PSYCHOLOGICAL ASPECTS OF THE REHABILITATION OF MOVEMENT CONTROL IN STROKE PATIENTS

by

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Abstract

Psychological models of motor control, although often developed by work with people who have specific pathologies, have been contained very much within the academic sphere of psychology. Physiotherapy and methods of movement rehabilitation have also been developed within the bounds of one profession. With the increasing trend towards working in multidisciplinary settings the opportunity now exists more readily to cross professional boundaries and integrate these two separate knowledge bases in order that better rehabilitation programmes can be developed and in recent years this has begun to happen.

With this in mind the research reported here set out to investigate the motor function of stroke patients who have reached a plateau of motor recovery, using dual task methodology. Two experiments were conducted, one involving the "automatic" movement of walking and the other more controlled hand and finger movements. In addition to information about movement it was hoped to investigate whether there was evidence for more than one central information processing system.

The results of the walking experiment were inconclusive because of a number of methodological issues which are discussed. The results of the second experiment indicate that there may be evidence for more than one central information processing system. They also showed that in a dual task situation stroke patients differentially allocate their cognitive resources in favour of the movement task. These results are interpreted in terms of stroke patients monitoring their movement more closely.

The results are discussed in terms of a psychological framework of movement control, and issues are raised about whether physiotherapists could make use of this type of approach in developing movement rehabilitation programmes for stroke patients.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

AUTHOR'S DECLARATION

At no time during the registration for the degree of Doctor of Clinical Psychology has the author been registered for any other University award.

The contents of this bound volume are identical to the volume submitted for examination in temporary binding except for the ammendments requested at the examination.

This study was conducted while the author was a Trainee Clinical Psychologist in the South West Region based in Frenchay Healthcare Trust and the research was conducted in collaboration with Frenchay Healthcare trust.

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Signed...*Sarah Connolly*....

Date.......2. 12. 93.......

CHAPTER ONE

INTRODUCTION

The third most common cause of death, following heart disease and cancer, is stroke, a stroke being localised brain damage caused by diminished blood flow, (Hopkins, 1993). In this country the annual incidence of stroke is approximately 195 per 100 000, and the prevalence of stroke survivors about 550 per 100 000 (Hopkins, op. cit.). In the United States having had a stroke is also the most common cause of adult disability (Zivin and Choi, 1991). Of the new victims each year, approximately 30 percent die, and 20 to 30 percent become severely and permanently disabled. The disability may range from unconsciousness, paralysis, impaired cognition, reduced coordination, visual disturbance, loss of sensation, or some combination of these.

These figures are in themselves startling but there are two other factors which further add to the distressing nature of a stroke. The first is that if one was to suffer a stroke today, there would be no way of limiting the damage, no matter how quickly one was seen by specialised medical staff. At most they would be able to treat any medical complications and attempt to prevent a recurrence. The second factor is more psychological in nature, in that by attacking the brain, a stroke attacks that which makes us human. In other words, unlike many other diseases, a stroke attacks our person rather than, or in addition to, our body.

Given that strokes are a major medical problem, both in terms of the number of people who suffer strokes or who care for a family member who has suffered a stroke, and in terms of the seriousness of the aftereffects of a stroke on survivors, there is a large role for physiotherapists, occupational

therapists, speech therapists rehabilitation nurses and psychologists to play. It is recognised that therapy cannot repair the brain damage itself, but nonetheless therapists can help a stroke survivor to make the best of their remaining capabilities, and to learn new strategies for successfully achieving function where old methods are no longer available.

Until fairly recently, the nature of therapy has depended on a series of therapy sessions with individual therapists. However, as stroke units and rehabilitation centres become more common, the emphasis is changing towards a more multidisciplinary approach. Therapists are working together and borrowing methodologies and theories from each others' disciplines and in the process developing more comprehensive, adaptive and useful rehabilitation for stroke patients.

The basis of the research reported here depends on the use of psychological theories of motor control and divided attention to investigate motor function of stroke patients who have reached a plateau of motor recovery. It is hoped that the results of this study can be usefully fedback to the rehabilitation programmes developed for stroke patients in the future. The remainder of this chapter provides a background to the nature of stroke, the movement problems which usually follow stroke, present rehabilitation programmes, a background to psychological models of motor control, an introduction to the theoretical background of present physiotherapy treatment and a suggestion for a psychological framework for movement rehabilitation.

1.1 The nature of Stroke

The brain depends on blood for a continuous supply of oxygen and glucose. If the blood supply is interrupted for as little as a few minutes then

certain highly vulnerable neurons will degenerate. If the interruption is sustained then all types of brain cells in the blood deprived area will die, including both neurons and supportive cells such as glia. Usually such tissue damage is irreversible within hours after a stroke begins. Furthermore there is evidence that not only the blood deprived tissue (or core) is damaged, but also the penumbra (containing surrounding cells that receive some blood from other arteries). Penumbral cells are likely to be damaged most by events begun when ischaemia induces neurons to oversecrete glutamate, an excitatory neurotransmitter (Zivin and Choi, 1991). The details are not important here, but the significant point is that the damage caused by a stroke can be widespread and functional disability can often be observed which one would not predict from the stroke site located on a CT scan, for example.

The diminished or interrupted blood flow which results in stroke can occur for a number of reasons. The most common kind of stroke is due to cerebral infarction or intracerebral haemorrhage as a result of atheromatous vascular disease, usually associated with hypertension. Other possible causes are occlusions of cerebral arteries due to emboli arising from the heart, arteritis, or sickled red cells. Whatever the cause, three main types of condition are often described by the term stroke.

A "mini" stroke, or transient ischaemic attack (TIA) refers to a focal neurological deficit with a vascular cause from which recovery is made within twenty-four hours. Such an attack may manifest itself as transient aphasia or weakness in a limb. If complete recovery occurs later than twenty-four hours then the incident may be referred to as a reversible ischaemic neurological deficit (RIND), or "minor" completed stroke. MRI or CT scans may reveal anatomical changes following both TIAs and RINDs but

to be defined as such there must be a complete clinical recovery. A completed stroke is one in which a permanent neurological deficit occurs. Despite this there is almost always some recovery of function in the weeks that follow a completed stroke.

Although cerebrovascular disease is usually associated with old age, twenty percent of strokes do occur in people younger than sixty-five. Despite the increasing number of older adults, several community surveys indicate that the morbidity of stroke declined by impressive amounts in recent years. For example in Rochester, Minnesota there was a fifty-five percent decline between the figures for 1975-9 compared to 1950-4. It was suggested that this decline was associated with treatment for hypertension, but as new evidence from Rochester shows the incidence beginning to rise again, there must be other crucial variables (reported in Kannel and Wolf, 1983). One such variable may well be the continued increase in the number of older adults.

Epidemiological information about TIAs is likely to be less reliable because it is probable that not all attacks are reported. However the medical records from Rochester suggest an incidence of 70 per 100 000 for the 55-64 year age group and of 220 per 100 000 for the 65-74 year age group. Perhaps more importantly in terms of treatment, although only about one' in ten patients have a TIA before a completed stroke, about one in three patients with a TIA will have a stroke in the next few years, most frequently within a few months of the TIA (Hopkins, 1993).

1.2 Movement problems following stroke

Perhaps the most common early symptom of a stroke is paralysis of one side. Langton Hewer and Wade (1986) suggest that some degree of

13

paralysis occurs in fifty to eighty percent of people who suffer a stroke, the degree of paralysis ranging from complete loss of any movement to slight weakness. This paralysis can result from damage to the pre-motor cortex (which is implicated in the planning and organisation of movement), the motor cortex, or the neural pathways from the cerebral hemispheres to the brain stem. The disruption is not only with the ability to send commands to muscles to make certain movements, but also in the background activity of other muscles which maintain tone and hence allow a person to maintain posture. If the paralysis is not total, the more skilled movements, such as threading a needle, are usually the first to be affected and the last to return, whereas more gross movements such as raising an arm, are more likely to be preserved.

A long-term consequence of damage to the motor pathways, as already stated, is that the fine balance of background activity in the muscles is lost. This can be detected by the changed pattern of reflexes following a stroke. Immediately following a stroke the stretch reflexes are less sensitive, but by about one month post stroke, the level of sensitivity increases and it becomes difficult to move the limb because of the increased tone or spasticity of the muscle.

Damage to other areas of the brain can also lead to a disruption of motor ability. Although damage to the cerebellum or its associated pathways is less common, when it does occur, the effects are a disruption in the coordination of the muscles resulting in strong but clumsy movements. Movements which involve the coordination of many muscles or muscle groups such as standing up or walking are impeded by this type of damage. Although it is not reported in the stroke literature, since the basal ganglia have been implicated in the initiation of movement (Rolls, 1983), in the speed

14

of execution of movement (Evarts, Teravainen and Calne, 1981), in a number of postural reflexes (Martin, 1967), and in the creation and automatic execution of learned motor plans (Marsden, 1982), damage to them as a result of stroke is likely to have a great effect on the ability to successfully perform controlled and well timed movements. The reason that this has not been reported is likely to be because the effects of paralysis caused by damage to other areas will be more prominent.

Poor control of movement may also be associated with damage to the somatosensory system. The somatosensory system has exterioceptive functions (sensitive to stimuli from the external environment), and proprioceptive functions (providing information about the relative position of body segments to one another and the position of the body in space). Impairment of this system leads to impaired feedback information about a movement and therefore to clumsy and often weak movements.

Twitchell (1951) describes in detail the recovery from upper limb hemiplegia in humans produced by thrombosis, embolism or stroke of the middle cerebral artery. Immediately following the occlusion, there is an onset of hemiplegia in which the muscles become completely flaccid, and all reflexes and voluntary movements are lost. Recovery occurs over a period of days or weeks and follows a relatively orderly sequence starting with the return of the tendon and stretch reflexes. Following this there is the development of rigidity, then the return of grasping which was facilitated by or occurred as part of proprioception (i.e. as part of postural reflexes of turning, righting, etc.). Next there is the development of voluntary grasping which Twitchell notes occurs in the sequence of shoulder, elbow, wrist and hand, first in the flexor musculature, then in the extensor musculature. The last two stages are the facilitation of grasping by tactile

15

stimulation of the hand and grasping that occurred predominantly under voluntary control. Recovery can become arrested at any of these stages.

1.3 Rehabilitation Programmes

Following a stroke, people are often offered periods of intensive rehabilitation either at specialist stroke units or in hospital physiotherapy, occupational therapy, and speech therapy departments. Specialist stroke units have the advantage of concentrating staff skills and interests in a collaboration which ensures a better quality of patient care (Isaacs, 1978). Such units avoid the pitfalls often encountered on general wards where the patients have no responsibility for their own rehabilitation and might be fed and cared for in other ways by a nurse and then delivered to short and relatively infrequent therapy sessions in a wheelchair, whether or not one is necessary because it is quick and easy and it is the way "patients" are transported.

In a study carried out by Feigenson, Gitlow and Greenberg (1979) the outcome of rehabilitation delivered by a stroke unit was compared with similar therapeutic treatment programmes on general wards. Although the group of patients at the stroke unit had more medical problems and more severe neurological and functional deficits, the study showed that they were more likely to go home after treatment and walked better at the time they were discharged. Support for stroke units also comes from a number of other authors (e.g. Garraway, Akhtar, Prescott and Hockey, 1980; McCann and Cuthbertson, 1976).

The objective of rehabilitation is to return patients to a level of function that approximates to their premorbid level. Bach-y-Rita (1980) reviewed some of the issues which are involved in meeting this objective

16

following brain injury. Early stimulation is important so that recovering abilities are not allowed to cease at an early stage. Closely related to this is the importance of encouraging a person to use their involved (weak) limb. If progress is to be maintained and furthered then the hemiplegic person needs to practice using their involved limb(s) thus prompting maximal recovery and avoiding learned non-use which causes the arrest of recovery of function of the paralysed limb at an early stage. This will need encouragement since it is usually easier to adapt to using the non-impaired limb. Practise needs to be extensive because increments may only be small and substitution behaviours may need to be developed to accomplish a particular goal. The tasks practised should be of functional relevance to daily life and should be prompted by all those involved with the patient, both professional staff and relatives. The motivation of the patient must be addressed since often they are working very hard and long for very small gains. Training needs to be maintained over long periods, even when plateaus are reached, in order that change is maintained and that further small changes can be achieved. Finally, particularly in the early stages of recovery, tasks need to be broken down into simpler components because attention span and/or motor abilities are limited. This should be done whilst maintaining the functional characteristics of the task wherever possible.

A description of the objectives of rehabilitation invite the conclusion that cooperative multidisciplinary programmes are likely to be more successful. Rehabilitation goals should be defined in terms of the functional needs of the patient rather than the academic and skills background of the available therapists. Not only does this approach lend itself to more thorough, comprehensive and continuous rehabilitation programmes, but it also enables the sharing of theoretical backgrounds between therapists and hence prompts development of successful techniques and their theoretical

descriptions. It is only by understanding and testing the theoretical underpining of the various techniques available that developments will be made. To this end psychologists have a role not only in dealing with the emotional consequences of stroke, but also in terms of how models from neuro and cognitive psychology can be used in the development of rehabilitation programmes. One area where collaboration may be fruitful is that of motor control.

1.4 The psychological models of motor control

A motor skill has been defined as "any human activity that has become better organised and more effective as a result of practice" (Annett, 1971). Everyday activities such as standing up from a sitting position therefore constitute motor skills. In describing motor skills a distinction needs to be made between their planning and control. In general, planning describes the processes which generate movement goals or intents, and control processes are responsible for realizing the planning goals.

Consider the example of picking up a cup of coffee to drink from. At a high level the planning involved in doing this task involves first visually defining the cup, its location and its size and shape. From the size and shape one can determine how the hand should enclose the cup in order to grasp it safely. A coordination strategy then needs to be planned so that the arm can be moved from its current position to the cup, then picking up the cup to the mouth, and finally tipping it safely so that the contents enter the mouth and are not spilt. It is the control processes that ensure that the movement plan is carried out.

Early theories of motor control considered that information gathered from the peripheral receptors was necessary and sufficient for coordinated

movement (Mott and Sherrington, 1895; Adams, 1971). In terms of the example given above this would be analogous to saying that control processes only were needed, in that movement control depended only on feedback. More recently a second approach has been proposed in which skilled motor acts can be carried out in the absence of feedback and are regulated rather by a central source (Kelso, 1977). These two types of theory have been described as closed-loop (peripheral) and open-loop (central).

In the closed-loop models feedback drives the movement. Each movement component is evaluated before a decision is made on the execution of the next component. An internal referent or standard specifies the required motor output. Once the movement has started, information about the response is fed back and evaluated against this referent to determine any error. The system uses the error detection process to minimise any deviation from the required movement path as specified by the referent.

Open-loop theories propose that higher centres of the central nervous system are responsible for the information about a required movement. These theories propose that a motor programme, or centrally stored plan for the movement sequence, is used. This type of control does not, therefore, depend on feedback for its regulation. Keele and Hawkins (1982) suggest that these motor programmes should not be thought of as specifications for a sequence of muscle movements, but as a hierarchic memory structure in which the skill is first specified at a gross level, and then at successive levels of hierarchy specificity is increasingly added. As the hierarchy is descended speed, intensity, size, limb, and finally particular muscles are specified.

This notion of open-loop, programmed movement has two major problems. First how does one perform a movement never made before using

a motor programme, and second, where can one store programmes for every movement one has made or might make? These problems were overcome by Schmidt (1975, 1976) in his development of an open-loop model for motor control. His schema theory overcomes the problems of novelty and storage by using a rule making or regression approach. The schema theory presumes a general motor programme which is made specific by manipulating certain parameters relevant to the movement to be made. When an individual makes a movement which attempts to satisfy some goal he stores four things; the initial conditions, the response specifications for the motor programme, the sensory consequences of the response produced, and the outcome of the movement. When a number of movements directed at the same goal have been made, a rule is extracted from the information stored, based on their relationships. The individual can then develop response production by inputting the desired outcome and initial conditions, and response recognition by generating expected sensory consequences.

Schmidt (1982) pointed out that movements cannot really be executed in the total absence of feedback because reflex systems such as the monosynaptic stretch reflex or the long-loop reflex can operate with times of only 30-80ms. This means that after the first 30ms of a movement, feedback will begin to have an influence, but only in respect to correction of errors in execution. This has led schmidt to redefine the motor programme as "an abstract structure in memory that is prepared in advance of the movement; when it is executed, the result is the contraction and relaxation of muscles causing movement to occur without the involvement of feedback leading to corrections for errors in *selection*." This allows for errors in programme *execution* to be handled by low-level peripheral reflex adjustments without the need to alter the programme itself.

Open-loop and closed-loop theories are no longer seen as opposing views on how to solve the same motor problems, but are usually used to describe different sorts of movement. Open-loop models are used to describe ballistic movements which are brief, fast, and thought to be preprogrammed, or operated without peripheral guidance such as throwing or kicking. Closed-loop models are used to describe ramp movements which are relatively long, slow, smooth, and highly responsive to control by peripheral sensory feedback, such as threading a needle. The marriage of these two concepts now goes further in that different parts of a single movement may be described by each model. For example Haaland and Harrington (1989) suggest that most movements are composed of an initial, open-loop component and followed by a corrective closed-loop component, but emphasize that performance may depend more on one component than the other.

In summary, motor plans are seen as comprising sets of feedforward commands for complex motor actions, learned from successful, previous motor performance. These plans are made up of programmes for various parts of the performance in a hierarchical manner. Postures and movements are guided by a mixture of programmes and sensory feedback, since calculations made ahead of time in the central nervous system are nearly always corrected after comparison to central and peripheral reports about the environment. The central nervous system succeeds in bringing about planned actions because it adapts its neural commands according to the prevailing circumstances, for example whether the movement is being resisted or not.

