observed in all brain-damaged groups, regardless of etiology or hemisphere of damage, on all motor tasks except grip strength and finger tapping. The authors noted that this second finding differed from that reported previously by Haaland et al (1977). Haaland and Delaney (1981) stated that the results of Haaland et al (1977) were incorrectly analyzed as they had failed to take into account the pronounced heterogeneity of variance across groups on each of these tasks. When this was done they found no significant difference in ipsilateral hand deficits between the right and left hemisphere groups, in agreement with their present results. The authors concluded that their findings suggested that on complex motor tasks requiring greater sensory-motor action, both hemispheres are necessary for normal performance, regardless of the hand used. Alternately, on simpler tasks (such as finger tapping and grip strength) which do not require continuous sensory-motor communication, deficits are more localized and only contralateral.

From these studies it appears that patients with right hemispheric lesions do not demonstrate deficits in the limb ipsilateral to the lesion on hand function tests involving simple familiar tasks (Thomas et al, 1961; Haaland and Delaney, 1981). Alternately, on more complex motor tasks patients with right hemispheric lesions demonstrate bilateral impairments (Haaland and Delaney, 1981). It was suggested by Haaland and Delaney (1981) that on complex motor tasks involving greater sensory-motor action both hemispheres are necessary for normal performance, regardless of the hand used.

b) <u>Effect on speed and accuracy</u>

The second subsection dealing with disorders in motor output examines the effects of hemispheric lesions on two specific parameters of motor performance, speed and accuracy.

Wyke (1967) conducted an investigation which examined the effect of unilateral cerebral lesions on the rapidity of voluntary movements of the right and left arms during single arm movements and repetitive movements. Subjects consisted of 20 patients with right lesions, 18 with left lesions and 30 healthy controls. The task measuring single limb movement time involved a typical "jump reaction time" situation in which the subject, on the presentation of a light, moved his hand from a rest across a distance to depress a target key. To measure the actual time required to perform the arm movement alone the visuomotor reaction time was subtracted from the total response time. The task measuring repetitive movements involved tapping alternately left and right of a line for 15 second intervals. For both tests, the left and right arms were tested independently for all subjects. The results indicated that relative to the controls left-sided lesions produced significant slowing of the arm contralateral to the lesion, with a lesser degree of slowing in the ipsilateral arm, whereas right sided lesions produced slowing only of contralateral arm movements only. In addition, it was found that the performance of a single movement by the patient group was slower in relation to the control group than the performance of repetitive movements and this difference was more evident in the right arms of patients with left sided lesions.

In her discussion of these findings, Wyke (1967) observed that the ability to execute a single movement rapidly and accurately depends on the visual perceptual input reinforced by the sensory information provided by the cutaneous and articular receptors in the moving limb. Consequently, she suggested that single movements may be selectively slowed down due to the presence of perceptual alterations of spatial orientation that are known to occur with lesions of the parietal area. In the case of repetitive movements, she suggested that the performance showed a relatively lesser degree of slowing because the sensory information from the moving limb is supplemented by the auditory input from the tapping noise and this sensory input was not disturbed. The author noted it had previously been suggested that acoustic information might contribute to the regulation of a sequence of purposeful skilled movements when other sources of sensory information are lacking. In terms of the different defects produced by left and right-sided cortical lesions she suggested this might be explained by the fact that ipsilateral control does not exist from the right cerebral hemisphere but added that further research was needed to reach a more definite explanation of such laterality effects.

Wyke (1968) noted that previous experimental investigations of disorders of motor ability associated with localized lesions in man had paid little attention to the analysis of complex limb movements that required timing and precision. She conducted a study designed to provide a quantitative measure of the alteration of such movements in a group of patients with unilateral brain lesions as compared to a control group. The subjects consisted of 20 patients with right lesions, 17 patients with left lesions and 30 control subjects. The task used was a modified version of the Purdue hand precision apparatus. Subjects were scored on the total number of correct responses for three 30 second trials for each hand independently. The results indicated that relative to the controls, the left and right-sided lesions produced significant alterations in the ability to perform precise movements in both the ipsilateral as well as the contralateral arm to the lesion. However, the results indicated that if patients with field defects were excluded, then the impairment was only contralateral in patients with right-sided lesions, while it remained bilateral in patients with left sided lesions. The author noted that this supported her previous findings regarding the effects of hemispheric lesions on speed of movement, that right hemispheric lesions produced contralateral deficits only, but felt that confirmation of these findings would require an objective evaluation of the influence of field defects in the perception of the targets.

In a later study, Wyke (1971b) examined the effects of brain lesions on the rapidity of bilaterally synchronous tapping movements and the precision of movements requiring manipulative skill. The subjects consisted of 20 patients with right hemispheric lesions, 20 patients with left hemispheric lesions and 20 control subjects. For the tapping task the apparatus employed consisted of two 10 cm. square plates placed 7.5 cm. apart. The Purdue pegboard test was employed for analysis of precise arm movements. The findings of interest here were the group comparisons between left and right arm performance. The results on the tapping task indicated that left hemispheric lesions produced significant impairment in the rapidity of repetitive movements with the ipsilateral as well as the contralateral arm, whereas right-sided lesions produced impairment in the contralateral arm only. These findings confirmed the earlier findings of Wyke (1967). The findings in the test of precise arm movements indicated that there were significant bilateral impairments in the presence of right as well as left-sided hemispheric lesions. These findings were in agreement with those of Wyke (1968) when the data was analyzed including the patients with field defects.

Thus, based on these findings, it appears that right hemispheric lesions produce deficits relative to controls in rapidity of movements in the limb contralateral to the lesion, but not in the ipsilateral limb (Wyke, 1967, 1971b). Alternately, in terms of precision of arm movements, right hemispheric lesions appear to produce deficits in the limb ipsilateral as well as contralateral to the lesion when patients with visual field defects are included (Wyke, 1968, 1971b). Wyke (1971b) suggested that this difference may occur because the performance on tasks requiring the precision of movements involves various elements which are likely to require complex sensorimotor integrations within the two cerebral hemispheres, regardless of the hand used to perform the task (Wyke, 1971b). She concluded that until accurate measurement of these elements is possible, speculation regarding mechanisms involved in impairment of complex bimanual precise movements in patients with unilateral cerebral lesions is pointless.

c) <u>Effect on motor learning</u>

This subsection discusses studies which have examined the ability of patients with hemispheric lesions to learn motor tasks.

Wyke (1971a) conducted a study which examined the ability of patients with unilateral cerebral lesions to learn a task requiring the precise coordination of movements of the left and right arm with one another. The subjects included 20 patients with right-sided lesions, 20 with left-sided lesions and 20 control subjects. The task used was a two-arm tracing apparatus which consisted of a pen mounted on the intersecting axis of two movable bars. The pen was moved by simultaneous manipulation of the two bars and the subjects were required to draw a star between the preprinted lines of a dual star pattern. The results indicated that all patients showed significant improvement in their performance with task repetition both in the number of errors made and the time taken to complete the task, but the pattern varied in relation to the cerebral lesion. Patients with left-sided lesions were significantly inferior to normal subjects in their ability to learn as well as in the proficiency ultimately achieved in the bimanual task. According to the author, these patients appeared to make initial satisfactory sensori-motor adaptations to the new task but further improvement in performance was limited by their inability to integrate the separate movements required into an adequately coordinated pattern. Alternately, patients with right-sided lesions showed only minor deficiencies in learning during practice and the degree of proficiency ultimately achieved was not significantly different from that of the control group. The author noted that overall, patients with right sided lesions demonstrated a pattern of task learning similar to normal subjects with only a minor impairment of the processes of initial adaptation to the task.

A second study which examined the ability of patients with unilateral brain lesions to learn a motor skill was conducted by Heap and Wyke (1972). This investigation was primarily concerned with an analysis of degrees of efficiency and rate of improvement on a task involving unimanual motor performance, the pursuit rotor. The subjects consisted of 20 patients each with right and left hemispheric lesions and 20 control subjects. All subjects performed 10 trials of 15 seconds each and the left and right arms were tested independently. The subjects in each group were further subdivided into two groups: those who started the test with the right arm followed by the left (R-L sequence), and those who carried out the test in the reverse sequence (L-R sequence). The results indicated that with the group of patients with right-sided lesions no significant improvement was evident with either hand when the hand was first in the testing sequence, although there was a significant improvement with both arms when they were second in the testing sequence. Alternately, patients with left-sided lesions on the whole showed improvement with task repetition. The authors suggested that the impairment in visuo-spatial abilities which are known to occur in patients with right-sided cerebral lesions may have limited the increase in proficiency with task repetition of this group since it is thought that "non-motor" abilities (ie., verbal and spatial) play a role in early learning, but their contribution decreases with practice relative to the "motor abilities".

Thus, based on these studies, it appears that in terms of learning a motor skill involving visual-spatial abilities, patients with right hemispheric lesions may demonstrate an initial deficit in this area. However, with repetition, this deficit may eventually be overcome (Wyke, 1971a; Heap and Wyke, 1972).

d) Effect on kinesthetic feedback

The inability of patients with cerebral disease to sustain simple motor activities which are initiated on command was called "motor impersistence" by Fisher (1956) who described it in 10 patients with lesions involving the right hemisphere. A follow-up study conducted by Joynt, Benton and Fogel (1962) involved 74 control subjects and 101 brain damaged patients who were given a battery of nine tests to assess motor persistence. The tests included such things as keeping the eyes closed, protruding the tongue, keeping the mouth open, and squeezing a dynamometer. The findings of this investigation indicated that "motor impersistence" was more closely associated with right-sided than left-sided cerebral lesions. It was also noted that this motor disturbance was associated with the presence of general mental impairment. Joynt et al (1962) concluded that the phenomenon of "motor impersistence" was another example of the oscillation in level of function which is frequently encountered in patients with cerebral disease.

Carmon (1970) suggested another explanation for this phenomenon, in view of the evidence which pointed toward specialized functions of the right hemisphere in man. He noted that the role of the right hemisphere in various activities which have spatial determinants has been well documented. He also noted that the maintenance and precision of motor activities in healthy subjects has been shown to be a function of kinesthetic sensory feedback. He reasoned that impaired performance on motor activities could result from damage to the central mechanisms which process the sensory feedback from the receptors. Thus, Carmon (1970) proposed a hypothesis which suggested that since kinesthetic sensation supplies information about the spatial location of the body parts, damage to the right hemisphere would result in impairment in the execution of sustained motor acts or "motor impersistence".

In order to investigate this hypothesis, Carmon (1970) conducted a study which compared the ability of patients with lesions of the right and left hemispheres and control subjects to utilize controlled amounts of sensory kinesthetic feedback in order to sustain a precise position of the upper extremity. The subjects included 20 patients with right hemispheric lesions, 20 with left lesions, and 20 control subjects. The apparatus consisted of a solid state proximity detector developed by the author which reacted to the approximation of a finger. Patients were required to approximate the index finger to a distance between two and five mm. from the detector. This was done without looking at the detector directly but by looking at a dial where the range was calibrated and marked. The task was performed in three conditions: 1) with kinesthetic feedback resulting from 450 gms. of pressure on the fingertip, 2) with kinesthetic feedback resulting from 150 gm. of pressure on fingertip, and 3) no kinesthetic feedback when the finger alone was approximated, with no pressure on the fingertip.

The test was carried out only with the hand ipsilateral to the hemispheric lesion in the patient groups. All subjects were scored for the time in seconds that their finger was not in the marked distance range during the sixty second period given for each of the three conditions.

The results indicated that increasing amounts of kinesthetic feedback, in the form of increased pressure on the fingertip, significantly improved the performance in the control group and the left hemispheric group but no such improvement was noted in patients with right hemispheric lesions. The author concluded that results of this study supported the hypothesis that "motor impersistence" is due to an impairment of a cerebral mechanism which utilizes spatial sensory information in the form of kinesthetic feedback to control sustained movements and this impairment is more closely linked to right hemispheric lesions than left (Carmon, 1970).

In one recent paper, Nishizawa and Saslow (1987) stated that relatively few studies have assessed asymmetry in the processing of kinesthetic input. They conducted a study designed to examine hemispheric differences in kinesthesis in normal subjects. Their subjects included 64 right handed college students. The test used measured unimanual kinesthetic discrimination of right and left thumb angular position for both active and passive movements. The results indicated that the left thumb had more sensitive angular position discriminability than the right thumb in right handed subjects. Passive versus active movements were not found to be related to the lateralization effect. The authors suggested that this lateralization effect may be a result of different processing of spatial information in the right and left hemispheres and concluded that this confirmed the right cerebral hemisphere dominance of spatial information processing by kinesthesis. Interestingly, this conclusion based on a study involving normal healthy subjects concurs with that of Carmon (1970) previously described.

e) Summary

Based on these studies which have examined various aspects of motor output in patients with hemispheric lesions it appears that there are some clear deficits associated with right hemispheric lesions and these will now be summarized.

In terms of whether deficits in motor performance occur in the ipsilateral as well as the contralateral hand following right hemispheric lesions, the literature describes two main findings. It appears that on hand function tests involving simple familiar tasks patients with right hemispheric lesions do not demonstrate motor deficits in the limb ipsilateral to the lesion (Thomas et al, 1961; Haaland and Delaney, 1981). However, on more complex motor tasks, patients with right-sided lesions appear to demonstrate performance impairments in both upper limbs (Haaland and Delaney, 1981). It is suggested that on more complex motor tasks involving greater sensory-motor action both hemispheres are necessary for normal performance, regardless of the hand used (Haaland and Delaney, 1981).

