SENSORY IMPAIRMENT AND RECOVERY AFTER STROKE

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ABSTRACT

Sensory impairment is common after stroke though problems with the assessment of sensation have hindered research into sensation and its recovery. The revised Nottingham Sensory Assessment [NSA] (Lincoln et al, 1998) is a standardised assessment but there have been difficulties interpreting results, as it is not possible to calculate total scores.

Therefore the purpose of this study was:

- To investigate the extent of sensory impairment and recovery in stroke patients
- To investigate if a total score for the NSA can be obtained
- To explore the factors that are related to sensory impairment and outcome

Method

Patients with a first stroke were recruited on admission to two rehabilitation units in Nottingham. The NSA, which measures tactile sensations, proprioception and stereognostic ability, was administered on admission and at two, four and six months after stroke. Rasch analysis was used to examine if total scores of the NSA could be calculated.

Results

Seventy patients were recruited during a fifteen-month period. Mean age was 71 years (SD 10.00) and 36 were men. Sensory impairment was common in stroke patients and was significantly related to stroke severity. Stereognosis was the most frequently and severely impaired sensation.

Rasch analysis enabled total scores of the NSA to be calculated. These totals showed significant recovery at six months post-stroke for upper limb tactile sensations, stereognosis and proprioception. Lower limb tactile sensations did not show significant recovery.

The severity of the stroke, initial sensory impairment and activities of daily living ability were significantly related to sensory recovery, however they only accounted for 46-71% of the variance.

Conclusion

Sensation is a complex ability and a problem in its own right. Sensory impairment was a reflection of stroke severity but low variance indicates other factors were involved. Therefore there is a need to assess sensory impairment after stroke.

Sensory outcome could not be accurately predicted, suggesting other potentially treatable factors such as cognitive and perceptual ability are involved.

Rasch analysis allowed calculation of total scores, but also importantly allowed the scale to be shortened, making the NSA a more useable outcome measure.

CHAPTER I: INTRODUCTION

1.1 Background

Stroke, or cerebrovascular accident (CVA) results in damage to the central nervous system (CNS) caused by either a thrombus or embolus impeding a cerebral artery, or by haemorrhage of the artery. The essential supply of oxygen and glucose to the nervous tissues is subsequently interrupted causing cell necrosis (Sherwood, 1997). Stroke is of high incidence, occurring in 1.7-2.0 per 1000 population per annum in the UK (Cifu and Lorish, 1994), and as such represents a major economic burden on the NHS, and to society as a whole.

It is estimated that 60% of patients with stroke have impaired sensory abilities, though the reported prevalence varies widely (Carey, 1995). The somatosensory system is the means in which we communicate and interact with our surroundings (Gaubert and Mockett, 2000). It is required for many activities of daily living; therefore if the system is compromised it will have a negative effect on many areas, including leisure, sexual activities and safety (Carey et al., 1997). Sensory deficits also have wide-ranging consequences in terms of treatment choice, since sensory impairment may be detrimental to motor recovery.

Both doctors and therapists agree that somatosensory ability present useful information for prognosis (Winward et al., 1999). Despite this, the aim of all current therapies converge on the main objective of improving motor function with sensory impairment and re-education somewhat neglected. This seems somewhat incongruous, as sensory deficits have been shown to be negatively

associated with motor recovery (Carey et al., 1997, DeSouza, 1983, Stephenson, 1993).

Sensation therefore, deserves more importance. Its assessment should be routine so that impairments can be detected and monitored, with their impact on rehabilitation and the patient's function accounted for. However assessment has proved to be problematic, with few standardised measures having established validity and reliability (Lincoln et al., 1991, Wade, 1992).

Sensory problems are common after stroke, and seem to relate to outcome. Little is known about sensory recovery over time, therefore the purpose of this study was to investigate sensory recovery. However in order to this it was first necessary to develop a reliable measure of sensory impairment in stroke.

CHAPTER II: LITERATURE REVIEW

2.1 Introduction

This literature review will cover the existing knowledge regarding sensory impairment and recovery after stroke. It will focus on the sensory system, the different sensory modalities, the relationship between sensation and perception, and the functional implications of sensory impairment. The literature regarding recovery after stroke, both general and sensory specific will be reviewed. The outcome measures available for assessing sensory impairment and the available literature on sensory rehabilitation will be appraised. The gaps in the literature will be identified and hypothesis regarding sensory impairment and recovery formulated.

2.2 Stroke

The World Health Organisation (1978) defined stroke as "a clinical syndrome typified by rapidly developing signs of focal or global disturbance of cerebral functions, lasting more than 24 hours or leading to death, with no apparent cause other than of vascular origin." Of first time strokes, 76% are due to cerebral infarction, 14% are due to cerebral haemorrhage, with the remainder of an unknown cause (Bamford et al., 1991). A stroke can be a life-changing event, with highly disruptive emotional, physical and social consequences (Rudd, 2004).

Stroke is the third most common cause of death and the most common cause of adult disability in the UK (Office of National Statistics, 1998). It was of high incidence in most Western countries, with more than 500 new strokes per year expected in a typical district of 250,000 people (Sudlow and Warlow, 1996). Almost one in four men and one in five women can expect to have a stroke if

they live to their 85th year (Clinical Effectiveness and Evaluation Unit, 2000). Of those who have a stroke, 24% will be dead at one month, 31% at one year and 55% at five years (Wade, 1994). Of those who survive to 6 months, 53% will be physically dependent and 9% will be severely disabled (Wade, 1994). It is estimated that 6 in every 1000 people have a stroke-related disability (Langton Hewer, 1990). Stroke represents a major economic burden on the NHS, with an estimated cost of £2.3 billion (Department of Health NHS Executive, 1996), constituting over 4% of NHS expenditure (The Intercollegiate Working Party for Stroke, 2000). In 1994, stroke patients occupied 20% of acute hospital beds and 25% of long-term hospital beds (Wade, 1994). However the true cost of stroke is difficult to estimate, as it affects not only health services, but also the sufferer, their family and society as a whole in terms of loss of earnings and production and unpaid carer time. Therefore, the effectiveness of assessment, rehabilitation and outcome in this population group has massive financial and social implications.

2.2.1 Clinical Features of Stroke

The clinical manifestations of stroke vary widely, depending on the site and extent of the lesion (Stone et al., 2000, Osler, 1982). Stroke can result in impairment of motor, sensory and/or cognitive abilities, swallowing and communication problems and incontinence. These impairments are not mutually exclusive. While each can have debilitating affects independently, impairment in one area will affect performance in another. For example disorganized sensation produces disorganized movement despite intact motor apparatus (DeSouza, 1983).

2.3 Somatic Sensation

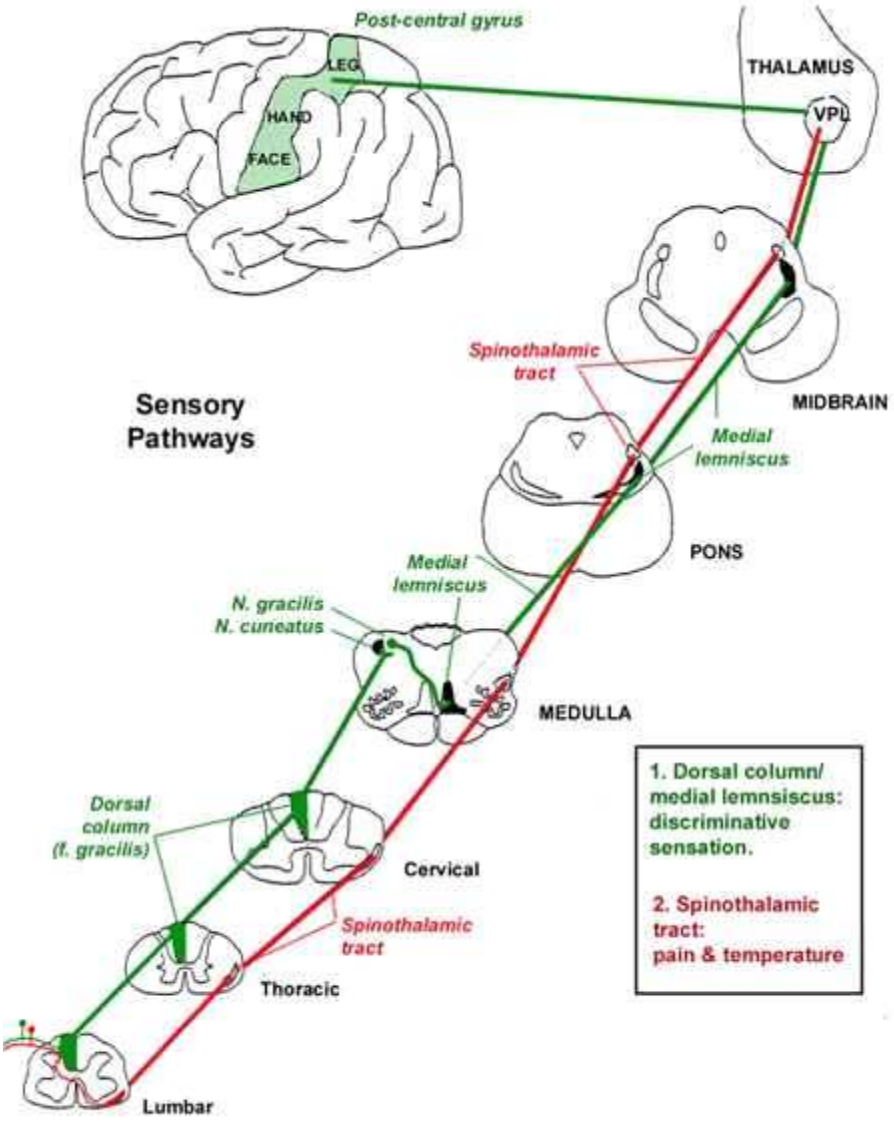
A common impairment following stroke is loss of sensation. The acquisition and evaluation of sensory information is a specialized process involving many receptors. Information received through sensory receptors is referred to as somatic sensation. This includes both exteroception and proprioception (Sherwood, 1997). Exteroception is the sensory information about the external environment received from receptors in the skin and subcutaneous tissue (O`Sullivan and Schmitz, 1988). Exteroceptors are responsible for perception of pain, temperature, light touch and pressure. Proprioception is awareness of body position in time and space, through receptors in muscles, tendons, ligaments and fascia (Sherwood, 1997). These specialised peripheral receptors respond to movement of the body. The information derived simultaneously from different receptors is integrated and transmitted to central structures using a neural code. The results are then related to past experience and information from other sensory modalities, such as visual and auditory systems (Hudspeth and Logothetis, 2000). Some aspects of the stimuli that are encoded include modality, intensity, frequency, spatial location, threshold and duration (Berne and Levy, 2000).

The sensory receptors form the peripheral endings of a primary afferent neurone. Neurones are arranged in series to form somatosensory pathways, with increasingly more sophisticated processing of the sensory information as the signals reach higher centres in the brain (Sherwood, 1997). The main somatosensory pathways are the spinothalamic tract and the dorsal column

lemniscus pathway (fig. 1), but others include the spinoreticular tract, the spinomesencephalic tract and the spinocerebellar pathway. The dorsal column lemniscus pathway is largely responsible for transmission of proprioceptive, pressure and light touch sensations (Berne and Levy, 2000). It originates from the dorsal column of the medulla. The second-order neurons are in the nucleus cuneatus and the nucleus gracillis, and are collectively known as the dorsal column nuclei. These have large receptive fields and may respond to more than one class of sensory receptor, as more than one primary afferent neurone may synapse on each dorsal column neurone. These nuclei project to the contralateral thalamus via the medial lemniscus, terminating in the ventral posterolateral (VPL) nucleus of the thalamus. Neurones from the VPL nucleus then synapse in the primary somatosensory (SI) cortex.

The spinothalamic tract is activated by noxious mechanical, thermal and chemical stimuli, with some neurones also stimulated by thermoreceptors and sensitive mechanoreceptors. Therefore this pathway commonly receives convergent excitatory input from several different sensory modalities. The first-order neurone arrives in the posterior horn of the spinal cord. It immediately synapses, with the second-order neurone projecting to several nuclei of the contralateral thalamus, including the VPL nucleus and several nuclei of the medial thalamus. A third-order neurone in turn projects to the SI cortex.

Figure 1: The Main Somatosensory Pathways



Understanding of the organization of the sensory cortex and its divisions into different areas has advanced rapidly with the development of imaging techniques. The somatosensory cortex is located in the parietal lobe and consists of five somatosensory areas. These are the primary somatosensory cortex (SI), a second somatosensory area (SII) known to be involved in tactile perception (Hamada et al., 2001), a parietal ventral area (PV) just anterior to SII, and thin somatosensory areas along the anterior and posterior edges of SI (Kaas and Collins, 2001). Each of these areas has somatotopic organisation,

with the location of cortical columns systematically related to the location of receptive fields on the body surface (Sherwood, 1997). This distribution of sensory input is known as the sensory homunculus and different parts of the body are not represented equally. Areas that require a higher degree of sensory perception such as the face, tongue, hands and genitalia have a larger representation, indicative of the relative proportion of the somatosensory cortex attributed to reception of sensory input from that area (Pitt-Brooke et al., 1998). This somatotopic organisation is also found at lower levels of the somatosensory system, including the dorsal column nuclei and the VPL nucleus of the thalamus (Berne and Levy, 2000).

Although the sensory homunculus is similar in all humans, there is considerable individual variation. This is because of neuroplasticity, with the cortical sensory areas much more adaptable and able to change than previously thought (Hudspeth and Logothetis, 2000). The somatotopic maps are not rigid but subject to constant modification dependent on experience, and are likely to be involved in perceptual learning (Carey, 1995). However despite this flexibility, there are some genetically established limits (Sherwood, 1997), which are discussed later. This has clinical implications in terms of cortical reorganisation following neurological damage, as there will be a limit to patients' recovery and this explains in part why many patients do not fully recover.

Sensory input is projected from the somatosensory cortex via white matter fibres to higher areas of the CNS for further analysis and integration. This is of

particular importance for complex sensations, such as the appreciation of texture and firmness, and object recognition. The higher centres also allow for the sensory inputs to be subject to emotional, attentional and cognitive influences (Dubner and Ren, 1999).

Though the main somatosensory pathways have been described, it is important to emphasize that these pathways are not parallel. They commonly cross each other, even in areas classically defined as primary and specialized (Meister and Laurent, 2001). There is interaction and integration between sensory modalities (Shimojo and Shams, 2001). The CNS is not hierarchical, but has areas that are activated simultaneously and the presence of many back-projections (Hudspeth and Logothetis, 2000). A lesion in the areas involved with the processing of sensory input leads to perceptual impairments, which are less than would be expected from impairment of one component in a hierarchically structured system. A sensory perception may require information from several sensory pathways that are processed separately. Though the majority of the ascending pathways cross over to the contralateral side of the brain, there are some ipsilateral pathways (Sherwood, 1997). The SII area has somatotopically organized representation of both sides of the body (Mountcastle, 1980). This shows the complex nature of the somatosensory systems as many different areas of the brain are involved. This accounts for the wide variation in sensory deficits found following a stroke. It also explains why the presumption of an "unaffected" ipsilateral side is not correct, due to the presence of ipsilateral pathways, and as central processing may be impaired.

Sensation is an active process. At all times we are bombarded with sensory stimuli, but we are only aware of a fraction of them. We attend to sensory cues that are relevant to us (Dubner and Ren, 1999). We only become conscious of other sensory cues when specifically thought about, for example, people are not aware of the feeling of their clothes against their skin unless they specifically attend to it. The thalamus acts as a relay station for all synaptic input and there are inhibitory receptive fields in the somatosensory pathways (Sherwood, 1997). However, the mechanisms by which meanings are attached to sensations and how the stimulus is regarded as relevant are poorly understood.

2.4 Sensation and Perception

Perception has been defined as the conscious mental registration of a sensory stimulus (Coren et al., 1979). In an adult, sensation and perception are inseparably linked (Yekutiel, 2000). Sensory information undergoes extensive attentional modulation as it becomes incorporated into our conscious awareness (Mesulum, 1998). This creates a highly edited subjective version of the world, with the limitations of the sensory systems setting the boundaries of conscience existence (Coren et al., 1979). Perception involves sophisticated brain processes and is individual, being subject to ongoing modification dependent on experiences (Livingston, 1978). It involves comparisons with memory stores to evaluate whether the sensation is recognisable, comparisons with past experiences, expectations and purposes. These perceptual skills reflect the capabilities to detect and analyse the physical environment (Ferrari de Castro and Cliquet, 2000). We have faith in our senses and the perception

that the world that is created by sensory inputs corresponds to actual reality. However this is not always the case. Sensory information allows us to create hypotheses about the nature of the external world, but these are not always reliable. In the somatosensory system, to some degree, tactile object recognition always requires a degree of guessing to match up the physical properties of the object to those stored in memory (Klatzky and Lederman, 1995). Despite these possible errors, perception provides our only access to reality.

Sensation and perception are also linked to action. In less-developed animals than humans, the CNS has limited processing ability and inflexible bonds are present between sensation and action. This leads to automatic responses, even when the consequences of such actions are negative (Mesulam, 1998). However in advanced mammals with a flexible CNS and higher level processing, identical sensory inputs can potentially trigger one of many different reactions. The pain caused by injury provokes very different responses in demanding situations such as war or sport competitions compared to unchallenging situations (Berne and Levy, 2000). We are able to predict the consequences of our own actions and are therefore unable to tickle ourselves despite identical sensory input (Blakemore et al., 1999). Though sensation does affect behaviour, it is not an exclusive factor, playing only a role in preparation and the consequences of actions.

2.5 Stereognosis

Stereognosis is the ability to recognize what the hand grasps in the absence of visual or auditory clues. It is an ability frequently required in everyday life.

The function of the hand is heavily dependent on many sensations to enable efficient movement and to allow interaction with the environment. Stereognosis (also known as tactile gnosis or haptic recognition) provides us with information regarding the weight, texture, size and shape of an object, allowing accurate object recognition usually within a few seconds (Klatzky et al., 1985). This ability is used, for instance, when reaching for a coffee cup that is not in the visual field, or trying to find a coin in a pocket. It requires the integration of many abilities, and is regarded as a complex sensation because of this. Haptic exploration provides an awareness of an object's linear dimensions (Turvey et al., 1998) without the need for visual input. The term "haptic" has been stated as an "information processing perceptual system" that utilizes both exteroceptive and proprioceptive input (Loomis and Lederman, 1986, Lederman and Klatzky, 1993, Turvey, 1996). Haptic exploration is taken for granted but is actually a demanding task, combining information from many different mechanoreceptors and proprioceptors. Additionally it requires the ability to integrate the afferent information and solve the perceptual problem of establishing what the object is from the information extracted (Roland, 1976a). Stereognosis requires transfer of information between hemispheres (Beason-Hazen et al., 1993), and many serial and sequential operations (Weder et al., 1999). Not only is the sensory system required to give information on the shape (sometimes referred to as the macrogeometric properties) of the object, but the CNS must also integrate information to perceive what the object actually is. For example, we know that an object, which is a thin cylinder with a point on the end, is possibly a pencil. By recording the brain potentials evoked by afferent input from fingers, studies have shown that basic motor and

somatosensory mechanisms are involved in object recognition (Tomberg and Desmedt, 1999), providing a non-visible awareness of an objects linear properties (Turvey et al., 1998). However, the mechanisms of higher order object recognition have not yet been identified (Diebert et al., 1999). Therefore it is unclear which areas of the brain need to be affected by stroke to result in a deficit of tactile recognition.

2.6 Sensory Impairment

The nature and severity of somatosensory loss is partially dependent upon the extent of the lesion (Barnett et al., 1986, Lamotte and Mountcastle, 1979, Roland, 1984, Carey, 1995). Somatosensory impairment ranges from involvement of just one type of sensation, such as light touch, to all somatosensory abilities being impaired. Sensory processing involves many somatosensory pathways and many areas of the brain. Therefore sensory impairment can result from a lesion anywhere from the brainstem to the cortex (Yekutiel, 2000). Areas of the brain which have been shown to affect somatosensory function when damaged include the postcentral gyrus (Semmes et al., 1960a, Roland, 1987a, Roland, 1987b), postparietal lesions (Semmes et al., 1960a, Evans, 1935) and lesions of the prefrontal cortex and its communication routes to the postcentral gyrus (Roland, 1987a, Roland, 1987b). The higher up the brain the injury, the more likely that discriminative sensory functions, such as recognition of shape, size or weight of objects are impaired, as opposed to primary sensations of touch, temperature or pain. Impairment may result in the patient being unable to feel a particular sensation,

or they may have a crude awareness of a sensation but be unable to differentiate intensities or the qualities of the stimulus.

Somatosensory loss is believed to be common following a stroke. However there is little literature, and there are large discrepancies in the reported prevalence of sensory impairment ranging from 11%- 60 % (Carey, 1995), though an incidence as high as 85% was found by Kim and Choi-Kwon (1996). This is due to differences in impairments and body areas assessed and the lack of a decent outcome measure.

The World Health Organisation (1971) stated that sensory impairment is found in about 50% of cases, however this is not referenced therefore it is not known from where this figure was derived from. Kim and Choi-Kwon (1996) investigated discriminative sensory impairment after stroke. Sixty-seven acute stroke patients (within 1 week of stroke onset) were examined on assessments of two-point discrimination, point localization, position sense, stereognosis and texture discrimination. The locations of the lesions were cortico-subcortical in 14 patients, lenticulocapsular in 24 patients, thalamic or thalamocapsular in 15 patients, and brain stem in 14 patients. Two-point discrimination was assessed from the tips of the thumb, third and fifth fingers using the Disk-Criminator (Dannenbaum and Jones, 1993). Texture discrimination was assessed using the method developed by Carey et al (1993) using moulds with ridged surfaces with patients asked to identify the rougher texture. A threshold of 80% accuracy for this test was set for both two-point discrimination and texture discrimination, but no justification was given as to how this was decided. Position sense was assessed using a specific manufactured device that involved

the patient having to replicate different positions of wrist flexion and extension. Proprioception was not assessed in any other joints. The sensory impairments were graded as slight, moderate or severe based on normative data. 85% of patients were found to be impaired. This high rate, the highest stated in the literature, is probably due to the number of impairments assessed and the detailed nature of the methods used.

Sommerfield and von Arbin (2004) investigated the effect of sensory performance on activity levels and length of hospital stay. They assessed 115 acute stroke patients on pinprick and light touch, using a dichotomous outcome of impaired or not impaired, on three areas of the upper limb and lower limb. They did not use a standardised method for these assessments. Therefore they only assessed limited areas on two modalities. They found a third of patients to be unassessable, and of those who could be assessed 40% were found to have impairment. However the reasons for non-assessment were not detailed, other than stating that patients were not reliable. They concluded that normal somatosensory function was related to high activity levels and short length of stay more often than somatosensory impairment was related to activity limitations and long length of stay.

Hanger and Sainsbury (1996) investigated sensory abnormalities after stroke based on patients' subjective descriptions, with no further details of the assessment given other than that patients were asked if they had any abnormal sensations or pain since their stroke. They found in a prospective cohort of 114 consecutive stroke patients that 41% had sensory impairments at some stage after stroke. However as this was only subjective with limited details of the

responses, and no further demographic data given, the results should be taken with caution.

Much of the research published to date is problematic since it fails to acknowledge that sensory impairment should incorporate both exteroception and proprioception of the whole body. As a result the reported incidence of impairment varies. This together with the subjective nature of sensation, variation in the areas of the body assessed and the disparate methods used for assessment make comparison between studies problematic. However the general consensus seems to be that sensory impairment occurs in approximately 50% of patients (Carey, 1995).

Sensory impairment and deficits in attention can be hard to distinguish. To attend to something means to be perceptually selective, as not everything we are exposed to becomes part of our conscious perceptual experience (Coren et al., 1979). Attentional problems may be present with or without sensory impairment. Following a stroke, a patient may be unaware of auditory, visual or tactile stimuli on the contralateral side to the lesion. Somatosensory extinction is when a person is able to detect a stimulus if touched on the contralateral side. However, if touched simultaneously on both sides of the body, only the touch on the ipsilateral side is recognised (Vaishnavi et al., 1999). This impairment can vary in severity, with some patients able to identify a stimulus on their "affected" side though the intensity is reduced or they are unable to accurately localise the stimulus (Yekutiel, 2000). As sensory inputs are received from multiple sensory types at any one time, there can also be attentional competition between sensations e.g. if there is simultaneous visual

and tactile stimuli (Mattingley et al., 1997). This clearly needs to be taken into account when undertaking sensory assessments.

A neurophysiological study by Hsiao et al (2002) found that in trained animals the focus of attention affected the firing of about 85% of neurons in the secondary sensory cortex when performing an orientation discrimination task. In humans, fMRI has shown that activation in the sensory cortices, particularly the secondary cortex, was influenced by attention when a monofilament was used to deliver tactile stimuli (Hsiao et al., 1993, Jiang et al., 1997). The concept of attention still requires much explanation (Yekutiel, 2000), but it is clear that sensation and attention are closely related and therefore difficult to separate, with impairment in one affecting the other (Hsiao et al., 2002).