1.5 Physiotherapy following a stroke and the need for a psychological framework for movement rehabilitation

At present the onus of treatment of stroke lies with the physiotherapist whether or not treatment is at a specialist stroke unit. The treatment approach adopted by the great majority of physiotherapists in this country is that of Bobath (1978). This approach focuses on attempting to rehabilitate movement of the involved side to as near normal as possible. The theoretical rationale behind this treatment regime stems from a hierarchical representation of the central nervous system ranging from higher executive control centres in the cortex, down to lower centres in the spinal cord. Bobath regards a lesion caused by stroke as resulting in a release of reflex activity from higher control. Treatment progresses by working upwards through a hierarchy of neurophysiological mechanisms towards reinstatement of cortical control. Treatment therefore consists of a gradual re-establishment of components of central nervous system functioning.

There are at least three problems with this approach. First it ignores the possibility that individual motor components may benefit by encouraging whole system motor function in terms of goal attainment. Second the rigid individual component practice involved in this treatment technique does not allow for the varied practice one would need for there to be an efficient transfer of skills learned in therapy sessions to everyday activities (c.f. Schmidt's schema theory, section 1.4), even if component functioning is restored - i.e. the flexibility of the system is compromised. Third it views motor acts to be just that, and not to involve perceptual, sensory or cognitive abilities. In neurological terms the distinction is made between exteroceptors, which provide information about the environment

and proprioceptors, which provide information about the position and movement of parts of the body relative to each other. Each receptor system is considered to subserve a unique function and so vision for example, which is classed as an exteroceptor sense, is not deemed to be relevant for the control of body movement. Information for this would be provided by the proprioceptive system. Indeed Bobath (1978) states that therapies relying on sensory input are of little value to the stroke patient:

> "working with various modalities of sensory input . . . is not, in our view, the answer to the problem . . . The patient sees and hears, he localises touch, his proprioception is normal and he perceives movement and postural changes. But notwithstanding this normal sensory input, the patient can react only with abnormal postures and movements. The reason for this is that the lesion in effect "cuts off" higher integrated activity and produces a kind of short circuit into the released abnormal patterns of spasticity."

However it is well established that vision provides important information for the control of movement. Furthermore Lough (1984) has demonstrated that visual monitoring of performance by a stroke patient can result in smoother, more expedient movement of the hemiparetic arm. In his experiment participants were asked to move a dowel from a home base to a target using midline extension of the arm. This was done in two conditions, with full sight of the arm and target, or blind whilst moving. The analysis consisted of viewing the velocity profiles of the wrist and partitioning the trajectory into its component submovements on the basis of the number of peaks present in the velocity profile. In another experiment Lough (1987)has suggested that rather than representing corrective movements, these peaks can be seen as "interuptions". The number of submovements

was reduced when vision was available, thus showing its role in overcoming a specific movement control deficit.

In a second experiment Lee, Lough and Lough (1984) investigated the effect of presenting timing demands extrinsically. In the classical neurophysiological taxonomy of the sensory system (Sherrington, 1906), this question makes no sense. Extrinsic timing demands were employed by asking stroke patients to reach for a moving ball and meet it at a particular position on its track. As a control, participants were also required to perform the same action when the ball was stationary and an equal distance away. The results of this experiment demonstrated that a reaching movement to a rolling ball was significantly less discontinuous and participants were more likely to make contact with it. So imposing spatio-temporal constraints on hemiparetic movement can actually improve it. These two experiments clearly demonstrate that visual input concerning movement of an hemiparetic limb and its relationship to external objects can improve impaired motor control.

Anderson (1981), using a video game task which demanded perceptual, cognitive and motor components, has demonstrated that participants found it more difficult to perform the component tasks than the composite task. Anderson notes that limitations imposed by a lower level component process are rendered irrelevant in the composite task because strategies were evolved to offset these limitations. In other words performance on certain tasks is improved not by making perfect imperfect solutions, but rather by discovering new routes to the same goal (Berstein, 1967). Bobath's techniques do not allow for this.

Anderson and Lough (1986) state that:

"Psychological systems which change, or are expected to change, do so primarily by virtue of a functional reorganisation of the system, in order that environmental goals may be achieved in spite of the limitations imposed by the components of the system."

If one accepts this as a psychological framework for movement rehabilitation following a stroke, there are two main implications. First at a theoretical level because theoretical models determine what is included and excluded from therapy, and second at the level of experimental investigation. More information is needed about disability so that the content of a rehabilitative therapeutic intervention can be tailored to the complexities of the disorder.

In the experiments described in this thesis, this psychological framework for movement rehabilitation is adopted to investigate how well recovered stroke victims control movement and how this is affected by doing more than one task at a time - a reflection of the multi-various nature of normal daily life. The first experiment investigates walking, which is considered automatic, and under mainly open-loop control, while the second investigates finer movements of the hand which are presumed to depend to a greater extent on closed-loop control. The results of the experiments will be considered in three ways. First in terms of how they inform us about the movement control of stroke patients; second how this information might be used in a rehabilitative strategy; and third whether they are compatible with present physiotherapy practice.

CHAPTER TWO

GENERAL METHODOLOGIES

The overall procedure for both the experiments reported here was that potential participants were contacted by letter and asked if they would be interested in taking part in the experiments. If they were interested a home visit was made where their suitability for the study was assessed and psychometric tests were conducted. People who had suffered another stroke more recently or who were significantly aphasic or confused were excluded from the study. Other information gathered during this visit included the main problems following the stroke, the problems which still remain as a result of the stroke, other illnesses or injuries which may have a bearing on movement, whether there were problems with vision or hearing, educational and employment background and retirement age and grounds. Where applicable this information was also gathered about the participants who had not had strokes.

Following the initial visit the people who were interested in continuing and who were suitable for the study were invited to come to the hospital to take part in either or both of the experiments (people who took part in both experiments did so on separate occasions). Both experiments assessed people in dual and single task conditions, one task being either a verbal or spatial cognitive task and the other task involving some movement (either walking or hand movements).

2.1 Participants

Stroke patients

The stroke patients who took part in the experiments reported here had suffered their strokes between January 1987 and December 1989 and had at least some of their subsequent treatment at the Stroke Unit at Frenchay hospital. At the time of testing (between July 1992 and June 1993) all participants had reached a stable plateau in their recovery where further spontaneous recovery was extremely unlikely.

Twenty-one stroke patients were visited at home. If people had significant mobility problems they were not invited to take part in the first experiment involving walking, but took part in the second experiment involving hand movements only.

Of the 21 stroke patients seen, eight people were not included in either experiment. These eight people did not appear to differ greatly from the people who did take part in terms of age or stroke site. Table 2.1 summarises the details of the stroke patients who were and were not included in the study.

	PARTICIPANTS	NON PARTICIPANTS
MEAN AGE (s.d.)	63.15 (10.65)	69.75 (11.12)
AFFECTED HEMI	6 Right, 7 Left	2 Right, 6 Left
DOMINANT HAND	11 Right, 2 Left	8 Right, 0 Left
SEX	6 Female, 7 Male	5 Female, 3 Male

Table 2.1. The mean age, hemisphere affected, dominant hand and sex of the stroke patients visited who did and did not take part in the experiments.

Two of the eight non participants were significantly aphasic, one was confused, four did not want to come to the hospital, and one did not wish to take part in the experiments.

Control Subjects

Control subjects were sought for each stroke patient taking part. Where possible the stroke patients' spouses acted as controls thereby matching roughly for age and education level. Eleven spouses were recruited but only eight took part in the experiments. Three other people were recruited to act as control subjects giving a total of eleven controls. The mean age of those who acted as control subjects was 59.64 (standard deviation, 11.78).

2.2 Psychometric Tests

During the home visit, prior to taking part in either experiment, participants were asked to complete a selection of psychometric tests. The data from these tests gave some indication of general verbal and spatial abilities which could be taken into account when assessing performance on the cognitive tasks. The tests completed were six subtests from the Weschler Adult Intelligence Score-Revised (WAIS-R); information, arithmetic, and similarities giving an indication of verbal abilities, and picture completion, block design and object assembly giving an indication of performance abilities. The stroke patients also completed the National Adult Reading Test, second edition (NART-2) so it was possible to detect whether, in addition to any decline in their abilities which may have resulted from their stroke, there was any indication of bilateral damage or dementia. One person showed signs of dementia and was therefore excluded from the study.

Although there was some data in the medical records suggesting whether the patients had shown signs of neglect following their stroke, this was also checked at the initial meeting by asking patients to copy a drawing of a clock face. People who experience the neglect syndrome will draw a circle correctly but will then tend to crowd all the numbers into the right half of their circle (Springer and Deutsch, 1989). None of the people tested showed signs of neglect and this was consistent with the information in their medical notes.

2.3 Cognitive Tasks

Two cognitive tasks were used in each experiment, a verbal task and a spatial task. Although there were some differences between the tasks in the two experiments, the general principles and overall structure did not differ and these are described below. Both the cognitive tasks were presented by audiotape and participants were asked to make verbal responses to the stimuli. These responses were recorded either on videotape or on audiotape and where possible the examiner also made a note of responses.

For the spatial task a continuous series of evenly spaced clock times was presented. Participants were asked to imagine a clock face and divide it in half between the 12 and the 6. When they heard a time their task was to say whether the hands of the clock lay on the same or opposite sides of this divide. This is illustrated in Figure 2.1. The times on the tape did not include "o'clocks" or "half-pasts", since the side would have been ambiguous.
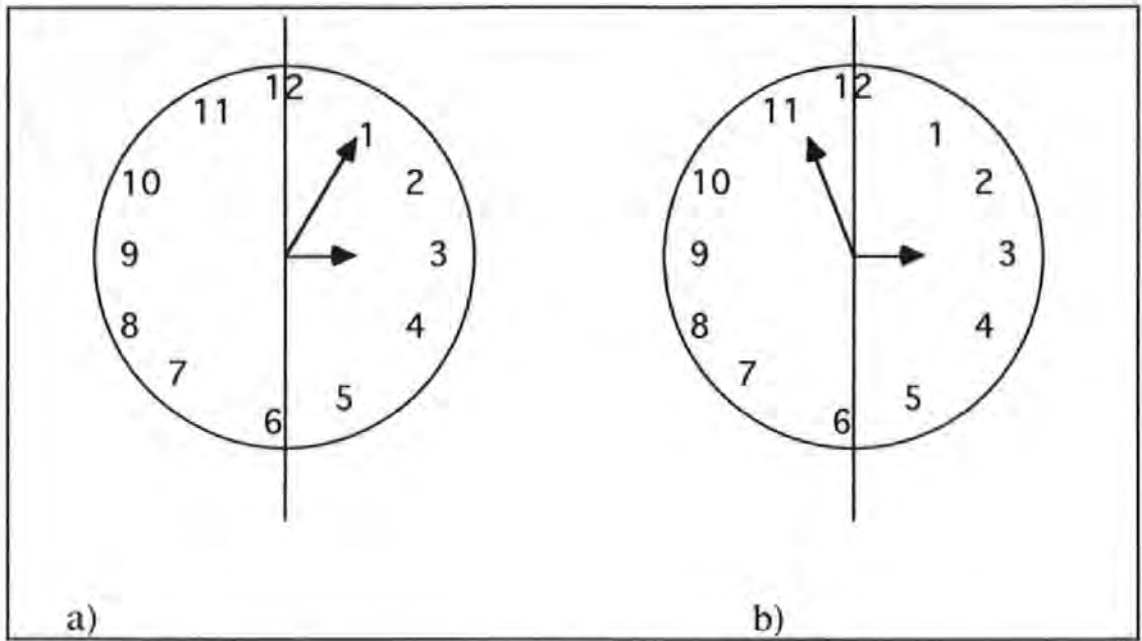
Figure 2.1. The spatial task. If the hands lay on the same side of the divide between 12 and 6, as for five past three (a), participants were required to say "same", if they lay on opposite sides, as for five to three (b), participants were required to say opposite.

For the verbal task a continuous series of evenly spaced numbers was presented and participants were asked to respond by saying yes when the number they had just heard and the one directly preceding it added together to make 18. For example, the participants might hear "...9...13...3...15...", and were expected to say yes after hearing "15" because "3" and "15" add up to 18. The numbers on the tape were between 1 and 17 inclusive.

Four tapes for each of the tasks were made and these were piloted on twelve people, 9 of whom had suffered strokes, to check they were of similar difficulty and that ceiling or floor effects did not occur. The pilot study indicated that the tapes were of similar difficulties and that the mean scores for the two tasks did not indicate that the tasks were either too easy or too difficult.

2.4 Ethical Considerations

Apart from the three participants who had not suffered a stroke and were not the spouse of someone who had suffered a stroke, all the participants had been involved in a previous study carried out at the Stroke Unit some years earlier. Following consultation the present study was deemed to be a continuation of the original study and it was not necessary to seek separate ethical consent.

Before contacting people a check was made with their G.P. on whether they had died or suffered further debilitating illness since last contacted by the hospital. This was done to ensure that added distress was not caused to relatives by contacting them with out-of-date information. Participants were contacted by letter initially (appendix 1) and were asked to return a form in a prepaid envelope indicating whether they were interested in taking part. It was therefore the case that participants had to opt into the study rather than opt out. Participants were not paid for their involvement. Following completion of the study all participants were written to with a brief summary of the results and thanked for their involvement (appendix 2).

2.5 Data Manipulation

Responses to cognitive tasks

Scoring for the spatial tasks in both experiments was out of ten, one for each possible correct response to the times presented on the tape. For the verbal task one point was awarded if the participant correctly responded "yes" to a pair of numbers adding to 18, and one point was awarded if the participant remained silent when the number pair did not add to 18. If there were n numbers, there were n-1 number pairs and scoring was therefore out

of n-1. This method of scoring took account not only of correct responses and missed responses but also of false positive responses.

Performance Operating Characteristics (POCs)

When considering performance in dual task situations, where a person must divide their attention between two tasks, Somberg and Salthouse (1982) have pointed out that it is necessary to measure divided attention independently of resource allocation. It is possible that poor performance by one group on a series of concurrent tasks is because they are less able to divide their attention, or it may be that they are allocating less of their attentional resources to a task than another group. In order to tease apart these two possibilities it is necessary to examine how a participants performance on one task varies as a function of their performance on concurrent tasks.

Norman and Bobrow (1975) have developed POCs to tackle this type of analysis. In a dual task situation performance on task 1 is plotted as a function of performance on task 2. As more resources are allocated to one task, fewer are available for the other, resulting in a negative correlation between performance levels on the two tasks. The plot frame delineates maximum performance achieved by the subject on each task. A point is then plotted in this frame which represents the score on each task in the dual task condition. If a line is drawn from the top left of the frame, via the marked point, to the bottom right of the frame, the area above the line is assumed to represent the divided attention cost, and is hence inversely related to the divided attention ability.

CHAPTER THREE

EXPERIMENT 1

3.1 Introduction

One of the most striking characteristics of everyday motor performance is automaticity. Many of our actions such as standing, walking, reaching and so on are performed without noticeable attention or effort. Most people become aware of this phenomenon only when they experience what Reason (1979) terms "capture errors". William James (1890) provides a famous example of such an error in his description of going upstairs to change and finding himself in bed. The explanation for this is that action initiation is occuring in parallel with some other activity. Shallice (1988) points out that unintended actions do not only occur when they are inappropriate, but can be both appropriate and unmonitored as in the following example.

> "... walking into a room I knew well and suddenly noticing that
> I was making a pulling movement with my arm, which I could
> not understand. I eventually realised what was obviously at
> some level 'known' - that the light switch in that room was
> controlled by a cord, which had got hooked up in a cupboard
> door. As the action was so mystifying at the time, it indicates
> that initiation and execution of this action was not normally
> controlled by a conscious intention to execute it."
>
> Shallice (1982)

Most people will recognise these types of experience and hence will have some concept of the notion of some actions as being automatic.

Despite the intuitive recognition of certain actions being performed automatically, there has been much debate over what constitutes automaticity. Schmidt (1987) reports the defining features of automaticity summarised by Neumann (1984) as "(1) a mode of operation that functions without capacity (attention), neither suffering nor causing interference; (2) a mode of control, in that it is under the control of stimuli rather than intentions (expectancies, plans etc); and (3) a mode of representation, in that it does not necessarily give rise to awareness." Norman and Shallice (1986) note that even when subjects are skilled and well practised, performance normally deteriorates somewhat when two tasks are combined, even though there appear to be no obvious grounds for structural or attentional interference.

Schmidt (1987) describes a way of viewing automaticity in skilled movement control from a different perspective which overcomes this problem and seems intuitively more sensible when considered from the position of models of motor control. His perspective takes the view that rather than making sensory information "automatic", the system reduces the need for sensory information by constructing and using motor programmes that can handle these details of movement. This represents a shift in control from more closed-loop (or feedback driven) processes to more open-loop (or preprogrammed) processes. Practise can then be seen as the construction of motor programmes that are "(1) more 'comprehensive' in the sense of controlling and coordinating more degrees of freedom, and (2) capable of controlling behaviour for a longer duration."

If a movement is under open-loop control and requires few cognitive resources as a result, then it will not interfere with other concurrent tasks that do require cognitive resources. Schmidt (1982) has demonstrated that

the formation and initiation of motor programmes does cause interference with some secondary tasks. However Shapiro (1978) has shown that with practice, motor programmes can control movement for longer durations, and as a result, formation and initiation need to occur far less frequently, thus reducing interference on secondary tasks.