Studies examining the effects of right hemispheric lesions on the parameters of speed and accuracy have indicated that right hemispheric lesions produce deficits relative to controls in rapidity of movements in the upper limb contralateral to the lesion but not the ipsilateral limb (Wyke, 1967, 1971b). Alternately, in terms of precision of arm movements, right hemispheric lesions appear to produce deficits in the ipsilateral as well as contralateral limb to the lesion (Wyke, 1968, 1971b). It is suggested that this difference may occur because performance on tasks involving the precision of movements involves various stages and consequently requires complex sensorimotor integration within the two cerebral hemispheres, regardless of the hand used to perform the task (Wyke, 1971b).

In terms of learning a motor skill involving visual-spatial abilities, it appears that patients with right hemispheric lesions may demonstrate an initial deficit in this area. However, the research indicates that with repetition this deficit may eventually be overcome (Wyke, 1971a; Heap and Wyke, 1972).

In terms of utilization of kinesthetic feedback it appears that patients with right hemisphere lesions exhibit specific deficits in this area described as "motor impersistence" which is a term used to describe the inability of patients with cerebral disease to sustain simple motor activities which are initiated on command. One hypothesis which has been proposed to explain this phenomena and has been supported by research findings suggests that "motor impersistence" is due to an impairment of a cerebral mechanism which utilizes spatial sensory information in the form of kinesthetic feedback to control sustained movements and for some reason this impairment is more closely linked to right hemispheric lesions than left (Carmon, 1970).

The apparatus proposed for the present study is the Tracometer which is a subject-paced complex motor task which appears to be an appropriate instrument to use in the measurement of psychomotor performance in patients who have sustained right hemisphere strokes. Some of the advantages of using the tracometer for the present study will now be described.

Previous research has demonstrated that the Tracometer can be used to obtain performance measures with a high degree of internal validity and test/retest reliability (Buck et al, 1981). In addition it meets the criteria of subject acceptability and experimenter convenience while collecting a large amount of data in a short period of time. Most of the studies which have examined various aspects of motor performance in subjects with hemispheric lesions have utilized relatively simple motor tasks and were focused on specific aspects of the skill. According to Buck et al (1981), one of the important advantages of the Tracometer as a measure of motor performance is that it provides discrete measures of more than one aspect of skill. This fact makes the performance on the Tracometer particularly relevant to the study of functional ability since each function is in itself a complex motor task.

It has been observed that performance on the Tracometer improves with practice, with the greater improvement occurring over the first four trials, each of 100 responses (Buck et al, 1981). Thus, repeated performance on the tracometer provides a measure of the subject's ability to learn a complex motor task. By including a total of three blocks of four trials the tracometer provides information not only about the individual's ability to learn, but also performance with additional and extended practice.

The Tracometer has another characteristic which would appear to make it particularly suitable for examining the phenomena of visual-spatial neglect in patients with right hemisphere lesions. Since the movements of the pointer and the steering wheel are in opposite directions, variations in performance between target lights in the left and right visual fields may provide some indication as to whether these differences are due to visual deficits or hemispatial hypokinesia as proposed by Heilman and Valenstein (1979).

Finally, previous research findings on the Tracometer involving a normal healthy population have indicated that, at least initially, the non-preferred hand compared to the preferred hand was superior in performance in terms of total response time, non-overshoot movement and overshoot movement times (Parker-Taillon and Kerr, 1988). It has been proposed by Todor and Doane (1978), that the motor performance of each of the hands mirrors the dominant processing mode of their contralateral hemisphere. Thus, it is suggested that performance on the Tracometer may to a large extent involve specific functions dominated by the right hemisphere. Consequently, it is felt that a lesion in this region would result in deficits in certain aspects of motor performance on the Tracometer.

Chapter III

Methodology

Subjects

The experimental group consisted of 10 right hand dominant subjects who had sustained a right hemisphere stroke. This group included five females and five males. The age range of the experimental subjects was from 58.3 to 79.8 (mean age = 68.1; S.D. = 6.7). The range for length of time since stroke was from 2 to 26 years (mean = 10.8 years; S.D. = 8.9 years). The Barthel Index scores for activities of daily living ranged from 45 to 100 (mean = 72). The experimental subjects were either In-patients or Geriatric Day Hospital patients from the Elisabeth Bruyere Health Centre who agreed to participate in the study and met the following criteria: 1) had sustained a stroke involving the right cerebral hemisphere at least one year prior to the time of testing and had some degree of left hemiparesis; 2) were free from specific major physical and mental health problems (Parkinson's Disease, Alzheimer's Disease, Diabetes); 3) had not been institutionalized on a long term basis but may have been presently receiving rehabilitation services; 4) were able to follow instructions and had an attention span and activity tolerance of at least 75 minutes. Further details concerning the characteristics for each of the experimental subjects is listed in Table 1.

The control group consisted of ten healthy right handed

Table 1: Characteristics of the Right Hemisphere Stroke Subjects

Subject	Age (Years)	Time since stroke (Years)	Barthel Index (Score)
1	66.1	7	90
2	72.5	26	85
3	69.3	2	90
4	70.8	7	50
5	62.7	24	100
6	67.0	5	45
7	59.8	4	70
8	74.8	18	50
9	58.3	3	65
10	79.8	12	75

subjects ranging in age from 58 to 78 years (mean age = 68.1; S.D. = 6.4). These subjects were all from the Ottawa area and volunteered to participate in this study as control subjects. These individuals were free from specific major physical and medical health problems (Stroke, Parkinson's Disease, Alzheimer's Disease, and Diabetes) and they were matched for age (within 18 months) and gender to the experimental subjects.

Apparatus

The apparatus used to measure psychomotor performance was the National Research Council Tracometer which is a discrete pursuit tracking task (Buck, Leonardo and Hyde, 1981). The tracking unit display (Figure 1) consists of five targets, 2.4 mm in diameter, which are placed 41 mm apart in a semicircular fashion. The task requires the subject to turn a control steering wheel to align a pursuit pointer with a light at one of the five target positions. Once the subject has successfully aligned the pointer with the target light for an uninterrupted period of 200 msec, that light is extinguished and a new one appears at one of the four other positions. One trial consists of a random sequence of 100 target presentations with the limitation that each of the 20 between target movements occurs five times. The task is made more difficult by incompatibility between the rotation of the wheel and movement of the pointer; in that, clockwise

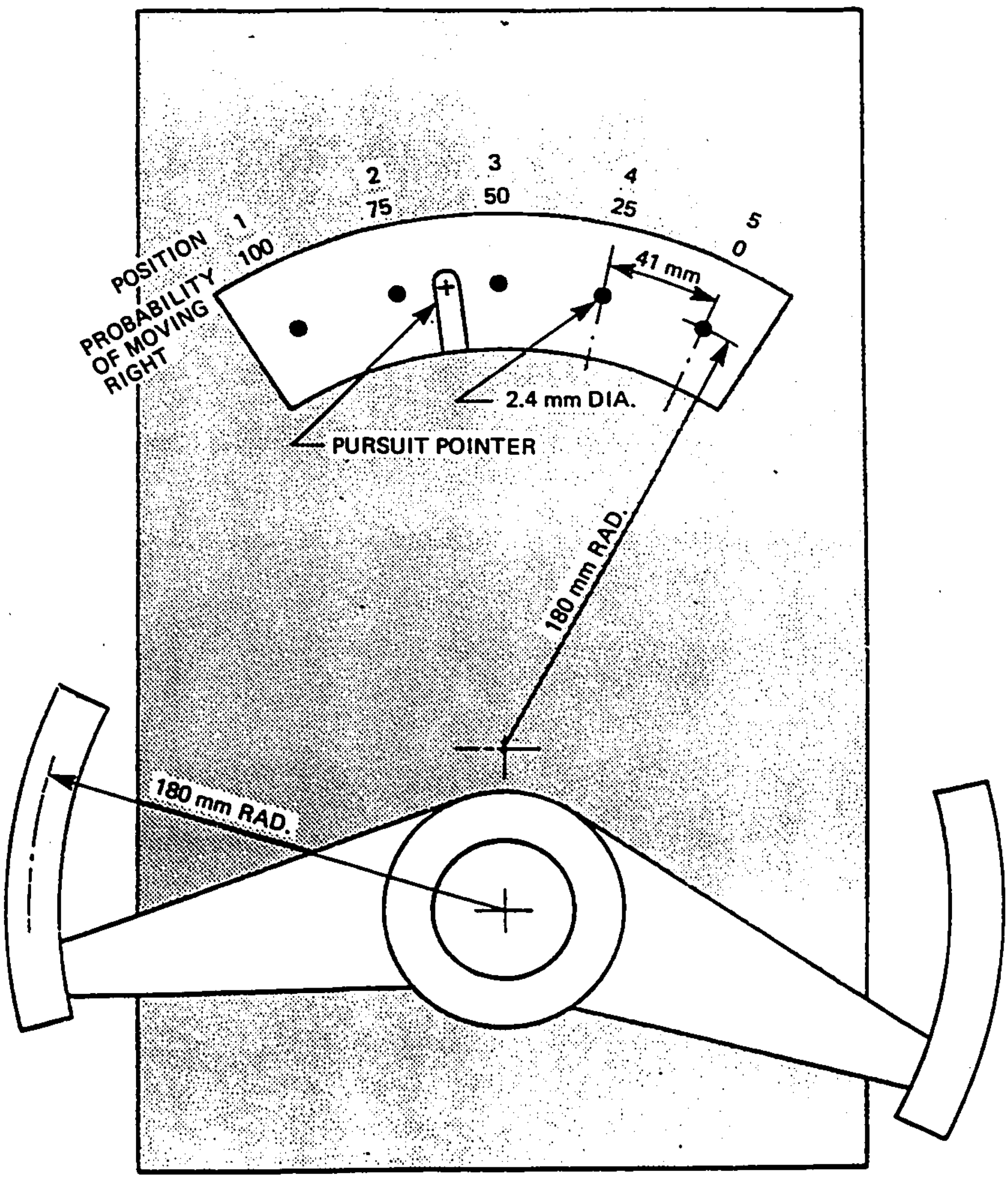

Figure 1: Front view of pursuit tracking task

rotation of the wheel produces a right to left movement of the pointer.

Since the subjects must rest for 200 msec at one target before the next is illuminated, the sequence can be regarded as 100 discrete responses. Any adjustment errors, such as initiating movements in the wrong direction or overshooting the target are recorded but must be corrected in order for the sequence to continue. The difficulty of the task is varied across four movement distances and four levels of directional probability (figure 1). When resting at position one, the probability that the next movement would be to the right is 100%. When resting at position four, the probability of moving right is 25%, but the probability of moving left is 75%. When resting at the central position three, the probability is 50% for moving in either direction.

Procedure

All subjects completed two test sessions on the Tracometer using the right upper limb. The first session consisted of a total of eight trials with each trial involving a random sequence of 100 target presentations. The second session consisted of a total of four trials and was conducted one week later to examine changes in the subject's performance over time and with extended practice. Each trial was performed successively with intertrial pauses of approximately three to five minutes.

Prior to testing, the following procedure was carried out with each subject: 1) the purpose of the study was explained; 2) instructions in performance on the task and the exact number of trials required were given; 3) the subjects were asked to sign a consent form (see Appendix C for information provided to subjects and consent form). Subsequently, a brief interview was conducted with each participant to obtain the following information: age, date of birth, and major medical diagnoses. Each subject was then verbally administered a modified version (i.e., questions 1 to 5) of the Oldfield Handedness Inventory (Oldfield, 1971) as proposed by Bryden (1977) to ensure only right hand dominant subjects were tested (see Appendix B). In addition to the above, the subjects in the experimental group were asked for information regarding the length of time since stroke.

The tracking unit was positioned on a table such that the centre of the unit coincided with the centre of the chair. Subjects were asked to sit directly in front of the tracking unit and the seat height was adjusted such that the target display was just below the line of sight. Indirect ambient lighting was used in order to avoid reflection. All of the experimental subjects were tested in a quiet room at the Elisabeth Bruyere Health Centre. The control subjects were tested in the location most convenient for them, either Elisabeth Bruyere Health Centre, or their homes. Since these subjects were unpaid volunteers and many of them were senior citizens, it was not feasible to test them all in the same location for this study.

Once seated in front of the tracking unit the subjects were instructed to use only the right hand and to hold the vertical hand grip firmly but not too tightly. They were told to hold the wheel of the tracking unit between targets two and three (see Figure 1) until the appearance of the first target light and were reminded to scan in both directions for the subsequent lights. Emphasis was placed on both speed and accuracy of performance. The overall pace of the task was subject dependent in that, a new target was not presented until alignment with the previous target was successfully achieved. The average length of an eight trial test was approximately 75 minutes. The subjects were given knowledge of results at the end of each trial in the form of total number of seconds taken to complete the run.

The current functional ability of the stroke patients was measured using the Barthel Index as described by Granger et al., (1979). These scores were attained by consulting with the attending physician and/or members of the multidisciplinary team who were familiar with the patient in order have scores which reflected the patient's abilities on a regular basis. The Barthel Index (see Appendix A) is a weighted scale measuring performance in self-care (feeding, bathing, personal toilet, dressing, bowel and bladder care) and mobility (transfers, ambulation and stair climbing). Mahoney and Barthel (1965) first described the Barthel Index and it was utilized to measure improvement during inpatient rehabilitation. Since that time, Barthel Index scores have been used in numerous studies of outcomes of patient care in rehabilitation settings (eg., Granger et al, 1979; Wade, Skilbeck and Hewer, 1983; Wade et al, 1984). For instance, Granger et al (1979) found that a score of 60 on the Barthel Index appeared to be a pivotal score where almost all of the stroke patients they studied were independent in basic skills and one-half were functioning with assistance in dressing, transfers and ambulation. Interrater and intrarater reliability for the Barthel Index were recently determined to be .96 and .99 respectively using Spearman rank order correlation coefficient (Loewen and Anderson, 1988), thus adding to the value of this scale as a measure of functional ability.