There is a negative association between sensory impairment and motor ability (Riddoch et al., 1995, Stephenson, 1993, Nudo et al., 2000). This has been shown in monkeys, which despite having an intact motor system, were unable to move their limbs once sensation was blocked (Musa, 1986, DeSouza, 1983). Normal movement requires an intact motor system but is also heavily dependent on sensory information for effective action in space (Vaishnavi et al., 1999). It is impossible for movement to be coordinated and effective if there is not precise awareness of the body's starting position, and if constant somatosensory feedback regarding the movement and any changes in the external environment is not received. Carey et al (1993) stated the primary importance of sensation is to provide the feedback needed to guide motor acts. The CNS needs to be in a position of knowledge. Awareness of the state of

muscles and joints is required so movement can be planned and executed smoothly, allowing controlled change from one position to another. Movement is a response to afferent information, which is received by the sensory cortex from the periphery. This information is decoded then sent to the association cortex to be interpreted, before the motor cortex, basal ganglia and cerebellum take over. The cerebellum requires constant feedback from the sensory systems, allowing movement to be matched both spatially and temporally to the environment and to behaviourally relevant goals (Gordon, 1990). Hence if sensory input is impaired, motor output will be inadequate (Dannenbaum and Dykes, 1988, Pitt-Brooke et al., 1998). A study by Nudo et al (2000) showed how motor impairment after damage to the motor cortex may at least partially be due to sensory deficit, or sensory/ motor disconnection. This is especially true for the upper limb, which is required for fine, skilled movement, and it has long been recognised that the upper limb is, in essence, useless with serious sensory impairment (Carey, 1995, Held, 1975, DeSouza, 1983). The fine control of purposeful delicate contractions of small muscles in the arm and hand needs a complete sensory system for feedback (Kuffofsky et al., 1982). The aim of therapy is to maximize patients' learning (Davies, 1985), through interaction with the environment and repeated experience. Since somatosensation is fundamental to this interaction, its impairment will hinder the learning of movement. Recognising and monitoring sensory impairments is crucial to the patient's treatment and rehabilitation outcome.

2.6.1 Functional Implications of Sensory Impairment

The somatosensory system is important not only for allowing co-ordinated movement, but also for allowing communication and interaction with our surroundings (Gaubert and Mockett, 2000). It allows us to explore our environment, alerting us to danger, and providing a means of communication with others. It is also a vital component of body image. It alerts us when a position becomes uncomfortable and potentially damaging, preventing pressure sores and frictional abrasions. Somatosensory deficits can therefore be detrimental to personal care, safety, work, leisure and sexual activities (Carey, 1995). They influence the ability to complete activities of daily living and can result in patients being unsafe in their domestic environment (Carey et al., 1997), therefore impacting on a persons` quality of life.

Deficits of the somatosensory system have detrimental effects on the learning of new motor skills, as the acquisition is reliant on feedback from sensory input (O`Sullivan and Schmitz, 1988). Somatosensory impairment is frequently permanent, however the extent of such deficits is often overlooked. Frequently, rehabilitation is focused on the motor deficits (Yekutiel et al., 1994, Gaubert and Mockett, 2000), with a patient having a "weak" or "affected" side. This bias towards motor impairment is demonstrated by the word "hemiplegia" being used often to describe stroke patients. It's meaning is a paralysis of half of the body (Martin, 2000), whereas the word "hemianaesthesia", meaning sensory loss of half the body, is rarely referred to. This seems somewhat incongruous as it has been established that sensory impairment is detrimental to motor recovery (Kuffofsky et al., 1982, Aglioti et al., 1996). Indeed the

therapy that too often focuses on regaining only motor control and function, relies on sensation to facilitate "normal" movement and inhibit abnormal movement (Bobath, 1978, Davies, 1985). In a study by Reding and Potes (1988) on 95 consecutive patients with unilateral hemispheric stroke, motor deficit plus somatic sensory deficit resulted in worse rehabilitation outcome compared with motor deficits alone.

One of the possible reasons for the neglect of sensory deficits is that they are not detected in many common neurological assessments, nor can they be observed directly. These sensory impairments may go some way into explaining the clumsiness of many stroke patients (Kim and Choi-Kwon, 1996). It has been shown that somatosensory training can lead to a significant increase in somatosensory performance (Yekutiel and Guttman, 1993, Smania et al., 2003) and consequently lead to improvement in motor recovery. If sensory impairment is not assessed and therefore not recognised, the therapist is not able to attempt to re-train the impaired sensation or monitor any improvement. More importantly, patients' treatment will not be tailored to their needs, hence their maximum outcome will not be achieved. Physiotherapists, occupational therapists and doctors have all been shown to agree that somatosensory assessment provides useful information for prognosis of functional ability and length of stay (Winward et al., 1999).

2.7 Recovery After Stroke

2.7.1 Time course of Recovery

The exact time course and extent of recovery of neurological impairment is poorly understood (Patel et al., 2000). Many factors affect recovery, including infarction size and location, age, and pre-stroke neurological status (Cramer and Bastings, 2000). Individual patients also recover differently, such that the timing and extent of individual patients' recovery is relatively unpredictable. Some functions recover spontaneously (Wade et al., 1983, Hallett, 2001) and there is some evidence to suggest that recovery occurs by two to three months post-stroke or the functions remain permanently lost (Steinberg and Augustine, 1997). Animal and human trials have indicated that the cerebral cortex undergoes functional and structural reorganisation for weeks to months following damage, with changes extending up to six months in those with more severe strokes (Green, 2003) By six months most intrinsic recovery seems to be over and restrictions in activities and participation have stabilized (Jorgensen et al., 1995b, Andrews et al., 1981). However some recovery can continue longer after stroke onset (Liepert et al., 1998, Steinberg and Augustine, 1997). This is particularly true with patients who are severely impaired initially (Duncan et al., 1992, Wade et al., 1983, Wade et al., 1987). Activity of the affected hand has been improved with training even four to 15 years after patients have had their stroke (Johansson, 2000).

Generally, the time course for recovery of stroke depends on initial severity of impairments. Jorgensen (1995c, Jorgensen et al., 1995b) undertook the Copenhagen Stroke Study, which included 1,197 acute stroke patients and

investigated impairment after stroke, using the Scandinavian Neurological Stroke Scale (SSS) and the Barthel Index, and recovery. They found that 95% of all patients reached their best neurological level as assessed by the SSS within 11 weeks, and ADL function as assessed by the Barthel Index by 12.5 weeks. People with milder strokes reached their maximal recovery earlier than those with more severe strokes. It was also found that best walking function was achieved within 4 weeks for those with mild motor impairment of the lower limbs, 6 weeks for those with moderate impairment, and 11 weeks for those severely impaired. In conclusion, recovery of impairments following stroke is at its greatest in the first 3 months, but can continue at a slower pace for many months. The time course of recovery is related to the initial stroke severity. However in terms of recovery much remains poorly understood, with the timing and extent of individual patients' recovery still relatively unpredictable.

2.7.2 Mechanisms of Recovery

Much investigation has been undertaken into the mechanisms of recovery. It is hoped that understanding the mechanisms will allow recovery to be maximised to achieve optimal outcome. Without this information, it is not possible to separate the effective and ineffective parts of rehabilitation. Consequently therapy development is limited (Carr and Shepherd, 1982). Since much of "rehabilitation" occurs in the early stages when there is spontaneous recovery, it is impossible to distinguish how much of the patient's recovery is wrongly attributed to rehabilitation when it is in fact natural recovery. Improvements in imaging techniques (position emission tomography (PET), functional magnetic resonance imaging (fMRI), and transcranial magnetic stimulation (TMS) have

increased our understanding of the neural reorganisation that takes place following stroke and how this relates to functional improvement (Rossini and Pauri, 2000). However, many questions remain unanswered.

In the acute phase, improvement is likely to be due to resolution of oedema and recovery of some ischaemic tissue that was damaged but not destroyed (Hallett, 2001). The area surrounding the lesion with decreased blood supply, known as the ischaemic penumbra, may have some recovery dependent on collateral circulation, medical intervention and general cardiovascular condition (Yekutiel, 2000). However, spontaneous recovery can be prolonged well past the resolution period of acute structural changes caused by the stroke, with recovery occurring 4-6 weeks post stroke (Brodal, 1973). Beyond the acute phase, recovery is likely to be due to neuronal plasticity. This is a relatively new concept. The central nervous system (CNS) was previously thought of as "hard-wired" or fixed and the consequences of damage irreversible (Moore and Schady, 2000). However it has been shown that the CNS can alter its structure, and neurones can change their function. This ability of neurons to alter some functional property as a reaction to changes in input means following lesions there may be significant potential for reorganization of representations and functions in both the sensory and motor cortex (Nudo and Friel, 1999). Neuroplasticity has been defined as the capability of cells, throughout their life, to change their phenotype in response to abnormal changes in their situation or environment (Winlow and McCrohan, 1987). Neural reorganisation is an important element in the restoration of function and is significantly influenced by experience and hence rehabilitation. It is said to occur via three

mechanisms: sprouting, unmasking of latent synapses and denervation supersensitivity (Kidd et al., 1992).

Sprouting of fibres from surviving neurons is one method of plastic reorganization. Growth of new synapses, via axonal sprouting or dentritic proliferation, makes connections with the synapses lost due to the damage from the stroke (Small and Solodkin, 1998). The exact mechanisms are unclear, but it has been shown that there are two types of sprouting in the spinal cord. Specific sprouting is where new synapses are associated with the formation of new functional pathways. The second type is non-specific sprouting, where cells make synapses so they have adequate stimulation to prevent them dying (Stephenson, 1993). This is said to begin within one week of the lesion. However, the distance is limited. Kidd et al (1992) stated the distance to be a maximum of 0.1mm. This shows the limitations of plasticity. Moreover, sprouting does not always lead to positive changes. Some areas are topographically precise; therefore replacement via another fibre may result in further impairment, as it will obscure the precision of the system. If a synapse is generated with a fibre that provides different information, the output may be nonsense and further increase the functional impairment.

The unmasking of existing circuits can enable the recovery of functional pathways. It is said that the brain contains 1,000 trillion synapses, which are apparently inactive (Kidd et al., 1992). Latent areas of the brain can specialize to take the place of those functions lost due to the lesion, although the extent to which this aids recovery is still a matter of debate (Rossini and Pauri, 2000). It

is not possible for neurons to grow following a lesion. However, the axons and dendrites can regenerate, though they are of poorer quality than the original (Bishop, 1982c). This can help patients reduce their impairment.

Denervation supersensitivity is another mechanism of neuroplasticity. It consists of deviation, when there is loss of the uptake of neurotransmitter substances pre-synaptically, leaving too much substance in the cleft leading to heightened response. This usually lasts for the first few days post-lesion. There is also non-deviation, a more chronic state, where a possible increase in receptor sites leads to increased sensitivity. This has been stated as a potential cause of increased tone and spasticity (Stephenson, 1993).

Neuroplasticity is not always beneficial. The experiences of the patient following stroke will affect recovery processes either positively or negatively (Carr and Shepherd, 1982, Small et al., 2002). Therefore therapy needs to concentrate on maximizing the productive effects of neuroplasticity and limiting the negative. This means therapy should reinforce normal pathways and direct axonal sprouting so it is as favourable as possible. It should also facilitate use of the latent synaptic chains in the CNS to allow normal movement through different routes (Kidd et al., 1992). It has been shown that physical rehabilitation post stroke is a strong modulator of brain plasticity (Nudo et al., 1997). It is facilitated by the patient participating actively, sensory input and by the patient feeling normal movement (Stephenson, 1993).

Evidence is contradictory regarding the association of neural re-organisation and recovery. It has been suggested that a causal relationship between functional recovery and neural plasticity remains speculative (Finger and Almli, 1985). The mechanisms of motor recovery are poorly understood (Bastings et al., 1997). Even though motor pathways in the unaffected hemisphere are greatly altered following stroke, they may have little significance in terms of recovery. Netz et al (1997) found no significant correlation between the existence of these pathways and clinical improvement. There is also little evidence to suggest that neural reorganisation happens to heal injured brains, and the neuroplastic response is better thought of as a developmental growth process as opposed to a healing process (Finger and Almli, 1985).

Recovery of function after a stroke is attributable to several factors, including events in the first few days (eg, resolution of oedema, tissue reperfusion). Consistent reorganisation and recovery after a stroke takes weeks or months and is attributable to neuronal reorganisation. Neuroplasticity encompasses all possible mechanisms of neuronal reorganisation including sprouting, unmasking of latent synapses and denervation supersensitivity. However, recovery from stroke can vary greatly among patients with identical clinical symptoms. As scientific knowledge about the mechanisms of recovery grows, it reveals broad principles on which new therapies should be based. For instance, somatosensory or touch feedback from normal activity or repetitive exercises is now known to be an important driver to recovery (Pomeroy and Tallis, 2002). There is still much that needs to be learnt about the mechanisms

of recovery and the evidence regarding the association of neural re-organisation and recovery needs to be clarified.

2.7.3 Sensory Recovery

It has previously been stated that changing the afferent input to the brain can modify somatosensory cortical maps. This means how the somatosensory organisation alters in response to a stroke is of interest as it may be a potential mechanism for recovery. Most studies examining somatosensory reorganisation following stroke have been on animals. However there have been some clinical human studies. Wikstrom et al (2000) using magnetoencephalography (MEG) found that the recovery of light touch and two-point discrimination 2-3 months after the stroke was paralleled by the growth of the somatosensory evoked magnetic fields, and suggested this was due to re-establishment of lateral inhibitory functions at the primary somatosensory cortex. This study had limitations in that only the primary somatosensory cortex was examined, and the spatial resolution of MEG is less than that of fMRI. Carey et al (1997) demonstrated the potential for re-emergence of activation of ipsilesional primary and bilateral secondary somatosensory cortices following stroke. This was in a case study of one patient with impaired touch discrimination as assessed by the Tactile Discrimination Test (Carey et al., 1997), who underwent whole-brain fMRI at 2 weeks, 3 months and 6 months after stroke. The return of activation was observed at 3 months, when marked sensory recovery occurred, and was maintained at six months. There was little evidence of changes in brain activation at 2 weeks, when sensory loss was severe. SEP results in the first week after stroke have been shown to correlate with clinical sensory recovery

three months later (Pereon et al., 1995). However they only classified sensation as “normal”, “decreased” or “no perception” and no further details as to how this was assessed were given. More recently Rapp et al (2002) described two individuals with left hemisphere damage who misperceived the locations of tactile stimuli whose presence or absence they could readily detect, providing evidence for systematic remodeling of somatotopic maps in humans. This suggests that afferent input is not just redirected to intact neural tissue, but also reorganised within available neural substrate. Therefore clinically, reorganisation of sensory representation parallels animal studies, as it occurs within intact neural tissue and generally preserves the original topography.

Julkunen and colleagues (2005) investigated the recovery of upper limb somatosensory deficits in five acute stroke patients using somatosensory evoked potentials (SEPs) at one week, three months and 12 months after stroke. They also measured quantitative sensory tests which included tactile detection thresholds using Semmes-Weinstein monofilaments, two-point discrimination, touch localisation, movement detection, graphesthesia, joint position sense, stereognosis, weight discrimination, size evaluation, material discrimination, thermal and vibratory thresholds, sensorimotor function, and subjective evaluation. They found that those patients with a normal SEP initially with sensory impairment showed good recovery, though those with an absent SEP initially did not necessarily result in poor outcome. Most of the recovery in the sensory assessments was found within the first three months after stroke, though warm detection threshold, vibratory detection threshold and two-point discrimination showed most improvement between three and twelve months after stroke. The recovery of subjective experience of sensory

impairment occurred in line with the improvement of the quantitative sensory tests. The most sensitive measure for somatosensory impairment early after stroke was graphesthesia, the tactual ability to recognise writing on the skin, which was measured in the upper arm, forearm and thenar with a blunt ended pin. This was examined by drawing three different figures on each body area and asking the patient to identify the figure from a picture. Performance was regarded as correct if the patient had greater than 50% accuracy. The study was limited by the small sample size, and the fact that patients with significant motor deficit were excluded because the nature of the sensory assessments used meant patients needed motor ability to be able to complete them.

Smith (1979) investigated the recovery of discriminative sensation after stroke in the elderly. He also found the most marked recovery within the first three months after stroke. Sensory impairment was also associated with poor prognosis and increased length of hospital stay. However this study had a number of limitations. It included 31 patients, but the inclusion and exclusion criteria were not detailed. The study excluded patients who had communication problems or who had severe mental impairment. However there was no mention as to how communication was assessed, and the modified Isaac Walkey mental impairment measure was used to assess mental function, though this assessment was not referenced and exact cut-offs not given. The assessments used were also not standardised. Therefore the conclusions from this study must be taken with caution.

In conclusion, sensory impairment is common in acute stroke and the time-course of recovery is similar to that found in other impairments e.g. ADL

ability (Jorgensen et al., 1995c), orientation (Pedersen et al., 1998), upper extremity function (Nakayama et al., 1994), walking function (Jorgensen et al., 1995a), with the major part of recovery early after stroke onset. However there has been little quality research investigating sensory recovery in detail or any that includes many different modalities and areas of the body. This warrants further investigation.

2.8 Sensory Rehabilitation

Research suggests that after a stroke, sensory impairment does show some recovery. As cortical representation is dependent on experience, this leads to the question whether it is possible to improve sensory recovery through sensory rehabilitation. It has been known for many years that both monkeys and humans with a history of somatosensory impairment can show improvement with training (Ruch et al., 1938). More recently, there have been several studies evaluating sensory rehabilitation with mostly positive results that are detailed below. Most literature is focussed on sensory rehabilitation of the upper limb, and is limited by sample size, methodological flaws and the lack of a decent outcome measure. Interventions vary widely, from thermal intervention (application of a hot or cold pack) (Chen et al, 2005), "sensory re-education" (emphasis on sensory tasks that the patient could do with constant use of vision and the "good" hand to teach tactics of perception) (Yekutiel & Guttman, 1993; Byl et al, 2003), "sensorimotor training" (patient positioned in a rocking chair with an inflatable splint to position the hemiplegic arm, with rocking movements perform for 30 minutes) (Feys et al, 1998), exercises aimed at stimulating sensory and motor functions for 30 training sessions

(Smania et al, 2003), and use of intermittent pneumatic compression on the upper limb (Cambier et al (2003)). Therefore it is difficult to draw conclusions on the overall effectiveness on sensory rehabilitation with such varied interventions and limited quality studies available.

Chen et al (2005) investigated the use of a thermal intervention to facilitate sensory and motor recovery in 46 acute stroke patients. The intervention consisted of either a heat pack (≈75°C) or cold pack (<0°C) wrapped in two towels being placed over the hand and wrist for up to 15 and 30 seconds respectively. Patients were encouraged to move their hand away from the stimulus if it became uncomfortable, thus also providing a motor component. A session of thermal stimulation, consisting of two alternate cycles of heating and cooling, was performed daily, five days a week for six weeks. There was a dropout rate of 37%. Sensation was assessed using the Semmes-Weinstein monofilament, with no assessment of temperature sensation undertaken. The performance of motor function as measured with Brunnstrom stage, active range of wrist extension and sensation significantly improved after the intervention. Higher recovery rates were also found in the experimental group for motor function, active range of movement and sensation compared with those of the control group. However the exact timing of the assessments was not stated. Due to the high drop out rate and small sample size the results must be taken with caution.

Yekutiel and Guttman (1993) evaluated sensory retraining of the hand in 20 patients who were two or more years after stroke. The intervention consisted of 45 minutes lessons three times a week for six weeks. Treatment was tailored to

the individual based on the following principles: the nature and extent of sensory loss was explored together with the patient, emphasis was placed on sensory tasks that the patient could do, which interested the patient and which promised to lead to sufficient failures and successes to promote learning, constant use of vision and the "good" hand was made to teach tactics of perception, frequent rest and change of subject were included to help maintain concentration, and no task used in assessment was used in training. Patients with communication problems, or significant cognitive or emotional disturbance were excluded from the study, but the criteria for deciding this was not stated. Outcome measures were non-standardised, but included tests of tactile localisation, sense of elbow position, two-point discrimination and stereognosis. Correct answers on each test were expressed as percentage scores, though it is not clear as to how a "correct" score was defined. Sensation was assessed before and after the intervention period, and in 19 control patients. The intervention group showed significant improvement in all sensory tests, while the control group showed no change. As this study was undertaken on patients who were two or more years after their stroke, the improvement cannot be attributed to spontaneous recovery. However there was no comparison of the two groups at the end of the intervention period.

Another study which investigated the effectiveness of an intervention late after stroke was by Byl et al (2003). They included 21 participants 6 months to 7 years post-stroke, and had specific inclusion criteria in terms of upper limb movement and walking ability (no less than 100 feet with or without a cane). Eligible patients were randomly assigned to Group A (sensory training 4 weeks, motor training 4 weeks), or Group B (motor training 4 weeks, sensory

training 4 weeks). Both motor and sensory training was tailored to the individual in terms of their ability, and required attention and repetition. Examples of treatments were listed. For example, for sensory training patients were asked to play games/ fine motor activities with eyes closed, to place their hand into a box filled with rice, beans and objects and to retrieve/ match objects. The aim of the sensory training was to "facilitate improved accuracy and speed in sensory discrimination and sensorimotor feedback as a foundation for facilitating fine motor control". Motor training included practising fine motor tasks such as dealing cards, picking up small objects such as nails and tacs, putting together puzzles etc. Therefore though the interventions were described as "sensory training" and "motor training" both required integration between both sensory and motor systems. The results showed more than 20% ($p<0.01$) improvement across both groups in terms of functional independence and upper extremity function. There was no significant difference in terms of sensory improvement over the 8 weeks between groups, though group B made significantly more improvement in terms of fine motor control compared to group A.

Feys et al (1998) evaluated the effectiveness of a sensorimotor treatment in a single blind multi-centre trial of 100 patients 2- 5 weeks after stroke. The intervention consisted of the patient positioned in a rocking chair with an inflatable splint to position the hemiplegic arm. The patients were asked to perform rocking movements for 30 minutes, and were encouraged to assist this with their hemiplegic arm. The control group were positioned in a rocking chair and rocked for the same length of time, but with their hemiplegic arm supported on their lap, and sham short wave therapy applied. This was applied

for five days a week for six weeks. The results showed that motor recovery, as assessed by Fugl-Meyer scores, was significantly higher at 6 and 12 months in the intervention group compared with controls. Limited assessment of sensory function was undertaken, therefore the effect of the intervention on sensory recovery was not evaluated. The results of the Action Reach Arm Test and Barthel Index showed no significant treatment effect at the level of disability. Therefore though this study is investigating the effect of a sensorimotor intervention, there is little consideration given to sensory recovery.

In a preliminary study, Cambier et al (2003) investigated the effect of intermittent pneumatic compression on the upper limb (10 cycles of 3 minutes with a peak of 40mmHg) in 11 patients who were less than one year post-stroke. A control group (11 patients) received sham short-wave diathermy on their hemiplegic shoulder for 30 minutes. Again inclusion criteria included the ability to understand oral instructions, with no reference made to how this was assessed, or whether cognitive impairment was considered. The main outcome measure used was the revised Nottingham Sensory Assessment. Total scores were summated for the tactile sensations (face, trunk and upper limb only), and for the proprioception and stereognosis subscales. Both the intervention and control group showed significant improvement in somatosensation over time, but with significantly more improvement in the intervention group. However with the small sample, and as there was no mention of the problems with summating ordinal data and comparison of change scores of an ordinal scale, the results must be taken with caution.

A study on sensory rehabilitation on patients with pure sensory stroke also showed positive results (Smania et al., 2003). This included four single case

studies of patients ranging from 6 to 20 months after stroke, all with chronic deficits of sensation and motor control of the contralesional hand. The intervention involved exercises aimed at stimulating sensory and motor functions for 30 training sessions of 50 minutes, and one-hour daily practice at home. The exercises were classified into nine categories: tactile discrimination, object recognition, joint position sense, weight discrimination, motor sequences, reaching and grasping, item grouping, grasping strength grading and daily life activities. All patients showed some improvement in sensory functions, subjectively 3 out of the 4 patients reported increased use of the affected arm in daily life. However this was measured by a visual analogue scale in which patients and their relatives evaluated the amount they were using their affected arm and this measure has not been validated.

In conclusion, the literature shows limited support for the effectiveness of sensory rehabilitation after stroke. There seems to be improvement in sensory and motor ability, but conflicting results in terms of improvement at the disability level. Further research is needed, as many of the studies are small and include different subgroups of patients. In most cases rehabilitation is focussed on sensory and motor function. As they are assessing different interventions there needs to be further investigation as to which of these are the most effective. As sensory and motor functions are interrelated, it is difficult to classify an intervention as a "sensory" intervention as it will undoubtedly affect the motor systems too. Therefore properly conducted controlled studies into sensorimotor rehabilitation programmes are required. They need to be bigger, well-designed with appropriate outcome measures. Little attempt has yet been

made to evaluate the use of the affected upper limb in activities of daily living and assess the impact of sensory rehabilitation on this. It may be that the outcome measures currently available at the disability level are not sensitive enough to detect any changes in sensory function, as they are not focussed on tasks that require a high level of sensory ability. They also need to include an accurate and reliable form of measurement at the impairment level as this is critical to the success of evaluation of interventions (The Academy of Medical Sciences, 2004). Therefore a sufficient standardised outcome measure for assessing sensory ability is required.

2.9 Outcome Measures

An outcome measure is a test or scale that has been shown to measure accurately a particular attribute of interest to patients and therapists and is expected to be influenced by an intervention (Mayo et al., 1994). With the focus on clinical effectiveness and evidence-based practice, outcome measures have become increasingly important, allowing for the quantifiable measurement of treatment effects. The Chartered Society of Physiotherapy's standards of practice stipulate that physiotherapists must use published, standardised outcome measures in their routine clinical practice (The Chartered Society of Physiotherapy, 2000). The importance of using standardised outcome measures for clinical practice and research is well recognised (Wade, 1992).