Automaticity of well-learned tasks therefore enables the subject to behave flexibly and to perform tasks simultaneously with other tasks. It is this ability that allows one to talk to passengers whilst driving or to write whilst listening to music. Allport, Antonis and Reynolds (1972) provide evidence of this ability in skilled piano players who could play the piano whilst concurrently repeating aloud prose they heard over headphones. However it is also apparent that the driver will stop talking when approaching a hazard in the road, that if the complexity of the writing task increases the writer will switch off the music, and that novice piano players cannot simultaneously read prose aloud. Using Schmidt's ideas of automaticity of skilled action, it is at this stage that control of the action is switched from predominantly open-loop control to predominantly closed-loop control and this will result in a greater demand on central processing resources which are limited in the information load they can handle.

Walking, despite being a relatively complex activity, is also considered, for the majority, to be an automatic activity which does not demand much in the way of central resources. Improved mobility in general and walking in particular are the goals most often stated by stroke patients (deWeerdt and Harrison, 1985; Mumma, 1986; Bohannon et al., 1988). Bohannon, Horton and Wikholm (1991) investigated which aspects of walking were most important to stroke patients in terms of four walking variables. They showed that the importance of these variables, from greatest

to least was independence, distance, appearance and speed. This suggests that following a stroke, patients are more likely to want to restore the functional capacity of the system, rather than to restore functioning in one component. This observation fits the notion of a psychological framework for movement rehabilitation discussed in Chapter 1.

Walking is an important indicator of independence, both functionally and psychologically. However for people with gross motor skill deficiencies, walking may well only be possible at the cost of considerable information processing capacity because it is no longer an automatic activity. Following a stroke a person must relearn how to walk and this involves redeveloping the motor programmes necessary to control walking. Once the pattern of walking stabilises, usually many months after the stroke, it might be assumed that such programmes have been regenerated, allowing for reduced motor ability.

Connolly (1990) investigated the walking ability of well recovered stroke patients whilst they were and were not doing a secondary cognitive task and compared them with age-matched control subjects. Although neither the walking speed nor the number of correct responses to the cognitive task of the stroke patients were more compromised than that of their controls, she found evidence of a disruption in their pattern of walking so that limps began to appear, or become far more noticeable, when they were asked to do a secondary cognitive task. She concluded that the stroke patients were using "general cognitive resources" to cover-up deficits in their walking ability when they were not doing a cognitive task, but that when they were asked to do a secondary task they redirected some of these resources towards that task and the movement deficit became apparent.

In terms of our present theory, these results can be explained in two ways. First when walking in a single task condition, participants were not operating in an automatic nature, but rather were making use of closed-loop strategies to check and modify their walking pattern. When they were asked to divide their attention, movement pattern rather than speed was compromised. The fact that it was movement pattern that was compromised might suggest that the stroke patients switched to using a more open-loop strategy in order that some processing capacity be freed-up to tackle the secondary task. In order to control their walking they therefore had to use motor programmes that were evidently poor in quality compared to their controls, but they no longer had the processing resources available to monitor and correct their movement so often. Second subjects may have monitored their movement as frequently, but because the secondary task and the monitoring process made demands on the same pool of resources, either the feedback from the monitoring or the subsequent adjustments were not as good, thus resulting in a poorer gait pattern.

Given that there is a theoretical relationship between the degree of automaticity of gross motor skills and the ability to perform safely and flexibly in everyday situations, the degree of dual task interference could be a relevant factor in the rehabilitation process. Geurts, Mulder, Rijken and Nienhuis (1991) have applied this idea to the rehabilitation of balance in people who have undergone a lower limb amputation and were learning to use a prosthesis. They predicted that during the first stages of learning the capacity to perform tasks simultaneously would be severely reduced and interference on a concurrent attention-demanding task would therefore be very evident at the start of rehabilitation therapy, but that this interference would be reduced at the end of a successful learning process. This is indeed what they found.

37

In both the examples quoted, the interference has been assumed to be the result of making demands that are too great on limited central processing capacities. However it is possible that central capacity is not single and global, but rather that several distinct information processing systems exist. In terms of rehabilitation this would be important to discover if performance in a dual task situation were to be used as an indicator of successful relearning or as a practice technique in relearning. If one assumes that central processing is served by a number of processors which are specific to certain types of task, then it is more likely that a secondary task of a spatial nature will interfere with the ability to monitor walking performance.

The study by Connolly was conducted with very few subjects (only five stroke patients were included) and both of the secondary tasks used were verbal in nature, one involving matching pairs of words and the other identifying number pairs which added to eighteen. It is likely that with more subjects more interference would have been demonstrated in terms of walking speed and correct responses to the secondary cognitive tasks for the stroke patients because the high variance levels of the stroke patients are likely to have been reduced.

If stroke patients are more dependent on monitoring their walking ability in order to maintain performance levels, then one would predict relatively more interference in their ability, as compared to neurologically normal control subjects, in a dual task situation where one task is walking and the other a spatial cognitive task. Experiment 1 attempts to replicate Connolly's earlier experiment by comparing stroke patients and normal controls in a dual task situation with walking, but one verbal and one spatial

task as secondary cognitive tasks to specifically test the prediction that the spatial task will cause more interference to both groups, and relatively more to stroke patients.

3.1.1 Hypotheses

1. In the dual task situation all participants will be more affected by the spatial task than the verbal, as will be apparent by changes in walking speed and/or the number of correct responses made to to cognitive tasks.

2. The walking speed and/or the number of correct responses on the secondary tasks of the stroke patients will be more compromised than that of their controls by the dual task situation.

3. This effect will be larger when the secondary cognitive task is spatial in nature.

4. The stroke patients will use cognitive resources to cover-up deficits in their gait and this will be measured as differences in raters' judgments of participants' overall balance and walking ability.

5. The resources stroke patients use for this compensation will be the same as those involved in the spatial cognitive task and hence the effect will be greatest in the dual task situation involving the spatial task.

3.2 Methods

3.2.1 Participants

Nine stroke patients and 9 controls took part in the experiment. Table 3.1 summarises information about the stroke patients.

MAIN PROB.	HAND	HEMI	INFORMATION FROM CT SCAN
RH=P, RLe=W	L	L	Small intracerebral bleed in Lbasal ganglia
RH=P,Rle=W. SP.	R	L	No Scan
RH=W	L	L	Lesion in L posterior internal capsule.
LH=P, LLe=W	R	R	No Scan
RH=W, RLe=W	R	L	L centrum semi-oval infarct.
LH=W, LLe=W	R	R	Small infarct adjacent to R basal ganglia
RH=P,RLe=W, SP	R	L	Bleed in L basal ganglia, lat. ventricles » R
LH=W, LLe=W	R	R	R posterior cerebral thalamus ?infarct
LH=W, LLe=W	R	R	No Scan

Table 3.1. Main problem since stroke, dominant hand, affected hemisphere and information from the CT scans of the stroke patients. (R=right, L=left, H=hand, Le=Leg, P=paralysed, W=weak, SP=some speech difficulty).

The scaled scores from the three spatial and three verbal subtests conducted at the initial visit were summed to give a spatial score and a verbal score for all participants. Table 3.2 summarises the means of these scores and the mean age of the two experimental groups.

40

	STROKE PATIENTS	CONTROLS
AGE (s.d.)	58.6 (9.9)	56.2 (10.8)
AGE RANGE	37 - 69	37 - 71
SPATIAL (s.d.)	24.55 (10.03)	28.67 (6.7)
VERBAL (s.d.)	25 (5.27)	32.78 (10.55)

Table 3.2. Summary of the mean and standard deviation of age (years), age range (years), and the mean and standard deviation of the spatial and verbal scores of the stroke patients and their controls.

It should be noted that the higher verbal and spatial scores for the controls were in part because the three control subjects who did not have a spouse who had had a stroke were from markedly different professional backgrounds than the other participants.

3.2.2 Apparatus and Stimuli

A walking track was marked out on the floor by a line of masking tape approximately 10m long. Small reflective markers were placed at 0.5m intervals along the edge of this track as reference points. A camcorder placed on a rotating tripod was used to film participants walking up and down the track from a lateral plane. A portable tape recorder was used to present the stimuli for the cognitive tasks to participants. There were four recordings of equivalent stimuli available for each of the cognitive tasks (lists of the stimuli on these tapes appear in appendix 3). In the spatial task ten clock times were presented at 10 second intervals and in the verbal task 20 numbers were presented at 5 second intervals, with 5 pairs of numbers adding up to 18.

3.2.3 Design

A quasi-experimental, mixed model design was employed. Two different types of task, walking and a cognitive task based on either spatial or verbal abilities, were performed both separately and concurrently. Each participant carried out five tasks; 1) walking alone, 2) the spatial (clock) task and 3) the verbal (numbers) task whilst seated, 4) the spatial and 5) the verbal task whilst walking. There were between subjects measures of experimental group (stroke and control groups) and within subjects measures comparing the single and dual task conditions for the walking and cognitive tasks for both walking speed and correct responses.

3.2.4 Procedure

The tasks were performed in a counterbalanced order. In the walking alone task participants were asked to walk up and down the length of the course at their preferred walking speed, "as if you are walking to the shops". They were filmed for three trials of up and back again whilst doing this. Chairs were available at either end of the track so that participants could rest if necessary.

The cognitive tasks have been described in the general methodology section. For the seated conditions the tapes with the tasks recorded on them were played on the tape recorder and the participants responses were recorded both on the videotape (the camera was left running for this condition) and by the examiner.

Each of the four stimuli tapes for both the verbal and spatial tasks began with the word "start" and ended with the word "stop", the stimuli being presented between. For the dual task conditions where participants were required to walk and do the cognitive task, they were asked to begin

42

walking when they heard "start" and to stop when they heard "stop". The presentation of the stimuli and the participants responses were recorded on the videotape.

3.2.5 Data Manipulation

Walking speeds

The video films of participants walking were dubbed onto new film with a stopwatch running over the top. It was then possible to calculate the mean speed of participants in each condition by measuring the times taken to walk along the track in seconds, and dividing this into the distance covered in metres. The first and last metre of the track were not included in the analysis to avoid the complication of including the turning phase of participants.

Correct responses

Responses to the cognitive tasks were collected from the soundtrack of the video film for each participant in each condition. The score for the verbal and spatial tasks in single and dual conditions for each participant was then calculated. Scoring for the spatial task was out of 10 and for the verbal task out of 19.

Ratings of gait pattern

The video films were edited to produce a new film consisting of three brief clips of each participant walking, one walking alone, one whilst doing the verbal task and one whilst doing the spatial task. The these clips were in a pseudo random order, counterbalanced so that the order of the type of clip was balanced across the possibilities. The order of participants on this film was chosen randomly.

Ten raters were recruited, three of whom were senior house officers and seven were psychologists. They were shown three clips of film of each participant, walking alone and walking whilst engaged in each of the cognitive tasks, in a random order. The raters were unaware of whether the participant was doing a cognitive task or not, and were unaware of whether the participant had had a stroke or not. The raters were asked to judge whether or not each participant had had a stroke. Following this for each clip of film for each participant they were asked to judge whether or not the participant was also doing a cognitive task and to rate their overall balance and walking ability by making a mark on a visual analogue scale. Figure 3.1 illustrates the visual analogue scale.

|_____|
Unable to walk   Normal Healthy
without the aid   gait
of another person.
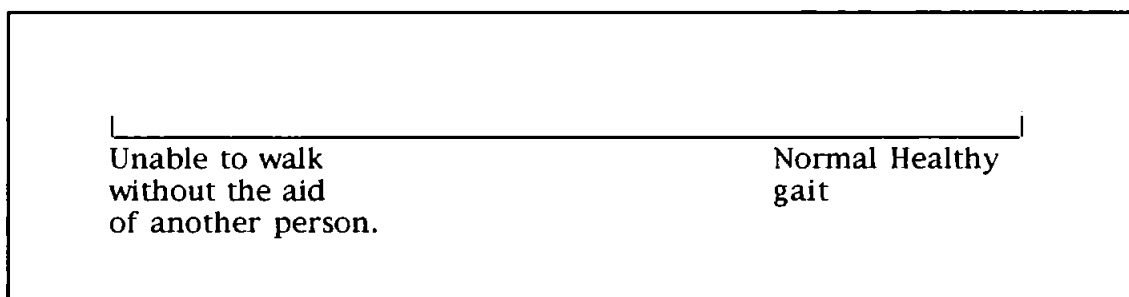
Figure 3.1. The analogue scale. If a person has great difficulty walking unaided the rater would strike a mark close to the left of the scale, if the person walks almost normally the mark would be struck on the right of the scale.

3.3   Results

3.3.1 Walking Speeds

The mean and standard deviations (S.D.) of walking speed for the two experimental groups in the single and both dual tasks are shown in Table 3.3.

	WALK ONLY	WALK+VERBAL	WALK+SPATIAL
STROKE (N=9)	0.750 (0.296)	0.696 (0.261)	0.698 (0.265)
CONTROL (N=9)	0.972 (0.127)	0.892 (0.210)	0.886 (0.233)

Table 3.3. Means (s.d.) of walking speeds for both experimental groups in the single and dual conditions.

44

Pearson's product moment correlations between age, spatial score, verbal score and walking velocity whilst doing each of the tasks were calculated. These are summarised in Table 3.4.

	WALK ONLY	WALK+VERBAL	WALK+SPATIAL
AGE	-0.2104, p=0.201	-0.1632, p=0.259	-0.2301, p=0.179
VERBAL	0.3315, p=0.09	0.5224, p=0.013	0.4520, p=0.03
SPATIAL	0.4982, p=0.018	0.5497, p=0.009	0.5606, p=0.008

Table 3.4. Correlations between age, verbal score, spatial score and walking speed in the single and dual conditions for all participants (N=18).

Since the verbal and spatial scores were significantly related to walking speeds in all conditions, they were included in the analysis as covariates. A mixed model analysis of variance with a between subjects factor of experimental group (stroke or control) and a within subject factor of task type (single=walk alone, dual=walk+verbal or walk+spatial) with spatial and verbal ability (as estimated by the spatial and verbal scores) removed as covariates. It was predicted that speed would be more affected by the spatial than the verbal task and this was taken into account in the type of contrast specified in the analysis.

The regression sums of squares (variability attributable to the covariate) was not significant, $F_{(2,14)}=2.50$, p=0.118. This indicates that removing the covariates did not account for a significant amount of the variability. There was no significant main effect of experimental group, $F_{(1,14)}=1.28$, p=0.276. There was a main effect of task type, $F_{(2,32)}=7.56$, p=0.002. Helmert contrasts indicated a significant difference between walking speeds when walking alone and whilst doing a cognitive task, $F_{(1,16)}=10.456$, p=0.005, but no significant difference between the walking

45

speeds whilst doing the two tasks, $F_{(1,16)}=0.015$, p=0.905. Participants walked fastest while not doing a cognitive task, but were equally slowed by the two cognitive task types. These results are illustrated in Figure 3.2.
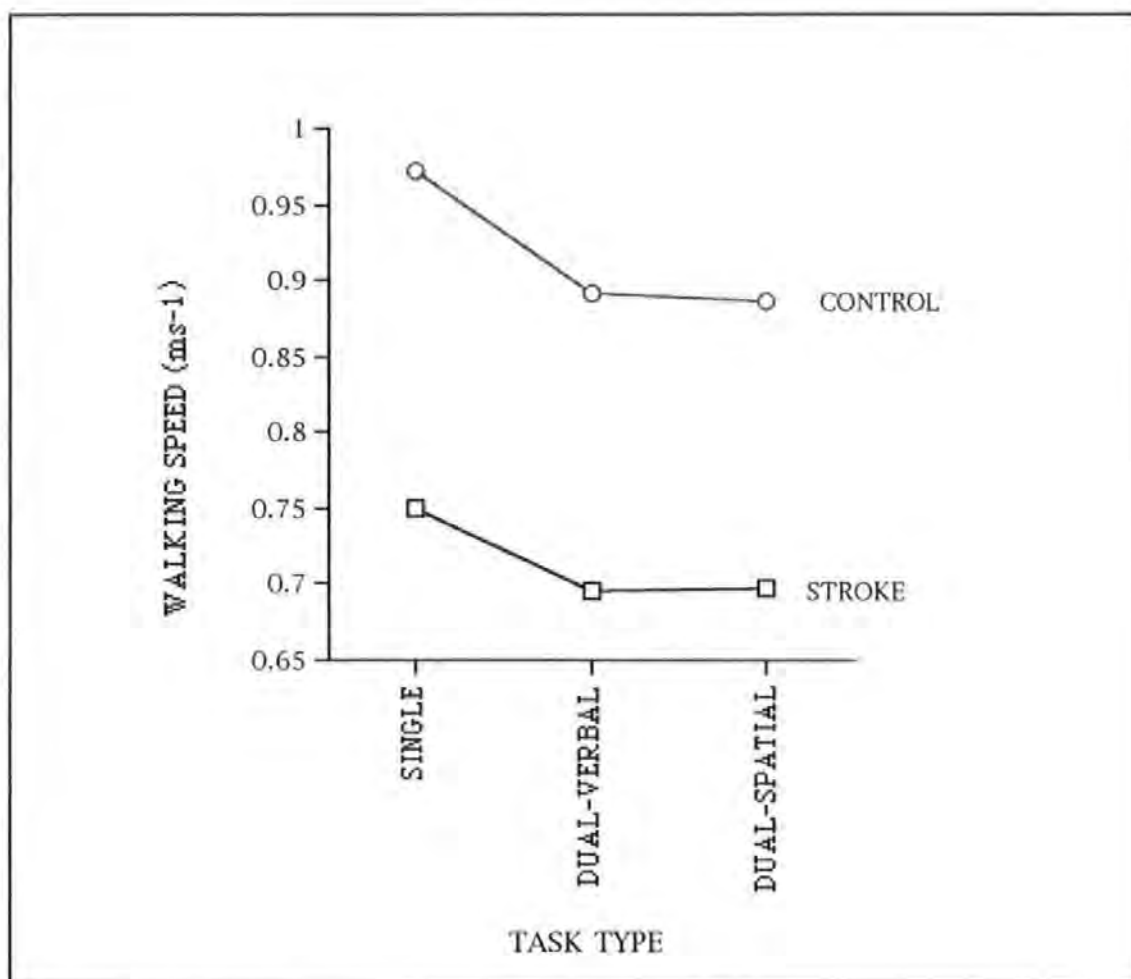
Figure 3.2. Mean walking speed (ms^{-1}) for both experimental groups in all conditions.