Design and Analysis

For the purposes of the analysis the twelve trials were divided into three blocks of four trials. The first two blocks were considered to be the initial learning and practice phase. The third block, conducted one week later, was utilized to examine changes in performance over time, and with extended practice.

The main variables of interest were: 1) total response time (TRT); the total time on average to complete a single response, 2) correct reaction time (CRT); the time interval between presentation of the target light and initiation of the response executed in the correct direction, 3) non-overshoot movement time (NOMT); the time interval between the initiation of the response and the beginning of a successful alignment of the pointer with the target, 4) overshoot movement time (OMT); the time interval between the initiation of the response and the beginning of a successful alignment of the pointer with the target in all movements where the subjects went beyond the target before correct alignment was achieved, 5) error score (ES); the percentage of movements initiated in the wrong direction, and 6) overshoot score (OS); the percentage of movements which overshoot the target light before correct alignment.

In order to examine the effects of right hemisphere lesions on psychomotor performance these variables were analyzed using the general form of a 2 X 3 X 4 (Group X Block X Trial) analysis of variance with repeated measures on the trial factor. Performance scores for all analyses were averaged within trials for each subject and simple main effects were used to describe the significant main effects.

In order to examine differences in performance in the left and right visual fields within the right hemisphere stroke group, a descriptive comparison was done using the mean scores for correct reaction times, nonovershoot movement times and overshoot movement times for target lights in the two visual fields.

In order to examine a possible relationship between the motor performance of the patients with right hemispheric lesions on the pursuit tracking task and their functional ability to perform activities of daily living, the scores for the Barthel Index and the mean scores for TRT, CRT, NOMT and OMT were ranked. A comparison between the Barthel Index and each variable was carried out using Spearman's rank correlation coefficient.

Prior to the analyses, a preliminary manipulation of the data was performed in order to remove atypical scores. Buck et al (1981) established error criteria for the very low atypical values of the distribution of data. Most of the atypical values for error time were 1 msec, so an error criterion of 11 msec was set. The error criterion of 11 msec presumably represents limits in the resolution of error movement detection (Buck et al., 1981). For overshoot times, the low values lie between 6 and 15 msec and are associated with misalignments on the near side of the target as distinct from true far side overshoots. The error criterion for overshoot time was set at 51 msec.

In addition to the error criteria, inclusion criteria were established for the high value atypical data. High values (e.g., over 10 seconds in duration) were presumably caused by breaks in attention. Therefore, inclusion criterion were set for both reaction time and movement time data to exclude atypical data which could bias the results.

Chapter IV

Results

Group means and standard deviations for the six main variables over three blocks are presented in Table 2. The Analysis of Variance Tables for Total Response Time, Correct Reaction Time, Nonovershoot Movement Time and Overshoot Movement Time are presented in Appendix D. Results of the analyses of each variables are described separately. In addition, differences in performances in the left and right visual fields, and the results of the comparison of the Barthel Index with the Tracometer performance of the stroke subjects on three main variables are described.

<u>Total Response Time (TRT)</u>

For the total time on average to make a single response, significant main effects were found for: Group ($F(1,18) = 20.99$, $p<.001$); Block ($F(2,36) = 20.73$, $p<.001$); and Trial ($F(3,54) = 18.22$, $p<.001$).

In terms of the significant main effect for Group, it appeared from the group means for TRT (see Table 2) that the Right Hemisphere Stroke (RHS) group was significantly slower than the control group for total response time.

For the main effect for Block, the post hoc analysis indicated that TRT in Block 1 was significantly different than Block 2 ($F(1,18) = 39.22$, $p<.001$) and Block 3 ($F(1,18) = 17.75$, $p<.001$). There was no significant difference in TRT

Table 2: Group Means and Standard Deviations over the Three Blocks for the Main Variables

	Right Hemisphere Stroke		Control	
Variable[a]	Mean	S.D.	Mean	S.D.
TRT*	2655	31.7	1665	18.4
CRT	596	13.7	431	6.1
NOMT*	1780	27.8	1194	19.9
OMT*	2942	56.0	1734	35.8
ES	27.5	.96	25.0	.98
OS	31.7	1.1	21.3	.86

[a] TRT = total response time (msec), CRT = correct reaction time (msec), NOMT = nonovershoot movement time (msec), OMT = overshoot movement time (msec), ES = error score (%), OS = overshoot score (%).

* Groups were significantly different ($p<.05$)

between Blocks 2 and 3. Thus, it appeared that for both groups most of the learning occurred during the first block of four trials (see Figure 2).

The significant main effect for Trial appeared to be the result of the fact that the TRT for both groups is greater in the first trial than the fourth trial of each block of trials (see Figure 2). Generally, the total response time for both groups decreased as the number of trials increased, thus indicating a practice effect. A significant Block x Trial interaction ($F(6,108) = 10.25$, $p<.001$) reflected again that the greatest amount of learning occurred in the first block of four trials.

Correct Reaction Time (CRT)

There was no significant difference between the two groups for correct reaction time. However, the means indicated a tendency for longer correct reaction times in the RHS group. In addition, there was more variability in performance within the stroke group. Significant main effects for CRT were found for: Block ($F(2,36) = 16.46$, $p<.001$); and Trial ($F(3,54) = 18.72$, $p<.001$).

The results of the post hoc analysis for Block indicated that CRT in Block 1 was significantly different than Block 2 ($F(1,18) = 22.62$, $p<.001$) and Block 3 ($F(1,18) = 18.14$, $p<.001$). However, there were no significant differences in CRT between Blocks 2 and 3. These results concur with those

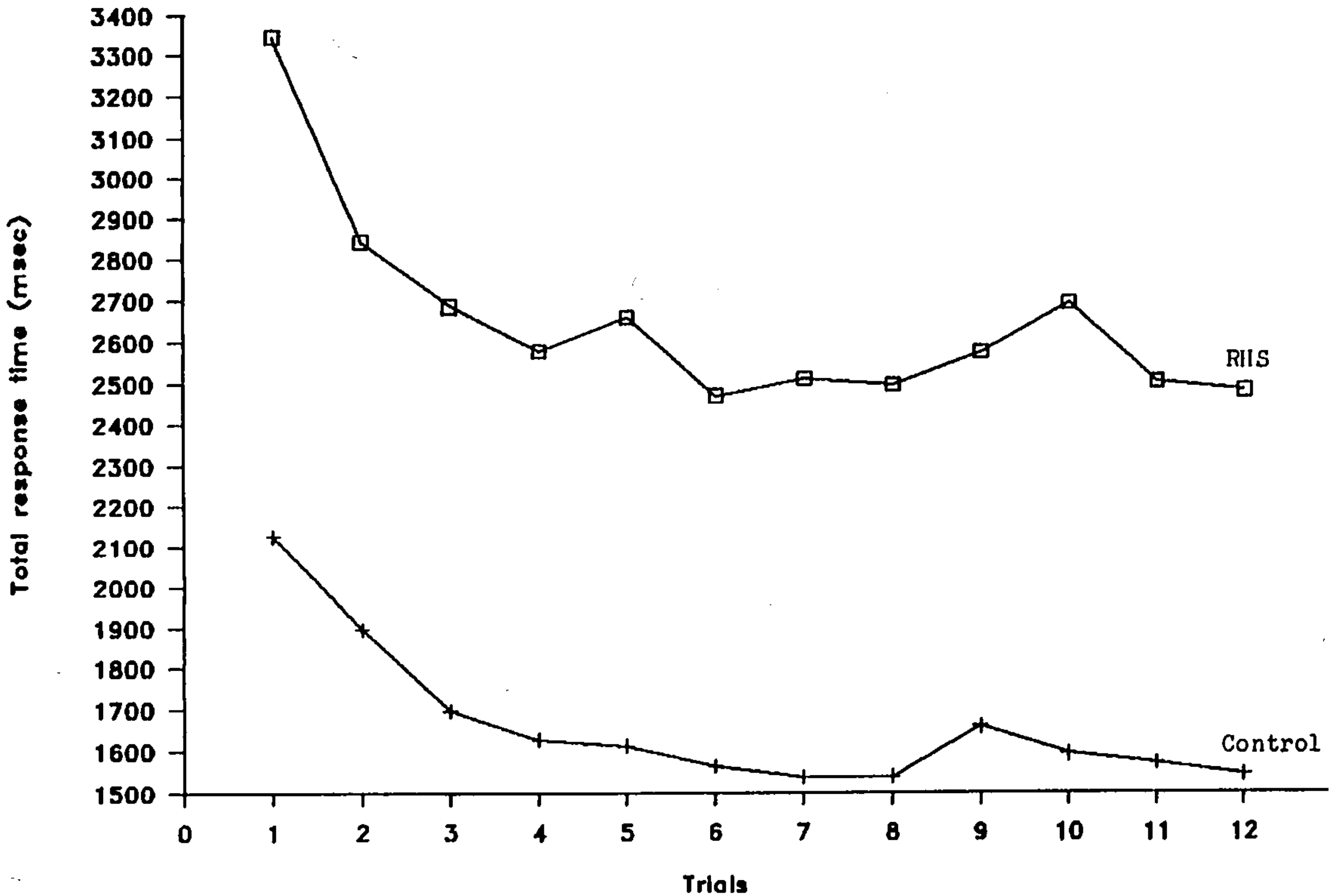

Figure 2: Total response time by group for all twelve trials

for TRT that for both groups most of the learning occurred during Block 1 (see Figure 3). The significant main effect of Trial and significant Block x Trial interaction ($F(6,108) = 9.70$, $p<.001$) also indicated a practice effect similar to that observed for TRT. An examination of the trial means for CRT supported this view.

In order to investigate further the nature of a significant Group x Probability interaction ($F(3,54) = 4.51$, $p<.01$) an analysis was performed on each probability level individually. The results indicated that the two groups were significantly different only at the 100% level of directional probability ($F(1,18) = 4.64$, $p<.05$). Since the two groups differed only at the 100% probability level, it seemed that the RHS group did not react to directional probability information at this level in the same manner as did the control subjects. An examination of the group means for CRT by level of directional probability presented in Table 3 indicated that, whereas the control group reacted faster for highly probable targets and more slowly for less probable targets, the RHS group subjects had their fastest reaction times at the lowest probability level (see Figure 4). When the CRT data for the RHS group was reorganized by target position (see Table 4) it was apparent that the CRTs did not increase as the level of difficulty in terms of directional probability increased. Instead, CRTs appeared to be affected by movement distance required (i.e., the longer movements had

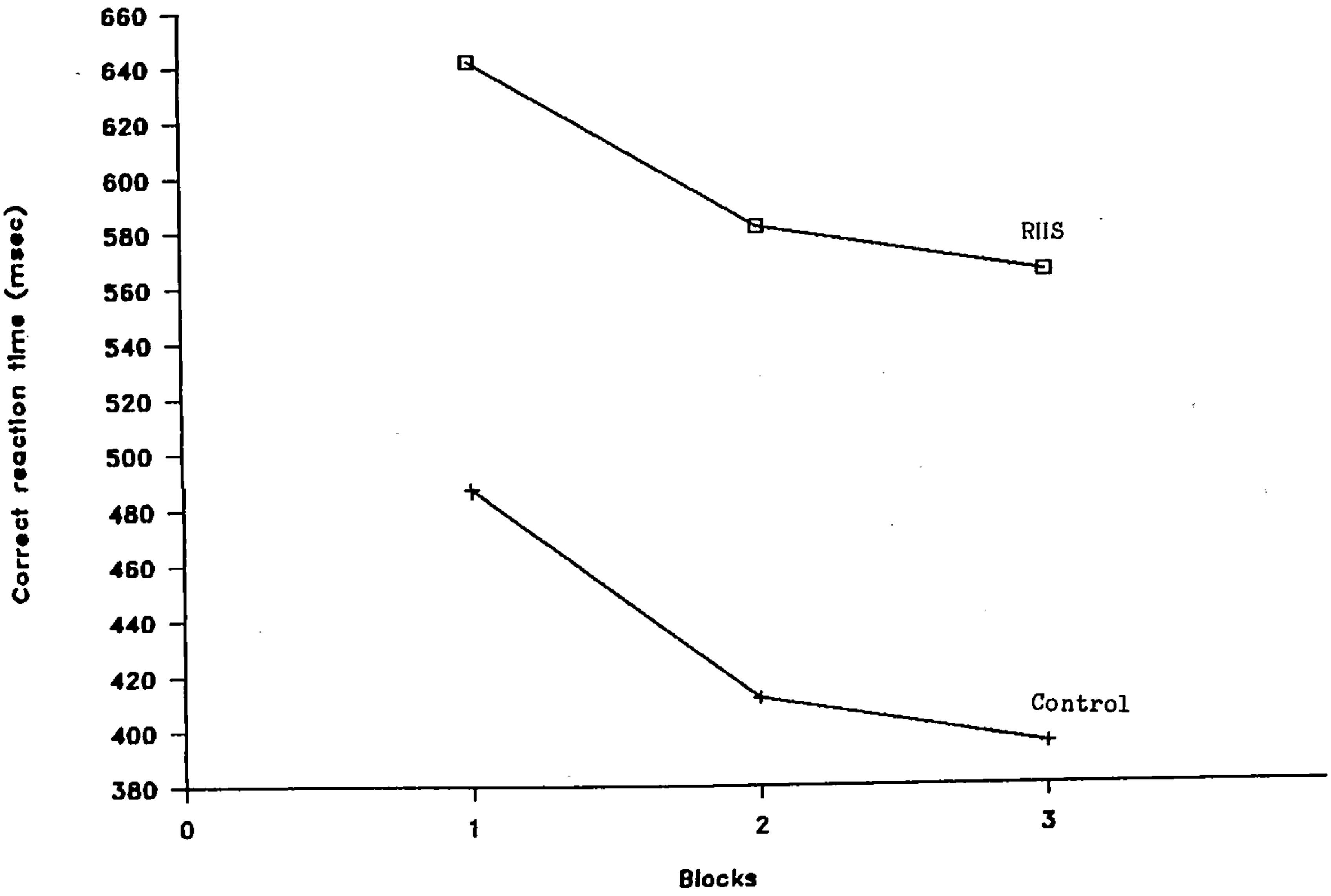

Figure 3: Correct reaction time by groups for all three blocks

Table 3: Group Means and S.D.'s for Correct Reaction Time (in msec) by Level of Directional Probability