An outcome measure should be valid, reliable, sensitive to change and feasible to use in the given setting. It should be standardised, with explicit instructions

for administration and scoring (McDowell and Newell, 1996). In terms of sensory outcome measures available, there are few that are standardised which have established validity and reliability. Bohannon (2003) recently recognised that there is still much work needed in the development of sensory outcome measures. In the clinical setting sensory assessment is often undertaken, with over 80% of therapists found to routinely perform somatosensory assessment (Winward et al., 1999). However the assessments used are often not standardised.

Some measures have been developed to assess sensation, though many fail to meet the criteria that an outcome measure should. They have problems with reliability, or are difficult to implement with stroke patients in a clinical environment, either because of the time needed to administer them or the equipment needed (Winward et al., 1999, Wade, 1992, Bohannon, 2003, Carey, 1995). Some sensory assessments are modality specific, whereas others attempt to incorporate several modalities in one complete sensory assessment.

The sensory scale of the Fugl-Meyer assessment (Fugl-Meyer et al., 1975) assesses light touch, using the touch of the assessors' finger on the patients' skin of both arms and legs, the palmar aspect of the hands and the soles of the feet. It also assesses position sense in the thumb, wrist, elbow and gleno-humeral joint in the upper limb, and the great toe, ankle, knee and hip joints in the lower limb. Thus it measures limited modalities, and although the scores are ordinal level they are added together to get a total score. A recent study into the psychometric properties of this scale found it had low to moderate

reliability, validity and responsiveness, suggesting its clinical use in stroke patients was not supported (Lin et al., 2004).

The Rivermead Assessment of Somatosensory Performance (RASP) is a relatively new clinical test developed by Winward et al (2002). It tests five primary sensations (sharp/dull discrimination, surface pressure, tactile localisation, temperature discrimination, joint movement and movement discrimination), and two secondary sensations (bilateral touch discrimination and two-point discrimination). To try and minimize problems with reliability, pieces of equipment were custom-designed. These were the "neurometer" that allows consistent amount of pressure to be applied to an area. The "neurotemp" that has temperature displays to ensure the exact temperature of the instrument is standardised when assessing temperature discrimination. The "two-point neurodiscriminator" is a four-pointed fixed distance discriminator used to evaluate two-point discrimination on the finger pads. Although these custom-made pieces of equipment may improve reliability, it means that the assessment is only available commercially. This cost limits the implementation of the assessments into clinical practice, but we must expect to pay for it as we do other measures and equipment in rehabilitation departments. All sensations on three body areas (face, hand and foot) are administered with the patient's eyes closed. The assessment consists of six trials on ten test regions (five on the left side and five on the right side of the body), including two sham trials. The reliability of the RASP has been studied. It showed good intra-rater and inter-rater reliability (Winward et al., 2002). However the inter-rater reliability was assessed using total scores for each of the sensations. This is despite the

fact that the scales are ordinal and should not be summated, though it recognised that the validity of summing scores across items needs further investigation. Also patients who were classified as “unreliable” because they produced false positives on six or more of the sham trials were excluded from the study. This means the study self-selected those patients that were known to be more reliable. The assessments ability to measure reliably on unselected populations has not been tested, as many patients could be “unreliable” in clinical practice.

Specific tests of light-touch include touch-pressure monofilaments such as the Semmes-Weinstein monofilament (Semmes et al., 1960b), and the Weinstein Enhanced Sensory Test (Weinstein, 1993b). These are more suitable for tests of peripheral rather than central lesions (Weinstein, 1993b). This is as the tests are static and administered to a passive hand and are not measures of functional sensory abilities, with results shown not to correlate well with hand function (Carey, 1995).

Carey (1993) developed the Tactile Discrimination Test, which was modified slightly (Carey et al, 1997) to address the limitations of many of the assessments of tactile discrimination. They aimed to develop a quantitative and standardised measure, which assessed active touch sensibility and was suitable for use in the clinical setting with stroke patients. The test involves finely graded plastic surfaces marked by ridges at set spatial intervals, in triplet sets. The patient tactually explores these (or is guided by the examiner if required due to motor impairment), and the patient is asked to indicate which texture is

different in the set of three. Based on a sample of 35 patients, test-retest reliability was high (r=0.92), and changes of the magnitude of 27 percent spatial increase (PSI) were detected with 95 per cent confidence. The modified stimulus matching procedure reduced the testing time from 20 minutes to complete per hand, to 10-15 minutes per hand. It has advantages over many measures of tactile discrimination in that it is quantitative, standardised and reliable and has normative guidelines. However the amount of time taken for the test is still problematic and only assesses the ability of the hand.

Dannenbaum et al (2002) developed methods to assess moving and sustained touch-pressure. A tactile intensity estimation task using brushes of different textures assessed moving touch-pressure, with participants asked to indicate which brush had contacted the skin. These were applied to the distal phalanx of the index finger. Sustained touch-pressure involved a light or heavy ball being lowered by string on to the hypothenar surface of the hand and then actively being held between thumb and index finger. Participants reported the intensity of the sensation felt at five time points over 20 seconds to assess whether the perception of the sensation faded over time. These assessments were found to have reasonable reliability, good concurrent validity and moderate construct validity (Dannenbaum et al., 2002). The responsiveness has yet to be evaluated. The assessments were found to be relevant to functional sensation such as object recognition (Dannenbaum et al., 2002). However the limitations with these assessments are that they only measure touch-pressure sensation of the hand.

Kim & Choi-Kwon (1996) used several methods to assess discriminative sensations. Two-point discrimination was assessed from the tips of the thumb, third and fifth fingers using the Disk-Criminator (Dellon, 1991, Dannenbaum and Jones, 1993). This is a two-point esthesiometer with point spacing from 2mm to 8mm. Problems have been found with the application of this assessment in terms of variation in the force and velocity of the stimulus making the tests unreliable over time and subjective (Bell-Krotoski, 1990, Moberg, 1991, Weinstein, 1993a). Actual assessment of two-point discrimination has been called into question (Carey, 1995), with it found to be unassessable in many patients after stroke, with no clear-cut separation found between normal and abnormal hands (Prescott et al., 1982). Texture discrimination was assessed in the Kim & Choi-Kwon study using the Tactile Discrimination Test method developed by Carey et al (1993) described earlier. A threshold of 80% accuracy for this test was set for both two-point discrimination and texture discrimination, but no justification was given as to how this was decided. Position sense was assessed using a specific device that was manufactured with the use if a semiconductor laser attached to the dorsum of the hand and aligned to the third finger. The patient had to replicate different positions of wrist flexion and extension, with the average error between the chosen angle and that indicated by the patient recorded. Proprioception was not assessed in any other joints.

In the Kim and Choi-Kwon study point localization was assessed using the method described in Corkin et al (1970). Point localization is a clinical test evaluating spatial accuracy of the somatosensory system. A four-spoked pattern of dots was stamped on each palm, with patients tested twice in

succession and asked to identify if the stimuli felt the same or different. This means it has limited use on patients with communication impairment, and the reliability and validity of this test has not been determined.

Therefore Kim & Choi-Kwon (1996) used several detailed methods to assess discriminative sensations, most of which were developed from earlier studies. However many of the methods were of uncertain validity, discriminated against some groups of stroke patients or were limited to one area of the body.

Tactile object discrimination had been assessed using many methods such as the identification of common objects (Klatzky et al., 1985, Lederman and Klatzky, 1990), or the use of spheres or cylinders of differing sizes (Roland, 1976b). When assessing stereognosis the use of artificial objects and two-dimensional displays should be avoided, with real everyday objects used instead (Klatzky et al, 1985). Kim & Choi-Kwon (1996) included 12 objects (bottle cap, box, cotton, eraser, extension plug, key, screw, spoon, safety pin and watch) which patients were asked to name. Smania et al (2003) also used non-standardised tests in which patients were asked to manipulate a group of small objects (e.g. rice, bolts, stones) and then discriminate visually among the 3 items, and to manipulate two objects simultaneously with the affected and unaffected hand and then report whether the objects were the same or different. These assessments have not been validated, and it was not stated how patients with motor impairment or communication problems were assessed.

An objective method of measuring sensory impairment in the laboratory setting is somatosensory evoked potentials (SEPs). Evoked potentials are the electrical

signals generated by the nervous system in response to sensory stimuli. Somatosensory evoked potentials consist of a series of waves that reflect sequential activation of neural structures along the somatosensory pathways following electrical stimulation of peripheral nerves. In clinical practice, SEPs are elicited typically by stimulation of the median nerve at the wrist, the common peroneal nerve at the knee, and/or the posterior tibial nerve at the ankle and recorded from electrodes placed over the scalp, spine, and peripheral nerves. The dorsal column-lemniscal system is the major anatomical substrate of the SEPs within the CNS.

SEPs provide information concerning the integrity of the pathway through the brain, brain stem, spinal cord, dorsal roots, and peripheral nerves. Generally abnormal sensory evoked potentials show good correlation with clinically tested sensory impairment, particularly with joint position sense (Watanabe et al., 1989, Mauguiere and Desmedt, 1991, Mauguiere and Isnard, 1995). SEPs in the first week after stroke have also been shown to have prognostic significance for sensory ability and functional outcome as measured by the Barthel index at three months after stroke (Pereon et al., 1995). The performance of motor tasks and SEPs combined have been found to have predict accurately arm motor recovery (Feys et al., 2000). However SEP findings must be interpreted carefully, because normal SEPs can be seen in patients with sensory impairment. For example, some patients with pure sensory strokes, due to lacunar infarcts, may have normal SEPs. Although SEPs may demonstrate intact conductivity between peripheral receptors and cortical brain areas, they are unable to indicate the patients' awareness or experience of the stimulation. This awareness or perception of the sensation is

of interest to the therapist. Therefore while SEPs may have some use in determining prognosis or localisation of lesions, they are not practical in the clinical setting and provide information of minimal use to the therapist. However the fact that SEPs have shown prognostic significance for functional outcome provides justification for investigating prognostic factors of sensory outcome as assessed by other methods.

2.10 Nottingham Sensory Assessment

The Nottingham Sensory Assessment (NSA) was the outcome measure used in this study. It was first developed in 1991 by Lincoln (Lincoln et al., 1991), and included assessments that were commonly used in clinical practice but in a more standardised format. It includes tests of light touch (applied using cotton wool), pressure (applied using the assessor's finger), pinprick (using a neurotip), and temperature (using hot and cold water in test tubes). It also assesses tactile localisation, bilateral simultaneous touch, proprioception (by mimicry), two-point discrimination and stereognosis. The NSA was found to have good intra-rater reliability but poor inter-rater reliability (Lincoln et al., 1991) and was a lengthy assessment. This led to revisions of the NSA (Lincoln et al., 1998), shortening the scale and producing a hierarchy of items so that testing could be discontinued if no impairment was detected in the distal part of the limb. The inter-rater reliability of the revised NSA was then investigated and found to be acceptable though not good (Lincoln et al., 1998). The stereognosis assessment within the NSA has also been investigated and found to reliable between raters (Gaubert and Mockett, 2000). The validity and responsiveness of the NSA has not been investigated. The NSA has been used

as a primary outcome measure in a study by Cambier et al (2003). However they only used the upper limb section of the assessment and calculated total scores for tactile sensations, proprioception and stereognosis. In the revised version of the NSA it was suggested that totals could be derived for the upper and lower limbs, and the stereognosis and proprioception subscales. However there was no mention of the fact that the scales are ordinal. As such the distance between values has no meaning therefore scores should not simply be summated. This means the outcome measures used in the intervention study by Cambier et al (2003) cannot be relied on, as they have used the total score of the NSA incorrectly.

The NSA is therefore a standardised outcome measure that can be used clinically, and has acceptable reliability. However its validity still needs investigating, and a method which allows results to be easily interpreted and total scores to be generated for statistical analysis, would be beneficial.

The NSA is not as detailed as the assessments used by Kim and Choi-Kwon (1996), which were time-consuming and required specialist equipment, yet remains sufficiently sensitive to detect clinically relevant impairment. For clinical use assessment should still be able to detect impairment that is clinically relevant. The practicalities of completing an assessment in terms of equipment and time are also important determinants of clinical use.

2.11 Summary and Hypotheses

In summary, there is some literature regarding sensory impairment and recovery after stroke, but it is limited. The fact that there are problems with the assessment of sensation has hindered research, and led to discrepancies in reported incidence of impairment and natural recovery. The lack of control groups is a limitation in many intervention studies. This study aimed to further develop the NSA so that total scores to be calculated and statistical analysis undertaken, in order to investigate sensory impairment and recovery after stroke. The overall aim of the study was to determine the nature of sensory impairment after stroke and to determine the extent to which these impairments recovered over time. The factors that are related to sensory impairment and outcome was then explored.

The hypotheses tested were:

Hypothesis 1

A high proportion of patients will have sensory impairment following first stroke

Hypothesis 2

There will be a higher proportion of problems in the more complex sensations of proprioception and stereognosis, compared with the primary sensations, such as light touch and pinprick.

Hypothesis 3

There will be no significant relationship between sensory impairment in one modality and another.

Hypothesis 4

There will be a significant difference in the frequency of sensory problems according to the part of the body assessed.

Hypothesis 5

The items of the NSA can be combined to provide overall scores.

Hypothesis 6

The scoring of the Nottingham Sensory Assessment (NSA) will show no significant differences between raters.

Hypothesis 7

There will be significant recovery in all sensory modalities over six months.

Hypothesis 8

There will be individual variation in the amount of sensory recovery.

Hypothesis 9

Sensory outcome at six months will be related to the initial level of sensory impairment.

CHAPTER III: METHOD

3.1 Design of the Study

This study was a prospective longitudinal study of sensory deficits and their recovery over time. It was undertaken in collaboration with CERISE (Collaborative Evaluation of Rehabilitation in Stroke across Europe), a comparative study of rehabilitation in different countries. The aim of CERISE was to examine differences in motor recovery and functional outcome in stroke patients across centres in Europe. Participants were recruited from the same cohort of patients in the English centre. This study was designed to examine the recovery if sensory impairment in the same cohort of patients.

3.2 Ethics

Ethical approval was obtained from Nottingham City Hospital and Queens Medical Centre Local Research Ethics Committees in April 2002 for the CERISE study, with the inclusion of an additional sensory assessment.

3.3 Recruitment of Patients

Patients were recruited consecutively from those admitted to two rehabilitation units in Nottingham hospitals (Nottingham City Hospital and Queens Medical Centre). At Nottingham City Hospital patients who were accepted by the Acute Stroke Service were identified on the acute ward, Patience One. At Queen's Medical Centre patients who were on the list awaiting transfer to the stroke unit were identified. Two researchers, LC & BS, went on to these wards most days and recorded the name, hospital number and date of birth from the medical notes of the stroke patients admitted.

At Nottingham City Hospital patients were either discharged home from Patience One or put on the waiting list for a rehabilitation bed. They could be transferred to Warren, Jenner or Beeston wards. Warren and Jenner were medical rehabilitation wards that had a multi-disciplinary approach although general medical, as well as stroke patients, were seen. Beeston ward was the stroke unit and was solely for stroke patients. The patients' destination depended ultimately on the availability of beds. At Queen's Medical Centre, stroke patients with rehabilitation potential were identified from the acute stroke service and waited on the acute ward until a bed became available on the stroke unit. For this study, patients were included from the two stroke units as they had a similar environment and ethos.

3.4 Procedure

Patients who were identified as eligible for inclusion were met by a researcher (LC or BS) to discuss the study and given a standard information sheet within their first week on the stroke unit. Patients were given at least twenty-four hours to decide and those who agreed to participate were asked for their written consent. For patients with cognitive or communication problems, which meant they were unable to give informed written consent (as determined by the researchers from examining patient's medical notes and in discussion with the multi-disciplinary team), assent was sought from the patients' relatives. The original completed consent/assent forms were securely filed, with a photocopy filed in the medical notes and a copy left with the patient. It was also documented in the medical notes that the patient was participating in this study.

The numbers of patients who refused consent or who did not fit the study criteria were recorded on a spreadsheet.

3.5 Selection of Patients

The inclusion criteria for the study were as follows:

- A primary first ever disabling stroke according to the WHO definition (World Health Organisation, 1978) of "rapidly developing clinical signs of focal or global disturbance of cerebral function, with symptoms lasting 24 hours or longer or leading to death, with no apparent cause other than that of vascular origin". This includes ischaemic stroke, intracerebral and subarachnoid haemorrhage. Patients were classified as having a first ever disabling stroke if they had no previous knowledge of a stroke, even if the CT scan revealed old infarcts of which the patient was previously unaware.
- Informed consent from the patient or assent from their family
- Lived within 50km of the two Nottingham stroke units, in order for follow-up assessments to be feasible
- Patients who were between the ages of 40 - 85 years old. Patients younger than 40years old were excluded as they are less representative of the general stroke population. Co-morbidity increases with age, which may affect sensory ability or the ability to undertake sensory assessment, therefore an upper age limit of 85 years was imposed.
- Admitted to the rehabilitation ward within 6 weeks of stroke onset to provide a relatively homogenous group with respect to time after stroke.

The exclusion criteria were:

- Other neurological impairments, such as previous stroke, head injury or multiple sclerosis. These might affect sensory ability independently of the stroke.
- Patients who were severely disabled prior to their stroke were excluded. This is to exclude those with other disabilities that may affect their ability to complete the sensory assessment, and the purpose of this study was to investigate sensory recovery in a sample of patients who required some rehabilitation. This was as determined by a pre-stroke Barthel (Collin et al., 1988) of less than fifty.
- Patients who were unable to speak English and for whom no interpreter was available

Patients were recruited from stroke rehabilitation units to ensure patients were stabilised medically and representative of those in rehabilitation. Patients with mild deficits and those who were discharged directly from an acute unit were not included.

3.6 Data Collection

Consenting patients were given a patient number and baseline data was collected to describe the sample and to measure factors that might be associated with recovery. The required information was obtained by the two researchers from the medical and multi-disciplinary notes, and from discussion with the medical staff, the patients and if necessary the patients' relatives. Demographic data was recorded including age, gender and address. Pre-stroke

Rankin (Van Swieten et al., 1988, Rankin, 1957) and pre-stroke Barthel were recorded following interviews with the patients and/or their family. The Bamford classification of stroke was recorded from the medical notes. Date of admission to the stroke unit was noted, and urinary incontinence on admission to the stroke unit was recorded on a three point scale: as "1" incontinent, "2" continent, or "3" catheterised, with the reason for catheterisation noted. The presence of swallowing problems were also recorded. Patients were scored as "0" no swallowing problems, "1" required thickened fluids, "2" required diet modification, "3" non-oral feeding. If patient fluids were thickened (score 1) and their diet also modified (score 2) then they scored 2. However this specific situation was recorded on a comments sheet.

Within five working days of admission to the stroke unit, initial assessments were completed. These usually took place in the physiotherapy gym. The assessments were usually undertaken by one researcher (LC or BS), but if the patient needed assistance of two people to transfer then both researchers were present. The patient was assessed on the National Institute for Health Stroke Scale (NIHSS) (Brott et al., 1989) and the Rivermead Motor Assessment (Lincoln and Leadbitter, 1979, Collen et al., 1990). These were administered according to the standard published instructions, however extra guidelines were made to clarify the assessment procedures further (see Appendix 2 and 3).

The revised Nottingham Sensory Assessment (Appendix 1) was administered on a separate occasion but also within five working days from admission on to the stroke unit. This was because the length of time taken to complete the

combined assessments might have resulted in patients becoming fatigued and hence affected their ability to complete all of the assessments. This was mainly administered by one assessor (LC), with another assessor administering the NSA only if needed to cover for holidays etc..

Researchers obtained information regarding planned discharge dates of participants from ward staff and case conferences. Each patient's length of stay was recorded, together with information on their destination. On discharge patients were given a letter informing them of dates of follow-up appointments. Letters were also sent to the patients' General Practitioners informing them of their patients' inclusion in the study.

The patients were followed up at two, four and six months after having their stroke. This was calculated as one month being equal to 30 days. This meant some of these assessments were due when patients were still in hospital. Therefore the researchers arranged a convenient time for the follow-up assessments to be carried out in the physiotherapy gym. If patients had been discharged home or to another destination, one of the researchers contacted them to arrange a convenient appointment. If patients preferred to come to the hospital, an appointment was arranged in a treatment room in the hospital. Patients were seen within a time-window of five working days before or after the due date stipulated. When home visits were being carried out, a community visit safety sheet was filled in to comply with the health and safety policy. Information regarding the researchers' method of transport, mobile phone number, place and time of appointment and expected return was documented

and left with another member of staff. If the researcher felt uncomfortable visiting a particular patient alone or the patient needed the assistance of two people to transfer then both researchers went on the visit.

At the two, four and six month appointments, the researchers administered the Rivermead Motor Assessment then the modified Nottingham Sensory Assessment. They also interviewed the patient, and if necessary the patient's carer, to assess the patient's independence in activities of daily living using the Barthel Index and the Nottingham Extended Activities of Daily Living Scale (Nouri and Lincoln, 1987) (see Appendix 4 and 5).

3.7 Outcome measures used

Below is a list of the outcome measures used in this study:

Stroke severity: National Institute for Health Stroke Scale (Appendix 2)

Motor ability: Rivermead Motor Assessment (Appendix 3)

Activities of Daily Living Ability:

Barthel Index (Appendix 4)

Extended Activities of Daily Living Scale (Appendix 5)

Sensation: Modified Nottingham Sensory Assessment (Appendix 1)

3.7.1 Stroke Severity Measure

National Institute for Health Stroke Scale (NIHSS) (Brott et al., 1989)

The NIHSS assesses neurological outcome and degree of recovery for stroke patients. This scale is a 15-item neurological examination stroke scale used to evaluate the effect of acute cerebral infarction on the levels of consciousness, language, neglect, visual-field loss, extra ocular movement, motor strength, ataxia, dysarthria, and sensory loss. A trained observer rates the patent's ability to answer questions and perform activities. Ratings for each item are scored with 3 to 5 grades with 0 as normal, and there is an allowance for untestable items. The examination requires less than 10 minutes to complete. Reliability was found to be excellent overall and moderate to excellent for most individual scales (Brott et al., 1989, Goldstein et al., 1989, Lyden et al., 1994). While the overall reliability of the NIHSS has been shown to be excellent, there is some disagreement as to which individual items have poor to fair reliability. The original authors evaluated the scale reliability using kappa statistic and found that, while most items had good to excellent reliability (Cronbach alpha> 0.5), two items, dysarthria and consciousness, rated fair to poor (Brott et al. 1989). Goldstein et al. (1989), in a separate analysis, found that of the 15 items making up the NIHSS, 13 showed no statistical difference between the observers. The observers had poor agreement on score in determining facial palsy and limb ataxia (alpha< 0.3). Lyden et al. (1994) reported similar findings Comparison of the NIHSS score with infarction volume as measured by CAT scan 1 week after event was used as a measure showing a high level of validity for the scale (r=0.68) (Brott et al. 1989). Comparison of the score with 3-month clinical outcome also shows high validity (r=0.79). Correlation

coefficients between the NIHSS and the Barthel Index, the Rankin Scale, and the Glasgow Outcome Scale were significant, but modest in magnitude both at baseline and 2 hours after stroke (Lyden et al., 1999). The predictive validity of the NIHSS three months after stroke is also high.

In summary, the NIHSS is simple and short, with the validity and reliability established but by trying to summarise all impairments in one scale it is rather a gross measure.

3.7.2 Motor Ability Measure

Rivermead Motor Assessment

Rivermead Motor Assessment (Lincoln and Leadbitter, 1979)

This is a widely used measure of motor function after stroke, consisting of three sections: gross function, arm and leg and trunk. The gross function and arm section can be used as hierarchical scales in acute stroke patients following Guttman scaling (Adams et al., 1997). However when non-acute stroke patients (six and twelve months after stroke) were investigated (Adams et al, 1997), this suggested problems with scaling, with only the gross motor function section meeting the scaling criteria.

3.7.3 Activities of Daily Living Measures

Barthel Index

The Barthel Index (Mahoney and Barthel, 1965) was chosen to measure ability on personal activities of daily living. It includes ten activities ranging from

bladder and bowel control, to walking ability. It is a well-documented scale that has been recommended for use with stroke patients (Wade and Collin, 1988) . It is thought of as the best measure of ADL ability to use, with reliability and validity well established (Wade, 1992).

The Extended Activities of Daily Living Scale

The Extended Activities of Daily Living scale (EADL) (Nouri and Lincoln, 1987) was chosen to assess patients' ability to carry out complex day-to-day activities. It contains 22 questions, split into four categories: mobility, kitchen activities, domestic activities and leisure activities. There are four responses to each question, but for scoring purposes each question is scored as dependent or independent. The validity (Gladman et al., 1993b, Lincoln and Gladman, 1992) and reliability (Gompertz et al., 1993, Nouri and Lincoln, 1987) of the Nottingham EADL scale have been well established.

3.8 Nottingham Sensory Assessment

3.8.1 Modifications of the Nottingham Sensory Assessment

The Nottingham Sensory Assessment (NSA) was developed by (Lincoln et al., 1991) and measures the patient's ability to recognise different sensory modalities in different regions of the body. The modalities assessed comprises six tactile sensations (light touch, temperature, pinprick, pressure, tactile localisation, and bilateral simultaneous touch), proprioception and stereognostic ability. The areas of the body tested are the face, trunk, shoulder, elbow, wrist, hand, hip, knee, ankle and foot. Each modality is scored 0, 1 or 2,

where 2 = normal sensation, 1= impaired sensation and 0 indicates severe impairment.