The interaction between experimental group and task type was not significant, $F_{(2,32)}=0.38$, p=0.688, indicating that stroke patients were not relatively more slowed by either of the dual task conditions than their controls.

3.3.2. Responses to the Cognitive Tasks

The mean and standard deviations of the correct responses for the two experimental groups in both the single and dual task conditions are shown in Table 3.5.

	VERB ALONE	SPAT ALONE	VERB+WALK	SPAT+WALK
STROKE, N=9	18.778 (0.441)	9.667 (0.500)	18.667 (0.707)	9.333 (1.414)
CON., N=9	18.333 (1.658)	9.667 (0.707)	18.444 (1.464)	9.556 (0.726)

Table 3.5. Means (s.d.) of the correct responses to both cognitive tasks by both experimental groups (stroke and control) in single and dual conditions.

Pearson product moment correlations between age, verbal score, spatial score and correct responses to the verbal and spatial task in the single task condition were calculated. These are summarised in Table 3.6.

	COR. RESP. VERBAL	COR. RESP. SPATIAL
AGE	0.2637,p=0.145	0.1626,p=0.260
VERBAL SCORE	0.4407,p=0.034	-0.2157,p=0.195
SPATIAL SCORE	0.0567,p=0.412	0.0772,p=0.380

Table 3.6. Correlations between age, verbal score, spatial score and the mean number of correct responses in the verbal and spatial cognitive tasks in the single task condition for all participants (N=18).

Since the verbal score was significantly related to the correct responses on the verbal cognitive task, it was included in the analysis as a covariate. A doubly multivariate mixed model analysis of variance was computed. The two dependent variables in the analysis were the correct responses on the verbal cognitive task and the correct responses on the spatial cognitive task. There was a between subjects factor of experimental group, comparing participants who had suffered a stroke with those who had

47

not, and a within subjects variable comparing the single task condition with the dual task condition.

The Box's M multivariate test of homogeneity could not be calculated because there were singular variance-covariance matrices for cells. For this reason in interpreting the analyses only the univariate statistics are considered. However multivariate statisitics are given in this section for information. Pillai's trace is reported because it is the most powerful and the most robust when assumptions are violated.

Pillai's trace indicates a significant effect of removing the covariate in the analysis, pillai=0.394, $F_{(2,14)}$=4.551, p=0.03. The univariate F-tests indicate that there was a significant effect of removing the verbal scores as a covariate in the analysis of the verbal task, $F_{(1,15)}$=9.750, p=0.007, but not in the analysis of the spatial task, $F_{(1,15)}$=0.00006, p=0.994. Multivariate tests indicated no significant differences between the experimental groups, pillai=0.244, $F_{(2,14)}$=2.264, p=0.141. However univariate F-test showed there was a significant main effect of experimental group for the verbal task, $F_{(1,15)}$=4.770, p=0.045, but not for the spatial task, $F_{(1,15)}$=0.063, p=0.806. This effect indicated that the control subjects did relatively worse on the verbal task than the stroke patients, when their initially higher verbal scores were accounted for, but that there was no difference between the groups on the spatial task.

Multivariate tests showed no main effect of task condition (dual or single), pillai=0.079, $F_{(2,15)}$=0.642, p=0.540. Univariate tests confirmed that there was no significant main effect of task condition for either of the cognitive tasks; spatial, $F_{(1,16)}$=1.306, p=0.270; verbal, $F_{(1,16)}$=0.457, p=0.509. Multivariate tests indicated no significant interaction between experimental

group and task condition, pillai=0.023, F(2,15)=0.180. The univariate statistics also indicatedinteraction between task condition and experimental group was not significant for either of the cognitive tasks; spatial, $F_{(1,16)}=0.326$, p=0.576; verbal, $F_{(1,16)}<0.0001$, p>0.999. These effects are illustrated in Figure 3.3.
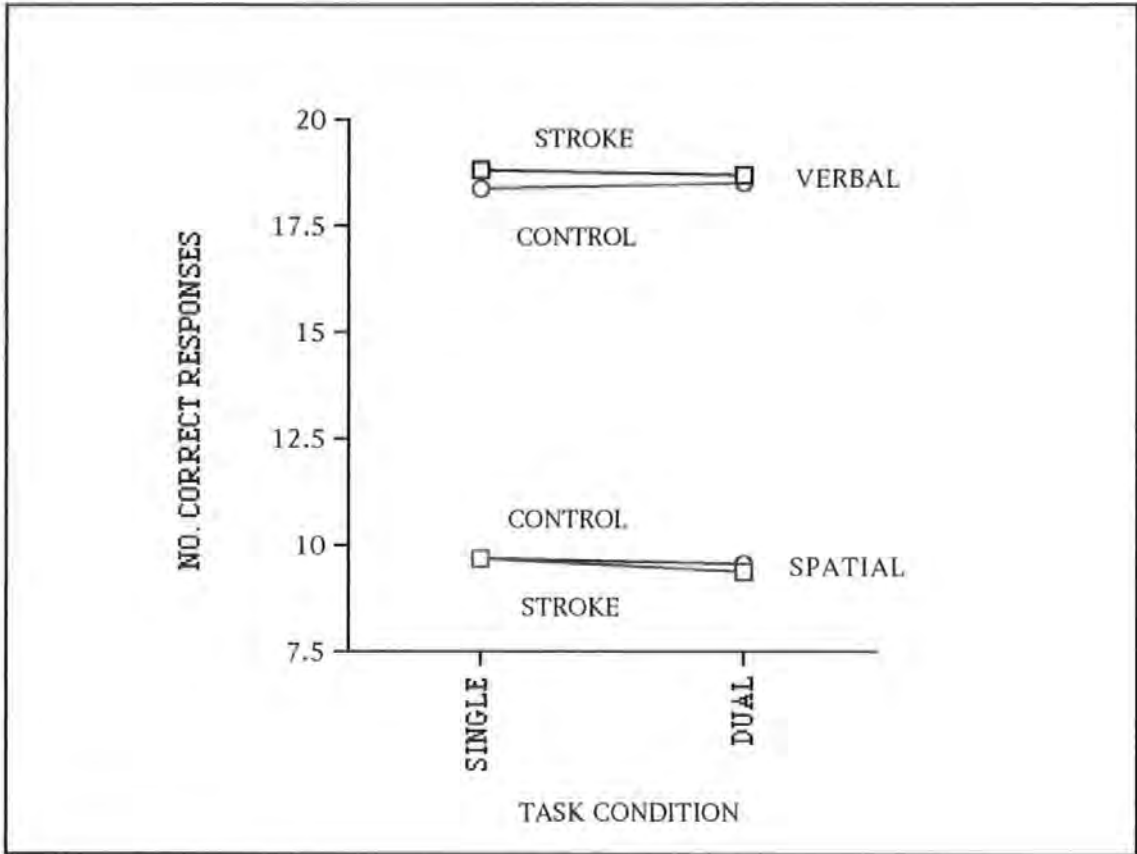
Figure 3.3. The mean number of correct responses for the experimental groups in the single and dual task conditions for the verbal and spatial cognitive tasks.

3.3.3 Gait Patterns

Identification of group and task

On average raters selected the correct experimental group for the participants in 78% of cases. This suggests they were fairly well able to distinguish between the participants who had had a stroke and those who had not. They were not as good at deciding whether a participant was or was not doing a cognitive task, with a mean correct response of 66%. A related t-test was calculated comparing the total number of correct responses for the

49

stroke patients with the total number of correct responses for the control group across raters. There was a significant difference between the ability of raters to detect whether the stroke and control groups were doing a cognitive task, t=-4.33, d.f.=9, p=0.002. Out of a possible 27, the mean number of correct responses for the stroke group was 14.9 (s.d.=4.383), or 55%, and the mean for the control group was 20.7 (s.d.=2.214), or 77%, thus indicating that the raters were better able to judge when the control group was doing a cognitive task than when the stroke group was.

A mixed model analysis of variance was conducted to investigate whether raters were better able to detect either the verbal or spatial task across the experimental groups. There was a between subjects factor of experimental group and a within subjects factor of task type. Table 3.7 summarises the means and standard deviations of the number of correct detections of cognitive task made by raters for both experimental groups and both types of task.

	VERBAL TASK	SPATIAL TASK
CONTROL GROUP	6.40 (0.966)	7.50 (1.434)
STROKE GROUP	5.50 (2.173)	6.10 (1.101)

Table 3.7. Mean (s.d.) number of correctly detected cognitive tasks by raters across experimental group and task type (maximum score in each cell=9).

There was a significant main effect of experimental group, F(1,18)=6, p=0.025, such that the raters were better able to judge whether the control subjects were doing a cognitive task. There was a marginally significant effect of task type, F(1,18)=3.2, p=0.091, indicating that the raters found it marginally easier to detect when participants were doing the spatial task rather than the verbal task. The interaction between task type and experimental group was not significant, F(1,18)=0.28, p=0.605, which indicates

50

that the raters ability to judge whether verbal or spatial cognitive task is being done is not relatively more affected in either experimental group. These results are illustrated in Figure 3.4.
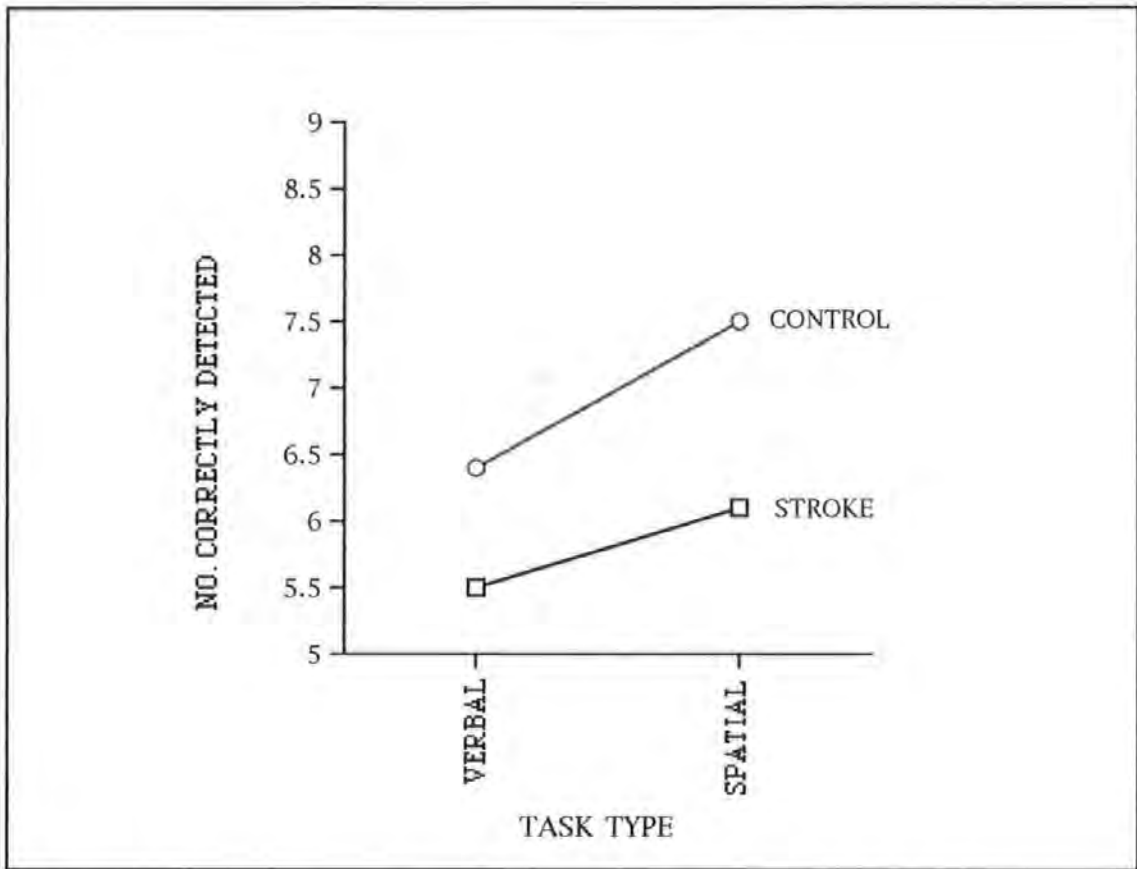
Figure 3.4. The number of times raters correctly identified participants as doing a cognitive task for both experimental groups and both types of task (maximum number of correct responses in any condition=9).

Analysis of gait scores

Ratings were measured in millimetres from the left of the scale and the analysis conducted on these measures. High values represent more normal gait patterns. The means (across raters) and standard deviations (s.d.) of the ratings for the experimental groups in the single and both dual conditions are shown in Table 3.8.

51

	WALK ALONE	WALK+VERBAL	WALK+SPATIAL
CONTROL	93.222 (5.564)	88.633 (7.980)	88.956 (7.340)
STROKE	57.5 (20.82)	58.122 (21.774)	57.033 (21.993)

Table 3.8. The means and standard deviations of the rated gait pattern for both experimental groups in the single and both dual task conditions.

Pearsons product moment correlations between age, spatial score, verbal score and gait pattern in the single and both dual conditions were calculated. These are summarised in Table 3.9.

	WALK ONLY	WALK+VERBAL	WALK+SPATIAL
AGE	-0.1877, p=0.228	-0.1632, P=0.259	-0.2378, p=0.171
VERBAL	0.2797, p=0.130	0.3236, p=0.095	0.3579, p=0.072
SPATIAL	0.4360, p=0.035	0.5188, p=0.014	0.5563, p=0.008

Table 3.9. Correlations between age, verbal score, spatial score and gait pattern in the single and dual conditions for all participants (N=18).

Since the spatial score was significantly related to the rating of gait pattern across the single and both dual conditions it was included in the analysis as a covariate. A mixed model analysis of variance was calculated on these data with a between subjects factor of experimental group and a within subjects factor of task type (i.e. single, dual with verbal task and dual with spatial task).

There was a significant effect of removing the spatial scores as a covariate $F_{(1,15)}=5.03$, p=0.040. There was a significant main effect of experimental group, $F_{(1,15)}=19.63$, p<0.001, indicating that raters judged the gait pattern of the stroke patients as worse than that of the control subjects. There was a significant effect of task type, $F_{(2,32)}=3.22$, p=0.053. Helmert contrasts revealed a significant effect between the single and dual task

conditions, $F_{(1,16)}=5.40$, p=0.034, but no significant difference between the two dual task conditions $F_{(1,16)}=0.176$, p=0.680. There was a significant interaction between experimental group and task type, $F_{(2,32)}=3.63$,p=0.038. Helmert contrasts indicated that the interaction lay between the single and dual conditions, $F_{(1,16)}=5.793$, p=0.029, but not between the two dual conditions, $F_{(1,16)}=0.597$,p=0.451. The interaction revealed that raters judged the gait pattern of the control subjects to deteriorate in a dual task condition but not that of the stroke patients. This is illustrated in Figure 3.5. Inspection of this figure also suggests that the main effect of task was due to the decline in gait pattern of the control subjects rather than the stroke patients.
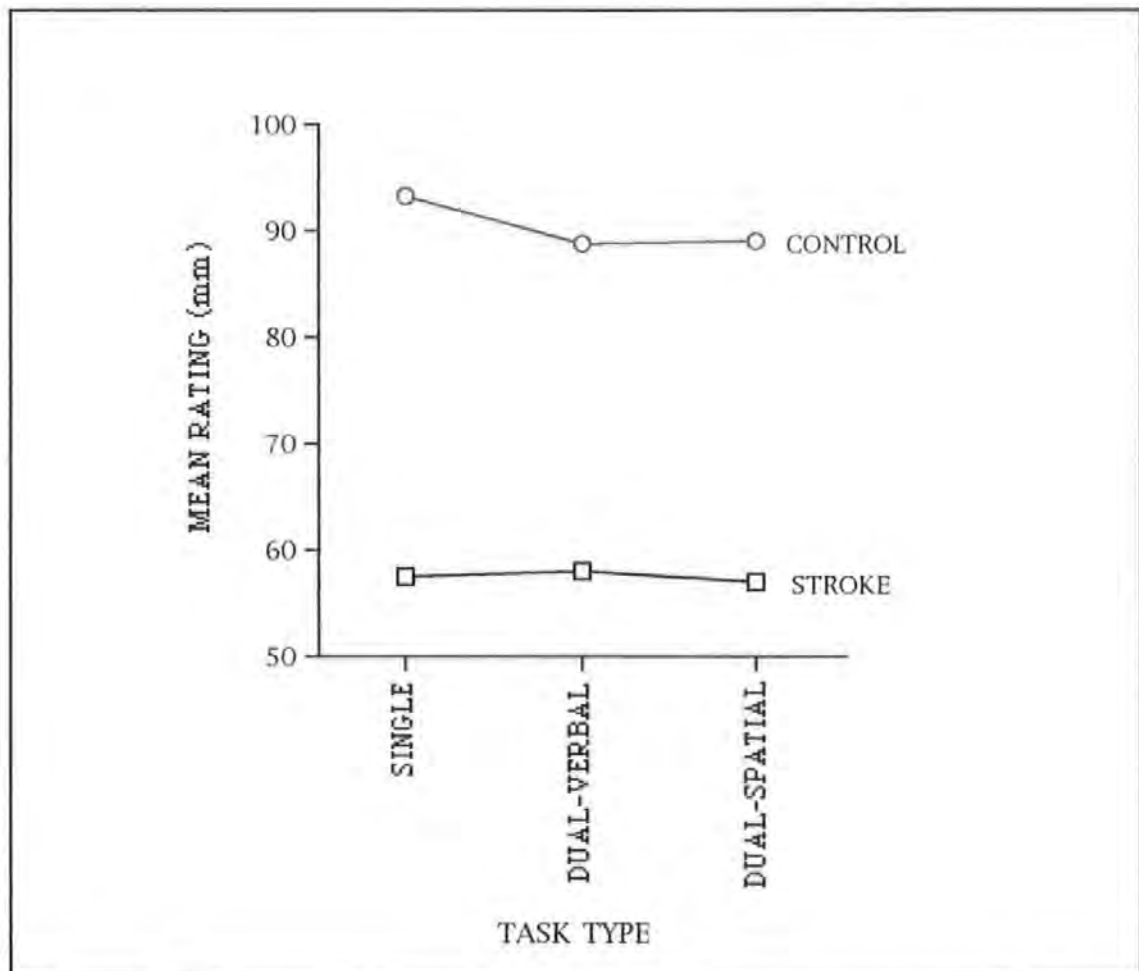
Figure 3.5. The mean ratings of gait pattern for both experimental groups in the single and both dual task conditions.