	Probability							
	25%		50%		75%		100%	
Group	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
RHS	576	27.5	585	24.4	633	31.0	591	26.7
Control	464	11.3	452	12.3	428	13.2	382	11.0

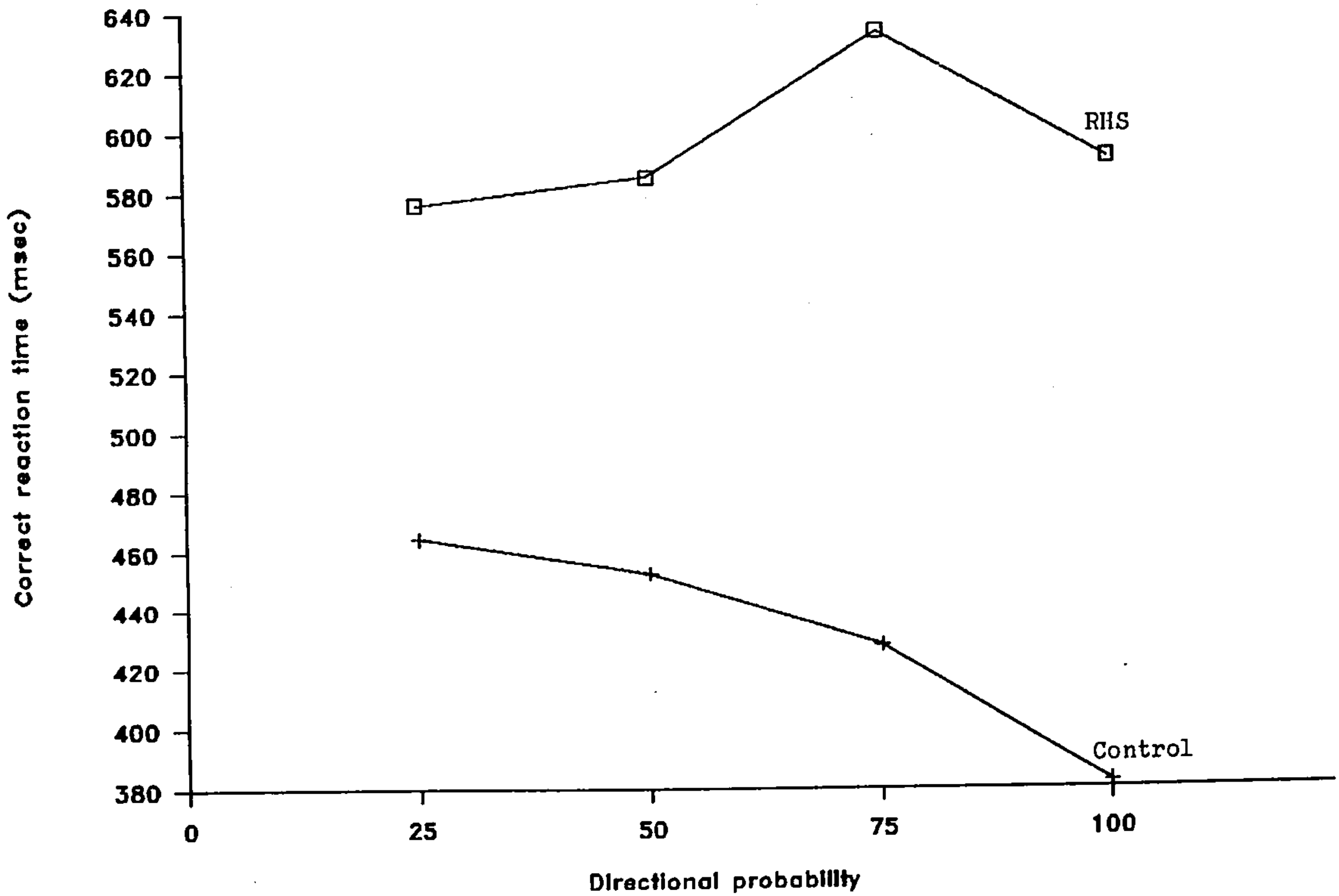

Figure 4: Correct reaction time by group for directional probability

Table 4: Correct Reaction Time (in msec) by Target Position for Right Hemisphere Stroke Group

	Target position				
Starting position	1	2	3	4	5
1	---	549	557	591	557
2	648	---	560	559	598
3	665	612	---	526	558
4	746	697	635	---	514
5	676	627	596	577	---

Note: The upper quadrant represents all movements from left to right. The lower quadrant represents all movements from right to left.

greater CRTs when direction was known). In addition, the CRT of the RHS group appeared to be affected by the movement direction required (i.e., movements from right to left had greater CRTs than did movements from left to right). This effect is described in more detail in the section dealing with performance differences in the left and right visual fields for the RHS group.

Nonovershoot Movement Time (NOMT)

In the analysis of movement time for movements without overshoots (NOMT), significant main effects were found for: Group ($F(1,18) = 10.70$, $p<.01$); Block ($F(2,36) = 6.22$, $p<.01$); Distance ($F(3,54) = 250.99$, $p<.001$) and Trial ($F(3,54) = 11.31$, $p<.001$).

In terms of the significant main effect for Group, it appeared from the group means for NOMT (see Table 2) that the RHS group was significantly slower that the control group (see Figure 5).

For the significant differences between Blocks, the post hoc analysis indicated that NOMT in Block 1 was significantly different from Block 2 ($F(1,18) = 18.64$, $p<.001$). There were no other significant differences between blocks. From these results it seemed that for both groups most of the learning occurred during Block 1. Once again, the significant main effect of Trial seemed to indicate a practice effect. That is, as the number of trials increased, the NOMT decreased.

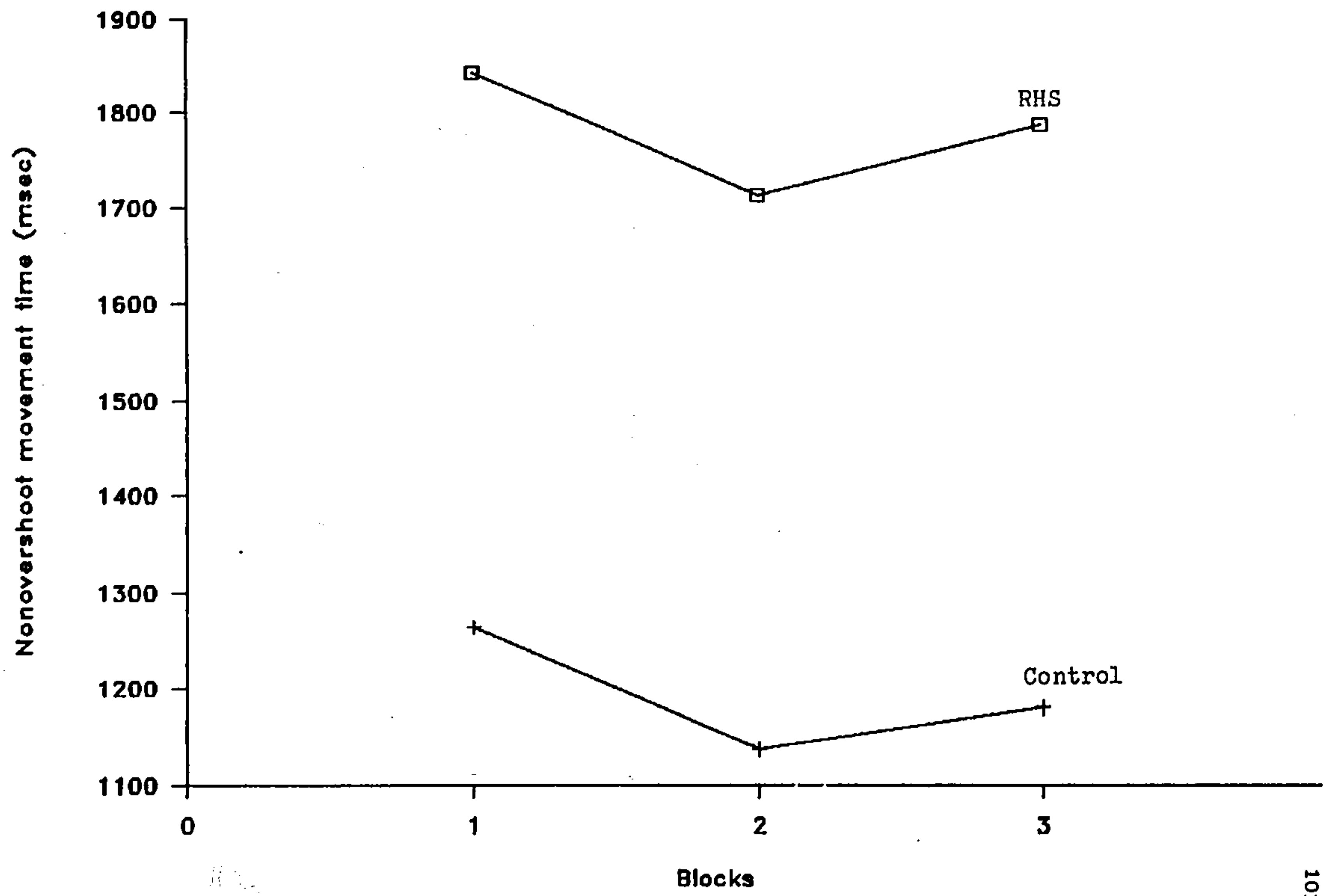

Figure 5: Nonovershoot movement time by group for all three blocks

An analysis of simple main effects for Distance revealed that for all paired comparisons, distance significantly affected NOMT ($p<.001$). An examination of Figure 6 indicates that an increase in the movement distance resulted in an increase in the NOMT for both groups. A significant Group x Distance interaction ($F(3,54) = 4.38$, $p<.01$) appeared to be due to the effect of longer distances on the RHS group. Thus, although the RHS group moved through all distances slower than the control group, the difference in performance was greater for the three longer distances. This was evident from the difference in slopes of the performance curves for the two groups (i.e., the slope is steeper for the curve of the RHS group).

Overshoot Movement Time (OMT)

An analysis of variance for overshoot movement time revealed significant main effects for Group ($F(1,18) = 17.82$, $p<.001$); Block ($F(2,36) = 5.59$, $p<.01$); and Trial ($F(3,54) = 6.29$, $p<.01$). An analysis of variance for Movement Distance could not be done on all three blocks for all four distances since several subjects in both groups did not produce any movement times with overshoots. In order to examine the distance factor an analysis of Block 3 for the three shorter distances produced significant main effects for distance ($F(1,18) = 17.01$, $p<.001$).