Concerns had been raised about the length of time required to administer the NSA, which affected its implementation into clinical practice (Lincoln et al., 1998). Therefore a further study (Lincoln et al., 1998) which investigated if the scale could be shortened without loss of information. Criteria were identified for discontinuing the assessment scale and reducing the assessment of the "unaffected" limb. For example if the patient had no impairment of a sensation in the hand and wrist, it was assumed there was no impairment in the elbow or shoulder. The original version (1991) of the NSA (assessing both sides of the body and all areas) was selected for use in this study. This was to allow a detailed description of sensory impairment over time. However some modifications were made. Two-point discrimination was not tested as it does not assess functional sensibility and has been shown not to correlate well with hand function (Carey, 1995), thus the value of assessing two-point discrimination following stroke is doubtful. As patients often have limited movement of their affected side and in order to copy effectively requires intact proprioception of both sides it was decided to test proprioception by copying the position of the affected limb with the unaffected limb. This differs from the original in which both sides of the body were tested if the patient had sufficient movement in their affected side. The original NSA specifies the part of the body to assess but not the exact location on that body part. In order to improve the standardisation, the areas where the sensation was to be assessed were more clearly defined, with a body chart developed to illustrate this (see Appendix 1).

To account for these changes a new assessment form and set of guidelines were produced (see Appendix 1). One of the researchers (LC) was familiar with the NSA and trained the other researcher (BS) in the assessment to ensure standardisation. Inter-rater reliability was checked and is shown in Appendix 7. Pilot assessments were carried out prior to data collection.

3.8.2 Procedure for the NSA

The NSA was administered in a quiet setting. In hospital this was the physiotherapy gym or in the patient's cubicle with the curtains drawn to reduce distractions. The patient was assessed in sitting and in a suitable state of undress so that the assessor could access all nine areas of the body. Even for participants wearing shorts it was impossible to test tactile sensation on the lateral aspect of the hip joint whilst maintaining patients' dignity and without moving clothing, thus giving the patient conflicting sensory signals. Therefore only proprioception was assessed on the hip joints. TED stockings, splints and dressings were removed if possible. If this was not appropriate e.g. open wound, then the affected area was scored as unable to test.

During the assessment, participants were asked to wear a blindfold to prevent visual information from being used. This was removed after each sensation had been tested, or before if the patients indicated they were uncomfortable and to prevent them becoming disorientated and distressed. The sensations were assessed in the following order: light touch, temperature, pinprick, pressure, tactile localisation, bilateral simultaneous touch, stereognosis and

proprioception. The areas tested were the face, trunk, shoulder, elbow, wrist, hand, hip, knee, ankle and foot. The tactile sensations were assessed on each test area on three occasions, to the left and right side in a variable order). Proprioception was tested by the examiner passively moving the patient's limb and asking them to copy the position with their other limb without the use of vision. All sensations were assessed using the guidelines (see Appendix 1).

3.8.3 Scoring of the NSA

When assessing tactile sensations, if the patient correctly identified the sensation on each occasion and detected no difference in intensity between sides, a score of "2" for normal sensation was given. If the patient did not always feel the sensation or felt it was duller in comparison to their other side, a score of "1" for impaired sensation was given. If patients were not aware of the sensation at all on a particular body area, they were scored "0" as absent sensation. Patients could indicate whether they felt the test sensation either verbally or with a body movement. A card with hot and cold signs was provided for those with communication problems to allow them to indicate their choice when assessing temperature.

For proprioception, a score of "0" was recorded if patients were not aware of their joint being moved. A score of "1" was awarded if patients could indicate that their joint was being moved but the direction was incorrect. If patients were aware of the joint moving in the correct direction but were inaccurate in its new position by greater than ten degrees as determined by observation, a score of "2" was given. If patients had intact joint position sense, accurately mirroring the test movement to within ten degrees, a score of "3" was given.

Stereognosis was scored on a three point scale, as "0 - absent", unable to identify the object in any manner. A score of "1 - impaired" was given if some features of the object were identified or attempts at description of the object were given. A score of "2 - normal" was given if the patient correctly named or matched the object. For each patient it was noted whether the examiner needed to move the object around the affected hand due to lack of active finger movement, or if the objects were manipulated independently.

If an area or sensation could not be tested, the reason was recorded. These were categorised as:

"4" Unable to detect pressure

"5" Physical reasons e.g. motor impairment preventing tactile localisation

"6" Unable to assess due to clothing/ dressing/ brace

"7" Communication problems

"8" Cognitive problems

"9" Pain or increased tone

"10" Sleepy, unable to concentrate

3.9 Training & Standardisation

Prior to beginning data collection on this study both researchers underwent a training programme. In collaboration with the CERISE project, a representative from the co-ordinating centre at the University of Leuven, Belgium, trained the researchers in the administration of the NIHSS, Barthel Index, RMA and Nottingham EADL. This was to ensure standardisation and involved training on the documentation to be used, the Rivermead Motor Assessment and the National Institute for Health Stroke Scale.

3.10 Equipment

To ensure standardisation of equipment, two identical equipment kits were obtained one for each researcher. These consisted of an eye patch and neurotips for the NIHSS. For the RMA a pencil, a volleyball, a tennis ball, a piece of paper, knife and fork, a plate, a container, putty, a bean bag, a shoe lace, a non-slip mat, a watch and a step with a height of 20cm were required. The equipment needed for the Nottingham Sensory Assessment was a blindfold, cotton wool balls, neurotips, two large test-tubes, talcum powder, a 10p, 2p and 50p coin, a biro, a pencil, a comb, a sponge, a flannel, a cup, a glass and a pair of scissors.

3.11 Data Analysis

For each patient, a folder was created that contained all the assessment paperwork. These were stored in a locked filing cabinet. All data was inputted into SPSS version 11.5 for Windows for analysis. The files were stored on a drive that had limited protected access to ensure the data was kept secure and confidential.

Prior to analysis of the extent of sensory impairment and its recovery in stroke patients, the internal construct validity of the NSA was evaluated in order to provide a total score for subsequent analysis. It seemed useful and logical to be able to combine scores to obtain total scores for the upper limb, lower limb, proprioception ability and stereognostic ability. Therefore the NSA was divided into these sub-scales. The measurement properties of these were checked using Rasch analysis.

3.11.1 Rasch Analysis

The Rasch measurement model is a statistical method for the analysis of test data developed by G. Rasch (Rasch, 1960). It is based on Item Response Theory, with the one-parameter logistic model extended for polytomous scales. The probability that a subject *i* of ability θ_i responds to item *j* of difficulty β_j answers through the category *h* (*h*=0,….,*m*) is defined as;

$$P(x_{ij} = h) = \frac{\exp [h\theta_i + (h\beta_j + \delta_h)]}{\sum_{h=0}^{m} \exp [h\theta_i + (h\beta_j + \delta_h)]}$$

(Masters, 1982)

The Rasch model was used because of the unique properties it embodies. It ensures unidimensionality of the scale, and that the scales have the properties of magnitude, additivity and specific objectivity. Since the data was of ordinal level, it was not possible to aggregate the scores, as the distance between values has no meaning. When data fit the model it allows for the transformation of cumulative raw scores into linear continuous measures of ability (for subjects) and difficulty (for items) (Tesio, 2003). Therefore if the NSA data fit the model, it will lead to improved scoring and interpretation of the NSA.

3.11.2 Rasch Analysis Procedure

Rasch analysis was undertaken using RUMM 2020 (RUMM Laboratory Pty Ltd., 2003). Once data was inputted into RUMM 2020, the fit to the Rasch model for each subscale was investigated.

The fit to the Rasch model was determined by the fit statistics. These are listed below, together with the criteria employed to indicate adequate fit to the model.

Item-Person Specification

The item-person specification tests the degree of consensus displayed collectively by all items of the scale across persons of differing abilities. A perfect fit to the model would be when the "item fit" and "person fit" have a mean of zero and a standard deviation of one, though the generally accepted value for a reasonable fit to the model is a standard deviation of less than 1.4.

Item-Trait Specification

This assesses whether the data fit the Rasch model for class intervals along the scale. If there is no significant deviation between the observed data and what was expected from the model, the chi-square probability value is greater than 0.01.

Person-Separation Index

This is indicative of the power of the construct to discriminate amongst respondents. A value of 0.8 or above indicates that statistically it is possible to

differentiate between two groups of patients, whereas above 0.9 indicates four or more groups of patients can be statistically differentiated between (Wright and Stone, 1979).

Where there is misfit to the model, there are several possible reasons including disordered thresholds and differential item functioning. These were investigated with procedures taken to improve measurement.

Disordered Thresholds

This is when items do not follow a predictable pattern, because the scoring categories are not functioning in a logical order. As patients' overall ability increases, they should be more likely to have a higher score on each item. Therefore if an item did not follow in a logical progressive order, items were rescored. This was done by combining categories to ensure that the categories function in the correct manner. Whilst rescoring, the fit of the individual item with the Rasch model is considered and the response categories selected which have ordered thresholds and best fit to the model. This is indicated by the fit residual score and the chi-square probability. The fit residual score is the level of divergence of the item from the model, with a residual of greater than plus or minus 2.5 classed as unacceptable. Another test of fit is the chi-square probability, with a value of higher than 0.01 indicating the item fits the Rasch model.

Differential Item Functioning

Another source of misfit is that items function differentially for different groups. The item should measure the same thing across gender groups, side of impairment and at different time points. This is tested using the ANOVA statistic; with a value of less than 0.01 meaning the item is significantly different for the groups. Where there is uniform differential item functioning (where an item was displaying a consistently greater ability with one group compared to another), it was possible to split the item. However this is a contentious issue as differential item functioning indicates the item is not unidimensional, therefore a decision may be made to delete them. If there is non-uniform differential item functioning (when the ability differences to confirm an item are inconsistent), the item is deleted from the scale.

After correction of thresholds and deletion of miss-fitting items, the revised scale is examined for fit to the Rasch model.

3.11.3 Regression Analysis

Regression analysis was undertaken to examine the relationship between variables that were significantly related to sensory ability. It was also used to indicate the extent to which the relation of these factors with sensory impairment was accounted for by their relationships with each other. It was decided to use multiple regressions as opposed to logistic regressions. This was to avoid loss of information. Therefore tests of normality were undertaken, and multiple linear regressions conducted.

CHAPTER IV

RESULTS AND DISCUSSION: Sensory Impairment

4.1 Patient Characteristics

Of the 154 patients admitted to the QMC Stroke Unit between 29th May 2002 and 29th July 2003,

35 patients (22.7%) had previous neurological impairment, such as previous stroke

7 patients (4.5%) had not had a stroke

24 (15.6%) patients refused consent

11 patients (7.1%) did not give consent/ assent within the time allocated

2 patients (1.3%) lived outside of the area (more than 50km away)

23 patients (21.4%) were over the age of 85 years old

2 patients (1.3%) were under the age of 40 years old

4 patients (2.6%) were admitted to the unit more than six weeks after their stroke

2 patients (1.3%) had a pre-stroke Barthel of less than 50

2 patients (1.3%) were unable to speak English and a translator was not available

3 patients (1.9%) had a planned discharge before the assessments could be carried out

4 patients (2.6%) were temporarily transferred to the stroke unit whilst awaiting a bed elsewhere

Therefore, 35 patients (22.7%) of the 154 patients admitted were recruited and assessed.

Of the 158 patients admitted to NCH Stroke Unit between 29th May 2002 and 29th July 2003,

30 patients (19.0%) had previous neurological impairment, such as previous stroke

9 patients (5.7%) had not had a stroke

22 patients (13.9%) refused consent

8 patients (5.1%) did not give consent/ assent within the time allocated

1 patient (0.6%) lived outside of the area (more than 50km away)

36 patients (22.8%) were over the age of 85 years old

1 patient (0.6%) was under the age of 40 years old

2 patients (1.3%) were admitted to the unit more than six weeks after their stroke

1 patient (0.6%) had a pre-stroke Barthel of less than 50

1 patient (0.6%) was unable to speak English and no translator was available

7 patients (4.4%) had a planned discharge before the assessments could be carried out

5 patients (3.2%) died

Therefore, 35 patients (22.2%) of the 158 patients admitted were recruited and assessed.

A total of 70 patients (22.4%) were recruited for the study from both hospitals. All of the participants were assessed on all measures at intake, 68 patients were assessed 2 months after stroke onset, 61 patients at 4 months and 58 patients had their final assessment 6 months after stroke. Twelve patients were lost to

follow-up. The reasons were that six patients refused follow-up assessments, two were medically unwell and unfit to be assessed within the time window of five working days, one patient had a further stroke and withdrew from the study and three people died.

4.2 Demographic Details

The demographic details of the patients at recruitment are shown in Table 1 below.

Table 1: Demographic Details of the Patients at Recruitment

Gender	men women	36 34
Age	Mean SD range	71 10 43-84
Time since onset (days)	median IQR	15 8-19.3
Side of lesion	right left no clear lateralisation	34 24 12
Type of Stroke (Bamford Classification)	TACS PACS LACS POCS	16 33 19 2
Ward	F20 (QMC) Beeston (NCH)	35 35
Pre-Stroke Rankin	Median Inter-Quartile Range	0 0-1
Pre-stroke Barthel	Median Inter-Quartile Range	100 100-100
Post-stroke Barthel	Median Inter-Quartile Range	50 25-80
Rivermead Motor Assessment at recruitment	*Gross Motor Function*: Median Inter-Quartile Range	 2 0-5.3

	Lower Limb: Median	4
	Inter-Quartile Range	1-7.3
	Upper Limb: Median	4
	Inter-Quartile Range	0-11
NIHSS	Median	6
	Inter-Quartile Range	2.8-9
Visual field deficit	No visual loss	56
	Partial hemianopia	7
	Complete hemianopia	7
Presence of ataxia	No ataxia	67
	Ataxia in 1 limb	2
	Ataxia in 2 limbs	1
Presence of aphasia	No aphasia	52
	Mild to moderate aphasia	12
	Severe aphasia	5
	Mute, global aphasia	1
Presence of dysarthria	Normal articulation	46
	Mild to moderate dysarthria	22
	Severe dysarthria	2
Presence of inattention	No inattention	42
	Inattention in 1 modality	22
	Inattention in >1 modality	6
Urinary Incontinence	Incontinent	15
	Continent	46
	Catheterised	9
Swallowing Problems	No Swallowing Problems	55
	Diet modified	9
	Non-oral feeding	8

4.3 Sensory Impairment

In this chapter, the results from the study investigating the frequency of sensory impairment will first be reported on and then discussed. This will include the extent of sensory impairment for tactile sensations, proprioception and stereognosis, for both sides of the body. The number of patients and the reasons for not being able to assess sensation will be explored.

4.4 Results - Frequency of Sensory Impairment

The frequencies of scores for all the sensations on the Nottingham Sensory Assessment at intake are shown, and are given for the "affected" and "unaffected" side. The affected side was defined as the side contralateral to the lesion, and the "unaffected" side as the side ipsilateral to the lesion. For patients with a bilateral lesion, the side of the body which was most affected by the stroke as defined by clinical signs and symptoms, was classified as the "affected" side.

The frequencies of scores for the tactile sensations of the affected side on admission are given in Table 2. This shows that on many of the tactile sensations if inspected individually, even on admission, a high proportion of patients had no impairment of some sensations e.g. only 7% of patients had impaired tactile localisation of the face. However impairment in other areas was common, e.g. over half of patients had impairment in wrist tactile localisation.

Table 2: Frequencies of the scores of the affected side for tactile sensations on admission

KEY: 0= absent, 1=impaired, 2=normal

	Score	Light Touch		Temperature		Pinprick		Pressure		Tactile Localisation	
		n	%	N	%	n	%	n	%	n	%
Face	0	3	5	3	5	6	9	2	3	1	2
	1	15	23	11	18	15	23	8	13	3	5
	2	47	72	49	78	44	68	54	84	57	93
Trunk	0	4	6	5	8	7	11	3	5	3	5
	1	10	15	15	24	17	27	7	11	17	28
	2	51	79	43	68	40	63	54	84	40	67
Shoulder	0	4	6	6	10	10	16	4	6	7	12
	1	16	25	18	29	17	27	11	17	10	17
	2	45	69	39	62	37	58	49	77	42	71
Elbow	0	6	9	7	11	13	20	9	14	11	20
	1	17	26	15	24	16	25	8	13	14	26
	2	42	65	41	65	35	55	47	73	30	55
Wrist	0	8	12	11	18	14	22	11	17	11	21
	1	15	23	15	24	16	25	7	11	17	32
	2	42	65	37	59	34	53	46	72	25	47
Hand	0	10	15	10	16	12	19	10	16	13	24
	1	13	20	18	29	18	28	7	11	10	19
	2	42	65	35	56	34	53	47	73	31	57
Knee	0	6	10	8	14	10	16	6	10	6	12
	1	13	21	14	24	15	24	10	16	10	19
	2	43	69	37	63	38	60	47	75	36	69
Ankle	0	7	12	9	17	11	18	6	10	1	3
	1	11	19	18	33	20	33	9	15	5	13
	2	39	68	27	50	30	49	45	75	32	84
Foot	0	8	14	9	17	11	18	6	10	1	3
	1	9	16	17	32	15	25	10	17	3	8
	2	40	70	28	52	35	57	43	73	33	89

Table 3 below shows the frequencies of scores for proprioception at intake. More people had impairment of proprioception on admission compared with tactile sensations. Distal joints were more impaired than proximal joints.

Table 3: Frequencies of the scores for the proprioception sensations on admission

KEY: 0= Absent, 1=Appreciation of movement taking place, 2= Direction of movement, 3= Joint Position sense

	Shoulder		Elbow		Wrist		Hand		Hip		Knee		Ankle	
Score	n	%	n	%	n	%	n	%	n	%	n	%	n	%
0	6	10	6	10	13	21	14	23	4	7	3	5	8	13
1	8	13	12	20	6	10	5	8	3	5	4	7	1	2
2	19	41	21	34	16	26	8	13	22	39	24	40	12	20
3	29	37	23	47	27	44	35	57	28	49	29	48	40	66

The frequencies of scores for stereognosis on admission are reported in table 4. This shows that stereognosis is also frequently impaired on admission, though some objects (comb, scissors, cup and sponge) presented less difficulty than others.

Table 4: Frequencies of the scores for stereognosis on admission

KEY: 0= absent, 1=impaired, 2=normal

Item	Score					
	0		1		2	
	n	%	n	%	n	%
10p	23	36	25	39	16	25
2p	24	38	33	52	7	11
50p	22	34	29	45	13	20
Biro	22	34	8	13	34	53
Pencil	18	28	19	30	27	42
Comb	19	30	1	2	44	69
Scissors	21	33	5	8	38	59

Sponge	16	25	10	16	38	59
Flannel	18	28	12	19	34	53
Cup	22	34	4	6	38	59
Glass	20	31	10	16	34	53

4.5 Summary

Sensory impairment was common after stroke in the "affected side". 7-53% of patients had impaired tactile sensations, 31-89% of patients had impaired stereognosis, and 34-64% of patients had impaired proprioception. Therefore a higher proportion of patients had impairment in stereognosis and proprioception, compared with tactile sensations. This data supports hypotheses 1 and 2, that a high proportion of patients will have sensory impairment following first stroke, with a higher proportion of problems in the more complex sensations of proprioception and stereognosis, compared with the primary sensations, such as light touch and pinprick.

4.6 Results- Sensory Impairment on the "unaffected" side

The frequencies of scores for the tactile sensations on the unaffected side on admission are given in table 5. This shows a high proportion of people with no impairment on admission. Most frequent were problems with perception of temperature, especially in the lower limb (17%). More patients had problems with pinprick than light touch or pressure. Therefore it would be impossible to detect recovery when most participants had no impairment of the unaffected side. Therefore the unaffected side was not evaluated further. The impairment in the "unaffected" side could be accounted for by the presence of ipsilateral pathways, peripheral neuropathies or over-sensitivity of the assessment tool. No normative data is available for the NSA, but it is known that somatosensory function decreases with age (Kenshalo, 1986, Kaplan et al., 1985, Desrosiers et al., 1996), therefore the NSA could be detecting this reduced function.

Table 5: Frequency of the scores of the "unaffected" side for the tactile sensations on admission

KEY: 0= absent, 1=impaired, 2=normal

	Score	Light Touch		Temperature		Pinprick		Pressure		Tactile Localisation	
		n	%	n	%	n	%	n	%	n	%
Face	0	1	2	0	0	0	0	1	2	0	0
	1	1	2	0	0	1	2	1	2	2	3
	2	63	97	63	100	64	98	62	97	60	97
Trunk	0	1	2	0	0	0	0	1	2	1	2
	1	2	3	2	3	1	2	0	0	3	5
	2	62	95	61	97	63	98	63	98	58	94
Shoulder	0	1	2	0	0	0	0	1	2	0	0
	1	2	3	3	5	0	0	0	0	6	11
	2	62	95	60	95	64	100	63	98	50	89
Elbow	0	1	2	0	0	0	0	1	2	1	2
	1	3	5	3	5	0	0	1	2	4	7
	2	61	94	60	95	63	100	62	97	49	91
Wrist	0	1	2	0	0	0	0	2	3	1	2
	1	4	6	2	3	3	5	0	0	4	8
	2	60	92	61	97	61	95	62	97	48	91
Hand	0	1	2	0	0	0	0	2	3	1	2
	1	3	5	1	2	4	6	0	0	3	6

	2	61	94	62	98	60	94	62	97	48	92
Knee	0	1	2	1	2	0	0	1	2	1	2
	1	3	5	8	14	4	6	4	6	4	7
	2	58	94	50	85	59	94	58	92	52	91
Ankle	0	1	2	1	2	3	5	2	3	0	0
	1	2	24	8	15	5	8	2	3	2	5
	2	54	95	45	83	53	87	56	93	37	95
Foot	0	3	5	1	2	2	3	2	3	0	0
	1	1	2	8	15	5	8	2	3	1	3
	2	53	93	45	83	54	89	55	93	37	97

4.7 Discussion – Frequency of Sensory Impairment

The results in this study showed that for each sensory modality in each body area, some patients had impairment of sensation on their "affected side". This variation depended on the sensation and area of body assessed. This suggests why the findings reported in the literature vary between 11 and 60% (Carey, 1995).

Tactile sensory impairment showed the greatest range, with an incidence from below that reported in the literature (Carey, 1995) (7%) to over half of the patients assessed having impairment. The reason for this variation may be that tactile sensations include several modalities, such as light touch, temperature and pinprick, whereas most studies only look at one. Where more than one modality are investigated, the reported incidence is higher e.g. Sommerfield and Von Arbin (2004) detected impairment in 40% of patients but assessed both light touch and pinprick.

Stereognosis impairment was more common than the published estimates which suggested impairment in up to 60% of patients (Carey, 1995). This may be because many studies of sensory impairment (Hanger and Sainsbury, 1996, Held, 1975, Sommerfield and von Arbin, 2004) do not assess stereognosis. When stereognosis was assessed a higher percentage of patients were found to

be impaired which is consistent with these results. For example in the study by Kim and Choi-Kwon (1996) who investigated discriminative sensory impairments after stroke including stereognosis, 85% of patients were found to be impaired. This suggests that stereognosis is commonly impaired and it is important to detect this impairment. Proprioceptive impairment was within the range of that reported in the literature (Kim & Choi-Kwon, 1996).

Given that the wide variation in frequency of impairment depended on the type of sensation and body area assessed, it shows that there is little to be gained from reporting one figure for the incidence of sensory impairment without clarification as to the modality and/ or area of the body assessed. The review by Carey (1995) is often referred to when stating that approximately half of stroke patients have somatosensory problems, but this fails to give the whole picture and can be misleading as there is considerable variation. It oversimplifies the highly complex nature of the somatosensory system. Some research is problematic since it fails to acknowledge the true nature of sensory impairment, which incorporates both exteroception and proprioception of the whole body. In some studies only a few specific body areas were assessed, often the upper limb (Smith, 1979, Carey et al., 1997, Dannenbaum and Dykes, 1988), while in some only one sensation was assessed (Hanger and Sainsbury, 1996). In some studies some modalities were measured in a few areas (Carey, 1993).

There are also differences in the number of patients found “unable” to be assessed. For example, Sommerfield and von Arbin (2004) assessed 115 acute

stroke patients on pinprick and light touch using a dichotomous outcome of impaired or not impaired, on three areas of the upper limb and lower limb. They found a third of patients to be unassessable, and of those who could be assessed 40% were found to have impairment. However the reasons for non-assessment were not detailed, other than stating that patients were not reliable. They were assessed earlier after stroke than in this study (median of 10 days after stroke, compared with a median of 15 days in this study). The number of patients unassessable was less in this study, and this will be discussed later.

The reported rates of sensory impairment need to be taken in context rather than taken to represent incidence of sensory impairment as a whole, and consideration given to the method of assessment and sensory modality considered. This is perhaps the main reason for the variations in the literature regarding the presence of sensory impairment, as the different studies are actually measuring different things e.g. some are measuring tactile sensory impairment, while others are measuring discriminative sensory function, some are measuring different body areas.

If the results of each sensation for each body area at recruitment were observed in isolation, it would appear that few people had sensory problems, with approximately 60-70% of patients having no impairment in each tactile sensation. However when the sensory ability of each patient was examined as a whole, few patients scored the maximum on all scales, indicating that most stroke survivors had a sensory deficit. However, there were very large variations between patients in the extent and nature of impairment. It may be

that if sensory assessment is sufficiently detailed, impairment will always be found.

Impairment needs to be considered in terms of other factors that may affect sensory function e.g. age, or peripheral neuropathy, and also in terms of what is relevant clinically. Kim & Choi-Kwon (1996) assessed sensory impairment in detail using measures of two-point discrimination, point localization, position sense, stereognosis and texture discrimination. They found the majority of patients to have some form of deficit (85%). This included some patients who had been classified as having had a pure motor stroke. The majority of these deficits were so minor that they did not affect the patients' function. However these subtle impairments may explain the clumsiness of many stroke patients.