The visual analogue scale allows raters to decide how they will use it and as a result the difference between raters may be high. In an attempt to overcome this a second analysis was computed. For each rater the mean difference between the score they gave for walking alone and walking whilst doing each of the tasks for each group was calculated. Two Wilcoxon tests were then done, one for the spatial task and one for the verbal task in which the mean differences between the single and dual ratings for the stroke group and the control group were compared across raters. There was a significant difference between the groups on the verbal task Z=-2.0896, p=0.0367 with the mean difference for the stroke group being 0.6 (s.d.=3.44), and for the control group 4.2 (s.d.=3.12). There was also a significant difference between the groups on the spatial task, Z=-2.0896, p=0.0367, with the mean difference for the stroke group being -0.69 (s.d.=4.23) and for the control group 4.61, (s.d.=3.09).

Performance operating characteristics were not calculated because ceiling effects were encountered.

3.4   Discussion

In terms of absolute walking speed, there was no overall difference between the two experimental groups; stroke patients and neurologically normal age-matched controls. This seems surprising from inspection of Figure 3.2 but the variance of these walking speeds is very high, as can be seen from Table 3.3. However, for both groups performing a secondary cognitive task at the same time as walking, slowed walking speed, although the nature of the cognitive task, verbal or spatial, did not make a difference to the speed. The pattern of data revealed that the stroke group were not

more compromised, in terms of walking speed, than their controls by the dual task situation.

A second analysis considered the number of correct responses made on the cognitive tasks. On the numbers (verbal) cognitive task, once the participants' verbal abilities had been accounted for, the control group actually made fewer correct responses than the stroke patients. Performance on this task did not vary according to whether it was being performed whilst sitting or walking and this was the same for both the stroke patients and their controls. On the clock (spatial) task, there was no difference between the groups overall or in either of the task conditions (single or dual), and no difference between the task conditions overall.

From the results reported above hypotheses 1, 2 and 3 from the introduction; that all participants would be more affected by the spatial task in the dual task condition, that the walking speed and/or the number of correct responses on the secondary tasks of the stroke patients would be more compromised than the controls by the dual task situation, and that the effect would be larger for the spatial task, should be rejected. However it is also important to note that unfortunately these scores represent a ceiling effect. The maximum possible score on the numbers task was 19 and the maximum possible score on the clocks task was 10. Inspection of Table 3.5 indicates that in both single and dual conditions, both groups had a mean score of greater than 18 for the numbers task and greater than 9 for the spatial task. In fact the stroke patients were correct on the verbal task 98.8% and on the spatial task 96.7% on average and the controls 96.5% and 96.7% correspondingly This is somewhat surprising given that in a pilot study (c.f. Chapter 2) no ceiling effects were found.

The third set of analyses conducted looked at the gait patterns of the participants in an attempt to address hypotheses 4 and 5 from the introduction; that the stroke patients will use cognitive resources to compensate for deficits in their gait and that the resources they use for this will be the same as those involved in spatial cognitive tasks. The gait patterns of all participants were therefore judged blind by a panel of raters as they walked in the single and both dual task conditions (verbal and spatial). Raters were also asked to judge whether or not each participant had suffered a stroke or not and whether they were doing a secondary task or not.

The raters were fairly well able to judge whether or not a person had suffered a stroke but were less good at detecting whether or not the person was doing a secondary task whilst walking. Investigation of this revealed that for the control subjects they were able to judge fairly well but for the stroke patients they were only correct just over half the time. Further investigation indicated that the raters found it marginally easier to detect the dual task condition when the task was spatial in nature.

The raters judged the gait pattern of the stroke patients to be worse than that of the controls, and they indicated a difference between the two experimental groups such that the gait pattern of the control group was judged to have deteriorated in either dual task condition (one was not worse than the other). The standard deviations of the ratings were very high, particularly for the stroke patients when the analysis was conducted in this way. One reason for this is that in using an analogue scale to make ratings on, raters may well have set different points on the scale to represent the same ability. In order to overcome this potential problem another analysis was done in which the difference between each raters rating for walking

alone and walking whilst doing a secondary task was calculated for each participant. A Wilcoxon test was then used to compare the differences between the scores which each rater gave to stroke patients and their controls for each of the secondary tasks. Data was thus summed across participants and each rater was compared against themselves. The results of this analysis confirmed the earlier one, showing a significant difference between the two experimental groups in each of the tasks, with the means indicating a greater judged difference between the scores for the control patients rather than their controls.

This finding contradicts that of Connolly (1990) and merits some discussion. On the basis of these results it seems that one should reject the hypothesis that the stroke patients would use cognitive resources to compensate for their gait abnormalities and accept instead that the control participants do this. This would be hard to reconcile with our present theoretical stance. However there is a more likely explanation for this somewhat unexpected result and this lies with the raters themselves.

In her earlier experiment Connolly used a group of raters who were experienced at assessing gait as part of their day-to-day work. In the present experiment that proved impossible for a number of reasons and in fact, only a third of the raters were experienced at assessing gait. The most obvious change in a person's gait when they are asked to do a secondary task is not in gait pattern but in speed. It is very likely that despite being asked to rate on gait *pattern*, at least some of the raters were actually influenced in their rating by gait *speed*. Although there was no significant statistical difference between the speed of walking of the stroke patients and the controls, for most there was an obvious clinical difference (c.f. Figure 3.2), furthermore the

way the participants slowed when doing a secondary task was not affected by which group they were in. Weber's law (Weber, 1834) states:

> "when noting a difference between things that have been compared, we do not perceive the difference between the things, but the ratio of the differences to their magnitude."

In other words equal ratios of stimulus change are approximately equally detectable. From these data the ratio of the change in speed to the original magnitude of speed for the stroke patients is smaller than for the control subjects. Hence, if one accepts that the raters were influenced by speed, then it is not surprising that they were more able to detect a change in speed for those who were walking faster.

A point worth noting is that raters found it marginally easier to judge accurately that people were doing a secondary task when the task was a spatial one. Given that there were ceiling effects in this experiment, it is not possible to judge whether participants would be more affected by the spatial task than the verbal one. However the possibility that it is easier to detect that secondary task is being done from observing a person's walking when that task is spatial in nature, suggests that the hypothesis should not yet be discarded, but rather deserves further investigation. However, it is not possible to say, from the results of this experiment, whether or not more than one central processor exists.

Given the ceiling effects and the likelihood that unskilled raters were not able to give a true picture of the gait patterns of participants, it would be premature to discard the hypotheses stated in the introduction. The predicted effects may well be found if the experiment was repeated using more difficult cognitive tasks, and if the gait raters were more experienced at rating gait patterns. Physiotherapists specialising in neurology would

probably be much better able to this. The difficulty would lie in recruiting them as they would have to come from a different health trust or authority or they would be rating patients they had treated. A larger number of subjects than recruited here would also tend to reduce the large observed variance in the various measures and this is likely to clarify the results.

Two further points need addressing from these results. The first is the somewhat surprising finding that even when verbal abilities are accounted for, stroke patients scored more highly on the numbers task than their controls. Given the ceiling effects noted, this result is difficult to understand, although it may be the stroke patients had more invested in the task and were therefore more motivated to pay attention and succeed. The second point to note is that there was a significant reduction in speed between the single and dual conditions for all participants. This is important to consider in the light of the discussion about what automatic behaviour is.

The slowing of subjects in the dual task condition can be explained in terms of schmidt's theory of automaticity in the following way. Motor programmes may be able to control long durations of walking but it seems likely that a new programme will be initiated at a turn or that the walking will come under a more closed-loop strategy at such times. Either way this will place some demand on a person's cognitive resources. The participants in this experiment had to make a 180 degree turn at ten metre intervals because of the length of the walking track. The slowing down when a participant was asked to do a secondary task could then be due to either of two reasons. The first being that they were monitoring their movement more frequently (i.e. dropping into more closed-loop control). This would not be sensible because it would add an additional strain on their cognitive. resources which are already having to tackle the secondary task. More

likely it is because at the end of the track when a new programme is initiated or the movement comes under closed-loop control, and two tasks are therefore demanding limited resources, the process takes longer. Participants are likely to anticipate this and begin their slowing earlier and take longer to build up speed again following a turn. It is not possible to assess this with the rather crude experimental method used here, one would need more sophisticated equipment such as a Selspot system.

CHAPTER FOUR

EXPERIMENT 2

4.1   Introduction

The previous experiment considered the effects of divided attention on walking as an example of an automatic activity. However walking is a very complex activity which is not yet well understood (e.g. Winter, 1983). What is known is that biped walking is an inherently unstable movement that requires complex control. Since visual and vestibular feedback systems are not critical for walking, it is likely that humans possess a gait pattern generator, which according to Lohr and Wisniewski (1987) lies above the spinal cord in the higher brain areas. Depending on the degree of automaticity, the gait thus generated is modified to the environment either by the use of motor programmes or by closed-loop feedback control. It seems then that walking is complicated for a number of reasons. With this in mind the present experiment considers the effects of the dual task situation on hand and arm movements.

Following a stroke, any spontaneous recovery of upper limb motor function that occurs is generally limited to the first six months (Twitchell, 1951; Parker, Wade and Langton Hewer, 1986). Furthermore there is a consensus that current rehabilitation techniques are less effective in improving upper limb motor function after six months (Basmajian, 1989). If this is the case then it is important to understand as much as possible about the process of upper limb function recovery and to be able to plot its progress.

Actions carried out by the hands are often of a finer, more controlled nature and therefore depend to a greater extend on closed-loop methods of control. It has already been noted in Chapter 1 that the fine control of the hand and fingers is usually the first thing affected by a stroke, and the last place for function to fully return, if indeed it does. A person who has suffered a stroke is likely to exhibit some uncertainty about his hand movement, either because of a degree of remaining paralysis, reduced or altered sensation, or because of a lack of confidence about his movement ability. In order to overcome this a person who has had a stroke is more likely to bring the control of their hand and arm under closed-loop control. If this is the case in a dual task situation they will experience greater interference effects than a neurologically normal person.

As in Experiment 1, a dual task methodology was employed to investigate whether movement control was accomplished in different ways by stroke patients as compared to neurologically normal control subjects. It was important to ascertain not just whether the stroke patients used different methods for control, but also what these methods might be, in order that they could be exploited in developing movement rehabilitation techniques. As before two secondary tasks were used, a spatial task and a verbal task to try and ascertain whether there was a distinct information processing system to deal with movement and spatial tasks

In order to overcome the problems encountered in Experiment 1 the following changes were made to the experimental protocol. First although the same principles were used, the cognitive tasks were made more difficult by decreasing the time between presentation of each stimulus item on the tapes. In the case of the numbers task an additional target pair was included and the distribution of targets was made more complex (compare appendices

3 and 4). Second, because of the difficulties encountered in finding experienced movement ability raters, a task was chosen where an obvious objective measure of movement quality was available, rather than a more subjective rating. This task was to place pegs in a pegboard. It is argued that this task is analogous not only with the speed of walking from Experiment 1, but also with the ratings of quality of gait. This is because in order to successfully place a peg, one must make an accurate movement. Placing the peg to the side of a hole will not be successful and will therefore reduce the number of pegs placed. This type of error could be seen as similar to a limp. The number of pegs placed in the board during the test was therefore taken to represent not only speed of movement, but also quality of movement.

Using this type of task, where a fair degree of control is required but the task can be accomplished with either hand is of added benefit because it allows a stroke patient to act as their own control. A comparison of involved and spared arm makes it possible to test whether stroke patients are simply less able to divide their attention between tasks, or whether the effect is specific to their involved side and hence an indication of more resources being directed to their movement on their involved side.

In summary in this experiment it was hoped to test the following:
1) whether the movement control of stroke patients differed to that of control subjects,
2) whether there was any indication of a specific movement/spatial task central processing capacity as distinct from a general cognitive resource,
3) whether stroke patients were worse at dividing their attention between tasks,
4) whether they directed more resources to their involved side in order to improve functioning on that side.

4.1.1 Hypotheses

1) In the dual task situation all participants will be more affected by the spatial task than the verbal and this will be picked up by differential performance on the number of pegs placed and/or correct responses made to each cognitive task in the dual task conditions.

2) The number of pegs placed and/or the number of correct responses on the secondary tasks of the stroke patients will be more compromised than that of their controls by the dual task situation.

3) This effect will be larger when the secondary cognitive task is spatial in nature.

4) These effects will be found on the stroke patients' involved side, but on their spared side they would not be so pronounced.

5) Stroke patients will be less able to divide their attention when using their involved side, as will be evidenced by their poorer performance on the peg and/or cognitive tasks when using their involved side.

4.2 Methods

4.2.1 Participants

Nine stroke patients and 8 control subjects took part in the experiment. However four of the stroke patients chose not to attempt the task with their weak hand so only the data from five stroke patients is included in the analyses. Table 4.1 summarises information about all nine patients, with the five who took part in all parts of the experiment in italics.

MAIN PROB.	HAND	HEMI	INFORMATION FROM CT SCAN
RH=P, RLe=W	L	L	Small intracerebral bleed in Lbasal ganglia
RH=W,Rle=P. SP.	R	L	Infarct, left temporal + parietal area.
RH=W	*L*	*L*	*Lesion in L posterior internal capsule.*
RH=W, SP	*R*	*L*	*No Scan*
RH=W, RLe=W	*R*	*L*	*L centrum semi-oval infarct.*
RH=W,RLe=P, SP	R	L	Infarct in L carotid territory.
LH=W, LLe=W,	R	R	No Scan.
LH=W, LLe=W	*R*	*R*	*R posterior cerebral thalamus ?infarct*
LH=W, LLe=W	*R*	*R*	*No Scan*

Table 4.1. Main problem since stroke, dominant hand, affected hemisphere and information from the CT scans of the stroke patients. (R=right, L=left, H=hand, Le=Leg, P=paralysed, W=weak, SP=some speech difficulty). Those in italics took part in all parts of the experiment.

Of these nine stroke patients, five had also taken part in Experiment 1. Of the five who completed all parts of Experiment 2, four had taken part in Experiment 1. There are no apparent distinguishing features of the stroke patients who did not wish to use their weak hand, except in one case where the hand was actually paralysed and picking up the pegs would have been impossible.

Of the eight control subjects, six had also taken part in Experiment 1. Of the two new control subjects one had incomplete data on the psychometric tests and was subsequently dropped from the analysis. The analyses are therefore based on five stroke patients and seven control subjects.

As in Experiment 1, the scaled scores from the three spatial and three verbal subtests conducted at the initial visit were summed to give a spatial score and a verbal score for all participants. Table 4.2 summarises the means of these scores and the mean age of the two experimental groups.

	STROKE PATIENTS	CONTROLS
AGE (s.d.)	64.6 (6.95)	58.0 (7.87)
AGE RANGE	57 - 73	48 - 67
SPATIAL (s.d.)	22.4 (10.94)	31.0 (4.40)
VERBAL (s.d.)	22 (5.96)	33.86 (10.45)

Table 4.2. Summary of the mean and standard deviation of the age (years), age range (years), and the mean and standard deviation of the spatial and verbal scores of the stroke patients (N=5) and their controls (N=7).

As in Experiment 1, three of the control subjects came from markedly different professional backgrounds than the other participants and this is a likely contributory factor for the higher verbal and spatial scores.

4.2.2 Apparatus and Stimuli

A circular pegboard with 121 one centimetre holes, spaced 1cm apart in a star shape was used. Sixty plastic pegs with rounded heads were provided. This set of board and pegs was used in preference to a standard Purdue Pegboard because the larger size of the pegs and holes made the task possible for stroke patients who had a significant weakness in one of their hands. Stimuli were presented on a portable tape recorder and a second

66

portable tape recorder was used to record the participants' responses. There were four recordings of equivalent stimuli available for each of the cognitive tasks (lists of stimuli on these tapes appear in appendix 4). Although the principle of these tasks was the same as in Experiment 1, the set up of the tapes was changed to try and overcome the ceiling effects observed in Experiment 1. For the spatial task once again ten clock times were presented but this time at 5 second intervals, and for the verbal task eighteen numbers were presented at 3 second intervals, with 6 pairs of numbers adding to 18. Each of the tapes lasted one minute.