In terms of the significant main effect for Group, it

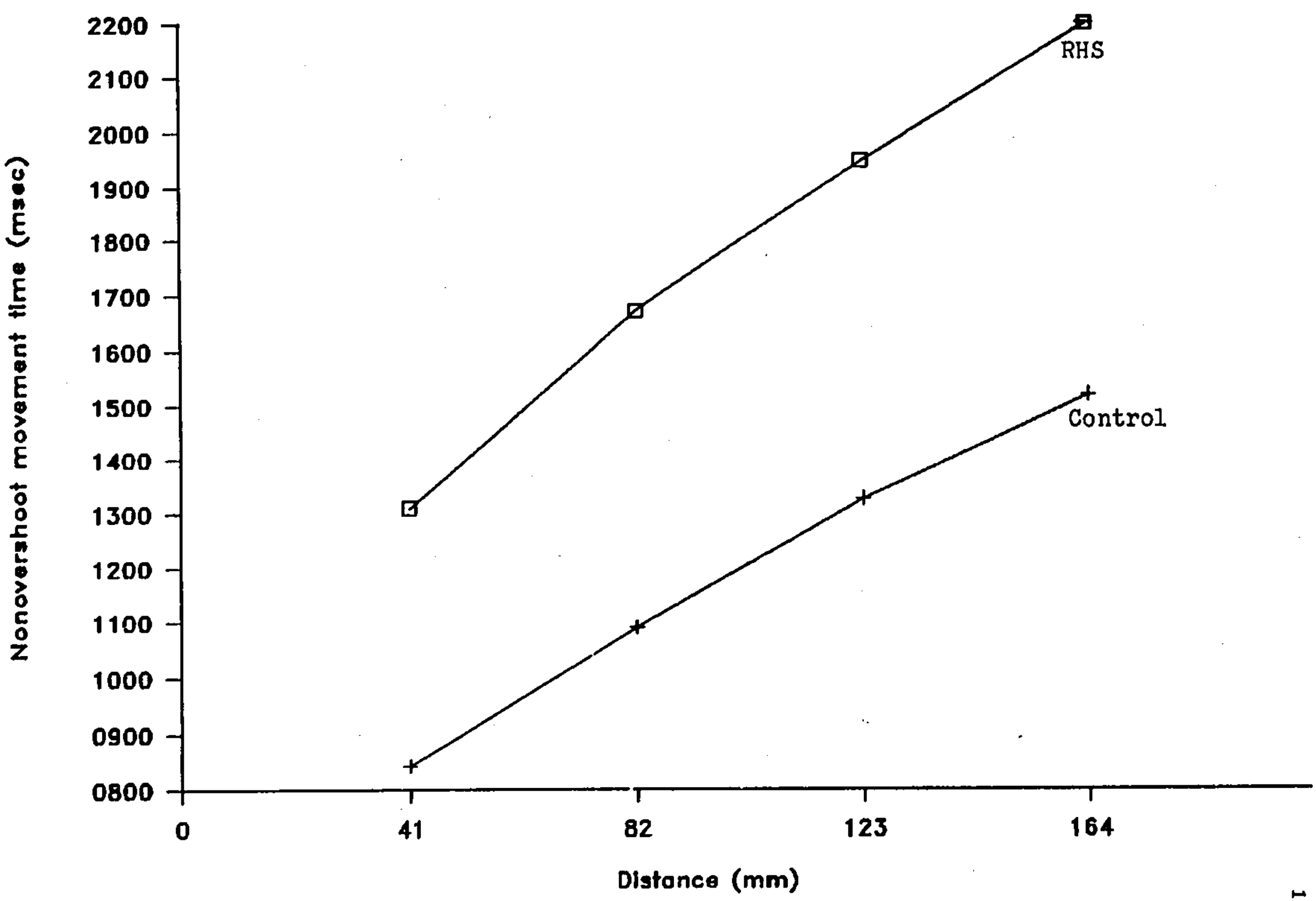

Figure 6: Nonovershoot movement time by group for movement distances

appeared from the means (see Table 2) that the RHS group was significantly slower than the control group for movements with overshoots.

For the significant main effect for Block, an analysis of simple main effects could not be done due to the missing scores for certain subjects. However, from an examination of the performance curves (see Figure 7) it appeared that for both groups the greatest decrease in OMT occurred during the first block of four trials. The significant main effect for Trials and a Block x Trial interaction ($F(6,108) = 4.33$, $p<.001$) for OMT appeared to be due to a practice effect similar to that observed for the other main variables.

An analysis of simple main effects for the three shorter distances in Block 3 indicated that for both groups, OMT was significantly increased for the distances of 82 mm ($F(1,18) = 43.30$, $p<.001$) and 123 mm ($F(1,18) = 24.16$, $p<.001$) when each were compared to 41 mm. However, there was no significant difference in OMT in the comparison of distances 82 mm and 123 mm.

<u>Error Score (ES) and Overshoot Score (OS)</u>

In terms of error score and overshoot score the two groups were not significantly different (see Table 2). Thus, it appeared that the significant group differences for overshoot movement time could not be attributed to a speed-accuracy tradeoff.

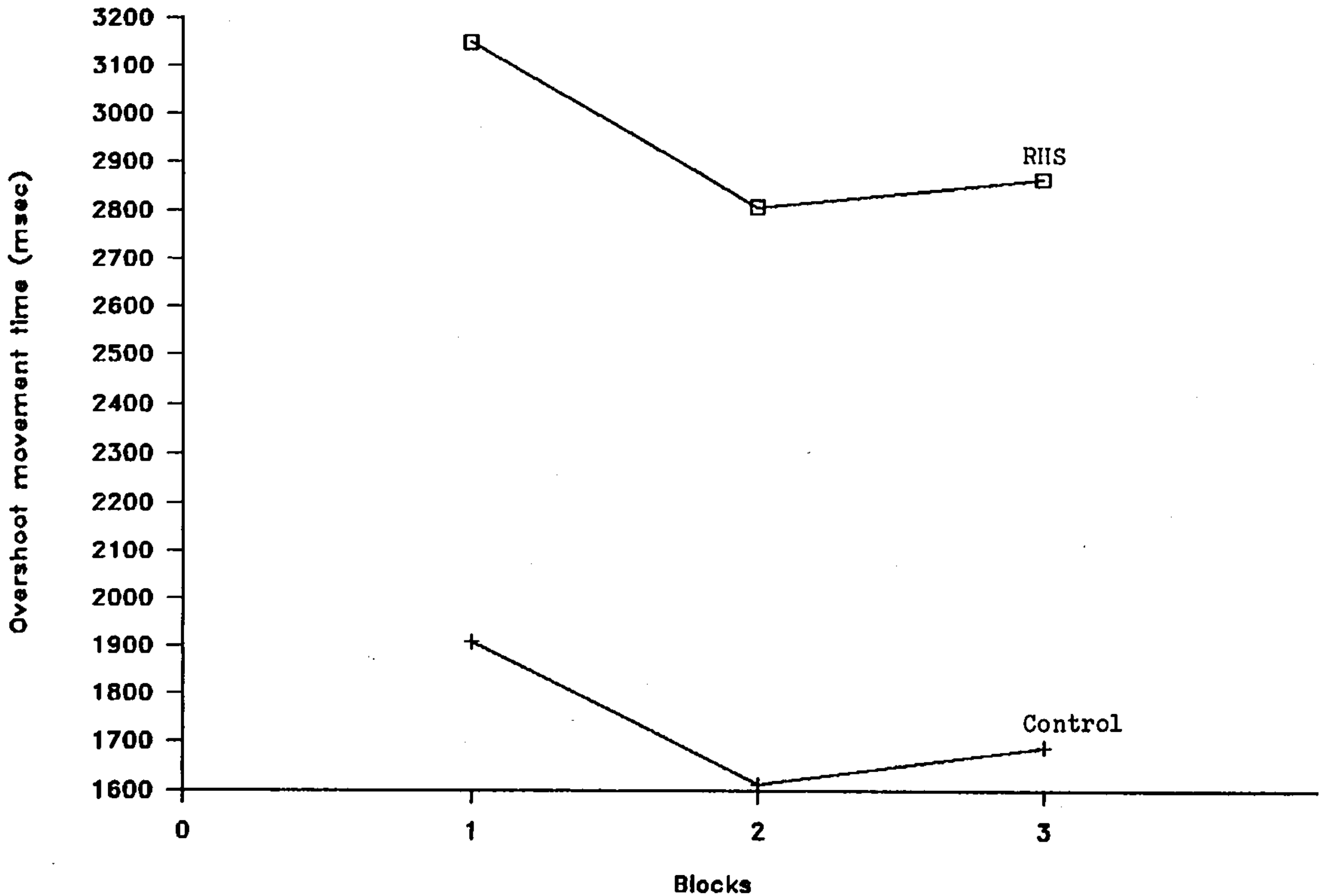

Figure 7: Overshoot movement time by group for all three blocks

Boundary distance is a within-task variable for overshoot score which Buck et al (1981) defined as the relative location of the target with respect to the boundary of the task in the direction of movement. Thus, Boundary Distance 1 represents the target closest to the boundary of the task and Boundary Distance 4 is the furthest, according to the direction of movement. It is interesting to note that examination of the mean overshoot rates for boundary distances by group indicated that both groups tended to make more overshoots when moving to the two targets furthest from the edge of the display, with the target furthest from the boundary having the highest number of overshoots.

Performance Differences in Left and Right Visual Fields

Performance differences in left and right visual fields for the RHS group were examined descriptively using the mean times by target position for the CRT and NOMT variables. Each of these will now be discussed.

In terms of CRT, it has already been noted that the RHS group did not react to directional probability information at the 100% probability level in the same way as the controls. Instead, the CRT's seemed to be affected by the movement distance and direction required. In terms of movement direction, movements from right to left had longer reaction times than did movements from left to right. In addition, the CRT means for movements occurring strictly in the left visual field (i.e., all movements occurring between target positions one and two) were slower than for the corresponding movements occurring solely in the right visual field (i.e., all movements occurring between target positions four and five) (see Table 4). Similar performance variations between left and right visual fields were not present in the control group data (see Appendix E). Thus, while there were no overall significant group differences for CRT, it appeared that the RHS group had longer CRT for movements performed in the left visual fields and for movements made from right to left.

The NOMT means (in msec) by target position for the RHS group are presented in Table 5. An examination of this data indicated a similar pattern as that noted for CRT. That is, the mean nonovershoot movement times were slower for movements performed in the left visual field and for movements made in the right to left direction.

Comparison of Barthel Index Scores and Tracometer Performance

In order to examine a possible relationship between performance on the Tracometer and functional ability for the RHS group, the Barthel scores and mean scores for TRT, CRT, NOMT and OMT were ranked (see Table 6). A comparison of the Barthel Index and each of these variables was performed using a Spearman's rank correlation coefficient. The results indicated that there was no significant correlation between

Table 5: Nonovershoot Movement Time Means (in msec) by Target Position for Right Hemisphere Stroke Group

	Target position				
Starting position	1	2	3	4	5
1	----	1115	1425	1830	2151
2	1584	----	1114	1620	1950
3	2060	1494	----	1276	1782
4	2112	1658	1172	----	1435
5	2263	1884	1345	1143	----

Note: The upper quadrant represents all movements from left to right. The lower quadrant represents all movements from right to left.

Table 6: Rank Order of Barthel Scores and Mean Scores for TRT, CRT, NOMT and OMT for RHS Subjects

		Performance measure			
Subject	Barthel	TRT	CRT	NOMT	OMT
1	2	3	3	7	3
2	4	9	9	9	10
3	2	5	2	4	5
4	8	2	4	1	2
5	1	1	7	2	1
6	10	10	10	10	6
7	6	4	8	3	4
8	8	8	5	5	7
9	7	6	6	8	9
10	5	7	1	6	8

the Barthel Index scores and any of the performance variables. It must be noted that the low number of subjects involved may be an important factor in this outcome and thus these results must be interpreted with caution.

Chapter V

Discussion

The basic purpose of this study was to assess, using a pursuit tracking task, the motor performance of subjects who had sustained a right hemisphere stroke in order to investigate the effects of non-dominant hemisphere lesions on psychomotor performance. The performance of the subjects with right hemisphere strokes was compared to a group of normal subjects matched for age and gender. The results of the study will now be discussed in terms of the eight original hypotheses and the related literature.

Total Response Time (TRT)

The original hypothesis for total response time was supported in this study. The subjects with right hemisphere strokes were significantly slower in TRT than control subjects, using the right hand.

Total response time can be considered an indicator of overall motor performance since it is a measurement of both the central processing and motor output. Thus, it appears that the right hemisphere stroke subjects displayed impairments in motor performance using the so-called "unaffected" right upper limb. This finding confirms that of Haaland and Delaney (1981) who suggested that on complex motor tasks involving greater sensory motor action, both hemispheres are necessary for normal performance, regardless of the hand used.

The significant main effects for Block and Trial indicated that for both groups there was a learning effect in terms of TRT. That is, with increased practice both groups showed improvement and there was no significant difference between the two groups in terms of rate of learning. It should be noted that a similar practice effect as that observed for TRT, was also present for CRT, NOMT, OMT and ES. This is in partial agreement with Wyke (1971a) and Heap and Wyke (1972) who found that, overall, patients with right sided lesions demonstrated a pattern of task learning similar to normal subjects. However, these authors also noted that subjects with right hemisphere lesions demonstrated a minor impairment in the initial adaptation to the task which they attributed to visuospatial impairments. In the present study, while there were significant differences in TRT, the RHS subjects did not appear to display an initial impairment in terms of learning the task as compared to the control subjects. However, this discrepancy may be due to a difference in the definition of trials and methodology.

Correct Reaction Time (CRT)

The original hypothesis for correct reaction time was partially supported in this study. Overall, there were no significant group differences for CRT. However, there were significant differences in how the two groups reacted to directional probability. In addition, CRT appeared to be affected by both the direction and distance of the movement to be performed. Each of these findings will now be discussed.

The finding that the two groups were not significantly different was contrary to most of the previous studies done in this area, such as DeRenzi and Faglioni (1965); Benson and Barton (1970) and Howes and Boller (1975). However, the group means appeared to indicate that the RHS had longer CRTs. The lack of significant difference between the groups may be due to the greater variability within the stroke group. Howes and Boller (1975) also noted a greater variability in reaction time in their group with non-dominant lesions. They felt that this indicated that there may be focal regions within the right hemisphere which are critical for reaction time. Based on their findings, they suggested structures in or near the basal ganglia and the posterior parietal region may be indicated. In the present study, the variability within the RHS group can not be discussed in terms of specific lesion site due to the lack of availability of this type of information for each patient.

While the results of the present study did not indicate a significant main effect for Probability, there was a significant Group x Probability interaction. In looking at the data, it appeared that the control subjects reacted faster for highly probable targets and more slowly for less probable targets, whereas the RHS group had their fastest reaction times at the lowest probability level. Clearly, the RHS group did not appear to react to directional probability information in the same manner as did the control group. Based on this experiment and previous research, several possible explanations arise and will now be discussed.

When the CRT data was reorganized by target position it was apparent that the distance of movement required (when direction was known) appeared to affect the reaction time of the RHS group, but not the controls. This finding for the RHS group was contrary to that of Megaw (1972) who found that movement extent did not influence reaction time within a unidirectional step tracking task in young subjects. The present findings for the RHS group were also contrary to those of Kerr and Teaffe (1987) who had demonstrated, using the Tracometer, that a group of seniors initially had longer reaction times for far versus near targets, but this was overcome by the final block of trials. In their discussion of these findings Kerr and Teaffe (1987) suggested that the seniors treated the two elements of location information (movement direction and movement extent) separately, being able to preprogram direction, but requiring considerable practice to develop a set of preselected responses relative to choices of movement extent. In the present study it is suggested that the RHS group was unable to develop a set of responses appropriate for movement distance, even with considerable practice. One possible explanation for this could be the difficulty in processing spatial information known to occur with right hemispheric lesions.