It could be argued that variation in the frequency of sensory impairment may also be due to errors in measurement. Patients may report detection of a stimulus when they can not and vice versa. Adding a sham trial when no stimulation is given could have been used to check this, but was not included as part of the NSA. Winward et al (2002) investigating the reliability of the Rivermead Assessment of Somatosensory Performance (RASP) excluded those patients they deemed unreliable. These were patients who produced false positive trials on six or more out of ten "sham" trials, where the examiner pretended to give a stimulus when in fact none was given. They showed good inter-rater and intra-rater reliability for total scores, though this may be partly attributed to self-selecting the patients as those who demonstrated inherent unreliability were excluded. This may be something that would be beneficial to include in the NSA and is a limitation of this study.

For the purpose of this analysis, patients were designated an "affected" side. In the case of 12 patients who had bilateral lesions the "affected side" was the side of the body most affected by the stroke, as defined by clinical signs and symptoms. There were insufficient numbers to investigate people with bilateral strokes separately, though it is noted there may be some differences in sensory impairment and recovery in this group when compared to patients with unilateral stroke. For patients with left or right lesions, their "affected" side was defined as the side contralateral to the lesion. However it is known that unilateral hemisphere stroke can cause bilateral impairment of sensory abilities (Jones et al., 1989, Kim and Choi-Kwon, 1996). This is similar to what is found in motor impairment, where a unilateral hemispheric stroke can result in ipsilateral impairment, but this is less pronounced than the contralesional deficits (Wyke, 1971, Haaland and Delaney, 1981, Smutok et al, 1989, Jones et al, 1989, Haaland and Harrington, 1996). This is because of the presence of ipsilateral somatosensory pathways. Although the majority of corticospinal fibres decussate in the medulla, approximately 25% remain uncrossed (Jones et al., 1989). It has also been suggested that both hemispheres may be required to perceive and interpret more complex sensory information (Haaland and Delaney, 1981, Jones et al., 1989) e.g. for stereognosis. Therefore if a person performs a simple task he/she may have no ipsilateral impairment of ability, whereas they may have ipsilateral impairment on more difficult tasks. However, Desrosiers et al (1996) found no significant relationships between the performance of both upper extremities according to the complexity of the task assessed. It was not possible to check this in this study, as there was not an increasing complexity of tasks and stereognosis was not assessed bilaterally.

Despite the occurrence of ipsilateral impairment, it is recognised that ipsilateral deficit is less common and less severe than that of the contralateral side (Kim and Choi-Kwon, 1996). This was confirmed by the results of this study. The number of patients with impairment on the tactile sensations assessed for each body area on the unaffected side, ranged from 0-17%. This is much lower than the comparable results for the affected side. These findings could be related to other factors such as peripheral neuropathy due to diabetes.

4.8 Results – Practicability of the NSA on admission

For each sensation scored, if the assessor was unable to carry out the assessment, the reason for this was recorded. This was a subjective assessment, but enabled the practicability of the NSA for use with stroke patients to be explored. The results for the tactile sensations at admission are shown in table 6 below.

Table 6: Reasons for being unable to assess tactile sensations on admission

		Reasons unable to assess													
		Unable to detect pressure		Physical Reasons		Clothing dressing / brace		Communication Problems		Cognitive Problems		Pain/ Tone		Sleepy/ unable to concentrate	
		N	%	n	%	n	%	n	%	n	%	n	%	n	%
Face	Light touch	0	0	0	0	0	0	4	5.7	1	1.4	0	0	0	0
	Temperature	0	0	0	0	0	0	5	7.1	0	0	0	0	2	2.9
	Pinprick	0	0	0	0	0	0	4	5.7	0	0	0	0	1	1.4
	Pressure	0	0	0	0	0	0	4	5.7	0	0	0	0	2	2.9
	Tactile Loc	2	2.9	0	0	0	0	4	5.7	1	1.4	0	0	2	2.9
	Bilat. Simult. Touch	4	5.7	0	0	0	0	4	5.7	0	0	0	0	2	2.9
Trunk	Light touch	0	0	0	0	0	0	4	5.7	0	0	0	0	1	1.4
	Temperature	0	0	0	0	0	0	5	7.1	0	0	0	0	2	2.9
	Pinprick	0	0	0	0	0	0	4	5.7	0	0	0	0	2	2.9
	Pressure	0	0	0	0	0	0	4	5.7	0	0	0	0	2	2.9
	Tactile Loc	3	4.3	0	0	0	0	4	5.7	1	1.4	0	0	2	2.9
	Bilat. Simult. Touch	5	7.1	0	0	0	0	4	5.7	0	0	0	0	2	2.9
Shoulder	Light touch	0	0	0	0	0	0	4	5.7	0	0	0	0	1	1.4
	Temperature	0	0	0	0	0	0	5	7.1	0	0	0	0	2	2.9
	Pinprick	0	0	0	0	0	0	4	5.7	0	0	0	0	2	2.9
	Pressure	0	0	0	0	0	0	4	5.7	0	0	0	0	2	2.9
	Tactile Loc	4	5.7	0	0	0	0	4	5.7	1	1.4	0	0	2	2.9
	Bilat. Simult. Touch	6	8.6	0	0	0	0	4	5.7	0	0	0	0	2	2.9
Elbow	Light touch	0	0	0	0	0	0	4	5.7	0	0	0	0	1	1.4
	Temperature	0	0	0	0	0	0	4	5.7	0	0	1	1.4	2	2.9
	Pinprick	0	0	0	0	0	0	4	5.7	0	0	0	0	2	2.9
	Pressure	0	0	0	0	0	0	4	5.7	0	0	0	0	2	2.9
	Tactile Loc	7	10.0	0	0	0	0	4	5.7	1	1.4	0	0	2	2.9
	Bilat. Simult. Touch	8	11.4	0	0	0	0	4	5.7	0	0	0	0	2	2.9
Wrist	Light touch	0	0	0	0	0	0	4	5.7	0	0	0	0	1	1.4
	Temperature	0	0	0	0	0	0	5	7.1	0	0	0	0	2	2.9
	Pinprick	0	0	0	0	0	0	4	5.7	0	0	0	0	2	2.9
	Pressure	0	0	0	0	0	0	4	5.7	0	0	0	0	2	2.9
	Tactile Loc	9	12.9	0	0	0	0	4	5.7	1	1.4	0	0	2	2.9
	Bilat. Simult. Touch	10	14.3	0	0	0	0	4	5.7	0	0	0	0	2	2.9

Table 6 (cont.): Reasons for being unable to assess tactile sensations on admission

		Reasons unable to assess													
		Unable to detect pressure		Physical Reasons		Clothing dressing/ brace		Communication Problems		Cognitive Problems		Pain/ Tone		Sleepy/ unable to concentrate	
		n	%	n	%	n	%	n	%	n	%	n	%	n	%
Hand	Light touch	0	0	0	0	0	0	4	5.7	0	0	0	0	1	1.4
	Temperature	0	0	0	0	0	0	5	7.1	0	0	0	0	2	2.9
	Pinprick	0	0	0	0	0	0	4	5.7	0	0	0	0	2	2.9
	Pressure	0	0	0	0	0	0	4	5.7	0	0	0	0	2	2.9
	Tactile Loc	8	11.4	0	0	0	0	4	5.7	1	1.4	0	0	2	2.9
	Bilat. Simult. Touch	10	14.3	0	0	0	0	4	5.7	0	0	0	0	2	2.9
Knee	Light touch	0	0	0	0	3	4.3	4	5.7	0	0	0	0	1	1.4
	Temperature	0	0	0	0	4	5.7	5	7.1	0	0	0	0	2	2.9
	Pinprick	0	0	0	0	1	1.4	4	5.7	0	0	0	0	2	2.9
	Pressure	0	0	0	0	1	1.4	4	5.7	0	0	0	0	2	2.9
	Tactile Loc	6	8.6	4	5.7	1	1.4	4	5.7	1	1.4	0	0	2	2.9
	Bilat. Simult. Touch	8	11.4	0	0	1	1.4	4	5.7	0	0	0	0	2	2.9
Ankle	Light touch	0	0	0	0	7	10.0	4	5.7	0	0	1	1.4	1	1.4
	Temperature	0	0	0	0	8	11.4	5	7.1	0	0	1	1.4	2	2.9
	Pinprick	0	0	0	0	3	4.3	4	5.7	0	0	0	0	2	2.9
	Pressure	0	0	0	0	4	5.7	4	5.7	0	0	0	0	2	2.9
	Tactile Loc	6	8.6	14	20.0	4	5.7	4	5.7	1	1.4	0	0	2	2.9
	Bilat. Simult. Touch	9	12.9	0	0	4	5.7	4	5.7	0	0	0	0	2	2.9
Foot	Light touch	0	0	0	0	7	10.0	4	5.7	0	0	1	1.4	1	1.4
	Temperature	0	0	0	0	8	11.4	5	7.1	0	0	1	1.4	2	2.9
	Pinprick	0	0	0	0	3	4.3	4	5.7	0	0	0	0	2	2.9
	Pressure	0	0	0	0	4	5.7	4	5.7	0	0	1	1.4	2	2.9
	Tactile Loc	6	8.6	14	20.0	4	5.7	4	5.7	1	1.4	1	1.4	2	2.9
	Bilat. Simult. Touch	9	12.9	0	0	4	5.7	4	5.7	0	0	1	1.4	2	2.9

Tactile Loc = Tactile Localisation,
Bilat. Simult. Touch = Bilateral Simultaneous Touch

At the initial assessment one of the main reasons for not being able to assess a patient were communication problems (5.7-7% of patients). A small percentage of patients (1.4-2.9%) lacked concentration or were too sleepy to participate in the assessment. In testing the lower limb, clothing and dressings limited assessment, with tactile localisation of the ankle and foot problematic to many (20% of patients) due to lack of motor ability. Tactile localisation and bilateral simultaneous touch were not assessed if the patient was unable to detect pressure, which excluded 6-14% percent of patients.

The reasons for not being able to assess proprioception on admission are listed in the table below.

Table 7: Reasons for being unable to assess proprioception on admission

	Reasons unable to assess Proprioception at Intake											
	Physical Reasons		Clothing dressing/ brace		Communication Problems		Cognitive Problems		Pain/ Tone		Sleepy/ unable to concentrate	
	n	%	n	%	n	%	n	%	n	%	n	%
Shoulder	0	0	0	0	5	7.1	1	1.4	1	1.4	1	1.4
Elbow	0	0	0	0	5	7.1	1	1.4	1	1.4	1	1.4
Wrist	0	0	0	0	5	7.1	1	1.4	1	1.4	1	1.4
Hand	0	0	0	0	5	7.1	1	1.4	1	1.4	1	1.4
Hip	1	1.4	0	0	5	7.1	1	1.4	5	7.1	1	1.4
Knee	1	1.4	0	0	5	7.1	1	1.4	2	2.9	1	1.4
Ankle	1	1.4	0	0	5	7.1	1	1.4	1	1.4	1	1.4

Again the main reason for not being able to assess proprioception was communication problems (7%), with one patient unable to concentrate and cooperate with the assessment. Pain and increased tone prevented some proprioception assessments (1.4-7.1% of patients), particularly of the hip. This did not prevent assessing tactile sensations

In the stereognosis subscale, five patients (7%) were unable to be assessed because of communication problems and one (1.4%) due to cognitive problems.

In conclusion, at the initial assessment the main reasons for not being able to assess a patient were communication problems (5.7-7% of patients). In the lower limb tactile localisation of the ankle and foot could not be assessed in 20% of patients due to physical reasons, in that they did not have the motor ability and sitting balance to be able to reach and touch their ankles or feet.

4.9 Results – Practicability of the NSA at six months

The reasons for not being able to assess patients and the number of patients affected may be different at later stages as opposed to the acute stages. The reasons for not being able to assess patients at six months are reported below.

Table 8: Reasons for being unable to assess tactile sensations at 6 months

		Reasons unable to assess													
		Unable to detect pressure		Physical Reasons		Clothing dressing/ brace		Communication Problems		Cognitive Problems		Pain/ Tone		Sleepy/ unable to concentrate	
		n	%	n	%	n	%	n	%	n	%	n	%	n	%
Face	Light touch	0	0	0	0	0	0	1	1.7	1	1.7	0	0	0	0
	Temperature	0	0	0	0	0	0	2	3.4	2	3.4	0	0	0	0
	Pinprick	0	0	0	0	0	0	1	1.7	2	3.4	0	0	0	0
	Pressure	0	0	0	0	0	0	1	1.7	2	3.4	0	0	0	0
	Tactile Loc	0	0	0	0	0	0	2	3.4	2	3.4	0	0	0	0
	Bilat. Simult. Touch	0	0	0	0	0	0	1	1.7	2	3.4	0	0	0	0
Trunk	Light touch	0	0	0	0	3	5.2	1	1.7	1	1.7	0	0	0	0
	Temperature	0	0	0	0	3	5.2	2	3.4	2	3.4	0	0	0	0
	Pinprick	0	0	0	0	3	5.2	1	1.7	2	3.4	0	0	0	0
	Pressure	0	0	0	0	3	5.2	1	1.7	2	3.4	0	0	0	0
	Tactile Loc	1	1.7	0	0	3	5.2	2	3.4	2	3.4	0	0	0	0
	Bilat. Simult. Touch	1	1.7	0	0	3	5.2	1	1.7	2	3.4	0	0	0	0
Shoulder	Light touch	0	0	0	0	1	1.7	1	1.7	1	1.7	1	1.7	0	0
	Temperature	0	0	0	0	0	0	2	3.4	2	3.4	0	0	0	0
	Pinprick	0	0	0	0	1	1.7	1	1.7	2	3.4	0	0	0	0
	Pressure	0	0	0	0	1	1.7	1	1.7	2	3.4	0	0	0	0
	Tactile Loc	1	1.7	0	0	1	1.7	1	1.7	2	3.4	0	0	0	0
	Bilat. Simult. Touch	1	1.7	0	0	1	1.7	1	1.7	2	3.4	0	0	0	0
Elbow	Light touch	0	0	0	0	0	0	1	1.7	2	3.4	0	0	0	0
	Temperature	0	0	0	0	0	0	2	3.4	2	3.4	0	0	0	0
	Pinprick	0	0	0	0	0	0	1	1.7	2	3.4	0	0	0	0
	Pressure	0	0	0	0	0	0	1	1.7	2	3.4	0	0	0	0
	Tactile Loc	2	3.4	0	0	0	0	2	3.4	2	3.4	0	0	0	0
	Bilat. Simult. Touch	2	3.4	0	0	0	0	1	1.7	2	3.4	0	0	0	0
Wrist	Light touch	0	0	0	0	0	0	1	1.7	2	3.4	0	0	0	0
	Temperature	0	0	0	0	0	0	2	3.4	2	3.4	0	0	0	0
	Pinprick	0	0	0	0	0	0	1	1.7	2	3.4	0	0	0	0
	Pressure	0	0	0	0	0	0	1	1.7	2	3.4	0	0	0	0
	Tactile Loc	4	6.9	0	0	0	0	2	3.4	2	3.4	0	0	0	0
	Bilat. Simult. Touch	4	6.9	0	0	0	0	1	1.7	2	3.4	0	0	0	0
Hand	Light touch	0	0	0	0	0	0	1	1.7	2	3.4	0	0	0	0
	Temperature	0	0	0	0	0	0	2	3.4	2	3.4	0	0	0	0
	Pinprick	0	0	0	0	0	0	1	1.7	2	3.4	0	0	0	0
	Pressure	0	0	0	0	0	0	1	1.7	2	3.4	0	0	0	0
	Tactile Loc	3	5.2	0	0	0	0	2	3.4	2	3.4	0	0	0	0
	Bilat. Simult. Touch	3	5.2	0	0	0	0	1	1.7	2	3.4	0	0	0	0

Tactile Loc = Tactile Localisation, Bilat. Simult. Touch = Bilateral Simultaneous Touch

Table 8 (cont.): Reasons for being unable to assess tactile sensations at 6 months

		Reasons unable to assess													
		Unable to detect pressure		Physical Reasons		Clothing dressing/ brace		Communication Problems		Cognitive Problems		Pain/ Tone		Sleepy/ unable to concentrate	
		N	%	n	%	n	%	n	%	n	%	n	%	N	%
Knee	Light touch	0	0	0	0	1	1.7	1	1.7	2	3.4	0	0	0	0
	Temperature	0	0	0	0	1	1.7	2	3.4	2	3.4	0	0	0	0
	Pinprick	0	0	0	0	0	0	1	1.7	2	3.4	0	0	0	0
	Pressure	0	0	0	0	0	0	1	1.7	2	3.4	0	0	0	0
	Tactile Loc	4	6.9	0	0	0	0	2	3.4	2	3.4	0	0	0	0
	Bilat. Simult. Touch	4	6.9	0	0	0	0	1	1.7	2	3.4	0	0	0	0
Ankle	Light touch	0	0	0	0	2	3.4	1	1.7	2	3.4	0	0	0	0
	Temperature	0	0	0	0	2	3.4	2	3.4	2	3.4	0	0	0	0
	Pinprick	0	0	0	0	1	1.7	1	1.7	2	3.4	0	0	0	0
	Pressure	0	0	0	0	1	1.7	1	1.7	2	3.4	0	0	0	0
	Tactile Loc	4	6.9	3	5.2	1	1.7	2	3.4	2	3.4	0	0	0	0
	Bilat. Simult. Touch	4	6.9	0	0	1	1.7	1	1.7	2	3.4	0	0	0	0
Foot	Light touch	0	0	0	0	2	3.4	1	1.7	2	3.4	0	0	0	0
	Temperature	0	0	0	0	2	3.4	2	3.4	2	3.4	0	0	0	0
	Pinprick	0	0	0	0	1	1.7	1	1.7	2	3.4	0	0	0	0
	Pressure	0	0	0	0	1	1.7	1	1.7	2	3.4	0	0	0	0
	Tactile Loc	4	6.9	3	5.2	1	1.7	2	3.4	2	3.4	0	0	0	0
	Bilat. Simult. Touch	4	6.9	0	0	1	1.7	1	1.7	2	3.4	0	0	0	0

Tactile Loc = Tactile Localisation, Bilat. Simult. Touch = Bilateral Simultaneous Touch

At six months, the main reasons for not being able to assess patients included cognitive problems (up to 3.4%), communication problems (up to 3.4%) and clothing/dressings (up to 5.2% when assessing trunk). Compared with at admission when 20% of patients were unable to be assessed in tactile localisation of the ankle and foot due to physical problems, a relatively small percentage of patients (5%) were still unable to be assessed on this at 6 months. At this stage none were too sleepy or unable to concentrate. The proportion that could not be assessed was therefore low.

The table below shows the reasons for being unable to assess proprioception at six months. The number of patients unable to be assessed due to communication problems (7%) was less than at admission, but a much higher number of patients (up to 15.5%) could not be assessed due to pain and increased tone.

Table 9: Reasons for being unable to assess proprioception at 6 months

	Reasons unable to assess Proprioception at 6 months											
	Physical Reasons		Clothing dressing/ brace		Communication Problems		Cognitive Problems		Pain/ Tone		Sleepy/ unable to concentrate	
	n	%	n	%	n	%	n	%	n	%	n	%
Shoulder	0	0	0	0	1	1.7	2	3.4	9	15.5	0	0
Elbow	0	0	0	0	1	1.7	2	3.4	5	8.6	0	0
Wrist	0	0	0	0	1	1.7	2	3.4	7	12.1	0	0
Hand	0	0	0	0	1	1.7	2	3.4	8	13.8	0	0
Hip	1	1.7	0	0	1	1.7	2	3.4	1	1.7	0	0
Knee	1	1.7	0	0	1	1.7	2	3.4	3	5.2	0	0
Ankle	0	0	1	1.7	1	1.7	2	3.4	4	6.9	0	0

When assessing stereognosis, at six months, there were still on average 5 patients (8.6%) who were unable to be assessed. Two of these patients (3.4%) were unable to be assessed due to cognitive problems, and three patients (5.2%) due to pain or increased tone.

In conclusion, the proportion of patients unable to be assessed at six months was relatively low. However proprioception could not be assessed in 15.5% of patients due to increased tone and pain.

4.10 Discussion- Practicability of Assessment

There was some missing data. This had implications for estimating the number of patients with sensory impairment as those who were unable to be assessed may have had sensory impairment. It also has implications for the practicalities of undertaking the NSA. Patients who have had a stroke may have impairments other than sensory problems, such as communication problems, and/ or cognitive impairment. This means that not all stroke patients will be able to undergo sensory assessment. However, rather than exclude particular groups of patients, such as those with communication or cognitive problems, attempts were made to assess all patients. In the past many of these patients would have been excluded from research. A study by Smith (1979) investigating sensory recovery excluded patients who had communication problems or who had severe mental impairment. However there was no mention as to how communication was assessed, and the modified Isaac Walkey mental impairment measure was used to assess mental function, though this assessment was not referenced and exact cut-offs were not given. Sommerfield and Von Arbin (2004) found a third of patients to be unassessable when assessing sensation with a non-standardised method, however the reasons for non-assessment were not detailed, other than stating that patients were not reliable. Kim & Choi-Kwon (1996) excluded patients with communication problems, decreased consciousness, severe dysarthria, or with emotional disturbance but it is unclear how these factors were assessed or how many people were excluded.

The reasons why assessments could not be performed were documented, though it is recognised this was subjectively based as opposed to using a standardised measure. There may also have been a combination of factors rather than one. Most of the reasons for being unable to assess a sensation were due to the nature of sensory testing, as the assessment was of the patients' perceptions of sensation and hence required a degree of communication and cognitive ability. This same would be true for other assessments of sensation e.g. RASP (Winward et al, 2002), rather than specific problems resulting from the methods of administration of the NSA. These reasons changed over time.

Communication problems were the main reason for not being able to assess patients at admission. The NSA is as inclusive as possible, since it allows the use of movements to indicate awareness of sensation, and communication prompt cards can be used. However there were still some patients who did not have sufficient ability to communicate using these methods.

Two patients were too sleepy to be assessed initially. However as only two patients out of the seventy assessed were too sleepy, it suggests the measure was appropriate early after stroke. The need for concentration was compounded by the length of the NSA. Some patients found it hard to tolerate the whole assessment, and required frequent breaks. Shortening the NSA may reduce this problem, and aid implementation into practice. By six months lack of concentration and sleepiness did not prevent any assessment.

In assessing the lower limb tactile sensations, clothing and dressing posed a problem, preventing eight patients at recruitment and two patients at six months from full assessment. In the protocol patients were required to be in a

suitable state of undress but this was not always possible. Patients had dressings or splints that could not be removed, and some patients were reluctant to remove clothing. This was particularly the case when the weather was colder. This needs to be considered when undertaking sensory assessment, as discomfort may distract the patient's attention from the actual sensations being assessed. The environment in which the assessment was carried out may have also been a factor. At later stages, assessments were increasingly carried out in patients' own homes. In patients' homes, the room temperature was impossible to control. Some patients did not want to undress at home because they felt cold. However the extent to which this will have made an impact is likely to be minimal. Again this problem is not specific to the NSA, but found with many sensory assessments.

At recruitment, a fifth of patients were unable to be assessed on tactile localisation of the foot and ankle due to physical problems. For elderly stroke patients, a high level of balance and motor ability is required to be able to reach down to their feet while in sitting. This limited assessment of some patients. An alternative would be to allow a verbal description of localisation, but this may compromise the reliability of the assessment, as there may be insufficient accuracy and increased subjectivity. It would also exclude patients with communication problems, therefore though the method used was limited for those patients with relatively severe motor and balance impairment, it was the best available. By six months the number of patients unable to be assessed due to physical problems was down from 20% to 6%. Therefore assessment of tactile localisation of the feet and ankles is suited to assessment later after stroke.

The assessment of proprioception was more complex for the patient than that of tactile sensations. Therefore more patients were excluded who were unable to understand this assessment. It is recognised that assessing proprioception using mimicry is rather crude and more specific assessments are available such as the Proprioceptive Discrimination Test (Carey, 1993). This test quantifies the ability to indicate wrist position following passive movement of the wrist, and is therefore limited to one aspect of proprioceptive discrimination and one joint. It involves specialised equipment; a box-like apparatus with a protractor scale and a splint which can fix the wrist in 20 different positions in the flexion/extension plane. However this requires specialist equipment takes a long time, there are not norms for this test and is limited to one joint thus limiting its use, and it is not necessarily feasible in a clinical setting.

The NSA proprioception component assesses passive position sense, rather than active position sense, which could be argued, is more relevant to function. It is a global measure of proprioception on both sides of the body, since accurate proprioceptive awareness of the ipsilateral and contralateral limbs are needed for accurate position replication. In stroke patients, pain, motor impairment and increased tone limit the feasibility of assessing active position sense (Stillman, 2002). Both pain and increased tone caused problems in assessing passive position sense using the NSA. Generally this became worse over the six months, as some patients' hypertonicity and pain meant joints could not be passively moved. This was particularly the case with the shoulder and hand, as by six months 16% and 14% of patients respectively were unable to be assessed on proprioception, as compared with 1.4% for shoulder and hand at recruitment. This also impacted on assessment of stereognosis at six months,

as 5% of patients were unable to open their hand wide enough to manipulate the objects whereas no patients had this problem at recruitment.

The problems encountered assessing stroke patients on the NSA were not specific to the NSA, rather a reflection of the complex nature of sensation and problems encountered assessing stroke patients due to the combination and variety of residual impairments. This study has demonstrated however that it is possible to assess most aspects of sensation to some degree on the majority of stroke patients.

4.11 Hypothesis 3: Results - Comparison of the Frequencies Across Sensory Modalities

The sensory impairments for each body area assessed were cross-tabulated to determine whether there was any relationship between impairments of different sensations. A strong relationship between two modalities would indicate that assessing both may be unnecessary. Cohen's Kappa values were calculated to investigate the level of agreement between the different sensory modalities. These are reported in tables 10-18 below.