4.2.3 Design

A quasi-experimental, mixed model design was employed. As in Experiment 1 two different types of task were used, putting pegs in the pegboard and a cognitive task based on either spatial (clock times) or verbal (numbers) abilities. These tasks were performed both separately and concurrently. There was a between subjects factor of experimental group and within subject factors comparing the single and dual task conditions for both the number of pegs placed and the number of correct responses to the cognitive tasks, and which hand was used to place the pegs.

4.2.4 Procedure

Each participant carried out eight tasks; 1) the numbers task alone, 2) the clock task alone, 3) and 4) placing pegs in the board alone with the good hand and the weak hand, 5) and 6) placing pegs in the board whilst doing the cognitive tasks with the good hand, 7) and 8) placing pegs in the board whilst doing the cognitive tasks with the weak hand. These tasks were performed in a counterbalanced order. All tasks lasted one minute.

The cognitive tasks have been described in the general methodology section. Stimuli were presented on a tape recorder and their presentation and the participants' responses were recorded on a second tape recorder. Each of the four stimuli tapes for both the verbal and spatial tasks began with the word "start" and ended with the word "stop", the stimuli being presented between. For the dual task conditions where participants were required to place pegs and do the cognitive task, they were asked to begin placing pegs when they heard "start" and to stop when they heard "stop".

4.2.5 Data manipulation

Since the control subjects did not have a good hand and a weak hand they were matched to the stroke patients in the following way. First all eight control subjects were matched as closely as possible to eight of the nine stroke patients in terms of age. For each matched pair a note was taken of whether the stroke patient's weak hand was their dominant or non-dominant hand. If their weak hand was their dominant hand then the dominant hand of their control was classed as "weak" and the non-dominant one as "good". If it was their non-dominant hand then the non-dominant hand of their control was classed as the "weak" hand and the dominant one as their "good" hand. This process was completed for each participant, whether or not they were included in later analyses.

4.3 Results

4.3.1 Number of Pegs Placed

The means and standard deviations of the number of pegs placed by each of the experimental groups in the single and both dual task conditions and with each hand are shown in Table 4.3.

	SIN GLE		DUAL VERBAL		DUAL SPATIAL	
	GOOD	WEAK	GOOD	WEAK	GOOD	WEAK
STROKE	28.8 (6.5)	21.8 (9.2)	24.2 (7.2)	19.6(10.3)	22.2(8.3)	16.6(8.6)
CONTROL	32.0 (4.8)	32.7 (4.7)	29.6 (3.8)	31.3(4.4)	27.8 (4.9)	27(2.2)

Table 4.3 The means (s.d.) of the number of pegs placed by both experimental groups in both single and dual conditions with each hand.

Pearson's product moment correlations were calculated between age, spatial score, verbal score and the number of pegs placed in each condition and by each hand. These are summarised in Table 4.4.

	SIN GLE		DUAL VERBAL		DUAL SPATIAL	
	GOOD	WEAK	GOOD	WEAK	GOOD	WEAK
AGE	- 0.4246	- 0.2144	- 0.3368	- 0.2952	- 0.3595	- 0.0993
	p=0.084	p=0.252	p=0.142	p=0.176	p=0.126	p=0.379
VERBAL	- 0.0555	0.4897	0.2236	0.5569	0.1653	0.5618
	p=0.432	p=0.053	p=0.242	p=0.03	p=0.304	p=0.029
SPATIAL	0.3515	0.5730	0.6701	0.6791	0.6220	0.7263
	p=0.131	p=0.026	p=0.009	p=0.008	p=0.015	p=0.004

Table 4.4. Correlations between age, verbal score, spatial score, and number of pegs placed in all conditions with each hand for all participants (N=12).

Since the verbal and spatial scores were significantly related to placing pegs with the weak hand in every case, and the spatial scores were also related to placing pegs with the good hand in the dual conditions, these scores were included in the analysis as covariates. A mixed model analysis of variance was computed with experimental group as a between subjects factor and task type (single, dual-verbal, or dual-spatial) and hand used as within subjects variables. The verbal and spatial scores were removed as covariates.

The regression sums of squares was not significant indicating that the amount of the variability accounted for by removing the covariates was not significant, $F_{(2,8)}=2.83$, p=0.118. There was no significant main effect of experimental group, $F_{(1, 8)}=3.28$, p=0.108, so one group did not manage more pegs than the other. There was no significant main effect of hand used, $F_{(1,10)}=2.84$, p=0.123, but a marginally significant interaction between hand and experimental group, $F_{(1,10)}=4.1$, p=0.07. This suggests that on average the stroke patients placed marginally fewer pegs with their affected hand than their controls. There was a significant main effect of task, $F_{(2,20)}=27.24$, p<0.001. Helmert contrasts revealed a significant difference between the single and dual task conditions, $F_{(1,10)}=39.317$, p<0.001; and a significant difference between the two dual tasks, $F_{(1,10)}=14.463$, p=0.003. Inspection of Figure 4.1 shows that as predicted, in terms of the number of pegs placed, the spatial task has a more adverse affect than the verbal task. There was no significant interaction between experimental group and task type, $F_{(2,20)}=0.52$, p=0.602, which indicates that the effect of task type was the same for both experimental groups. The interaction between hand and task type was not significant, $F_{(2,20)}=1.87$, p=0.180, and neither was the three-way interaction between experimental group, hand and task type, $F_{(2,20)}=1.02$, p=0.379. Therefore, in terms of placing pegs in a pegboard, the stroke

patients were not relatively more adversely affected by either dual task condition than their controls.
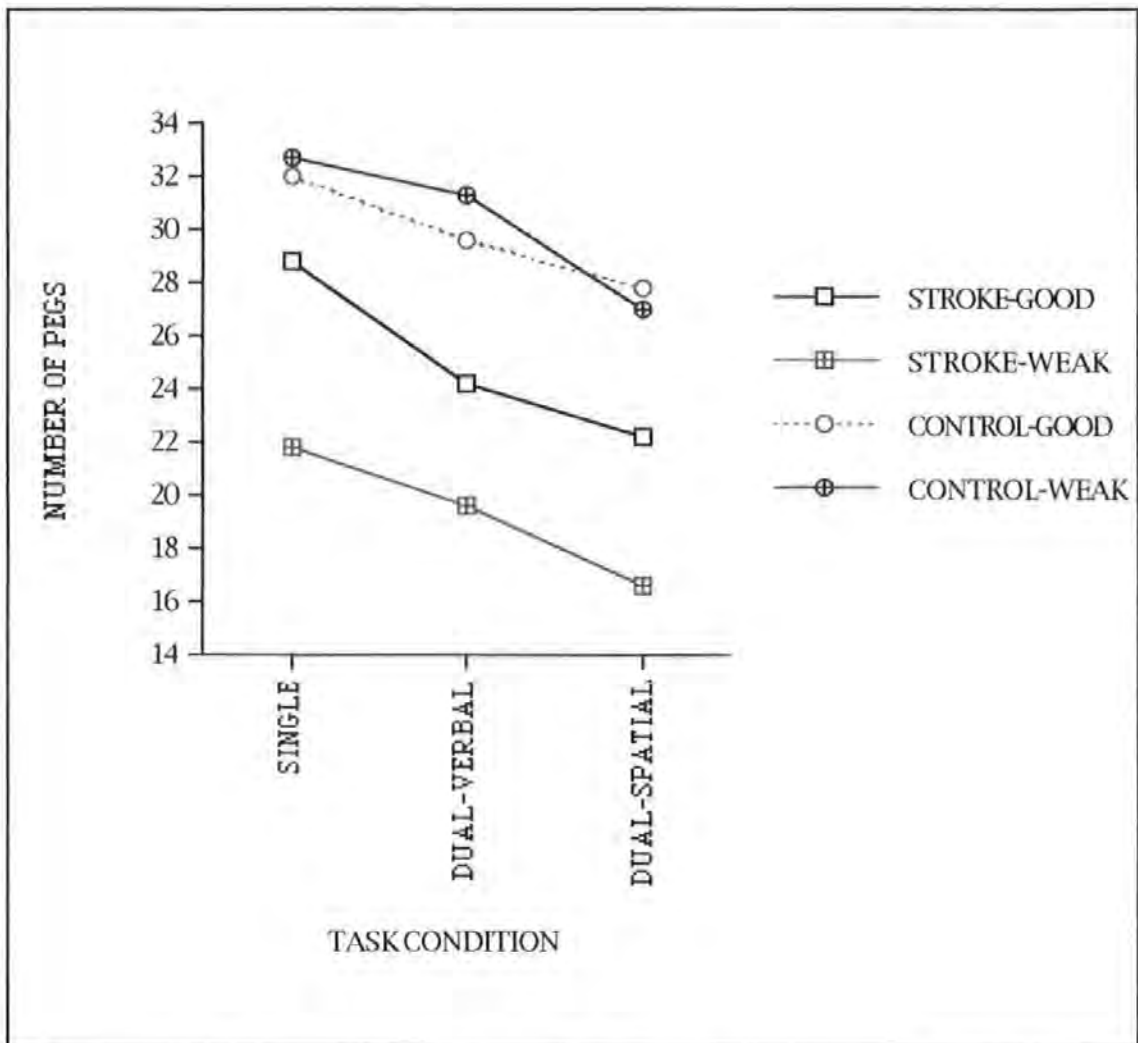
Figure 4.1. The number of pegs placed by each experimental group in each of the task conditions with each hand.

4.3.2 Responses to the Cognitive Tasks

The mean and standard deviations of the correct responses for the two experimental groups in both the single and dual task conditions, with the distinction made between which hand is used in the dual conditions are shown in Table 4.5.

	VERBAL			SPATIAL		
	ALONE	+GOOD	+ WEAK	ALONE	+GOOD	+ WEAK
STROKE	14.6(1.67)	15.8(0.84)	15.6(0.89)	8.4(2.3)	8.2(3.03)	6.8(2.59)
CONTROL	16.7(0.49)	16.8(0.39)	16.7(0.49)	9.3(1.50)	9.6(0.79)	9.6(0.54)

Table 4.5. The means (s.d.) of the correct responses of both experimental groups in both single and dual conditions. In the dual conditions a distinction is made between whether the weak or good hand is used.

In the single task conditions the overall percentage correct on the verbal task was 86.95% (81.1% for the stroke group and 92.8% for the control group) and 88.5% (84% for the stroke group and 93% for the control group) for the spatial task. The task difficulty was therefore successfully increased though scores remained close to ceiling. The two tasks did not differ in difficulty.

Pearson's product moment correlations were calculated between age, spatial score and verbal score, and the correct responses for the numbers task and the clock task in the single task condition for all subjects. The results of this are shown in Table 4.6.

	AGE	VERBAL	SPATIAL
NUMBERS TASK	-0.2438, p=0.223	0.4176, p=0.088	0.4009, p=0.098
CLOCK TASK	0.4457, p=0.073	0.1595, p=0.310	0.5862, p=0.023

Table 4.6. The correlations between age, verbal score, spatial score and the number of correct responses on the two cognitive tasks for all participants (N=12).

In this case the only significant correlation was between the spatial score and the clock task and so only the spatial score was used as a covariate in the analysis. A doubly multivariate mixed model analysis of variance was

computed. The two dependent variables in the analysis were the number of correct responses on the verbal (numbers) task and the spatial (clock) task. There was a between subjects factor of experimental group and a within subjects factor of task condition (single, dual-verbal, dual-spatial). The spatial scores were removed as a covariate.

As in Experiment 1 the Box's M multivariate test of homogeneity could not be calculated because there were singular variance-covariance matrices for cells. As a result, in interpreting the analyses only the univariate statistics are considered. However the multivariate statistics are reported here and once again Pillai's trace is used because it is the most robust when assumptions are violated.

Pillai's trace indicates a significant effect of removing the covariate in the analysis; pillai=0.625, $F_{(2,8)}$=6.676, p=0.020. The univariate statistics indicate removing the covariate was marginally significant in the clock task, $F_{(1,9)}$=4.66, p=0.059, but not significant for the numbers task, $F_{(1,9)}$=3.37, p=0.099. Multivariate tests indicated a significant difference between the groups; pillai=0.540, F(2,8)=4.703, p=0.045. The univariate statistics revealed that there was a significant main effect of experimental group for the numbers task, $F_{(1,9)}$=6.58, p=0.03, indicating that the control group made more correct responses than the stroke patients, but not for the clock task, $F_{(1,9)}$=0.325,p=0.583.

Averaged multivariate statistics revealed a significant effect of task condition,; pillai=0.440, $F_{(4,40)}$=2.820,p=0.038 and univariate tests showed that there was a significant main effect of task condition on the numbers task, $F_{(2,20)}$=3.654, p=0.044, but not on the clock task, $F_{(2,20)}$=2.153,p=0.142. Helmert contrasts indicated a marginally significant difference between the single

73

and dual conditions on the numbers task, $F_{(1,10)}=3.843$, p=0.078, but no significant differences between the scores in the two dual task conditions (i.e. which hand is used to place the pegs whilst doing the numbers task), $F_{(1,10)}=2.069$, p=0.181. This indicated that participants actually scored higher in the dual task conditions.

Averaged mulitvariate tests revealed a significant interaction between task condition and experimental group; pillai=0.418, $F_{(4,40)}=2.646$, p=0.047. However univariate statistics indicated that it was not significant for the numbers task, $F_{(2,20)}=2.653$, p=0.095, but was marginally significant for the clock task once the covariate had been removed, $F_{(2,20)}=3.351$, p=0.056. In the clock task, Helmert contrasts revealed the interaction was a marginally significant between the single and dual conditions, $F_{(1,10)}=3.858$, p=0.078, but not between the two dual task conditions (i.e. which hand was used), $F_{(1,10)}=2.977$, p=0.115. This pattern suggests that the significance of the interaction is between the single task and using the involved hand. These results are illustrated in Figure 4.2.
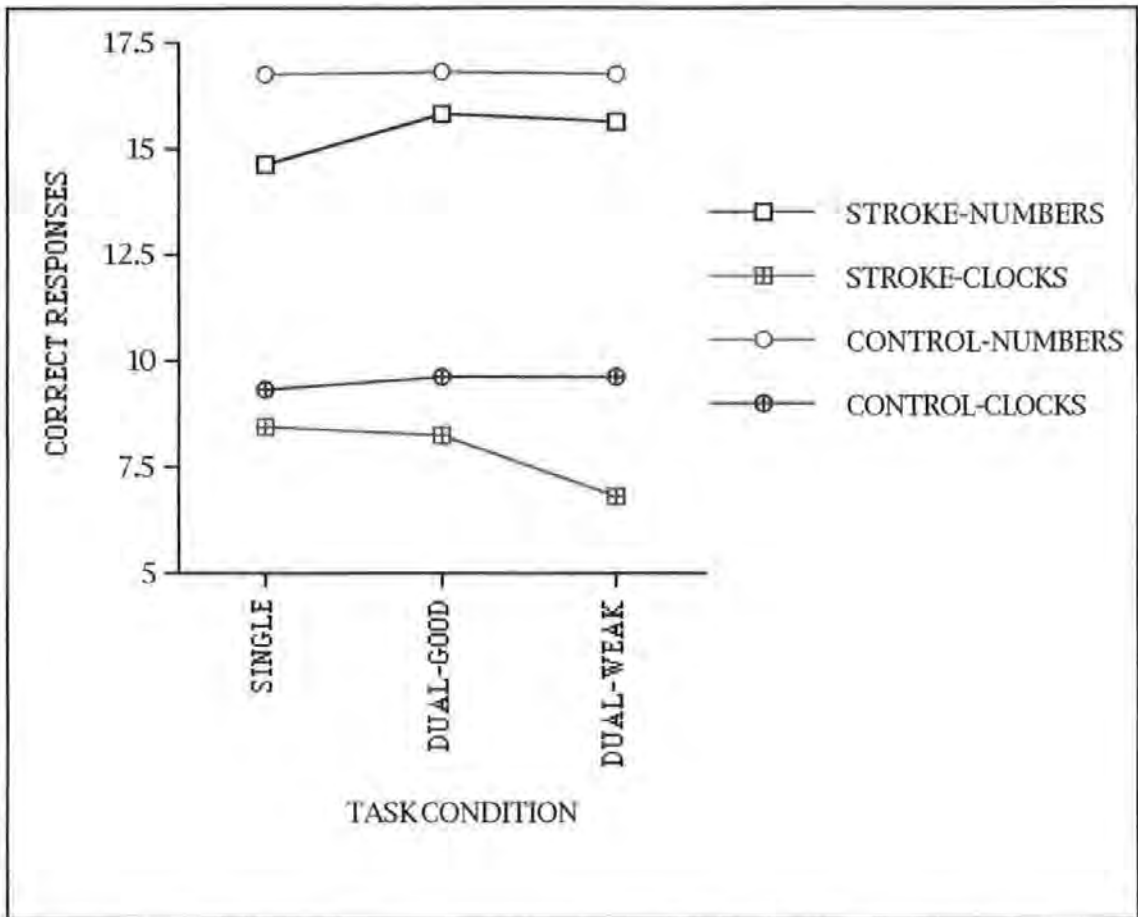
Figure 4.2. The number of correct responses to the secondary tasks by both groups for both the verbal and spatial task.

4.3.3 Performance Operating Characteristics

For the purposes of comparing the two groups on POCs, a smaller control group was used, as in this instance it was not possible to control for spatial and verbal abilities using covariates and including all the control subjects may have biased the comparison. To attempt to overcome this five control subjects were chosen matched on spatial ability (from the WAIS-R) as closely as possible with the five stroke patients.