Kerr and Blais (1985) and Kerr and Blais (1987) also reported a study where movement extent rather than directional probability influenced reaction time. Their study involved the performance of Down syndrome subjects on the Tracometer. In their discussion, Kerr and Blais (1985) noted that Nettlebeck and Brewer (1976) had made a similar observation in retarded adults and had suggested that when stimuli were at a distance these subjects made additional inspections before responding, except when the signals were very discriminable, as in lights at the end of the display. It is interesting to note that the end lights on the Tracometer represented those involved in the most difficult level of probability and both the Down syndrome group in the study by Kerr and Blais (1985) and the RHS group in the present study had their fastest reaction times at this level.

Kerr and Blais (1985) discussed another possible explanation for their subjects not reacting to directional probability. They noted that the reaction times were faster for adjacent lights (ie., moving from 3 to 2 versus 3 to 1) and more so for the end lights. They suggested that this could reflect either a narrow focus of attention, or a specific strategy that was applied regardless of target position, ie., some type of sequential search. In the present study a similar pattern was noted in the reaction time data for the RHS group when it was reorganized by target position (Table 4). Cohen (1973) has suggested that the left hemisphere processes stimuli using an analytic serial procedure while the right hemisphere processes visual stimuli in a holistic, "gestalt", or parallel fashion. Thus, the subjects who had sustained right hemisphere lesions may not have made assumptions in terms of directional probability because they were unable to capture the "gestalt" or overall picture of the task. Rather, they performed by responding to one light at a time in a sequential fashion and even after 12 trials this pattern did not change.

One other interesting finding in terms of reaction time was that CRT's were longer in the RHS group for movements performed from right to left, than the reverse. This finding is discussed in detail in the subsection dealing with performance differences in the left and right visual fields for the RHS group.

Nonovershoot Movement Time (NOMT)

The original hypothesis for nonovershoot movement time was not supported by this study. With regard to executing a correct motor response, the RHS group was significantly slower than the control group. This difference in performance was greater for the three longer distances.

The finding that the two groups were significantly different in terms of NOMT was contrary to that of Wyke

(1967) and Wyke (1971b) who examined the effects of brain lesions on the rapidity of arm movements using tapping tasks. In both studies the results indicated that right hemispheric lesions produced deficits, relative to controls, in the rapidity of movements in the limb contralateral to the lesion, but not in the ipsilateral limb. Haaland, Harrington and Yeo (1987) demonstrated similar findings in a study involving Fitts tapping task in which the complexity was systematically varied. Their results showed no evidence of a right hemisphere role in ipsilateral performance on either the narrow or the wide range task. Thus, the slowness in making movements exhibited by the RHS group in the present study may have been a function of the demands of the Tracometer task. The tapping tasks used in previous studies generally require open loop processing, that is, the movements occur so quickly that they are automatic and are performed without feedback control. Alternately, the Tracometer task requires closed loop processing in which performance involves careful monitoring based on continual feedback. In terms of whether the two hemispheres perform differentially on open loop and closed loop tasks, Carmon (1971) demonstrated that patients with right hemispheric lesions were impaired relative to those with left hemisphere lesions on a slow paced tapping task, which was presumably more closed loop. Thus, the slowness in making movements of the RHS group relative to the control group may have been due to a monitoring difficulty which was most evident with longer movements which required precision.

Overshoot Movement Time (OMT)

The original hypothesis for overshoot movement time was supported in this study. That is, the RHS group were significantly slower at correcting a motor response after having overshot the target light. This effect appeared to be worse for the longer movement distances.

This finding confirmed the suggestion made in the previous subsection that the right hemisphere group appeared to be impaired relative to the control group on movements, especially longer ones, requiring feedback control. The inability of patients with hemispheric lesions to utilize kinesthetic feedback has been previously documented (Carmon, 1970), as has the right hemisphere dominance of spatial processing by kinesthesis (Nishizawa and Saslow, 1987). Thus, it is suggested that the longer overshoot movement times exhibited by the RHS group may be a reflection of their difficulty in utilizing kinesthetic feedback.

Error Score (ES)

The original hypothesis in terms of movements initiated in the wrong direction was not supported by this study. The results indicated that there was no significant Group difference in terms of error score. Thus, it appears that the overall rate of directional errors of RHS group did not differ from the controls.

Overshoot Score (OS)

The original hypothesis for overshoot score was not supported by this study. The results indicated that the two groups were not significantly different in terms of the rate of overshoots. This was surprising, especially in view of the previously discussed difficulty in utilizing kinesthetic feedback observed in patients with right hemispheric lesions. However, this indicated that the significant differences in speed of response between the two groups could not be attributed to the use of alternative strategies in terms of a speed-accuracy tradeoff.

The finding that the two groups did not differ in terms of overshoot score was contrary to the results of Wyke (1968) and Wyke (1971b) which indicated that patients with right hemispheric lesions demonstrated ipsilateral deficits relative to controls in terms of precision as measured by the Purdue pegboard test.

Examination of the mean overshoot rates for boundary distance by group indicated that both groups tended to make more overshoots when moving to the two targets furthest from the edge of the display, with the target furthest from the boundary having the highest number of overshoots. This finding is in agreement with Buck (1976) who noted that for normal subjects performing on the Tracometer the overshoot rate decreased as the distance between the target and the boundary of the display in the direction of movement decreased. In support of his results, Buck (1976) cited Welford (1968) who had hypothesized that a skilled movement consists of a primary distance-covering ballistic movement followed by a secondary corrective movement. Welford (1968) had concluded that the accuracy of ballistic movements depends on some absolute appreciation of end position, rather than distance moved. In the present study, since both groups demonstrated a similar pattern of overshoots by boundary distance, it appeared that RHS subjects may have had some perception of the boundary of the task and, while their movements were slower than the control group, they did not differ significantly in terms of accuracy.

Differences in Right and Left Visual Fields

The original hypothesis that subjects in the RHS group would demonstrate differences in performance between targets in the left and right visual fields was supported, at least descriptively, by this study. It should be noted that while these field differences were observed and are discussed in terms of the hemispatial neglect literature, the RHS subjects in this study were not preselected for manifestations of neglect. The findings of left versus right field differences will be discussed for CRT and NOMT.

For CRT there were two main findings in terms of left versus right differences: 1) movements from right to left had longer CRTs than those from left to right; and 2) CRTs for movements occurring strictly in the left visual field (LVF) were slower than for movements occurring in the right visual field (RVF). In addition, it was noted that the reaction times for movements in the RVF were slower for the RHS group than for the controls.

The result that reaction times were longer for movements from right to left is in agreement with the findings of Heilman et al (1985). However, they described this effect as directional hypokinesia which they defined as a difficulty initiating limb movements toward the hemispace contralateral to the lesion. In their discussion, Heilman et al (1985) noted that their task did not involve seeing or attending to a stimuli in the left hemispace. Consequently, they felt that the asymmetrically slowed reaction time could not be attributed to sensory loss or inattention, but rather was due to a difficulty inducing movements toward the neglected hemispace. In the present study the task required the subjects to attend to visual stimuli. However, due to the indirect relationship of the movement direction of the pointer and the steering wheel, the subjects were required to produce an arm movement toward the right in order to move the pointer to the left. Thus, in this study the reaction times were longer for arm movements produced away from the neglected hemispace. This finding is in disagreement with the explanation of Heilman et al (1985) for their findings. However, it is in agreement with the explanation proposed by Weintraub and Mesulum (1987) who felt that the motor components of neglect were due to a difficulty occurring at the level of active scanning within the extrapersonal space, and not at the level of more elementary motor organization.

In terms of the distribution of attention within the extrapersonal space, it has been suggested by several authors that the left hemisphere may contain neural units for directing attention only to the contralateral right hemispace while the right hemisphere may contain neural units for directing attention to the left hemispace, and to a lesser extent, the ipsilateral right hemispace (Heilman and Van Den Avell, 1979; Weintraub and Mesulum, 1987). In the present study this hypothesis is supported by two findings. First, the RHS subjects had longer reaction times for movements performed in the LVF than the RVF, regardless of the direction of movement. Secondly, the RHS group had longer reaction times than the controls for movements occurring in the RVF. These two findings together appeared to indicate that relative to the controls, the RHS group demonstrated attentional deficits in the contralateral left hemispace and to a lesser extent in the ipsilateral right hemispace.

The results for NOMT for the RHS group also indicated differences in performance in the two visual fields similar to that described for CRT. The finding that movement times were slower for movements produced in a right to left direction was contrary to that of Heilman et al (1985) who noted that while the right hemisphere group were slower overall than the controls, they did not show evidence of directional or hemispatial bradykinesia. This difference could be explained by the fact that in the study of Heilman et al (1985) there was no stimulus to be seen or attended to in the left hemispace. Alternately, the Tracometer required the subjects to attend to a stimuli in the left hemispace and in addition, perform precise movements involving both visual and kinesthetic feedback.

Comparison of Barthel Index and Tracometer Performance

As mentioned, no significant correlation was found between the Barthel Index scores for the RHS group and the Tracometer performance variables of TRT, CRT, NOMT and OMT using Spearman's rank correlation coefficient. The low number of subjects involved may have been a factor in this outcome. Thus, a larger study involving more subjects is required in this area.

It is interesting to note that the mean Barthel Index score for the RHS group was 72 and the majority of these subjects were living in the community. This verifies the findings of Granger et al (1979) that a Barthel Index score of 60 appeared to be a pivotal score in terms of functional independence. In the present study, the findings on the Tracometer indicated that the RHS group had definite differences in performance relative to the controls. Thus, it appears that while the right hemisphere subjects were able to perform the basic functional skills for activities of daily living, they exhibited different strategies and specific deficits relative to controls in the performance of a complex motor task.

Conclusion

Overall, the results of this study suggested that subjects who had sustained right hemispheric lesions demonstrated specific differences in performance on a complex motor task using their ipsilateral hand, when compared to a group of age-matched controls.

Within the limitations of this study, the following conclusions could be made with respect to performance across the test trials:

1) The RHS group showed definite deficits in motor performance using the upper limb ipsilateral to the lesion.

2) It was demonstrated that the RHS group were able to learn a complex motor task, and their rate of improvement did not vary from the controls.

3) The RHS subjects did not appear to use directional probability information for correct reaction time, rather they appeared to be affected by direction and distance of the

movement to be performed.

4) With regard to executing a correct motor response, the RHS group were significantly slower than the control group, particularly for the three longer distances.

5) The RHS group were significantly slower at correcting a motor response after having overshot the target light, particularly for the longer movement distances.

6) The two groups did not differ in terms of the rate of movements initiated in the wrong direction.

7) The two groups did not differ in the rate of overshoots of the target light before achieving correct alignment. This finding rules out the possibility that the differences in the speed of response between the two groups were due to a speed-accuracy trade-off.

8) The subjects in the RHS group demonstrated differences in performance between the left and right visual fields. Both CRT and NOMT were slower in the right visual field than the left. The CRT and NOMT were also slower for movements from right to left than for movements from left to right.

Recommendations

The Tracometer has been demonstrated to have merit as a task which can be utilized to examine the psychomotor performance of patients who have sustained right hemisphere strokes. The following recommendations are made for future research in this area;

1) A study involving a larger sample size would be valuable to examine the relationship between Tracometer performance and functional ability.

2) Right hemisphere stroke subjects should be tested for neglect, and those who demonstrate this symptom should be considered separately from those who do not.

3) Detailed information regarding the exact location of the lesion should be obtained for each stroke subject.

4) A study in which early stroke patients are followed through the process of recovery would be of value to see if the observed deficits change with time.

5) A study involving teaching the right hemisphere stroke patients the strategy in terms of directional probability would be of value to examine how this information is utilized by these individuals.

References

Adams, G.F. Treatment of hemiplegia complicated by sensory defects. Physiotherapy, 1966, 10, 345-349.

Arrigoni, G., & DeRenzi, E. Constructional apraxia and hemispheric locus of lesion. Cortex, 1964, 1, 170-197.

Battersby, W., Bender, M., Pollack, M., & Kahn, R. Unilateral "spatial agnosia" ("inattention") in patients with cerebral lesions. Brain, 1956, 79, 68-93.

Benson, D.F., & Barton, M.I. Disturbances in constructional ability. Cortex, 1970, 6, 19-46.

Benton, A.L. Constructional apraxia and the minor hemisphere. Confinia Neurologica, 1967, 29, 1-16.

Benton, A.L., & Joynt, R.J. Reaction time in unilateral cerebral disease. Confinia Neurologica, 1958, 19, 247-256.

Birch, H.G., Proctor, F. & Bortner, M. Perception in hemiplegia IV: Body surface localization in hemiplegic patients. Journal of Nervous and Mental Disorders, 1961, 133, 192-202.

Blackburn, H.L. & Benton, A.L. Simple and choice reaction time in cerebral disease. Confinia Neurologica, 1955, 15, 327-338.

Bobath, B. Adult Hemiplegia: Evaluation and Treatment. London: William Heinemann Medical Books, 1978.

Boller, F., Howes, D., & Patten, D. A behavioral evaluation of brain-scan estimates of lesion size. Neurology, 1970, 20, 852-859.