Where no Kappa value is given, this is because it could not be calculated as none of the patients scored on one particular category.

KEY: Interpretation of Kappa values (Landis, 1977)	
< 0	Agreement weaker than chance
0 -0.2	Slight
0.2 - 0.4	Fair
0.4 - 0.6	Moderate
0.6 - 0.8	Substantial
0.8 - 1.0	Almost Perfect

Table 10: Kappa values showing agreement between sensory modalities for the face

Face	Light Touch	Temp.	Pinprick	Pressure	Tactile Loc.	Bilat. Touch
Light Touch						
Temp.	0.351					
Pinprick	0.491	0.329				
Pressure	0.378	0.458	0.337			
Tactile Loc.	0.134	0.035	0.003			
Bilat. Touch		0.258	0.014		-0.040	

Table 11: Kappa values showing agreement between sensory modalities for the trunk

Trunk	Light Touch	Temp.	Pinprick	Pressure	Tactile Loc.	Bilat. Touch
Light Touch						
Temp.	0.205					
Pinprick	0.427	0.391				
Pressure	0.464	0.260	0.394			
Tactile Loc.	-0.053	0.256	0.275			
Bilat. Touch						

Table 12: Kappa values showing agreement between sensory modalities for the shoulder

Shoulder	Light Touch	Temp.	Pinprick	Pressure	Tactile Loc.	Bilat. Touch
Light Touch						
Temp.	0.164					
Pinprick	0.466	0.418				
Pressure	0.378	0.282	0.502			
Tactile Loc.	0.223	0.197	0.282			
Bilat. Touch		0.218	0.257		0.317	

Table 13: Kappa values showing agreement between sensory modalities for the elbow

Elbow	Light Touch	Temp.	Pinprick	Pressure	Tactile Loc.	Bilat. Touch
Light Touch						
Temp.	0.300					
Pinprick	0.525	0.316				
Pressure	0.406	0.426	0.449			
Tactile Loc.	0.048	0.369	0.150	0.169		
Bilat. Touch	0.169	0.249	0.176	0.221	0.343	

Table 14: Kappa values showing agreement between sensory modalities for the wrist

Wrist	Light Touch	Temp.	Pinprick	Pressure	Tactile Loc.	Bilat. Touch
Light Touch						
Temp.	0.141					
Pinprick	0.424	0.459				
Pressure	0.418	0.386	0.548			
Tactile Loc.	-0.103	0.337	0.145	0.079		
Bilat. Touch	0.126	0.169	0.198	0.231	0.231	

Table 15: Kappa values showing agreement between sensory modalities for the hand

Hand	Light Touch	Temp.	Pinprick	Pressure	Tactile Loc.	Bilat. Touch
Light Touch						
Temp.	0.224					
Pinprick	0.424	0.463				
Pressure	0.538	0.372	0.488			
Tactile Loc.	-0.036	0.189	0.126	0.156		
Bilat. Touch	0.136	0.161	0.122	0.238	0.359	

Table 16: Kappa values showing agreement between sensory modalities for the knee

Knee	Light Touch	Temp.	Pinprick	Pressure	Tactile Loc.	Bilat. Touch
Light Touch						
Temp.	0.323					
Pinprick	0.428	0.393				
Pressure	0.513	0.418	0.521			
Tactile Loc.	0.203	0.328	0.353			
Bilat. Touch		0.261	0.095		0.505	

Table 17: Kappa values showing agreement between sensory modalities for the ankle

Ankle	Light Touch	Temp.	Pinprick	Pressure	Tactile Loc.	Bilat. Touch
Light Touch						
Temp.	0.120					
Pinprick	0.388	0.391				
Pressure	0.642	0.191	0.414			
Tactile Loc.		0.094	0.417			
Bilat. Touch	0.113	0.226	0.149			

Table 18: Kappa values showing agreement between sensory modalities for the foot

Foot	Light Touch	Temp.	Pinprick	Pressure	Tactile Loc.	Bilat. Touch
Light Touch						
Temp.	0.136					
Pinprick	0.434	0.400				
Pressure	0.562	0.179	0.489			
Tactile Loc.	-0.013	0.243	0.345			
Bilat. Touch	0.028	0.188	0.198			

The kappa values for all body areas when comparing sensory modalities were low (<0.4), showing at best a moderate agreement (0.4-0.6). This showed that ability on the different sensory modalities assessed was not strongly related. This supports the hypothesis that different sensory modalities are independent and reflect different domains of sensory impairment.

4.12 Discussion- Comparison of the Sensory Modalities

Cross-tabulations showed only slight agreement between impairment in the different sensory modalities. This may be because different anatomical pathways exist for different sensory modalities. The dorsal column lemniscus pathway is largely responsible for transmission of proprioceptive, pressure and

light touch sensations (Berne and Levy, 2000), therefore it might be expected that these would be closely related. The spinothalamic tract is activated by noxious mechanical, thermal and chemical stimuli, with some neurones also stimulated by thermoreceptors and sensitive mechanoreceptors. Although these pathways exist, it can no longer be assumed that they are as separate and distinct as once thought (Shimojo and Shams, 2001). A fundamental principle of the CNS is that of parallel processing, in which several pathways are involved in transmitting information about a sensory perception. Anatomically separate pathways mean different features of a complex stimulus are processed separately, though there may be overlap in their functions (Carey, 1995). For example proprioception afferents have been shown to project along other pathways as well as the dorsal column lemniscal pathway (McCloskey, 1978). Recent behavioural and brain imaging studies have shown that there is much interaction and integration between the sensory modalities, with the notion of different sensory modalities acting independently of each other now out-dated (Shimojo and Shams, 2001). It is therefore surprising that the agreement between modalities in this study was generally low. This may be due to the nature of the assessment evaluating the different sensations in isolation as opposed to functionally when interplay between modalities is more extensive.

Tactile detection and localisation have been found to be doubly dissociated (Halligan et al., 1995, Rapp et al., 2002), suggesting these functions are performed by different neural structures. However Harris et al (2004) suggest that these modalities are not mutually independent, but localisation is subject to detection in a serially organized sensory processing hierarchy. However Harris et al (2004) used simulated data generated by computational models, which may not correspond to real life. The results of this study show a slight agreement (kappa

values 0.08 – 0.17) between pressure and tactile localisation. However not all kappa values could be calculated because in some of the categories no one scored. The double dissociation hypothesis was neither supported nor refuted in this study, since it is not possible to test this through association. Furthermore, the NSA procedure states that if the patient is unable to detect pressure, tactile localisation is not assessed. Therefore it was not a true test of the hypothesis as there was no opportunity for tactile localisation to be present but pressure sensation impaired. This is as this study did not intend to test this hypothesis.

There are known problems with the length of the NSA (Gaubert and Mockett, 2000), but these results indicated that it *is* necessary to include all of the sensory modalities because agreement between them is low.

4.13 Hypothesis 4: Results - Comparison of the Different Body Areas

To investigate sensory impairment further, relationships between impairment in each of the body areas was compared for each sensory modality. This was to determine whether sensory impairment can selectively affect different body areas or indeed if all of the body areas were strongly related suggesting it may not be necessary to assess all of the body areas. In the development of the NSA (Lincoln, 1998) it was suggested that four subscales were incorporated (the upper limb, lower limb, stereognosis and proprioception scales). The face and trunk were not included in any subscale. Therefore it was necessary to determine whether sensory impairment of the face and trunk were independent of the other body areas. This was examined by cross-tabulating the body areas for each sensation. Cohen's Kappa values were calculated to investigate the level of agreement between the different body areas. These are reported in tables 19-26 below.

KEY: Interpretation of Kappa values (Landis, 1977)	
< 0	Agreement weaker than chance
0 -0.2	Slight
0.2 - 0.4	Fair
0.4 - 0.6	Moderate
0.6 - 0.8	Substantial
0.8 - 1.0	Almost Perfect

Table 19: Kappa values showing agreement between body areas for light touch

Light Touch	Face	Trunk	Shoulder	Elbow	Wrist	Hand	Knee	Ankle	Foot
Face									
Trunk	0.649								
Shoulder	0.545	0.629							
Elbow	0.540	0.553	0.809						
Wrist	0.513	0.555	0.622	0.759					
Hand	0.519	0.592	0.595	0.702	0.822				
Knee	0.295	0.563	0.643	0.596	0.599	0.602			
Ankle	0.400	0.661	0.661	0.539	0.497	0.527	0.743		
Foot	0.432	0.479	0.582	0.464	0.417	0.406	0.591	0.777	

Table 20: Kappa values showing agreement between body areas for temperature

Temperature	Face	Trunk	Shoulder	Elbow	Wrist	Hand	Knee	Ankle	Foot
Face									
Trunk	0.513								
Shoulder	0.521	0.557							
Elbow	0.467	0.579	0.663						
Wrist	0.389	0.520	0.684	0.619					
Hand	0.285	0.412	0.518	0.426	0.643				
Knee	0.407	0.422	0.578	0.572	0.537	0.608			
Ankle	0.246	0.436	0.516	0.551	0.629	0.541	0.686		
Foot	0.299	0.529	0.575	0.545	0.563	0.476	0.619	0.817	

Table 21: Kappa values showing agreement between body areas for pinprick

Pinprick	Face	Trunk	Shoulder	Elbow	Wrist	Hand	Knee	Ankle	Foot
Face									
Trunk	0.569								
Shoulder	0.562	0.603							
Elbow	0.437	0.479	0.707						
Wrist	0.474	0.513	0.604	0.637					
Hand	0.414	0.509	0.602	0.584	0.845				
Knee	0.457	0.534	0.663	0.427	0.541	0.594			
Ankle	0.346	0.441	0.539	0.413	0.524	0.547	0.590		
Foot	0.423	0.441	0.662	0.473	0.588	0.614	0.770	0.810	

Table 22: Kappa values showing agreement between body areas for pressure

Pressure	Face	Trunk	Shoulder	Elbow	Wrist	Hand	Knee	Ankle	Foot
Face									
Trunk	0.886								
Shoulder	0.669	0.765							
Elbow	0.523	0.609	0.693						
Wrist	0.416	0.498	0.628	0.784					
Hand	0.482	0.567	0.695	0.853	0.928				
Knee	0.591	0.683	0.840	0.774	0.707	0.775			
Ankle	0.573	0.669	0.746	0.805	0.767	0.761	0.835		
Foot	0.540	0.633	0.793	0.770	0.733	0.727	0.798	0.960	

Table 23: Kappa values showing agreement between body areas for bilateral simultaneous touch

	Face	Trunk	Shoulder	Elbow	Wrist	Hand	Knee	Ankle	Foot
Face									
Trunk	0.608								
Shoulder	0.453	0.515							
Elbow	0.227	0.395	0.403						
Wrist	0.370	0.293	0.365	0.788					
Hand	0.190	0.218	0.361	0.716	0.859				
Knee	0.455	0.466	0.521	0.479	0.445	0.363			
Ankle	0.287	0.257	0.425	0.425	0.427	0.424	0.643		
Foot	0.320	0.288	0.466	0.316	0.318	0.314	0.697	0.932	

Table 24: Kappa values showing agreement between body areas for tactile localisation

Tactile Localisation	Face	Trunk	Shoulder	Elbow	Wrist	Hand	Knee	Ankle	Foot
Face									
Trunk	0.265								
Shoulder	0.272	0.500							
Elbow	0.064	0.203	0.321						
Wrist		0.311	0.344	0.620					
Hand	0.073	0.208	0.277	0.610	0.694				
Knee	0.147	0.353	0.246	0.195	0.152	0.349			
Ankle		0.180	0.281	0.171		0.143	0.447		
Foot		0.275	0.386	0.254		0.090	0.387	0.776	

Table 25: Kappa values showing agreement between body areas for proprioception

Proprioception	Shoulder	Elbow	Wrist	Hand	Hip	Knee	Ankle
Shoulder							
Elbow	0.485						
Wrist	0.434	0.411					
Hand	0.417	0.409	0.685				
Hip	0.294	0.173	0.313	0.333			
Knee	0.377	0.278	0.234	0.247	0.477		
Ankle	0.289	0.268	0.256	0.432	0.352	0.415	

The results show that there was generally high agreement between those body areas assessed that are in close proximity to each other. This was particularly true with the wrist and hand, and the ankle and foot, where there was substantial or almost perfect agreement on all the sensations tested. Generally there was a higher level of agreement with the upper limb areas when compared with the lower limb body areas. There were substantial differences between the extent to which there was consistency between body areas according to the sensory modality. There was a moderate or high agreement between all body areas for pressure, compared with many areas only having slight agreement between body areas for tactile localisation. Face and trunk were independent of the upper limb and lower limb, though there was almost perfect agreement between face and trunk for pressure.

These results support the need to examine impairment and recovery in several body areas, but suggest that it may not be necessary to assess both hand and wrist, and ankle and foot.

4.14 Discussion- Comparison of the Sensory Impairment in Body Areas

Cross-tabulations showed high agreement between impairments within each sensory modality in different body areas. This was particularly true for the wrist and hand, and ankle and foot, and was generally higher in the upper limb than in the lower limb. This may be because of the systematic relationship between position within the primary somatosensory cortex and the surface of the body, known as the sensory homunculus. The sensory areas for various body surfaces are organized adjacent to each other, with similar somatotropic organisation also found at lower levels of the somatosensory system. The regions where afferent sensations from various body areas are processed can be mapped on the surface of the cortex (Dubin, 2002), and the wrist and hand, and ankle and foot are adjacent to each other on the primary sensory cortex. Therefore a lesion in the cortex that affects sensation of the wrist is likely also to affect sensation of the hand, suggesting it may be possible to omit some body areas from the assessment.

The sensory representation of body areas is not proportionate to the size of the body part. Although the NSA is a detailed assessment, the sensations are only assessed in one area for each body part. This means that some subtle sensory disturbances may not be detected, for example only the palmar aspect of the hand is assessed, not the dorsum or the fingers. This means that despite the fingers having a large cortical representation, impairment in sensation selectively in this area will not be detected.

4.15 Summary- Sensory Impairment

Sensory impairment is common in stroke patients. Stereognosis was the most frequently impaired sensation. The different sensations showed only slight agreement between impairment in the same body areas, supporting the hypothesis that the different sensory modalities are independent of each other. Higher agreements were found in different body areas between impairments within each sensory modality, suggesting not all areas need to be assessed.

CHAPTER V

RESULTS AND DISCUSSION:
Scoring of the Nottingham Sensory Assessment

5.1 Hypothesis 5: Developing a scoring system for the NSA and evaluating construct validity

Rasch analysis of the NSA was conducted. The purpose of this was twofold:

- To allow total scores to be calculated for upper limb, lower limb, stereognosis and proprioception sub-scales
- To evaluate the construct validity of these sub-scales

The Rasch model is a mathematical model that ensures unidimensionality of the scale, and that the scales have the properties of magnitude, additivity and specific objectivity. For this analysis it is not the patients who are analysed, but rather the data about sensory impairments at different time points, to determine whether the scales fit the Rasch model and thus to establish whether the scale's psychometric properties are sound.

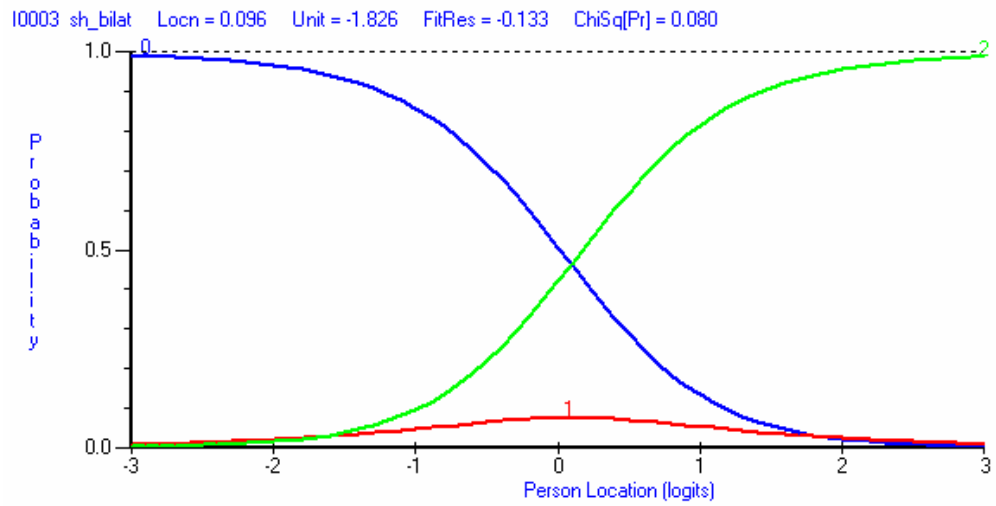
For the purpose of this analysis, only the data from the affected side was included. Data for all patients at each time point was included in the analysis, since a measurement scale needs to measure the same, regardless of time. It is possible to check whether this is the case by investigating for differential item functioning. Differential item functioning is when items function differentially for different groups e.g. gender, time point. All extreme cases (where the patients scored minimum or maximum scores throughout) were removed from the analysis. If patients scored a total of zero, it would have been impossible to know whether their level of impairment was just below the scale or massively below it. Conversely, if patients scored the maximum on a scale, it would have been impossible to know whether their ability was just at that level or much

higher. One assessor carried out most assessments, though when required some were undertaken by a second assessor. A third assessor carried out four of the assessments. Since this was too few to assess the reliability of this assessor, these four cases were removed from the analysis. This meant 253 cases were considered for the Rasch analysis. Following removal of extreme cases, 161 cases were included in the analysis for the upper limb scale, 153 cases for the lower limb scale, 187 cases for the stereognosis scale and 151 cases for the proprioception scale.

5.2 Upper Limb Scale

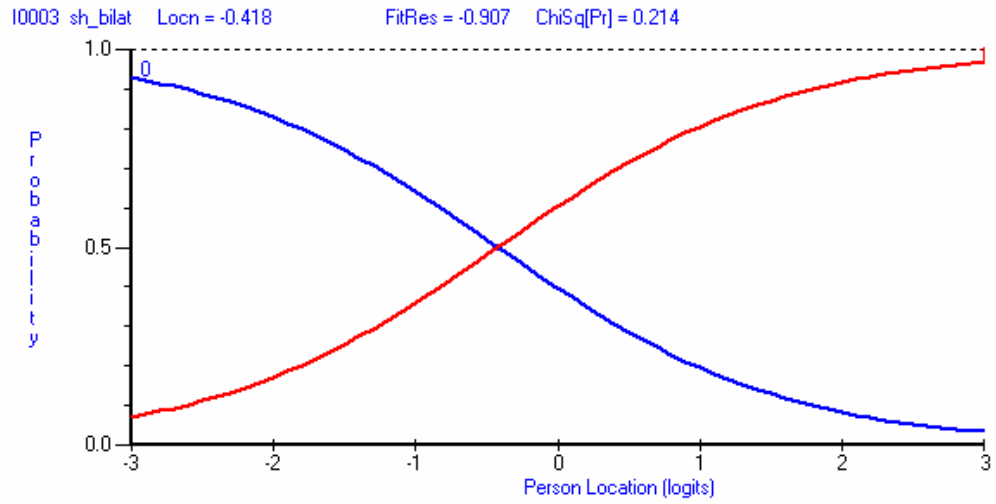
Rasch analysis was carried out as described in the method. The original scale did not fit the model suggesting it did not have adequate construct validity. Therefore individual items were investigated and procedures taken to improve the items ability to measure and the measurement tool as a whole. All items were scored on a three-point scale (0=absent, 1=impaired, 2=normal), but investigation showed some of the thresholds were disordered. An example of disordered thresholds can be seen for the item "shoulder bilateral simultaneous touch" in Graph 1. Person locations (logits) are plotted on the horizontal axis ranging left to right from patients who found it difficult to affirm the item to those who found this easy. In addition, the probability of a particular response category being chosen is plotted on the vertical axis and the three curves are labeled according to the respective response categories - 0 for *absent*, 1 for *impaired*, 2 for *normal.*

Graph 1: Scoring Thresholds for Bilateral Simultaneous Touch of the Shoulder



This shows that for bilateral simultaneous touch of the shoulder, the probability of scoring is not hierarchical. The probability of scoring a "1" is never greater than the probability of a score in the other two categories. Therefore this item was re-scored as a dichotomous item, with categories "0" and "1" collapsed together. The ordered threshold map can be seen in Graph 2, with the item fit residual of –0.907 (>-2.5) and a chi-square probability of 0.214 (>0.01) within the desired ranges.

Graph 2: Scoring Thresholds for Bilateral Simultaneous Touch of the Shoulder as a Dichotomous Item



The threshold properties of all items were checked and rescored as necessary, as per the example given previously. Table 26 below reflects which items had disordered thresholds, and the effects of re-scoring:

Table 26: The scoring thresholds for the items in the upper limb scale, and the effects of re-scoring

Item	Ordered Threshold?	Re-scored	Ordered Threshold?	Item Fit Residual (within +/- 2.5)	x^2 Prob. (>0.01)
Shoulder bilateral simultaneous touch	✗	0, 0, 1	✓	-0.907	0.214
Shoulder Light Touch	✓				
Shoulder Pinprick	✓				
Shoulder Pressure	✓				
Shoulder Temperature	✓				
Shoulder Tactile Localisation	✓				
Elbow Bilateral Simultaneous Touch		0, 0, 1	✓	-0.717	0.088
Elbow Light Touch	✓				
Elbow Pinprick	✓				
Elbow Pressure	✓				
Elbow Temperature	✓				
Elbow Tactile Localisation	✓				
Wrist Bilateral Simultaneous Touch	✗	0, 0, 1	✓	-0.703	0.317
Wrist Light Touch	✓				
Wrist Pinprick	✓				
Wrist Pressure	✗	0, 0, 1	✓	-1.719	0.027
Wrist Temperature	✓				
Wrist Tactile Localisation	✗	0, 0, 1	✓	1.416	0.020
Hand Bilateral Simultaneous Touch	✗	0, 0, 1	✓	-1.015	0.357
Hand Light Touch	✓				
Hand Pinprick	✓				
Hand Pressure	✗	0, 0, 1	✓	***-2.794****	***0.001****
Hand Temperature	✓				
Hand Tactile Localisation	✓				

KEY	
Ordered Threshold	- whether the probability of scoring a higher score increases with higher ability
Item Fit Residual	- the level of divergence of the item from the model, with a residual of greater than plus or minus 2.5 classed as unacceptable
X^2 probability	- chi-square also tests the fit to the Rasch model. Values higher than 0.01 indicate the item fits the model.

Those items in which fit was improved by re-scoring were bilateral simultaneous touch at the shoulder, wrist, elbow and hand, wrist pressure and wrist tactile localisation. Hand pressure did not fit the model however the categories were collapsed. It was therefore deleted.

Following rescoring, the items were checked for uniform and non-uniform differential item functioning (DIF) by assessor. This was tested using the ANOVA statistic. Values of less than 0.01 meant the items significantly differed according to assessor. Individual items were then checked for their fit to the Rasch model. Those items which did not fit the model or functioned differently depending on the assessor were deleted from the scale. This procedure is summarised in table 27. Items were also checked for differential item functioning (DIF) by time. No items functioned significantly differently dependent on time and therefore this was not included in the table.

Table 27: Results for the individual items for the upper limb scale for DIF by assessor and their fit to the Rasch model

Item	DIF by assessor (ANOVA) Uniform	Non-uniform	Item Fit Residual (within +/- 2.5)	x^2 Prob. (>0.01)	Item Deleted?
Shoulder bilateral simultaneous touch	>0.01	>0.01	-0.552	0.535	No
Shoulder Light Touch	>0.01	>0.01	-0.366	0.693	No
Shoulder Pinprick	>0.01	>0.01	-1.983	0.070	No
Shoulder Pressure	>0.01	>0.01	0.044	.216	No
Shoulder Temperature	**0.005**	>0.01			**Deleted**
Shoulder Tactile Localisation	>0.01	>0.01	**2.400**	**0.0002**	**Deleted**
Elbow Bilateral Simultaneous Touch	>0.01	>0.01	-0.353	0.236	No
Elbow Light Touch	>0.01	>0.01	-0.628	0.125	No
Elbow Pinprick	>0.01	>0.01	-1.781	0.094	No
Elbow Pressure	>0.01	>0.01	-1.330	0.294	No
Elbow Temperature	>0.01	>0.01	-1.602	0.232	No
Elbow Tactile Localisation	>0.01	>0.01	**2.843**	**0.0001**	**Deleted**
Wrist Bilateral Simultaneous Touch	>0.01	**0.002**			**Deleted**
Wrist Light Touch	>0.01	>0.01	-1.695	0.075	No
Wrist Pinprick	>0.01	>0.01	**-4.064**	0.002	**Deleted**
Wrist Pressure	>0.01	>0.01	-1.893	0.077	No
Wrist Temperature	>0.01	>0.01	1.331	0.195	No
Wrist Tactile Localisation	>0.01	>0.01	**2.629**	**<0.001**	**Deleted**
Hand Bilateral Simultaneous Touch	>0.01	**0.0017**			**Deleted**
Hand Light Touch	>0.01	>0.01	-1.727	0.453	No
Hand Pinprick	>0.01	>0.01	-2.027	0.030	No
Hand Pressure	>0.01	>0.01	**-2.867**	**0.003**	**Deleted**
Hand Temperature	>0.01	>0.01	0.863	0.690	No
Hand Tactile Localisation	**0.0005**	>0.01			**Deleted**

KEY	
DIF by assessor	- differential item functioning (DIF) by assessor is if the item measures the same thing independent from who is assessing
Uniform DIF	- if an item was displaying a consistently greater ability with one group compared to another, as shown by an ANOVA of >0.01
Non-uniform DIF	-when the ability differences to confirm an item are inconsistent, as shown by an ANOVA of >0.01
Item Fit Residual	- the level of divergence of the item from the model, with a residual of greater than plus or minus 2.5 classed as unacceptable
X^2 probability	- another test of fit to the Rasch model, with a value of higher than 0.01 indicating the item fits the model

The items shoulder temperature, wrist and hand bilateral simultaneous touch, and hand tactile localisation were removed due to significant differential item functioning by assessor. Shoulder, elbow and wrist tactile localisation, wrist pinprick and hand pressure were also deleted, since despite having ordered thresholds and functioning the same regardless of assessor, they still significantly differed from the Rasch model. This was shown by the item fit residual being greater than plus or minus 2.5 and/or the chi-squared probability being less than 0.01.