In order to assess the divided attention costs, performance operating characteristics (POCs) were calculated for each hand for both experimental groups for the spatial task. POCs were drawn for both hands of all participants and the area corresponding to the divided attention cost was calculated for each. In the following figures the area corresponding to the

75

divided attention cost is represented by the unshaded area. Wilcoxon tests were then performed on the data to assess whether stroke patients were less able to divided their attention between the tasks and whether any effect was dependent on which hand they were using. The following comparisons were made: 1) between the involved hand of the stroke patients and the corresponding hand of the controls, 2) between the spared hand of the stroke patients and the corresponding hand of the controls, and 3) between the involved and spared hands of the stroke patients.

1) Figure 4.3 illustrates the mean divided attention costs for the stroke and control participants when they are using their involved hand.
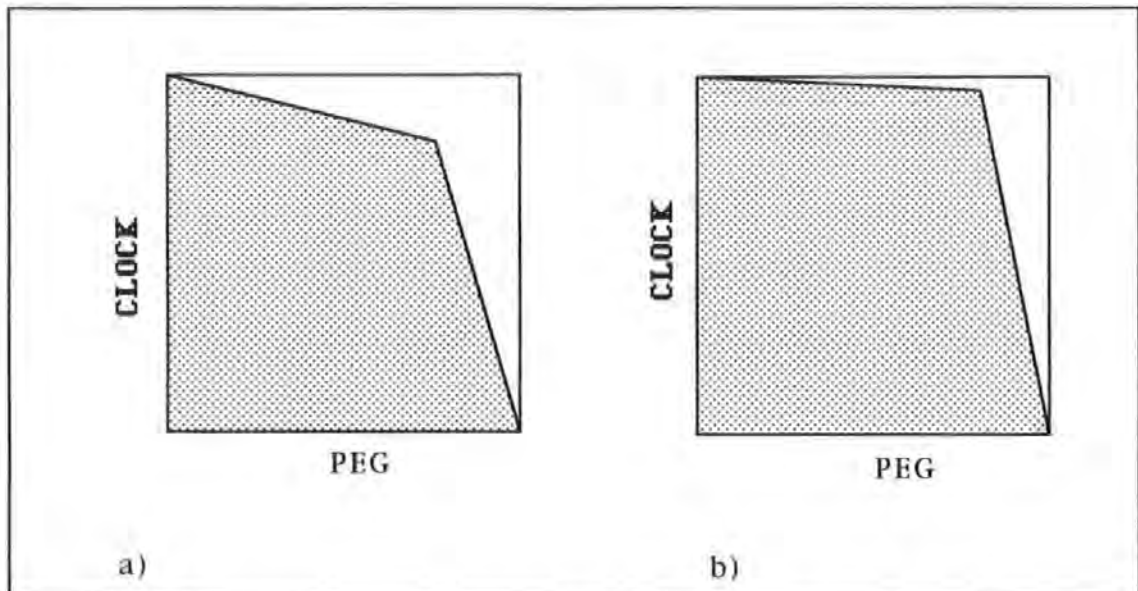
Figure 4.3. Mean POCs for the involved hand, showing the stroke patients on the left (a) and the controls on the right (b). The vertical axis represents performance on the clock task and the horizontal axis performance on the pegs task.

The Wilcoxon test revealed a significant difference between the groups, Z=-2.0226, p=0.022, with the mean divided attention costs for the stroke patients being 10.64 and for the controls 5.69.

2) Figure 4.4 illustrates the mean divided attention costs for the stroke and control participants when they are using their spared hand.
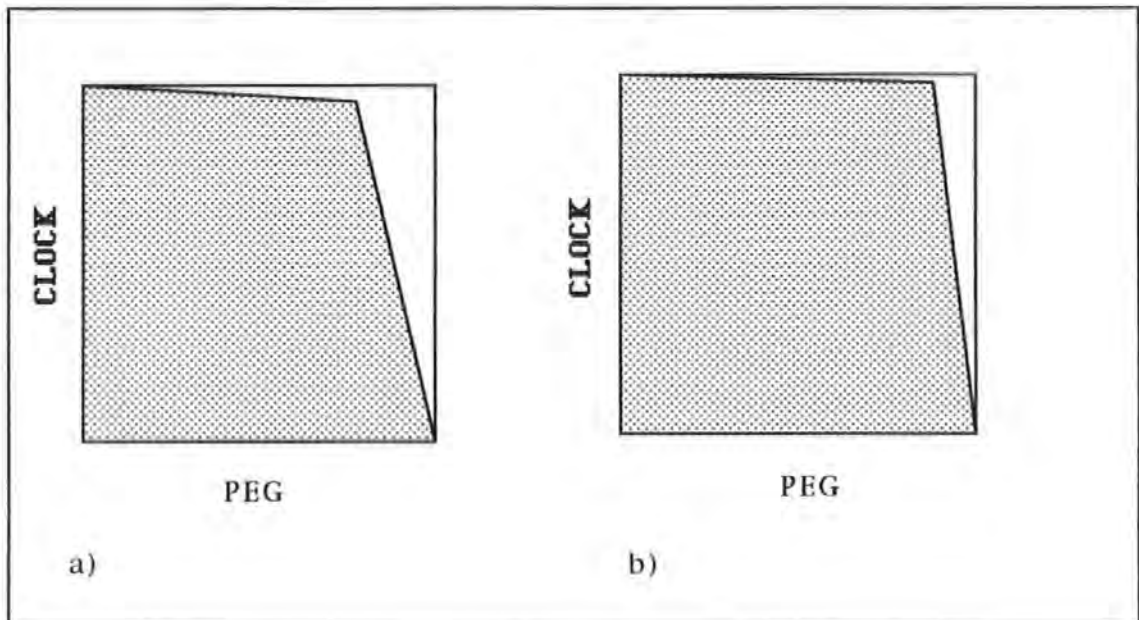
Figure 4.4. Mean POCs for the spared hand, showing the stroke patients on the left (a) and the controls on the right (b). The vertical axis represents performance on the clock task and the horizontal axis performance on the pegs task.

The Wilcoxon test revealed no significant difference between the groups, Z=-0.4045, p=0.3429, with the mean divided attention costs for the stroke patients being 6.68 and for the controls 3.71.

3) Figure 4.5 illustrates the mean divided attention costs for the stroke patients when they are using their involved and spared hands.

77
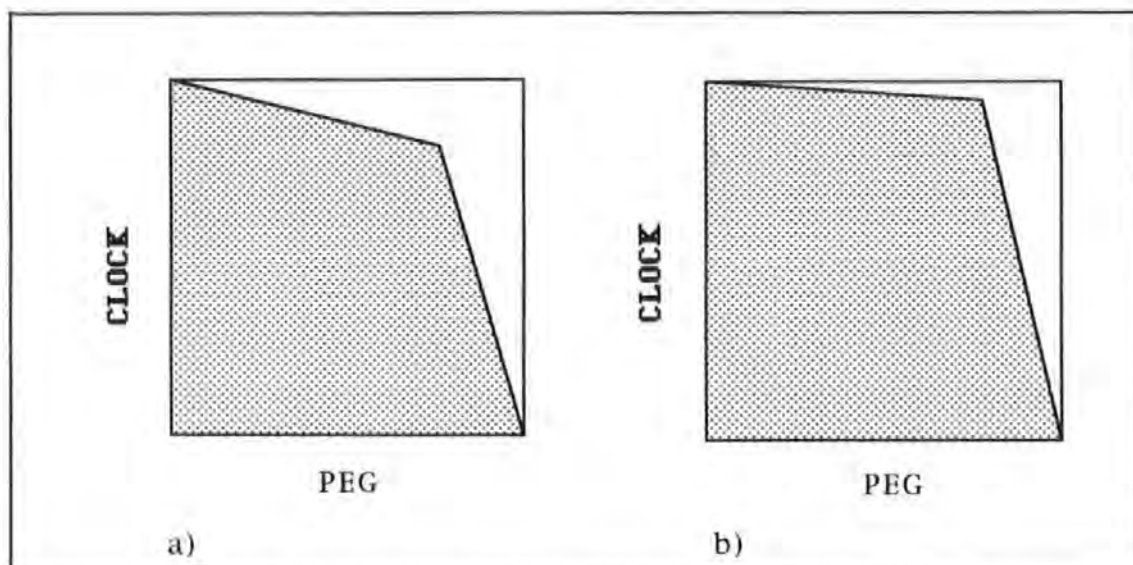
Figure 4.5. Mean POCs for the involved hand (a) and the spared hand (b) of the stroke patients. The vertical axis represents performance on the clock task and the horizontal axis performance on the pegs task.

The Wilcoxon test revealed no significant difference between the hands, Z=-0.9439, p=0.1726, with the mean divided attention costs when using the involved hand being 10.64 and the preserved hand 6.68.

4.4   Discussion

It should be noted that the results discussed here should be treated with a degree of caution since the subject numbers in both groups are very small. A pilot study was not conducted on the cognitive tasks to see whether their difficulty was successfully increased but data from both groups indicate that it was. The number of correct responses made by the two experimental groups is still high, and for the control group at least, is still close to a ceiling level. The difficulty of the two tasks remains approximately the same.

In terms of the number of pegs placed there was no overall difference between the stroke patients and the control subjects and neither was there a difference between which hand was used. However there was a marginal

78

interaction between experimental group and the hand used which, on inspection of Figure 4.1, it is safe to interpret as the stroke patients placing fewer pegs with their involved side.

There was an effect of task type and contrasts revealed not only a difference between the single and dual task conditions, but also a difference between the two dual task conditions, with all participants placing fewer pegs when also engaged in the spatial task. Although this needs to be considered in conjunction with the number of correct responses, given that the spatial task was not harder than the verbal task, it does suggest that hypothesis 1 is confirmed and provides some evidence that there are distinct processors for verbal and spatial information. However the number of pegs placed by the stroke patients was not relatively more affected by concurrently doing either cognitive task than the number placed by the control group.

So far the results suggest that all participants place fewer pegs when doing a secondary task and this implies that the motor control necessary for placing pegs in a pegboard is under closed-loop control and therefore demands some cognitive resources. The fact that the spatial task had more effect than the verbal task suggests that the resources needed to do the task successfully were also needed to place the pegs. The performance of the stroke patients did not appear to be more compromised by either of the cognitive tasks, regardless of which hand they used, and hence suggests that these stroke patients were not using extra cognitive resources to overcome movement deficits. However it is possible that there was a trade-off between the number of pegs placed and the number of correct responses made to the secondary tasks and so these must also be considered.

79

For the verbal (numbers) task there was a significant difference between the two groups with the control group making more correct responses than the stroke patients. Contrasts revealed that the difference lay between the dual and single task conditions with participants actually performing better in the dual task condition. This is surprising and there are at least three possible explanations. The first is that participants found putting the pegs in the board arousing and that the motor task acted as a stimulant, however if this were to be the case we might expect a similar pattern with the spatial task and as we shall see this was not the case. The second possible reason is that subjects directed more of their resources to the task in the dual condition. If one accepts that participants were using separate processors for placing the pegs and for doing the numbers task then this is more likely, but it does not explain why participants should "try harder" or "pay more attention" in the dual condition. Finally it seems that possibly the most likely reason is that this is a fluke result because of the small number of participants. Furthermore it should be noted that although the interaction between the task condition and the experimental group is not significant, it does approach significance (p=0.095) and inspection of Figure 4.2 does suggest that this effect is almost entirely due to the stroke patients. It is possible that this is because the control subjects are operating at a ceiling level. If this is the case then these results are not only complex but quite probably unsafe.

For the spatial (clock) task, there was no difference between the number of correct responses made by the two experimental groups and nor was there any difference between the the dual and single task conditions. However the interaction between task condition and experimental group was marginally significant. Contrasts revealed that the most likely base of the interaction was between the the single task condition and the dual task with

the involved hand. In other words the stroke patients made fewer correct responses when they were using their weak hand than when they were doing the task alone, but the control subjects did not differ in the number they got right between the single task condition and the dual task.

From the data so far it seems that in terms of the number of pegs placed all subjects were more affected by the spatial task. In addition to this the stroke patients made marginally fewer correct responses to the spatial task when they were using their involved hand than when they were doing the task alone. This was not the case for the control subjects. Taken together these results may well indicate that stroke patients are more adversely affected than their controls when they are asked to do a movement task with their weak hand and a cognitive spatial task at the same time. This suggests that they are not simply worse at dividing their attention for a dual task, but rather they are actually dividing their attention in favour of the movement when this is made with their involved side. This was investigated further by looking at the performance operating characteristics of the participants for both their hands.

Performance operating characteristics (POCs) provide a way of looking at the costs of dividing attention independent of the resource allocation strategies, although it is also possible to see how resources were allocated. Details about the construction of POCs were given in Chapter 2 but the basic idea is that one takes the maximum scores in the single task conditions as a base to compare with the score in the dual task. Hence it does not matter whether the scores on the single task were high or low or very different from each other because the comparison is the relative amount that the scores fall, given that the scales are equalised, when the tasks are performed together. POCs were compared between the two experimental

groups on each hand and then the involved and spared hand of the stroke patients were compared.

The comparison between the involved hand of the stroke patients and the equivalent hand of the controls showed that the divided attention costs for the stroke patients were higher. From Figure 4.3 it can be seen that the costs are split fairly evenly between the two tasks for the stroke patients whereas the costs for the controls were mainly on the pegs. When a comparison was made between the stroke patients using their spared hand and the controls, there was no difference between the two groups. Figure 4.4 indicates that not only were the divided attention costs very similar for the two groups, but also they were almost entirely on the number of pegs placed. The magnitude of the divided attention costs did not significantly differ between the two hands of the stroke patients but Figure 4.5 illustrates that they did differ in terms of their nature. When using their involved hand the costs were split between the two tasks but when using their spared hand they were mainly associated with the pegs task.

There is evidence that the occurrence of interference in in dual-task paradigms is typically unidirectional, from non manual to manual (Hiscock and Kinsbourne, 1980). This is exactly what these data show in every case except for the stroke patients when they are using their involved hand. In this case something different appears to be happening. It seems that when attention must be divided between two tasks, and one is a hand movement, people usually allocate their resources in favour of the task which does not have a movement component. This is also the case for stroke patients when they are using their spared hand. When they use the hand that has been affected by the stroke the divided attention costs are greater, probably because dividing attention is more difficult. Furthermore they appear to

allocate their limited resources in a different fashion so that they allow a greater drop-off in cognitive task scores, presumably in order that their movement scores are not as affected as they would otherwise be. It is possible that in addition to the problems they experience as a result of their stroke, the divided attention costs are greater for the stroke patients in this condition because it is more difficult for humans to allocate resources to a movement task in preference to a cognitive one.

If the difference between the divided attention costs of the involved and spared hand of the stroke patients had been significant, this would have added to the argument. As it is there may be a very simple reason why this was not the case, and that is that no control was possible for the dominant hand. In the other POC analyses this was accounted for in the way that the hands of the control subjects were matched. It is not possible to investigate whether indeed this was the case with so few subjects.

In summary, the results of this experiment provided tentative evidence for a separate central processing capacity existing for dealing with information about movement or spatial tasks. The ability of stroke patients to perform in this experiment was not different to that of control subjects when they used their spared hand but became apparent when they used their involved hand. The nature of this effect was such that the patients seemed to be covering up some of their movement deficits by allocating extra processing resources to them. This is likely to be a reflection of a greater dependence on closed-loop methods of motor control than they required for their spared hand or that the control subjects required. This experiment cannot address whether this was due to sensory deficits (of an exteroceptive or proprioceptive nature) or whether an element of lack of confidence was also present.

83

It is acknowledged that these data cannot be definitive since so few subjects were included in the analysis and there was still some tendency towards ceiling effects, nonetheless it seems that the evidence lies in favour of accepting the hypotheses and further investigation of these issues would certainly prove valuable.

CHAPTER FIVE

GENERAL DISCUSSION

Experiment 1 was designed to investigate two main issues; whether the walking of stroke patients is more affected by doing a concurrent cognitive task than that of neurologically normal controls, and second whether the type of cognitive task made a difference and hence gave evidence for more than one central information processing system. The walking was investigated both in terms of speed and gait pattern and account was taken of the number of correct responses made to the secondary tasks. It was predicted that the stroke patients would be more compromised by the dual task condition than the controls because they would make use of cognitive resources to cover-up deficits in their movement, and that this would be most apparent when the cognitive task they were doing concurrently was spatial in nature. A comparison was also made between a spatial cognitive task and a verbal one, with the prediction that the spatial task would cause more interference to participants walking if a separate information processing system existed for movement and spatial tasks.

Unfortunately a number of problems were encountered in this experiment and it is therefore not possible to address all these predictions. The first two analyses looked at the walking speeds and the number of correct responses made to the cognitive tasks. It was the case that all participants walked slower in the the dual task condition but there were no differences between the groups nor between the cognitive tasks. This was in part because of the high variance associated with the walking speed and in part because both groups showed ceiling effects in the number of correct responses they made in both of the cognitive tasks.

The gait pattern analyses revealed that the raters were slightly better able to judge whether a person was doing a secondary task if the task was spatial. They also rated the gait pattern of stroke patients as worse than that of the controls. However they judged the gait pattern of the controls to deteriorate when a secondary task was being done but not that of the stroke patients. It was argued that this was a reflection of using naive raters rather than a real difference.