Brust, J.C.M. Stroke: Diagnostic, Anatomical, and Physiological Considerations. In E.R. Kandel & J.H. Schwartz (Eds.), Principles of Neural Science. New York: Elsevier/North-Holland, 1981.

Bryden, M.P. Measuring handedness with questionnaires. Neuropsychologia, 1977, 15, 617-624.

Buck, L. Boundary distance effects on overshooting. Journal of Motor Behaviour, 1976, 8, 35-41.

Buck, L., Leonardo, R., & Hyde, F. Measuring impaired performance with the N.R.C. "stressalyser". Applied Ergonomics, 1981, 12, 231-236.

Campbell, D.C. & Oxbury, J.M. Recovery from unilateral visuo-spatial neglect? Cortex, 1976, 12, 303-312.

Carmon, A. Impaired utilization of kinesthetic feedback in right hemispheric lesions. Neurology, 1970, 20, 1033-1038.

Carmon, A. Sequenced motor performance in patients with unilateral cerebral lesions. Neuropsychologia, 1971, 9, 445-449.

Carmon, A. & Benton, A.L. Tactile perception of direction and number in patients with unilateral cerebral disease. Neurology, 1969, 19, 525-532.

Cohen, G. Hemispheric differences in serial versus parallel processing. Journal of Experimental Psychology, 1973, _97_, 349-356.

Corkin, S. Tactually-guided maze learning in man: Effects of unilateral cortical excisions and bilateral hippocampal lesions. _Neuropsychologia_, 1965, _3_, 339-351.

Dee, H.L. & Van Allen, M.W. Simple and choice reaction time and motor strength in unilateral cerebral disease. _Acta Psychiatrica Scandinavica_, 1971, _47_, 315-323.

Denes, G., Semenza, C. Stoppa, E., & Lis, A. Unilateral spatial neglect and recovery from hemiplegia: A follow-up study. _Brain_, 1982, _105_, 543-552.

DeRenzi, E., & Faglioni, P. The comparative efficiency of intelligence and vigilance tests in detecting hemisphere cerebral damage. _Cortex_, 1965, _1_, 410-433.

DeRenzi, E., Faglioni, P., & Scotti, G. Impairment of memory for position following brain damage. _Cortex_, 1969, _5_, 274-284.

DeRenzi, E., Faglioni, P., & Scotti, G. Hemispheric contribution to exploration of space through the visual and tactile modality. _Cortex_, 1970, _6_, 191-203.

DeRenzi, E., Scotti, G. & Spinner, H. Perceptual and associative disorders of visual recognition. _Neurology_, 1969, _19_, 634-642.

DeRenzi, E., & Spinnler, H. Visual recognition in patients with unilateral cerebral disease. _Journal of Nervous and Mental Disease_, 1966, _142_, 515-525.

Fisher, M. Left hemiplegia and motor impersistence. Journal of Nervous and Mental Disease, 1956, 123, 201-218.

Fontenot, D.J. & Benton, A.L. Tactile perception of direction in relation to hemispheric locus of lesion. Neuropsychologia, 1971, 9, 83-88.

Gowland, C. Recovery of motor function following stroke: profile and predictors. Physiotherapy Canada, 1982, 34, 77-84.

Granger, C.V., Dewis, L.S., Peters, N.C., Sherwood, C.C., & Barrett, J.E. Stroke rehabilitation: Analysis of Repeated Barthel Index Measures. Archives of Physical Medicine and Rehabilitation, 1979, 60, 14-17.

Haaland, K.Y., Cleeland, C.S., & Carr, D. Motor performance after unilateral hemisphere damage in patients with tumor. Archives of Neurology, 1977, 34, 556-559.

Haaland, K.Y., & Delaney, H.D. Motor deficits after left or right hemisphere damage due to stroke or tumor. Neuropsychologia, 1981, 19, 17-27.

Haaland, K.Y., Harrington, D.L. & Yeo, R. The effects of task complexity on motor performance in left and right CVA patients. Neuropsychologia, 1987, 25, 783-794.

Heap, M., & Wyke, M. Learning of a unimanual motor skill by patients with brain lesions: An experimental study. Cortex, 1972, 8, 1-18.

Heilman, K.M., Bowers, D., Coslett, H.B., Whelam, H., & Watson, R.T. Directional hypokinesia: Prolonged reaction times for leftward movements in patients with right hemisphere lesions and neglect. Neurology, 1985, 35, 855-859.

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

Heilman, K.M. & Van Den Abell, T. Right hemispheric dominance for mediating cerebral activation. Neuropsychologia, 1979, 17, 315-321.

Howes, D., & Boller, F. Simple reaction time: Evidence for focal impairment from lesions of the right hemisphere. Brain, 1975, 98, 317-332.

Hurwitz, L.J., & Adams, G.F. Rehabilitation of hemiplegia: Indices of assessment and prognosis. British Medical Journal, 1972, 1, 94-96.

Joynt, R.J., Benton, A.L., & Fogel, M.L. Behavioral and pathological correlates of motor impersistence. Neurology, 1962, 12, 876-881.

Kerr, R. Psychomotor Learning. Philadelphia: Saunders College Publishing, 1982.

Kerr, R., & Blais, C. Down syndrome and extended practice of a complex motor task. American Journal of Mental Deficiency, 1987, 91, 591-597.

Kerr, R., & Blais, C. Motor skill acquisition by individuals with Down syndrome. American Journal of Mental Deficiency, 1985, 90, 313-318.

Kerr, R., & Teaffe, M. Aging and the response to changes in task difficulty. Unpublished manuscript, 1987.

Kimura, D. Right temporal-lobe damage. Archives of Neurology, 1963, 8, 264-271.

Kimura, D. Left hemisphere control of skilled movements. CSPLSP/SCAPPS Abstracts, 1985.

Kimura, D., & Archibald, Y. Motor functions of the left hemisphere. Brain, 1974, 97, 337-350.

Lawson, I.R. Visual-spatial neglect in lesions of the right cerebral hemisphere. Neurology, 1962, 12, 23-33.

Lehmann, J.F., DeLateur, B.J., Fowler, R.S., Warren, C.G., Arnhold R., Schertzer, B., Hurka, R., Whitmore, J.J., Masock, A.J., & Chambers, K.H. Stroke rehabilitation: Outcome and prediction. Archives of Physical Medicine and Rehabilitation, 1975, 56, 383-389.

Loewen, S.C., & Anderson, B.A. Reliability of the Modified Motor Assessment Scale and the Barthel Index. Physical Therapy, 1988, 68, 1077-1081.

Mahoney, F.I., & Barthel, D.W. Functional evaluation: The Barthel Index. Maryland State Medical Journal, 1965, 14, 61-65.

Marteniuk, R.G. Information Processing in Motor Skills. New York: Holt, Rinehart and Winston, 1976.

McFie, J., Piercy, M.F., & Zangwill, D. Visual spatial agnosia associated with lesions of the right hemisphere. Brain, 1950, 73, 167-190.

Megaw, E. Direction and extent uncertainty in step-input tracking. Journal of Motor Behaviour, 1972, 4, 171-186.

Mehta, Z., Newcombe, F. & Damasio, H. A left hemisphere contribution to visuospatial processing. Cortex, 1987, 23, 447-461.

Mills, V.M., & Digenio, M. Functional differences in patients with left or right cerebrovascular accidents. Physical Therapy, 1983, 63, 481-488.

Milner, B. Visually-guided maze learning in man: Effects of bilateral hippocampal, bilateral frontal and unilateral cerebral lesions. Neuropsychologia, 1965, 3, 317-338.

Milner, B. Visual recognition and recall after right temporal-lobe excision in man. Neuropsychologia, 1968, 6, 191-209.

Mulley, G.P. Practical Management of Stroke. London: Croom Helm, 1985.

Nakamura, R., & Taniguchi, R. Reaction time in patients with cerebral hemiparesis. Neuropsychologia, 1977, 15, 845-849.

Nettelbeck, T., & Brewer, N. Effects of stimulus-response variables on the choice reaction time of mildly retarded adults. American Journal of Mental Defeiciency, 1976, 81, 85-92.

Nishizawa, S., & Saslow, C.A. Lateralization of kinesthetically guided spatial perception. Cortex, 1987, 23, 485-494.

Newcombe, F. & Ratcliff, G. Long-term psychological consequences of cerebral lesions. In M. Gazzaniga (ed.), Handbook of Behavioral Neurobiology (Vol. 2). New York: Plenum Press, 1979.

Oldfield, R.C. The assessment and analysis of handedness: The Edinburgh Inventory. Neuropsychologia, 1971, 9, 97-113.

Orstein, R.E. The Psychology of Consciousness (2nd ed.). New York: Harcourt, Brace, & Jovanovich, 1977.

Oxbury, J.M,., Cambell, D.C., & Oxbury, S.M. Unilateral spatial neglect and impairments of spatial analysis and visual perception. Brain, 1974, 97, 551-564.

Parker-Taillon, D. & Kerr, R. Manual asymmetries within the performance of a complex motor task. In press, 1988.

Paterson, A. & Zangwill, O. Disorders of visual space perception associated with lesions of the right cerebral hemisphere. Brain, 1944, 67, 331-358.

Piercy, M. & Smyth, V.O.G. Right hemispheric dominance for certain non-verbal intellectual skills. Brain, 1962, 85, 775-790.

Pimental, P.A. Alterations in Communication: Biopsychological aspects of aphasia, dysarthria and right hemispheric syndromes in the stroke patient. Nursing Clinics of North America, 1986, 21, 321-337.

Rose, F.C., & Capideo, R. Stroke: The Facts. Toronto: Oxford University Press, 1981.

Ross, E.D., & Mesulam, M.M. Dominant language functions of the right hemisphere? Prosody and emotional gesturing. Archives of Neurology, 1979, 36, 144-148.

Rudel, R.G., Denckla, M.B., & Spalten, E. The functional asymmetry of Braille letter learning in normal, sighted children. Neurology, 1974, 24, 733-738.

Ryerson, S.D. Hemiplegia resulting from vascular insult or disease. In D.A. Umphred (Ed.), Neurological Rehabilitation. Toronto: C. V. Mosby Co., 1985.

Searleman, A. A review of right hemisphere linguistic capabilities. Psychological Bulletin, 1977, 84, 503-528.

Semmes, J. Hemispheric specialization: A possible clue to mechanism. Neuropsychologia, 1968, 6, 11-26.

Semmes, J., Weinstein, S., Ghent, L., & Teuber, H.L. Spatial orientation in man after cerebral injury: I. Analysis by locus of lesion. Journal of Psychology, 1955, 39, 227-244.

Smith, C.G. Basic Neuroanatomy. Toronto: University of Toronto Press, 1971.

Stern, J.A., Oster, P.J. & Newport, K. Reaction time measures, hemispheric specialization and age. In L.W. Poon (Ed.), Aging in the 1980's. Washington: American Yale Association, 1980.

Thomas, C.W., Spangler, D.P., Izutsu, S., & Peszczynski, M. An analysis of psychomotor responses of adult hemiplegic patients. Archives of Physical Medicine and Rehabilitation, 1961, 42, 185-188.

Todor, J.I., & Doane, T. Handedness and the hemispheric asymmetry in the control of movements. Journal of Motor Behavior, 1978, 10, 255-300.

Vaughan, H.G. & Costa, L.D. Performance of patients with lateralized cerebral lesions II: Sensory and motor tests. Journal of Nervous and Mental Disorders, 1962, 134, 237-243.

Venfaellie, M., Bowers, D., Heilman K.M. Hemispheric asymmetries in mediating intention but not selective attention. Neuropsychologia, 1988, 26, 521-531.

Wade, D.T., Langton-Hewer, R., Skilbeck, C.E., & David, R.M. Stroke: A Critical Approach to Diagnosi, Treatment and Management. London: Chapman and Hall, 1985.

Wade, D.T., Lanton-Hewer, R., & Wood, V.A. Stroke: Influence of patient's sex and side of weakness on outcome. Archives of Physical Medicine and Rehabilitation, 1984, 65, 513-516.

Wade, D.T., Skilbeck, C.E., & Langton-Hewer, R. Predicting Barthel ADL score at 6 months after an acute stroke. Archives of Physical Medicine and Rehabilitation, 1983, 64, 24-28.

Weintraub, S., & Mesulum, M.M. Right cerebral dominance in spatial attention. Archives of Neurology, 1987, 44, 621-625.

Welford, A.T. Fundamentals of Skill. London: Methuen, 1968.

Welford, A.T. Motor performance. In J.E. Birren and K.W. Schaie (Eds.) Handbook of the Psychology of Aging. New York: Van Nostrand and Co., 1977.

Wyke, M. Effect of brain lesions on the rapidity of arm movement. Neurology, 1967, 17, 1113-1120.

Wyke, M. The effect of brain lesions in the performance of an arm-hand precision task. Neuropsychologia, 1968, 6, 125-134.