Following deletion of the above items, the item “Elbow Light Touch” was found to be misfitting the model (Chi-square prob. <0.01) and was also deleted.

Following these procedures, the revised upper limb scale fitted the model. The results are shown below:

Item-Person Interaction

Item fit residual	mean -0.259	SD 1.108
Person fit residual	mean -0.237	SD 0.981
Person location	mean 2.795	SD 2.430

Item-Trait Interaction

ChiSq 57.700, p>0.01

Person Separation Index 0.961

All individual items fitted the model (ChiSq prob > 0.01, Fit residuals <2.5)

KEY

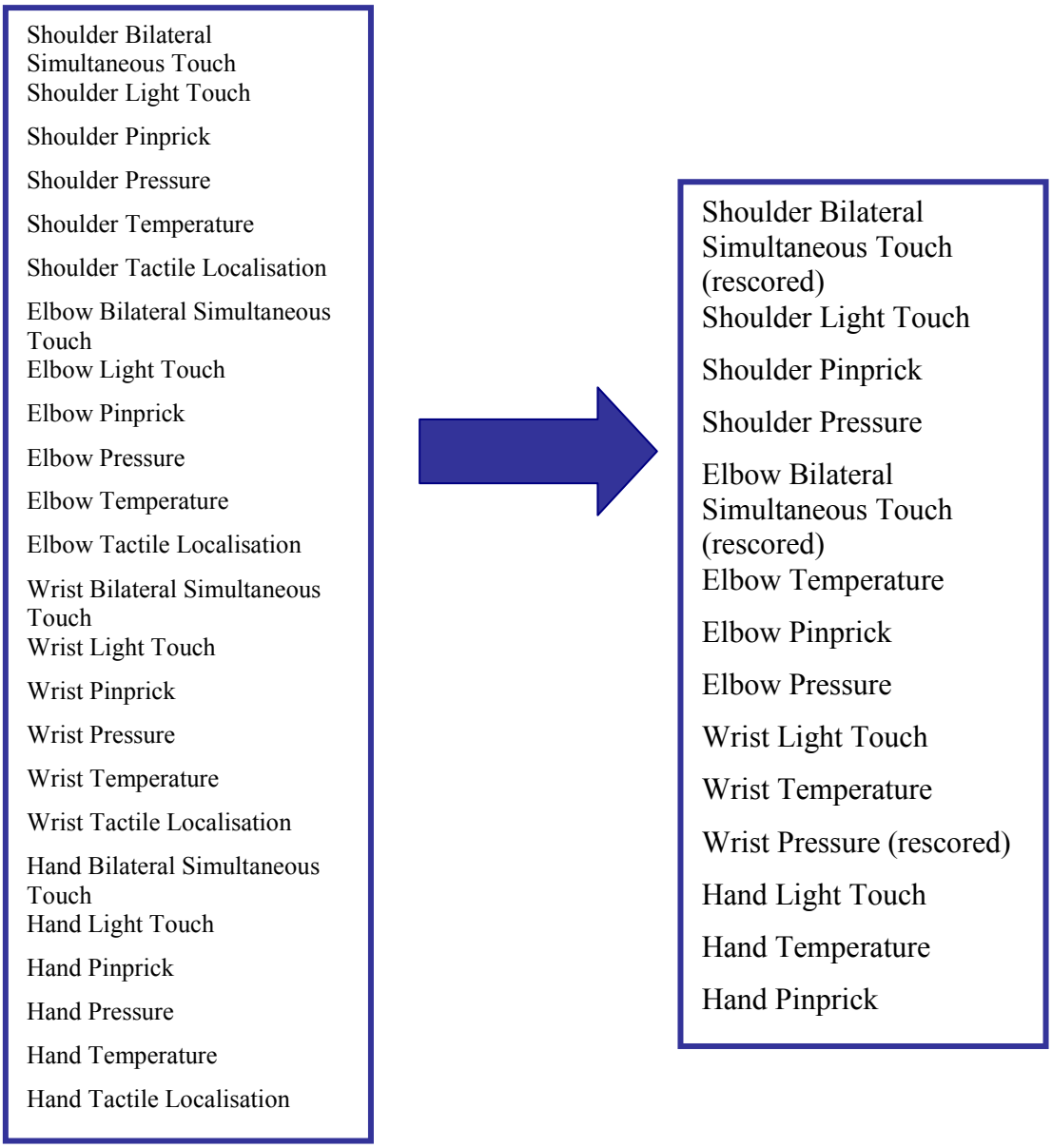
Item-Person Interaction - tests the degree of consensus displayed collectively by all items of the scale across persons of differing abilities. A perfect fit to the model would be when the "item fit" and "person fit" have a mean of 0 and a SD of 1 (acceptable if SD <1.4). The person location gives an indication of the ability of the population.

Item-Trait Interaction - assesses whether the data fit the Rasch model for class intervals along the scale. If there was no significant deviation between the observed data and what was expected from the model, the chi-square probability value is greater than 0.01.

Person Separation Index - indicative of the power of the construct to discriminate amongst respondents. A value of > 0.8 indicates that statistically it is possible to differentiate between 2 groups of patients, whereas > 0.9 indicated four or more groups of patients can be statistically differentiated between (Wright and Stone, 1979).

The development of the upper limb scale from the original to one that fits the Rasch model is summarised below in figure 3.

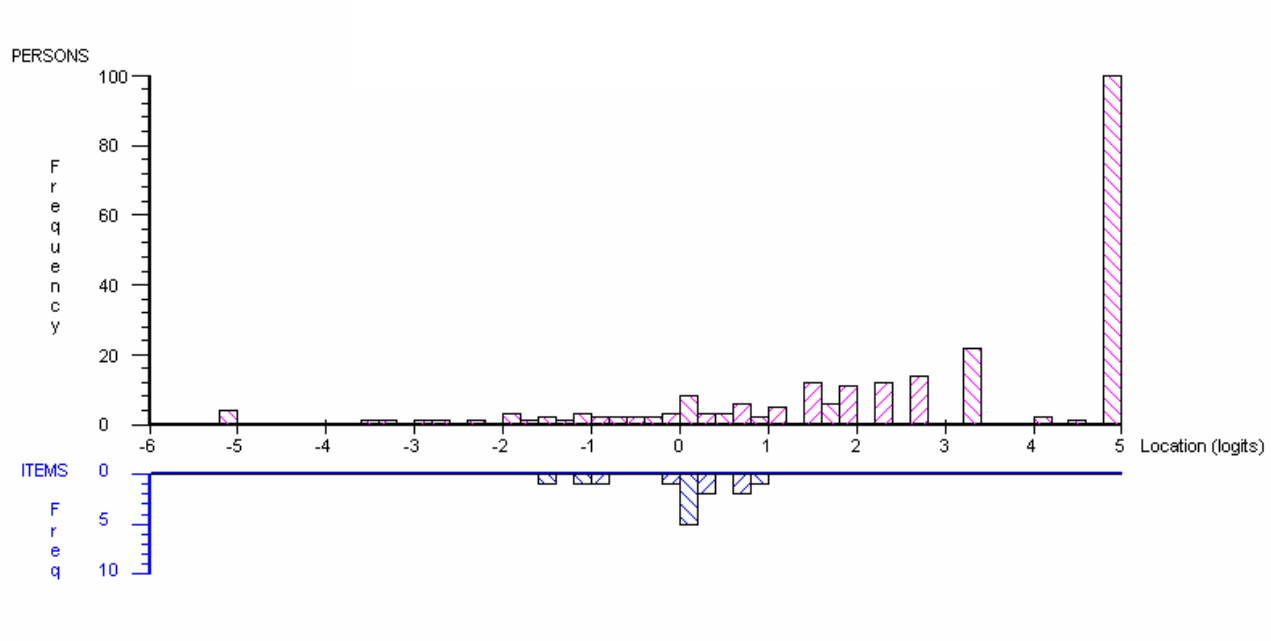
Figure 2: Development of the Upper Limb Scale



Person/item Location

Graph 3 below shows the distribution of patients in terms of the difficulty of the items. The upper part of the graph represents groups of patients and their ability levels, with the lower part representing the item locations and their distribution.

Graph 3: Person-Item Location Distribution for the Upper Limb Scale



This graph shows many of the item thresholds are clustered around the central locations, with the higher blue bars showing that some items are duplicating the ability to discriminate at that level of difficulty. Some of the respondents were above and below the range of measurement captured within the scale. Many patients were above the ceiling, as also indicated by the mean person location score of 2.80.

5.3 Lower Limb Scale

Rasch analysis for the lower limb scale was carried out as described in the method. The original scale did not fit the model, therefore individual items were investigated and action taken to improve the measurement. All items were scored on a three-point scale (0=absent, 1=impaired, 2=normal), but investigation showed some of the thresholds were disordered. These were rescored as necessary as in the example previously. This is summarised in the table below:

Table 28: The scoring thresholds for the items in the lower limb scale, and the effects of re-scoring

Item	Ordered Threshold?	Re-scored	Ordered Threshold?	Item Fit Residual (within +/- 2.5)	x^2 Prob. (>0.01)
Knee bilateral simultaneous touch	✗	0, 0, 1	✓	1.131	0.169
Knee Light Touch	✓				
Knee Pinprick	✓				
Knee Pressure	✓				
Knee Temperature	✓				
Knee Tactile Localisation	✗	0, 0, 1	✓	**3.292***	**<0.001***
Ankle Bilateral Simultaneous Touch	✗	0, 0, 1	✓	0.279	0.533
Ankle Light Touch	✓				
Ankle Pinprick	✓				
Ankle Pressure	✓				
Ankle Temperature	✓				
Ankle Tactile Localisation	✓				
Foot Bilateral Simultaneous Touch	✗	0, 0, 1	✓	-0.266	<0.001
Foot Light Touch	✓				
Foot Pinprick	✓				
Foot Pressure	✓				
Foot Temperature	✓				
Foot Tactile Localisation	✓				

KEY	
Ordered Threshold	- whether the probability of scoring a higher score increases with higher ability
Item Fit Residual	- the level of divergence of the item from the model, with a residual of greater than plus or minus 2.5 classed as unacceptable
X^2 probability	- another test of fit to the Rasch model, with a value of higher than 0.01 indicating the item fits the model

Those items in which fit was improved by re-scoring were bilateral simultaneous touch at the knee, ankle and foot. Knee tactile localisation remained disordered whichever way it was re-scored. It was therefore deleted from the scale.

Following rescoring of items with disordered thresholds, the items were checked for uniform and non-uniform differential item functioning (DIF) by assessor and by time. Those items which did not fit the model or functioned differently according to who had scored them were deleted from the scale. This procedure is summarised in the table 29.

Table 29: Results for the individual items for the lower limb scale for DIF by assessor and their fit to the Rasch model

Item	DIF by assessor (ANOVA) Uniform	DIF by assessor (ANOVA) Non-uniform	DIF by time (ANOVA) Uniform	DIF by time (ANOVA) Non-Uniform	Item Fit Residual (within +/- 2.5)	x^2 Prob. (>0.01)	Item Deleted?
Knee bilateral simultaneous touch	>0.01	>0.01	>0.01	>0.01	1.008	0.046	No
Knee Light Touch	>0.01	>0.01	>0.01	**0.005**			**Deleted**
Knee Pinprick	>0.01	>0.01	>0.01	**0.003**			**Deleted**
Knee Pressure	**0.005**	>0.01	>0.01	>0.01			**Deleted**
Knee Temperature	>0.01	>0.01	>0.01	>0.01	-0.355	0.739	No
Knee Tactile Localisation	>0.01	>0.01	>0.01	>0.01	**2.949**	**0.001**	**Deleted**
Ankle Bilateral Simultaneous Touch	>0.01	>0.01	>0.01	>0.01	-0.540	0.863	No
Ankle Light Touch	>0.01	>0.01	>0.01	**0.002**			**Deleted**
Ankle Pinprick	>0.01	>0.01	>0.01	>0.01	-0.073	0.350	No
Ankle Pressure	>0.01	**0.002**	>0.01	>0.01			**Deleted**
Ankle Temperature	>0.01	>0.01	>0.01	>0.01	0.154	0.791	No
Ankle Tactile Localisation	>0.01	>0.01	>0.01	>0.01	-0.226	0.676	**No**
Foot Bilateral Simultaneous Touch	>0.01	>0.01	>0.01	>0.01	-0.974	0.637	**No**
Foot Light Touch	>0.01	>0.01	>0.01	**0.009**			**Deleted**
Foot Pinprick	>0.01	>0.01	>0.01	>0.01	-1.637	0.738	No
Foot Pressure	>0.01	>0.01	>0.01	>0.01	0.178	0.748	No
Foot Temperature	>0.01	>0.01	>0.01	>0.01	-1.312	0.797	No
Foot Tactile Localisation	>0.01	>0.01	>0.01	>0.01	-0.810	0.043	No

KEY

DIF by assessor	- differential item functioning (DIF) by assessor is if the item measures the same thing independent from the assessor
DIF by time	- differential item functioning (DIF) by time is if the item measures the same ability regardless of the time of assessment
Uniform DIF	- if an item was displaying a consistently greater ability with one group compared to another, as shown by an ANOVA of >0.01
Non-uniform DIF	-when the ability differences to confirm an item are inconsistent, as shown by an ANOVA of >0.01
Item Fit Residual	- the level of divergence of the item from the model, with a residual of greater than plus or minus 2.5 classed as unacceptable

Knee and ankle pressure were removed from the scale because of differential functioning by assessor. Knee, ankle and foot light touch, and knee pinprick were deleted due to significant differential item functioning by time. The item knee tactile localisation was also deleted, since despite having ordered thresholds and not functioning differently by assessor or time, it still did not fit to the Rasch model.

Following these procedures, the revised lower limb scale fitted the model. The summary statistics are shown below:

Item-Person Interaction

Item fit residual	mean –0.510	SD 0.737
Person fit residual	mean -0.427	SD 1.164
Person location	mean 2.302	SD 2.232

Item-Trait Interaction

ChiSq 23.974, p>0.01

Person Separation Index 0.937

All individual items fit the model (ChiSq prob > 0.01, Fit residuals <2.5)

KEY

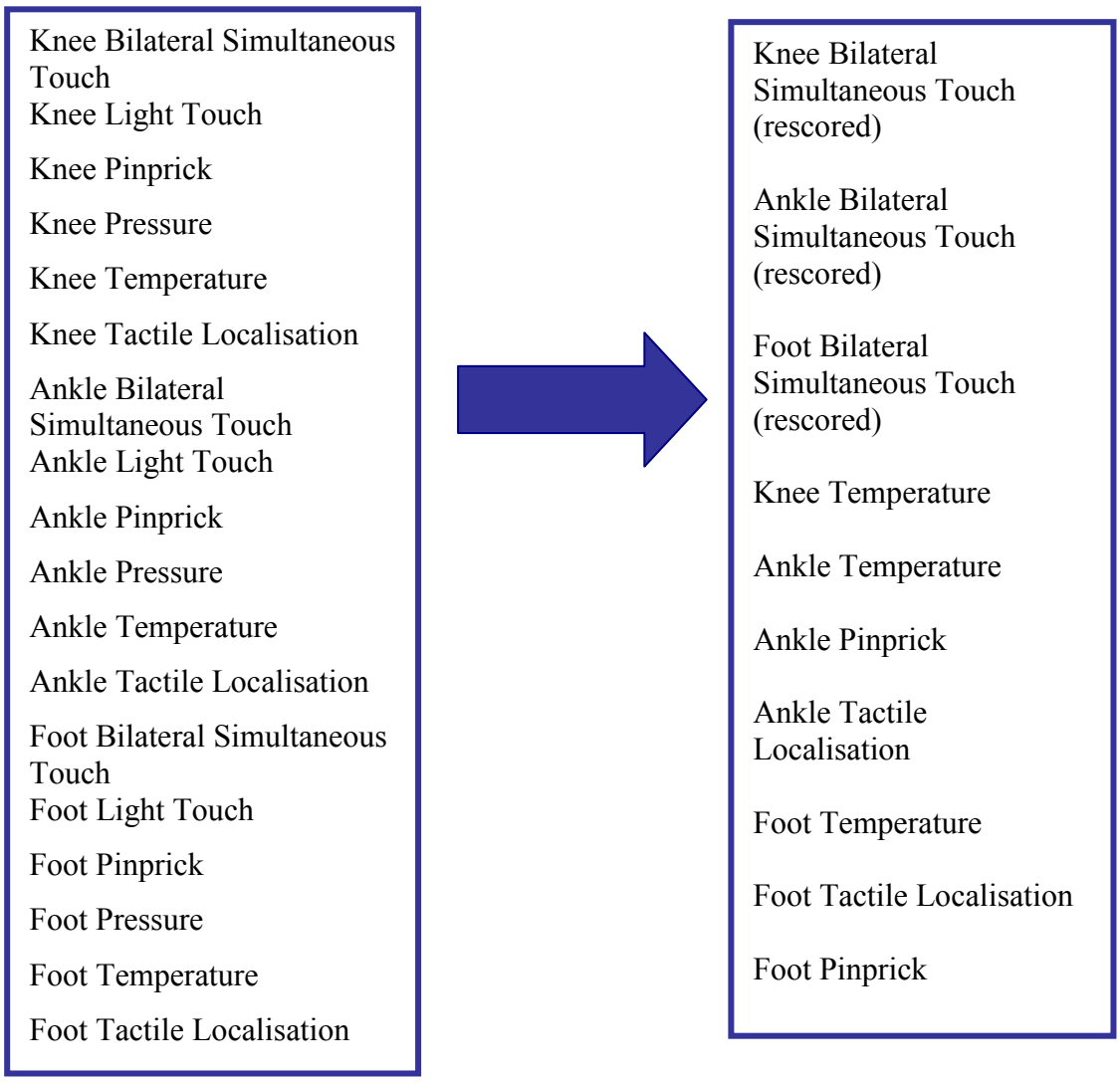
Item-Person Interaction - tests the degree of consensus displayed collectively by all items of the scale across persons of differing abilities. A perfect fit to the model would be when the "item fit" and "person fit" have a mean of 0 and a SD of 1 (acceptable if SD <1.4). The person location gives an indication of the ability of the population.

Item-Trait Interaction - assesses whether the data fit the Rasch model for class intervals along the scale. If there was no significant deviation between the observed data and what was expected from the model, the chi-square probability value is greater than 0.01.

Person Separation Index - indicative of the power of the construct to discriminate amongst respondents. A value of > 0.8 indicates that statistically it is possible to differentiate between 2 groups of patients, whereas > 0.9 indicated four or more groups of patients can be statistically differentiated between (Wright and Stone, 1979).

The development of the lower limb scale from the original to one that fits the Rasch model is summarised below in figure 4.

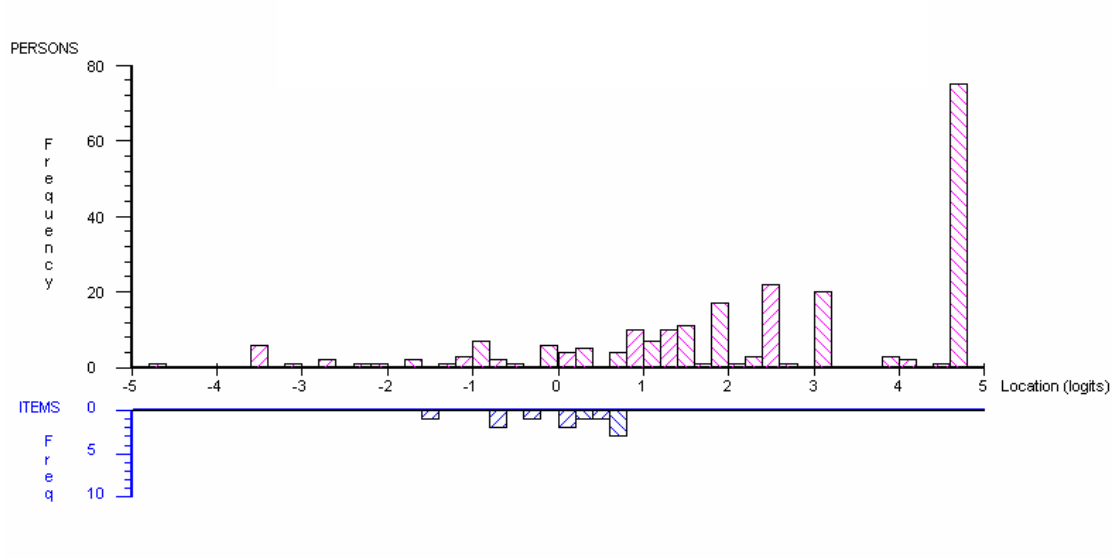
Figure 3: Development of the Lower Limb Scale



Person/item Location

Graph 4 below shows the distribution of patients in terms of the difficulty of the items.

Graph 4: Person-Item Location Distribution for the Lower Limb Scale



The lower limb scale shows similar distribution to that of the upper limb scale, with items again clustered around the central location. Several patients were above the ceiling.

5.4 Stereognosis Scale

Rasch analysis was carried out as detailed in the method.

The threshold properties of all items were checked and rescored as previously described. This is summarised in table 30 below:

Table 30: The scoring thresholds for the items in the stereognosis scale, and the effects of re-scoring

Item	Ordered Threshold?	Re-scored	Ordered Threshold?	Item Fit Residual (within +/- 2.5)	x^2 Prob. (>0.01)
Ten pence piece	✓				
Two pence piece	✓				
Fifty pence piece	✓				
Biro	✗	0, 0, 1	✓	-1.162	0.071
Pencil	✓				
Comb	✗	0, 0, 1	✓	-0.890	0.754
Scissors	✗	0, 0, 1	✓	-1.562	0.160
Sponge	✓				
Flannel	✓				
Cup	✓				
Glass	✗	0, 0, 1	✓	-1.811	0.034

KEY

Ordered Threshold	- whether the probability of scoring a higher score increases with higher ability
Item Fit Residual	- the level of divergence of the item from the model, with a residual of greater than plus or minus 2.5 classed as unacceptable
X^2 probability	- another test of fit to the Rasch model, with a value of higher than 0.01 indicating the item fits the model

Following re-scoring of biro, comb, scissors and glass, the items all had ordered thresholds and did not significantly deviate from the Rasch model.

Following re-scoring of the four items listed previously, the items were checked for uniform and non-uniform differential item functioning (DIF) by assessor and over time. No items functioned significantly differently over time or by assessor, with all ANOVA values being greater than 0.01. Individual items were then checked for their fit to the Rasch model. Those items that did not fit the model were deleted from the scale. The high negative items (10p, 2p and cup) show these items were over-discriminating, therefore not providing any new information. This procedure is summarised in the table 31 below:

Table 31: Results for the fit to the Rasch model for the individual stereognosis items

Item	Item Fit Residual (within +/- 2.5)	x^2 Prob. (>0.01)	Item Deleted?
Ten pence piece	**-3.280**	0.077	**Deleted**
Two pence piece	**-3.398**	0.041	**Deleted**
Fifty pence piece	-1.049	0.437	No
Biro	-1.805	**0.007**	**Deleted**
Pencil	-0.474	0.025	No
Comb	-1.022	0.413	No
Scissors	-1.994	**0.009**	**Deleted**
Sponge	-0.815	0.402	No
Flannel	-0.668	0.292	No
Cup	**-2.695**	**0.001**	**Deleted**
Glass	-1.602	0.153	No

KEY

Item Fit Residual	- the level of divergence of the item from the model, with a residual of greater than plus or minus 2.5 classed as unacceptable
X^2 probability	- another test of fit to the Rasch model, with a value of higher than 0.01 indicating the item fits the model

The ten and two pence coins were removed along with the biro, scissors and cup. This left six items that measured consistently over time and by assessor, and fit the Rasch model.