Experiment 2 set out to address similar questions but this time looking at the finer control of hand and arm movements. An investigation was made of whether stroke patients found it more difficult to divide their attention between a pegboard task and a cognitive task than control subjects. Again two types of cognitive task, one verbal, one spatial, were compared to ascertain whether more than one central processor existed. In this instance it was also possible to compare the involved and the spared hand of the stroke patients to see whether, if stroke patients were more affected, this was a result of a generally reduced ability to divide their attention between two tasks, or whether it was because they were directing more of their cognitive resources to their movement. It was predicted that the stroke patients would be more adversely affected than the control subjects by the dual task situation when they were using their involved hand but not when they were using their spared hand.

The results of the experiment indicated that the performance of all participants was compromised by the dual task situation and more so by the spatial task than by the verbal one, thus suggesting that there are indeed separate information processing systems for verbal tasks as compared to spatial/movement tasks. It was also found that the stroke patients, unlike the

controls, found it more difficult to do a spatial task when they were also using their involved hand to place pegs. Since the effect appeared to be associated with their involved hand rather than their spared one it was proposed that this was not simply a result of them being less able to divide their attention. This was confirmed by the performance operating characteristics of the participants and it was suggested that the stroke patients were differentially allocating their limited cognitive resources in favour of the movement task in order that movement performance did not drop substantially. In other words they were monitoring their movement more closely and making greater use of closed-loop control.

Let us consider first the possibility of there being more than one central information processor. The argument is that if there was only one for processing feedback about movement and planning of movement in addition to all other information processing tasks, then doing any sort of secondary cognitive task should produce an effect. Given that the two tasks used here were of similar difficulty, but that the spatial one had a more adverse effect than the verbal one, it does suggest that the verbal task was processed separately from the movement task but that the spatial one was not.

It would be possible to get differential effects from two tasks even if there was only one central processor if there was response competition, for example if the secondary task was also a manual task. On the face of it it seems that this would not be the case with the spatial task used here in conjunction with the movement task. However there is evidence that visual spatial imagery involves the visual system (Finke, 1980; Shepard, 1984). Since vision is an important aspect of the pegboard task it may be that the added interference in the dual spatial condition of the present experiments is

a reflection of response competition rather than an indication of a separate processing system. Although this is an interesting question academically, in terms of clinical rehabilitation what is important is the knowledge that in dual task conditions involving movement, secondary spatial tasks lead to greater interference than verbal tasks. Kerr, Condon and McDonald (1985) made a similar observation that spatial memory tasks interfered to a greater extent with the maintenance of body posture than verbal memory tasks.

Although not definitive, the evidence of the present thesis is that stroke patients do rely to a greater extent on closed-loop control to maintain their movement patterns. In other words they direct a greater proportion of their limited central resources to overcoming movement deficits. This interpretation is more likely than that they are simply worse at using closed-loop control because they are more compromised when they have to divide their attention. If they were simply worse at using closed-loop methods then one would expect their movement to be poorer than controls in both the single and dual conditions, but one would not predict relatively more effect in the dual task situation.

This finding has both a positive, in terms of possible exploitation in rehabilitation, and a negative aspect. The positive aspect will be discussed later in terms of the development of a psychologically guided rehabilitation programme. The negative aspect is that in much of daily life we need to be able to do two things at once reasonably efficiently. In terms of the examples given in Chapter 3, of driving and talking, or listening to music and writing, this may not seem relevant since either one would not expect stroke patients to be more effected, or it would not matter, except perhaps in terms of speed, if they were. However when there is competition between tasks for central processing capacities, and when this competition concerns a mixture of tasks

involving movement, or spatial aspects, or a combination of these as components, then this is likely to prove more difficult for stroke patients and possibly dangerous. Two examples when this may be the case follow.

First consider crossing the street. In order to achieve this safely, unless one religiously obeys the green men, trusts drivers to, and can move fast enough to be off the crossing before the red man reappears, one needs to be able to assess the speed of oncoming cars, to estimate the distance between oneself and oncoming traffic, to be able to judge one's own speed, and to be able to control one's walking. This task obviously demands a good ability to process spatial and movement information in parallel, an ability that for the most part adults do possess. The evidence of this thesis is that stroke patients may find this more difficult. However, as has already been discussed, walking is considered an automatic ability. This thesis has not provided any evidence that automatic movement is affected in the same way as non-automatic movement. Since it has not disconfirmed it either no conclusions can be drawn without further work.

The second example is of driving. Many people may consider experienced drivers to function automatically unless there is a particular hazard. However driving is very different from walking since walking is something that people learn for themselves as an infant without being taught whereas this is not the case with driving. K.J. Connolly (1987) draws the distinction between biologically fixed skills which are developed from the inside out and culturally fixed skills which are directed from the outside in. If we accept this distinction then it is likely that in the cognitive disruption following a stroke, the culturally fixed skill of driving is no longer such an "automatic" skill as it was premorbidly. Since driving also involves parallel processing of a number of visual, spatial and movement

information, one must consider how safe a person who has suffered a stroke will be as a driver. This would seem an area worthy of further investigation. It is also possible that the simple dual task situation employed in Experiment 2, in conjunction with other tests could be adapted for use in evaluating a person's safety as a driver following a stroke.

The information gathered from this thesis does suggest that the neurophysiological basis behind Bobath's physiotherapy techniques are not a good representation of how movement is controlled and are likely to lead to inadequate therapy as a result. Neurophysiology would not predict that there would be any interference between the movement tasks and the cognitive tasks. This would be the case in both the walking task and the peg task since according to Bobath the movement should be controlled by proprioception and not be interfered with by the exteroceptive information provided by the cognitive task, regardless of what that task is. This was not the case in either Experiment 1 or Experiment 2 since the cognitive task interfered with movement on both occasions.

Bobath argues that the deficits in movement following a stroke are a result of higher integrated activity being cut-off, producing a "short circuit into the abnormal patterns of spasticity." The results of Experiment 2 contradict this notion, instead implying that stroke patients, at least in the later stages of recovery, depend more on higher integrated activity to overcome deficits at a lower level. Furthermore if stroke patients are depending more on an ability to monitor and adjust their movement according to the environment, then they must be using exteroceptive information to achieve this. In any physiotherapy programme it would surely make sense to exploit this in order to maximise a return of function.

In both the experiments described here there was a goal, however artificial it may have seemed. Participants undertook to attempt a complex action be it walking or the reaching, grasping, transporting and placing required in the pegboard task. Performing these actions therefore involved the body system and not an isolated muscle. What was required in these conditions was function rather than perfectly accurate movement, even though movement patterns were assessed. Bobath argues that the more normal a patients walking and standing can be, the less likely he will be treated as an invalid and therefore that he will become one. Bohannon et al. (1991) suggest this is not the perception of stroke patients who are concerned first about independence and one might extrapolate that function is therefore more important to them than quality.

The World Health Organisation (1980) make a distinction between impairment and disability and carrying that to this situation one could interpret Bobath's methods as reducing impairment but not disability. Concentrating on improving function rather than movement patterns is more likely to reduce disability. Furthermore the evidence of Anderson (1981) quoted in Chapter 1, that complete tasks are more successfully performed than their individual constituents, suggests that practising movements which are goal directed and functional may improve the constituents of the movement anyway.

Finally on this point, it is likely that functionally directed movement rehabilitation will be more successful because it is more motivating for the patient, it is easier to explain a functional exercise and it is often easier to practice such exercises on ones own between physiotherapy treatment sessions. It is also possible to build such exercises into the treatments of other therapists and into daily life if the rehabilitation set-up is

multidisciplinary in nature and needs led, such as that found in specialist stroke units.

The information so far discussed has great implications for the design of a successful movement rehabilitation programme. I would propose that a psychological framework which allows for a whole system approach rather than the component approach adopted by Bobath is likely to be more successful. This would provide a theoretical underpining from which a comprehensive treatment approach, taking account not only of only of movement, but also of the role of sensory and central information and processing for the maintenance of motor control. Psychological models of movement control, in conjunction with the specialised knowledge of psychologists about motivational and emotional matters could lead to a very powerful collaboration with the specialised knowledge of physiotherapists about the processes of movement.

What has not so far been addressed is that rehabilitation is a process not an entity. It would therefore be very useful to have an objective measure of progress. This is where the observation that stroke patients tend to control their movements by closed-loop methods may have a positive application. Obviously in the early stages of recovery changes are fairly apparent. However there may come a time when a therapist feels that a plateau of recovery has been reached and that on economic or waiting list grounds it is time to reduce or stop treatment. If one uses a single task to identify when this position has been reached it is possible that treatment will be terminated prematurely, when active recovery is still being made.

Since it is important to maximise functional recovery, and much of the time we are engaged in more than one activity, it may be more appropriate to

terminate treatment when a plateau has been reached in a dual task situation. The types of task used in these experiments might therefore provide a means of plotting recovery and of identifying when a dual task plateau has been reached. Furthermore they are likely to be less susceptible to the specific practice effects of repeating standard psychometric tests which are also sometimes used.

Two Australian physiotherapists have recently suggested a more up-to-date treatment approach which they have termed the Motor Relearning Programme (Carr and Sheppard, 1987). They have developed this treatment from the basis that it was their job as "applied movement scientists" to derive clinical implications from the experimental work of researchers into movement control. The model is rehabilitative in nature and therefore involves the relearning of real-life activities which have meaning for the patient, and does not involve the facilitation or practise of non-specific exercises. They state that the major assumptions about motor control underlying their model are the following:

> "1) that regaining the ability to perform motor tasks such as walking, reaching and standing up involves a 'learning' process, and that the disabled have the same learning needs as the non-disabled (i.e. they need to practice, get feedback, understand the goal etc.); 2) that motor control is exercised in both anticipatory and ongoing modes and that postural adjustments and focal limb movements are interrelated; 3) that control of a specific motor task can best be regained by practice of that specific motor task, and that such tasks need to be practiced in their various environmental contexts; and 4) that sensory input related to the motor task helps modulate action."

The programme is based on four factors known to be essential for the learning of motor skill and therefore assumed to be essential for the relearning of motor control following stroke. These are the elimination of unnecessary muscle activity, feedback, practice, and the interrelationship between postural adjustment and movement.

One of the strengths of the Motor Relearning Programme is that it is flexible. There is still much research work needed if the complexities of hemiplegia following stroke are to be untangled and successful treatment developed. A starting point might be to repeat the research described here with more subjects and more taxing cognitive tasks so that firmer conclusions can be drawn, but also far more complex issues need to be investigated. For example Haaland and Harrington have found that people with left hemisphere lesions following stroke may have greater difficulty with the initiation and correcting of movement (Haaland and Harrington, 1989; Haaland, Harrington and Yeo, 1987). The differences between left and right hemisphere lesions must therefore be investigated not only to discover possible differential deficits, but also where treatment needs to be concentrated and what methods or techniques might be most usefully employed. No investigation of the different effects of the hemispheres can be conducted successfully without also taking account of issues surrounding the dominant hand.

Another avenue of research which is likely to prove fruitful in providing information for rehabilitation programmes is how new movements are learned. It is important to know whether stroke patients are as able to learn new movements, given the physical constraints on their movement range, as other people. It is also important to know whether they go about doing this in a different way and if so how their methods differ

from others. A distinction should be made here between the learning of predictable and unpredictable movements since these two types of movement are likely to be controlled in different ways, with predictable movements being more under the auspices of open-loop control and unpredictable more closed-loop. This type of comparison could also provide information about the speed of learning.

No controlled trial demonstrating therapeutic effect on either impairment or disability has been reported for any of the methods of physiotherapy currently used for stroke patients (Yekutiel and Guttman, 1993). Possible reasons for this include the historical isolation of physiotherapy as a profession from detailed research (now changing) and the impoverished theoretical underpining to the methods of physiotherapy used in the treatment of stroke. Newer models of therapy such as that proposed by Carr and Sheppard, not only describe the therapeutic tools used in terms of modern models of motor control, but also, by breaking into what has been a very static field, may act to inspire the necessary control trials and to elicit new developments of the theory of hemiplegic motor control.

Given that stroke is common and as yet medically untreatable and patients complain most about problems with movement, the development of superior movement rehabilitation programmes should be a high priority. It seems that after a stagnant few years when the prevailing treatments have not been challenged or developed, things are now beginning to change and new treatments are being considered. I believe that clinical neuropsychologists have a great deal to offer in this field and with the move towards more multidisciplinary work in the field of rehabilitation they also have more opportunity to become involved. This opportunity should not be missed.

Frenchay Healthcare Trust

Directorate of Neurosciences, Frenchay Hospital, Frenchay Park Road, Bristol BS16 1LE,
Telephone: (0272) 701212

Dear Mr and Mrs

I am writing in relation to Mr   's treatment in the stroke unit at Frenchay Hospital a few years ago. We are currently undertaking a research project looking at how people regain their ability to control movements following a stroke. Although much work has been done in this general area already, we will be concentrating on how people actually plan and initiate a movement rather than the movement itself. There is very little work specifically in this area and more information may be a great help when teaching people to relearn movements following a stroke.

We would be grateful for your participation in this study, which would involve answering some questions and doing a few short puzzles. If you are interested in participating it would be helpful if you could both take part, if possible, so that we could compare people who have had a stroke with people who have not. I would be happy to come to your home at a time convenient to you. Following this initial visit I may ask if you would mind if I made a second brief visit to assess your hand movement.

I would be grateful if you would return the slip at the bottom of this letter to me in the prepaid envelope enclosed, indicating whether you would like to take part. I have tentatively suggested a time that I could visit, but if this is not convenient (I do realise this is very short notice) please ring Bristol 701212, extension 2243. If I am not there please leave a message and I will be happy to return your call and arrange another time.

If you would like further details of the study then please do not hesitate to contact me.

I look forward to meeting you.

With thanks for your cooperation,
Yours sincerely,

Sarah Connolly
RESEARCH PSYCHOLOGIST

....

NAME:

I am/am not* willing to take part in the study on regaining movement control.

.... (Signature) .... (Date)

The time of 4.00pm on Friday the 28th of May will/will not* be convenient.
(* Please delete as appropriate)

SOUTHWEST

Recycled Paper

NHS

Frenchay Healthcare Trust

Directorate of Neurosciences, Frenchay Hospital, Frenchay Park Road, Bristol BS16 1LE,
Telephone: (0272) 701212

Dear

    The research project looking at how people regain their ability to control movement following a stroke, which you took part in for the stroke unit at Frenchay hospital, is now finished and I am writing to let you know the outcome.

The most important finding was that people who have suffered a stroke seem to control their movements in a different way to those who have not. Movement can be controlled either by planning in advance the movements you need to make to achieve something (though we are not ususally conscious of this), or by monitoring movement carefull as it is made. An example of a planned movement would be throwing a ball, since once you let go you cannot change the ball's path and an example of a carefully monitored movement might be threading a needle. The research you took part in showed that people who had suffered a stroke were more likely to use the monitoring method of controlling their movement, and could use brain resources to do this which would not normally be involved.

This is important information for physiotherapists to have when they are planning a therapy programme for someone who has recently had a stroke. The type of task I asked you to do could also be very useful in seeing how a person's recovery is progressing. This information will be passed on and hopefully physiotherapists will be able to use it when they are developing their therapy programmes.

I am very aware that without the goodwill of our volunteers this research would not have been possible. I am extremely grateful to you for taking part with such willingness and interset. If you would like further information about this work then please do not hesitate to get in touch with me.

With all good wishes.
Yours sincerely,

Sarah Connolly
RESEARCH PSYCHOLOGIST

SOUTHWEST

NHS

Recycled Paper

APPENDIX 3

<u>Experiment 1</u>
The numbers tapes

A	B	C	D
1	2	8	4
5	16	10	14
7	10	16	10
4	8	3	8
1	1	14	17
17	6	4	3
9	13	2	10
9	5	1	5
15	6	12	14
3	17	6	9
9	11	9	6
10	8	9	12
2	1	3	15
5	3	17	3
16	4	4	10
2	14	12	2
7	15	10	13
17	3	5	5
6	14	11	10
12	16	7	1

Numbers at intervals of 5 seconds

The times tapes

A	B	C	D
1/4 past 3	25 to 10	1/4 to 9	5 to 3
1/4 to 11	1/4 to 3	20 past 3	25 past 9
20 to 4	10 past 5	10 to 5	5 past 7
10 past 5	1/4 past 7	5 past 7	1/4 to 11
25 past 7	5 to 8	25 past 8	1/4 past 4
10 to 1	20 past 2	5 to 10	25 to 3
25 past 9	10 to 4	10 past 1	5 to 8
5 to 9	25 past 11	20 to 2	20 past 1
20 past 5	20 to 5	1/4 past 4	5 past 2
5 to 3	5 past 4	25 to 3	20 to 5

Times at intervals of 10 seconds.

APPENDIX 4

Experiment 2
The numbers tapes

A	B	C	D
1	9	5	11
11	9	11	7
7	12	12	10
6	5	6	13
13	2	12	16
5	1	3	2
12	17	9	6
6	1	9	12
9	6	13	5
14	17	2	8
8	14	16	10
10	4	17	4
8	8	3	3
16	10	3	1
4	15	15	15
2	6	10	3
3	12	8	15
15	7	17	7

Numbers at intervals of 3 seconds

The times tapes

A	B	C	D
1/4 past 3	25 to 10	1/4 to 9	5 to 3
1/4 to 11	1/4 to 3	20 past 3	25 past 9
20 to 4	10 past 5	10 to 5	5 past 7
10 past 5	1/4 past 7	5 past 7	1/4 to 11
25 past 7	5 to 8	25 past 8	1/4 past 4
10 to 1	20 past 2	5 to 10	25 to 3
25 past 9	10 to 4	10 past 1	5 to 8
5 to 9	25 past 11	20 to 2	20 past 1
20 past 5	20 to 5	1/4 past 4	5 past 2
5 to 3	5 past 4	25 to 3	20 to 5

Times at intervals of 5 seconds.

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