Wyke, M. The effects of brain lesions on the learning performance of a bimanual co-ordination task. Cortex, 1971, 7, 59-72. (a)

Wyke, M. The effects of brain lesions on the performance of bilateral arm movements. Neuropsychologia, 1971, 9, 33-42. (b)

Appendix A

The Barthel Index

Barthel Index* Subject___________________________

Index item	Pts	Description
Feeding	10	Independent. Able to apply any necessary device. Feeds in reasonable time.
	5	Needs help, ie, for cutting.
Bathing	5	Performs without assistance.
Personel Toilet (grooming)	5	Washes face, combs hair, brushes teeth, shaves (manages plug if electric razor).
Dressing	10	Independent. Ties shoes, fastens fasteners, applies braces.
	5	Needs help but does at least half of task within reasonable time.
Bowel Control	10	No accidents. Able to use enema or suppository, if needed.
	5	Occasional accidents or needs help with device.
Bladder Control	10	No accidents. Able to care for collecting device if used.
	5	Occasional accidents or needs help with device.
Toilet transfers	10	Independent with toilet or bedpan. Handles clothes, wipes, flushes or cleans pan.
	5	Needs help for balance, handling clothes or toilet paper.
Chair/bed transfers	15	Independent, including locks of wheelchair and lifting footrests.
	10	Minimum assistance or supervision.
	5	Able to sit but needs maximum assistance to transfer.
Ambulation	15	Independent for 50 yards. May use assistive devices, except for rolling walker.
	10	With help for 50 yards.
	5	Independent with wheelchair for 50 yards, only if unable to walk.
Stair climbing	10	Independent. May use assisitive devices.
	5	Needs help or supervision.

*Granger et al, 1979.

Total Score ____________

Appendix B

Handedness Questionaire

Handedness Questionnaire*

Name____

Subject Number________________ Sex_______________

Date of birth_________________ Age_______________

Answer the following questions carefully. Imagine yourself performing the activity described before answering each question. Answer by placing a check in the appropriate column to the right of the question.

Which hand do you use:

	Always Left	Usually Left	Both Equally	Usually Right	Always Right
1. To write with	_____	_____	_____	_____	_____
2. To throw a ball	_____	_____	_____	_____	_____
3. To draw with	_____	_____	_____	_____	_____
4. To hold scissors	_____	_____	_____	_____	_____
5. To brush teeth	_____	_____	_____	_____	_____

Total Score_______________

Hand Preference____________________________________

*Source: Bryden, 1977.

Appendix C

Subject consent form

CONSENT FORM

DEPARTMENT OF KINANTHROPOLOGY

UNIVERSITY OF OTTAWA

Dear participant,

Any research involving human subjects requires that volunteers fully understand what will be expected of them during the study before it begins so they may make an informed choice whether or not to participate. What follows is a brief description of the purpose of this research as well as the subjects role in it.

Investigator: Dianne Parker-Taillon
University of Ottawa, Department of Kinanthropology
Advisor: Dr. Robert Kerr
Office: 564-9134

PURPOSE OF STUDY:

This research project involves subjects who have had a stroke more than one year ago which affected the right side of their brain. These subjects will be matched in age and sex to an equal number of subjects who have not had a stroke. Using a motor test the researcher hopes to obtain information about:

a) the effects of this type of stroke on the planning and performance of arm movements.
b) how the ability to perform the motor test compares to the ability to perform activities of daily living.

DESCRIPTION OF PROCEDURES:

- Volunteers in this project are asked to participate in two testing sessions, one week apart, which will be conducted by the investigator, Dianne Parker-Taillon.
- Each testing session will last from 45 minutes to one hour.
- The first testing session will begin with the investigator asking the participant five questions about the hand they use to perform certain everyday activities.
- The participant will then be asked to perform the motor test on a machine called the Tracometer which will now be described.

Information on the Tracometer:

- This machine measures your ability to respond to a stimulus by measuring the time you take to react to a light (reaction time) and the time you take to perform the task, ie, to move towards the target light and turn it off (movement time). This machine also measures errors (starting in the wrong direction) and overshoots (overshooting the target light).
- The machine includes a wheel, a pointer and five lights.

*The wheel and pointer go in oppposite directions which means that when you want to move the pointer to the right, you turn the wheel to the left or vice-versa.
*There is a cross on the pointer. To turn off the target light, you have to cover the light with the cross for an uninterrupted period of 200 milliseconds otherwise the light will not turn off.
*The display shows five target lights that will appear one at a time. No other target will appear before you complete a successful alignment.
*The task is to move the pointer towards the target light and to align it for a period of 200 msec for the light to turn off and for the next one to appear. You are to try to accomplish the task as fast and accurately as you can.
*One trial consists of 100 target movements. The first testing session includes eight trials (total 800 target movements). The second testing session will include four trials (total 400 target movements). You will have a short rest after each trial.
*At the end of each trial, that is after 100 target lights, the system will stop by itself and the investigator will give you the time it took you to complete the trial. The goal is to reduce this time as much as you can.

PLEASE NOTE:

a) This task is designed so that the overall pace of the test is dependent on the participant, in that a new target is not presented until alignment with the previous target is successfully achieved.
b) The researcher wishes to emphasize that while any degree of participation is gratefully appreciated, stopping during the testing sessions, or complete withdrawal from the project at any point will in no way jeopardize the outcome of the research or reflect on the participant.
c) Once the relevent information has been collected, the participants name will be removed from all documents and a number assigned to ensure the participants anonymity. Should the subject or any family members wish to examine the results of the study, these will be available upon request.

Any further information may be obtained by calling Dianne Parker-Taillon at 830-9428 or Dr. Robert Kerr at the University of Ottawa 564-9134.

Thank you,

Dianne Parker-Taillon

Agreement to participate:

I, ______________________________, have read the above and
(volunteers name)
agree that any information I provide may be used for scientific research. I understand that this information will not be publically identified as my own and that confidentiality will be maintained to the greatest possible extent.

Date: ____________________________

Signature of participant: ____________________________

Witness: ____________________________

Appendix D

Analysis of Variance Tables

for

Total Response Time, Correct Reaction Time, Nonovershoot Movement Time and Overshoot Movement Time

Effects of Right Hemisphere Strokes on Psychomotor Performance
Source file: EXPT07.SCO;1 1-SEP-1988 13:37:55

Total response time score (1)
Total response time score (2)
Total response time score (3)
Total response time score (4)
Total response time score (5)

Factor 1 group all 2 levels
Factor 2 subject all 10 levels
Factor 3 block all 3 levels
Factor 4 trial all 4 levels
Factor 5 quint all 5 levels
Scores averaged for following factors
Factor 5 quint

Source	Deviance	df	Variance	F
Between-subjects				
(1) group	58761064.00	1	58761064.00	20.99**
residual	50386676.00	18	2799259.75	
Within-subjects				
(2) block	4424410.50	2	2212205.25	20.73**
(3) grou bloc	40365.52	2	20182.76	0.19
residual	3841459.75	36	106707.22	
(4) trial	2910567.25	3	970189.06	18.22**
(5) grou tria	110411.45	3	36803.82	0.69
residual	2874790.75	54	53236.87	
(6) bloc tria	2239321.25	6	373220.22	10.25**
(7) grou bloc tria	302063.00	6	50343.83	1.38
residual	3932125.38	108	36408.57	
Total	129823254.90	239		

* p<.01 ** p<.001

Effects of Right Hemisphere Strokes on Psychomotor Performance
Source file: EXPT07.SCO;1 1-SEP-1988 13:37:55

Correct reaction time score (1)
Correct reaction time score (2)
Correct reaction time score (3)
Correct reaction time score (4)
Inclusion criteria for reaction times: 1 and 4300
Error criterion: 11

Factor 1 group all 2 levels
Factor 2 subject all 10 levels
Factor 3 block all 3 levels
Factor 4 trial all 4 levels
Factor 5 probabil all 4 levels
Scores averaged for following factors
Factor 5 probabil

Source	Deviance	df	Variance	F
Between-subjects				
(1) group	1625987.38	1	1625987.38	2.87
residual	10210836.50	18	567268.69	
Within-subjects				
(2) block	311077.03	2	155538.52	16.46**
(3) grou bloc	4141.01	2	2070.50	0.22
residual	340200.86	36	9450.02	
(4) trial	137379.86	3	45793.29	18.72**
(5) grou tria	11575.57	3	3858.52	1.58
residual	132126.09	54	2446.78	
(6) bloc tria	136392.56	6	22732.09	9.70**
(7) grou bloc tria	6472.07	6	1078.68	0.46
residual	253181.74	108	2344.28	
Total	13169370.67	239		

* p<.01 ** p<.001

Effects of Right Hemisphere Strokes on Psychomotor Performance
Source file: EXPT07.SCO;1 1-SEP-1988 13:37:55

.
Correct reaction time score (1)
Correct reaction time score (2)
Correct reaction time score (3)
Correct reaction time score (4)
Inclusion criteria for reaction times: 1 and 4300
Error criterion: 11

Factor 1 group all 2 levels
Factor 2 subject all 10 levels
Factor 3 block all 3 levels
Factor 4 trial all 4 levels
Factor 5 probabil all 4 levels
Scores averaged for following factors
Factor 4 trial

Source	Deviance	df	Variance	F
Between-subjects				
(1) group	1618245.75	1	1618245.75	2.85
residual	10230821.00	18	568378.94	
Within-subjects				
(2) block	306383.91	2	153191.95	16.07 **
(3) grou bloc	4712.57	2	2356.29	0.25
residual	343266.88	36	9535.19	
(4) probabil	63590.82	3	21196.94	2.47
(5) grou prob	116067.48	3	38689.16	4.51
residual	463236.70	54	8578.46	
(6) bloc prob	17240.67	6	2873.44	1.66
(7) grou bloc prob	3427.79	6	571.30	0.33
residual	186605.77	108	1727.83	
Total	13353599.32	239		

* p<.01 ** p<.001

Effects of Right Hemisphere Strokes on Psychomotor Performance
Source file: EXPT07.SCO;1 1-SEP-1988 13:37:55

Non-overshoot movement time score (1)
Non-overshoot movement time score (2)
Non-overshoot movement time score (3)
Non-overshoot movement time score (4)
Inclusion criteria for non-overshoot movement times: 1 and 8000
Overshoot criterion: 51

Factor 1 group all 2 levels
Factor 2 subject all 10 levels
Factor 3 block all 3 levels
Factor 4 trial all 4 levels
Factor 5 distance all 4 levels
Scores averaged for following factors
Factor 5 distance

Source	Deviance	df	Variance	F
Between-subjects				
(1) group	20653014.00	1	20653014.00	10.70*
residual	34756712.00	18	1930928.50	
Within-subjects				
(2) block	663382.19	2	331691.09	6.22*
(3) grou bloc	11517.11	2	5758.56	0.11
residual	1921173.06	36	53365.92	
(4) trial	519625.28	3	173208.42	11.31**
(5) grou tria	22042.42	3	7347.47	0.48
residual	827250.25	54	15319.45	
(6) bloc tria	235665.77	6	39277.63	2.03
(7) grou bloc tria	74718.35	6	12453.06	0.64
residual	2085904.44	108	19313.93	
Total	61771004.87	239		

* p<.01 ** p<.001

Effects of Right Hemisphere Strokes on Psychomotor Performance
Source file: EXPT07.SCO;1 1-SEP-1988 13:37:55

Non-overshoot movement time score (1)
Non-overshoot movement time score (2)
Non-overshoot movement time score (3)
Non-overshoot movement time score (4)
Inclusion criteria for non-overshoot movement times: 1 and 8000
Overshoot criterion: 51

Factor 1 group all 2 levels
Factor 2 subject all 10 levels
Factor 3 block all 3 levels
Factor 4 trial all 4 levels
Factor 5 distance all 4 levels
Scores averaged for following factors
Factor 4 trial

Source	Deviance	df	Variance	F
Between-subjects				
(1) group	20653014.00	1	20653014.00	10.70*
residual	34756712.00	18	1930928.50	
Within-subjects				
(2) block	663382.19	2	331691.09	6.22*
(3) grou bloc	11517.11	2	5758.56	0.11
residual	1921173.06	36	53365.92	
(4) distance	20373806.00	3	6791268.50	250.99**
(5) grou dist	355893.38	3	118631.13	4.38*
residual	1461118.19	54	27057.74	
(6) bloc dist	52329.75	6	8721.62	1.79
(7) grou bloc dist	57342.72	6	9557.12	1.96
residual	525882.59	108	4869.28	
Total	80832171.00	239		

* p<.01 ** p<.001

Effects of Right Hemisphere Strokes on Psychomotor Performance
Source file: EXPT07.SCO;1 1-SEP-1988 13:37:55

Overshoot movement time score (1)
Overshoot movement time score (2)
Overshoot movement time score (3)
Overshoot movement time score (4)
Inclusion criteria for overshoot movement times: 1 and 13600
Overshoot criterion: 51

Factor 1 group all 2 levels
Factor 2 subject all 10 levels
Factor 3 block all 3 levels
Factor 4 trial all 4 levels
Factor 5 distance all 4 levels
Scores averaged for following factors
Factor 5 distance

Source	Deviance	df	Variance	F
Between-subjects				
(1) group	82147848.00	1	82147848.00	17.82 **
residual	82994386.00	18	4610799.00	
Within-subjects				
(2) block	3453754.50	2	1726877.25	5.59 *
(3) grou bloc	32257.21	2	16128.60	0.05
residual	11128906.50	36	309136.28	
(4) trial	2959023.25	3	986341.06	6.29 *
(5) grou tria	103449.49	3	34483.16	0.22
residual	8469667.00	54	156845.69	
(6) bloc tria	3221611.00	6	536935.19	4.33 **
(7) grou bloc tria	301663.28	6	50277.21	0.41
residual	13397224.50	108	124048.38	
Total	208209790.94	239		

* p<.01 ** p<.001

Appendix E

Table of Correct Reaction Time Means (in msec) by Target Position for Control Group

Table of Correct Reaction Time Means (in msec)

by Target Position for Control Group

Starting position	Target position 1	2	3	4	5
1	---	369	369	378	389
2	465	---	395	401	437
3	463	474	---	435	437
4	457	446	441	---	459
5	398	389	381	382	---

Note: The upper quadrant represents all movements from left to right. The lower quadrant represents all movements from right to left.