The fit of the revised scale to the Rasch model is shown below:

Item-Person Interaction

Item fit residual	mean –0.938	Standard Deviation 0.391
Person fit residual	mean –0.416	Standard Deviation 0.947
Person location	mean 1.312	Standard Deviation 2.546

Item-Trait Interaction

ChiSq 23.423, p>0.01

Person Separation Index 0.908

All individual items fit the model (ChiSq prob > 0.01, Fit residuals <2.5)

KEY

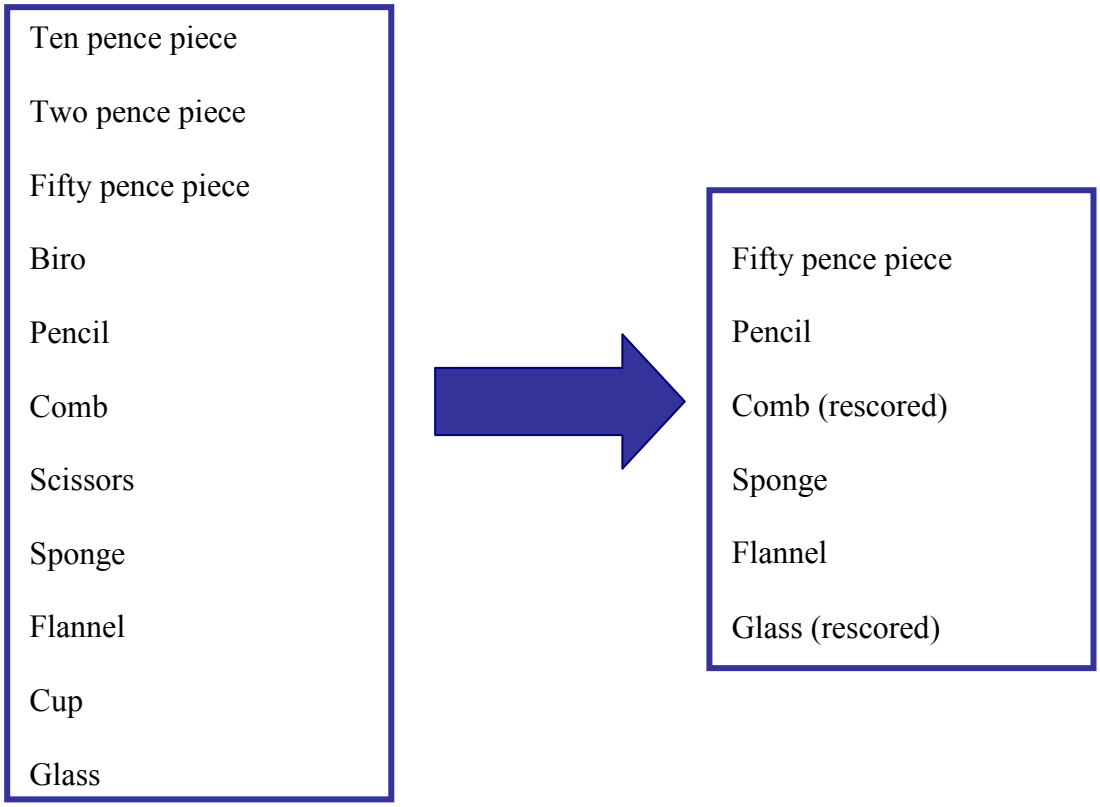
Item-Person Interaction - tests the degree of consensus displayed collectively by all items of the scale across persons of differing abilities. A perfect fit to the model would be when the "item fit" and "person fit" have a mean of 0 and a SD of 1 (acceptable if SD <1.4). The person location gives an indication of the ability of the population.

Item-Trait Interaction - assesses whether the data fit the Rasch model for class intervals along the scale. If there was no significant deviation between the observed data and what was expected from the model, the chi-square probability value is greater than 0.01.

Person Separation Index - indicative of the power of the construct to discriminate amongst respondents. A value of > 0.8 indicates that statistically it is possible to differentiate between 2 groups of patients, whereas > 0.9 indicated four or more groups of patients can be statistically differentiated between (Wright and Stone, 1979).

Following rescoring of two items and deletion of five items the stereognosis scale fitted the model. The development of the stereognosis scale from the original to one that fits the Rasch model can be summarised in figure 5 below.

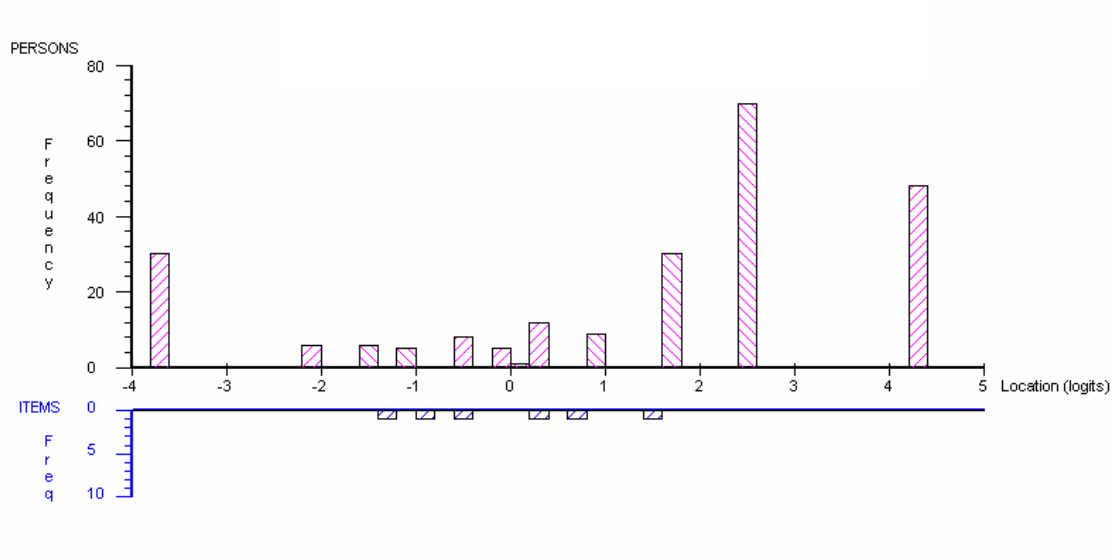
Figure 4: Development of the Stereognosis Scale



Person/item Location

The graph below shows the distribution of patients in terms of the difficulty of the items.

Graph 5: Person-Item Location Distribution for the Stereognosis Scale



This graph shows that the remaining stereognosis items all measure different abilities, though there is a slight gap between them at zero on the logit scale. This means the scale will not discriminate between patients at that ability level. As with the other subscales, there is a floor and ceiling effect.

5.5 Proprioception Scale

Rasch analysis was carried out as detailed in the method. Once again the original scale failed to fit the model, therefore the items were investigated and procedures taken to improve the measurement. All items were scored on a four-point scale (0=absent, 1=appreciation of movement, 2=direction of movement, 3=normal joint position sense), but investigation showed some of the thresholds were disordered and were rescored as necessary. The items were checked for uniform and non-uniform differential item functioning (DIF) by assessor and over time. Only the item "wrist proprioception" functioned differently depending on the assessor (p=0.000), and was therefore deleted from the scale. Individual items were then checked for their fit to the Rasch model. Those items that did not fit the model were deleted from the scale. These procedures are summarised in the table below:

Table 32: The scoring thresholds for the items in the proprioception scale, and the individual items fit to the Rasch model.

Item	Ordered Threshold?	Re-scored	Ordered Threshold?	Item Fit Residual (within +/- 2.5)	x^2 Prob. (>0.01)	Item Deleted?
Shoulder Proprioception	✓			-0.907	0.822	No
Elbow Proprioception	✓			-2.277	0.347	No
Wrist Proprioception						**Deleted**
Hand Proprioception	✗	0, 0, 1, 2	✓	-1.089	0.136	No
Hip Proprioception	✗	0, 0, 1, 2	✓	1.327	0.158	No
Knee Proprioception	✗	0, 0, 1, 2	✓	1.353	0.717	No
Ankle Proprioception	✗	0, 0, 1, 1	✓	-0.690	0.762	No

KEY	
Item Fit Residual	- the level of divergence of the item from the model, with a residual of greater than plus or minus 2.5 classed as unacceptable
X^2 probability	- another test of fit to the Rasch model, with a value of higher than 0.01 indicating the item fits the model

Following rescoring of four items and deletion of one item the proprioception scale fit the model. The results are shown below:

Item-Person Interaction

Item fit residual	mean –0.380	Standard Deviation 1.244
Person fit residual	mean –0.337	Standard Deviation 0.850
Person location	mean 2.553	Standard Deviation 2.240

Item-Trait Interaction

ChiSq 17.476, p>0.05

Person Separation Index 0.906

All individual items fit the model (ChiSq prob > 0.01, Fit residuals <2.5)

KEY

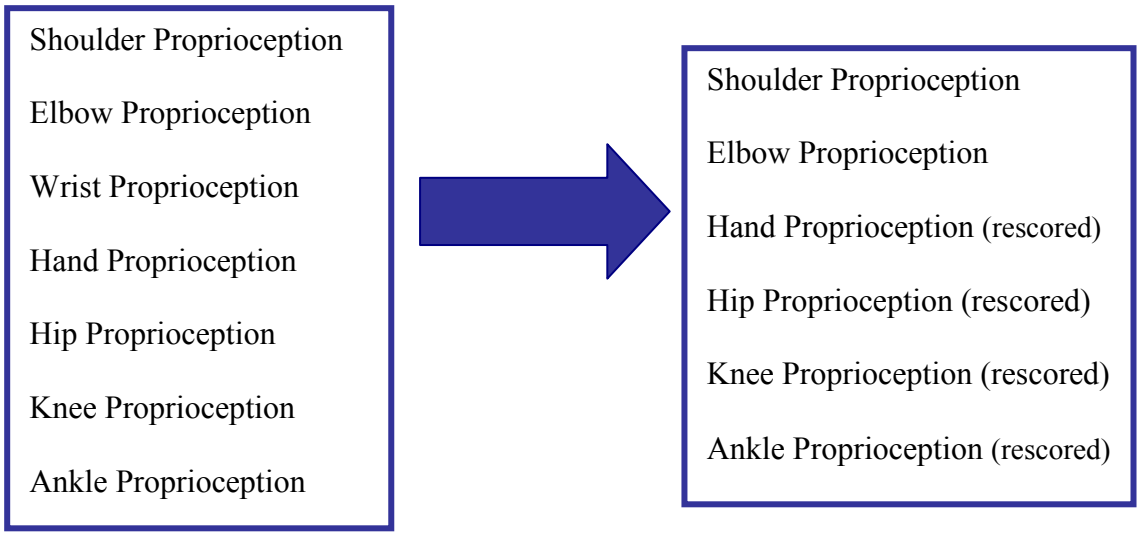
Item-Person Interaction - tests the degree of consensus displayed collectively by all items of the scale across persons of differing abilities. A perfect fit to the model would be when the "item fit" and "person fit" have a mean of 0 and a SD of 1 (acceptable if SD <1.4). The person location gives an indication of the ability of the population.

Item-Trait Interaction - assesses whether the data fit the Rasch model for class intervals along the scale. If there was no significant deviation between the observed data and what was expected from the model, the chi-square probability value is greater than 0.01.

Person Separation Index - indicative of the power of the construct to discriminate amongst respondents. A value of > 0.8 indicates that statistically it is possible to differentiate between 2 groups of patients, whereas > 0.9 indicated four or more groups of patients can be statistically differentiated between (Wright and Stone, 1979).

The development of the proprioception scale from the original to one that fits the Rasch model is summarised in figure 6 below.

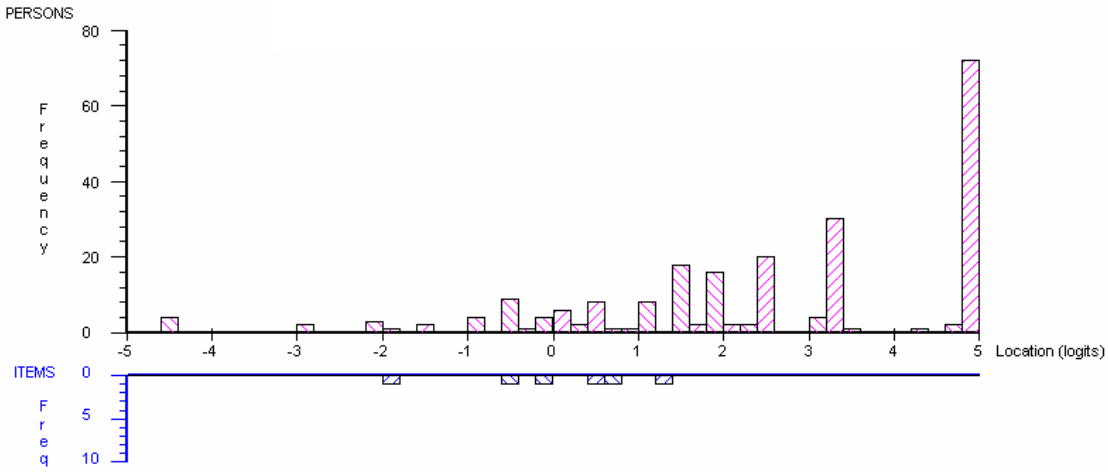
Figure 5: Development of the Proprioception Scale



Person/item Location

The graph below shows the distribution of patients in terms of the difficulty of the items.

Graph 6: Person-Item Location Distribution for the Proprioception Scale



This graph shows some of the respondents are above and below the range of measurement captured within the scale. Many patients are above the ceiling, as indicated by the mean person location score of 2.540.

5.6 Summary of Rasch Analysis of Sensory Subscales

Four subscales were developed which fitted the Rasch model following deletion of mis-fitting items, and re-scoring of items that had disordered thresholds.

Upper limb (UL) subscale: 24 items to 14 items (with 3 re-scored)

Lower limb (LL) subscale: 17 items to 10 items (with 3 re-scored)

Stereognosis subscale: 11 items to 6 items (with 2 re-scored)

Proprioception subscale: 7 items to 6 items (with 4 re-scored)

Therefore short subscales were developed, which had good construct validity and total scores were calculated for analysis of recovery.

5.7 Calculation of Total Scores for the Subscales

As all items in each subscale fitted the Rasch model, individual person location scores were transformed to scores for use in parametric analysis using the following formula:

s = (wanted range)/ current range

m = (wanted low)-(current low *s)

Person Score = m + (s*location)

Total scores for each patient for each subscale were calculated, with each subscale having a range of 0 to 100. The means and standard deviations of these totals for each time point are in table 33 below:

Table 33: Total scores for the subscales at each time point

Scale	Time Point	N	Mean	S.D.
Upper Limb	0	65	70.58	24.70
	2	62	78.32	23.86
	4	55	82.67	23.78
	6	55	82.58	22.87
Lower Limb	0	61	71.23	25.68
	2	62	73.98	23.59
	4	55	75.21	22.75
	6	55	77.14	21.69
Stereognosis	0	64	52.46	32.70
	2	60	62.95	29.72
	4	52	68.44	30.80
	6	54	67.33	31.68
Proprioception	0	62	67.14	27.61
	2	57	77.45	23.95
	4	53	76.87	22.57
	6	55	80.55	21.46

Following Rasch analysis it was possible to calculate total scores for the NSA. At baseline, the mean transformed total scores were 71% for the upper limb tactile sensations subscale, 71% for the lower limb tactile sensations scale, 52% for the stereognosis scale and 67% for the proprioception scale. Stereognosis was therefore the most severely impaired as well as the most commonly impaired sensation.

5.8 Discussion: Hypothesis 5 - Developing a scoring system for the NSA and evaluating construct validity

Rasch analysis on the sensory subscales enabled the internal construct validity of the scales to be evaluated and total scores to be calculated. Lincoln et al. (1998), suggested use of the upper limb, and lower limb, stereognosis and proprioception scales as separate assessments. However, it is unclear how these scales were devised. The original assessment (Lincoln et al., 1991) included the body areas based on those which were used clinically. The face and trunk areas did not fit in any category, and the proprioception subscale included both upper limb and lower limb joints. However since these subscales were logical, they were used as a basis for Rasch analysis.

When observing the scoring thresholds, it was apparent that all the bilateral simultaneous touch items had disordered thresholds. This was because few people scored as impaired, and were either unable to discriminate between being touched on one or both sides, or had normal bilateral simultaneous touch ability. Therefore these variables were dichotomized into absent or present.

Some items showed differential item functioning dependent on assessor. This was despite both assessors having been trained on how to carry out the NSA. This could be due to a number of factors, including the amount of pressure applied when assessing some of the sensations and differences in terms of experience and professional background. However there was no obvious pattern to items showing differential item functioning, which one would expect if this were the case (e.g. one assessor always scoring higher for a particular sensation). Some items did show uniform differential functioning but not in a particular pattern. The wrist proprioception item was deleted from the proprioception subscale due to DIF by assessor. This could have been due to different handling skills due to the assessors being from different professions

(physiotherapist and occupational therapist), and having differing experience. One reason that temperature items showed differential functioning may be due to differences in the environments where the assessments took place. One of the assessors (LC) did most of the assessments in the stroke units, whereas home visits were divided between both assessors. The temperature of the water used for assessing hot and cold is not standardised in the NSA, but is more likely to be consistent in the hospital environment. In patients' homes it was more variable depending on what was available e.g. whether the hot water was taken from the kettle or from the hot tap. This led to some variability in the assessment. The temperature of the water could have been checked with a thermometer but the relative difference would be minimal and is unlikely to have had a large impact on the results. There are instruments available that allow standardisation of pressure applied and temperature, such as those used in the Rivermead Assessment of Somatosensory Performance (RASP) (Winward et al., 2002). However these were not used in the original NSA. These could be included to potentially improve the NSA. However it may limit the usability of the NSA and such factors have hindered implementation of more standardised sensory assessments in the past (Carey, 1995).

Four items on the lower limb subscale had non-uniform differential item functioning over time. These were knee, ankle and foot light touch, and knee pinprick. This may be because as time after stroke increased, patients were generally more alert and able to concentrate throughout the assessment, but it is not predicted that this should have a selective effect on these items It could also reflect the effects of different environments with more of the later assessments carried out at home. However because the items functioned non-

uniformly different, they were not consistently harder or easier, it is more likely due to the items having low reliability.

The item-location distributions showed that patients were above and below the range of the measurement scale. Those above were people without sensory problems. This is a reflection of the population, as the NSA was carried out on an unselected sample of stroke patients, not those specifically with sensory problems. Many would be expected to be above the ceiling. It is also unclear what the scores of normal elderly patients would be, though it would be expected that many of these would be at the ceiling of the NSA. Those below the measurement scale had severe sensory problems. Once severe sensory impairment has been detected the scale may not need to differentiate between severe and very severe impairment.

As patients were recruited consecutively from those admitted to the stroke units rather than for specifically having sensory impairments, many patients scored very highly on the NSA. This meant not all participants were available to include in the Rasch analysis as this excludes extreme cases. However the method of analysis used, which allows data from all time points to be included (as it is the data as opposed to the patients that is investigated), meant the number of cases were still sufficient for Rasch analysis.

Achieving fit to the Rasch model meant deletion of items from all four subscales, with a large number deleted from the upper limb, lower limb and stereognosis subscales. The question could be posed, should you make the items fit the construct or the construct fit the items? It could be argued that this is excessive deletion of items, with the process of refining the outcome measure attempting to over simplify the complexity of the problem. However,

if an item is not measuring consistently it can be argued that there is little point in measuring it at all. It can be difficult to convince people that deleting mis-fitting items is important. Concerns include the need to include items for historical reasons, e.g "they are all we have", for technical reasons e.g. they are the only items left to represent certain categories. However it is philosophically better to delete mis-fitting items, achieving "specific objectivity". If the measurer wants to preserve the meaningfulness of the distance in a construct map, i.e. to achieve interval level data, the measurer has no option but to seek item sets that fit the Rasch model (Wilson, 2004). Deletion of items should not be done without thought, as the item that is showing poor fit may be a crucial one either because of its rarity in the item sample with respect to content or with respect to location. If possible further items of a similar nature should be developed. However, in this case, this was not possible, as items could not be replaced and the study was concerned with the development of a pre-existing scale. Hence the judgement was taken to delete the mis-fitting items.

The upper limb scale had the most items deleted. The fact that previously kappa values showed that there was high agreement between body areas that are in close proximity to each other such as wrist and hand, was then supported by high negative residual values for wrist pinprick and hand pressure when investigating these items fit to the Rasch model. This was the reason for misfit to the Rasch model, as these items were over-discriminating and therefore redundant. All tactile localisation items in the upper limb were deleted due to misfit to the Rasch model. These were due to DIF by assessor and may therefore be improved by clarifying assessment instructions. However elbow tactile localisation did not show DIF but still did not fit the model. This may

be as tactile localisation may be part of a separate construct, as motor ability will have impacted on the ability to localise the sensation. However this was not consistent in the lower limb, as only knee tactile localisation was deleted. Ankle and foot tactile localisation did fit the Rasch model, though it has been mentioned that early after stroke 20% of patients with poor motor ability were unable to be assessed on ankle and foot tactile localisation which may mean those with good motor ability have been self-selected.

5.9 Results- Sensory Impairment Total Scores

The means of the total scores of the sensory subscales at recruitment show that stereognosis was the most severely impaired. The results for each patient in ascending stereognosis total score order are listed in table 34 below. The quartiles for the stereognosis totals are shown, and all sensory totals in the upper quartile highlighted.

Table 34: Total Scores at Recruitment for the Four Sensory Subscales

Patient I.D.	Stereognosis Total Score	UL Total Score	LL Total Score	Proprioception Total Score
1	.	.	.	.
25	.	84	100	.
27	.	.	61	.
38	.	.	100	.
57	.	18	67	36
73	.	.	76	.
5	0	23	90	16
13	0	57	100	30
17	0	58	100	63
40	0	.	63	.
42	0	67	82	30
46	0	41	63	69
48	0	49	82	.
49	0	51	61	42
53	0	65	76	0
62	0	39	76	36
65	0	0	54	0
70	0	39	100	48
31	19	43	100	42
16	27	78	77	55
26	27	31	50	42
30	27	65	100	42
39	27	47	50	53
54	27	53	70	42
3	33	73	76	42
43	33	16	60	0
51	33	67	100	63
11	39	70	76	83
15	39	100	82	100
4	51	56	100	100
9	51	78	100	100
32	51	65	51	42
45	51	51	50	83
22	58	78	100	100
37	58	100	100	48
10	66	84	71	80
14	66	70	61	100
18	66	70	50	69
23	66	100	50	69
28	66	53	50	75
33	66	74	50	80
36	66	100	100	58
61	66	100	76	75
64	66	62	57	100
74	66	100	82	63
75	66	70	71	75
2	77	74	50	53
20	77	74	71	100
24	77	70	82	100
34	77	84	82	83
35	77	100	82	75
50	77	100	71	100
52	77	84	100	75
55	77	100	50	75
56	77	100	76	63
58	77	84	13	83
59	77	70	82	100
60	77	51	76	63
63	77	84	54	63
72	77	65	63	75
8	100	100	29	82
12	100	100	100	100
29	100	100	51	100
41	100	100	39	83
44	100	100	53	100
47	100	100	100	63
67	100	100	100	100
68	100	84	100	83

The results show that almost one third (31%) of patients were in the upper quartile for stereognosis impairment at recruitment. Only two patients (3%) scored the maximum on all four subscales. This may be as sensory ability is known to deteriorate with age (Kenshalo, 1986, Kaplan et al., 1985, Desrosiers et al., 1996), and the sample were generally elderly with a mean age of 71 years. Therefore even if the stroke had not affected their sensory ability, their performance may not be optimal due to age.

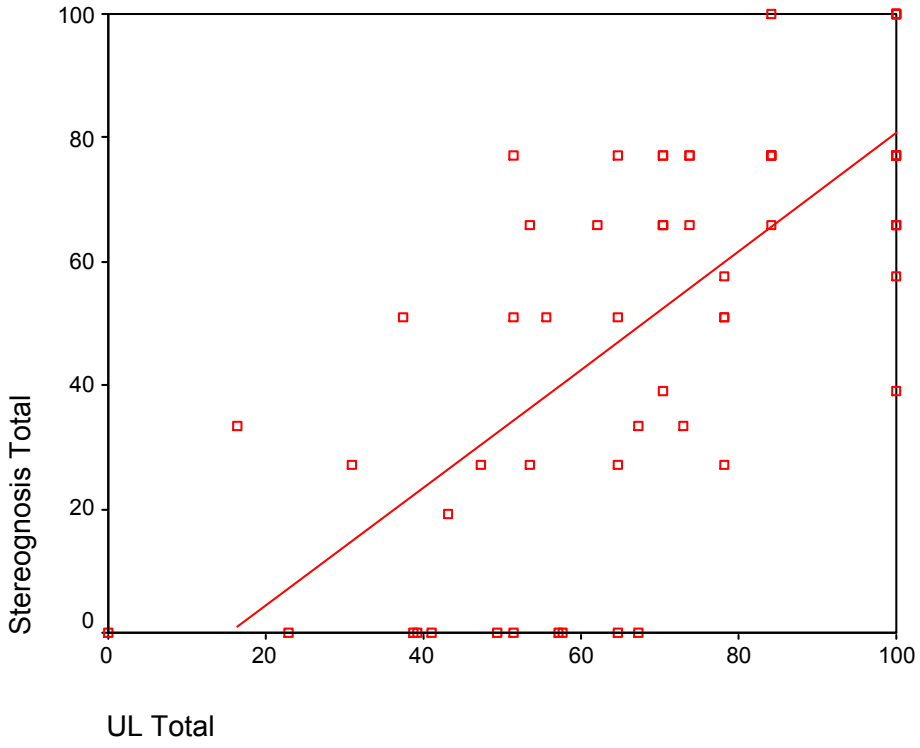
The table indicates a relationship between stereognosis performance and upper limb sensation, and to a lesser degree with proprioception. Performance on the lower limb scale does not seem to relate to stereognosis, with many patients in the lowest quartile for stereognosis ability being in the upper quartile for lower limb ability. As stereognosis is a combined sensation, requiring both exteroceptive and proprioceptive input, it suggests that stereognosis could be used as a screening procedure, with those patients who have intact stereognosis not requiring detailed assessment of the individual sensations. This was checked with the results.

Eight people (11%) scored the maximum on the stereognosis scale. Of these seven scored maximum in the upper limb scale (88%), with the remaining person scoring in the upper quartile. On the stereognosis scale, 4 scored maximum (50%), with 3 of the remaining patients scoring in the upper quartile. For the lower limb scale, 4 of the patients (50%) also scored maximum but the remaining patients had scores in the lower quartiles. This suggests that stereognosis could be used as a screening tool for the upper limb, with those

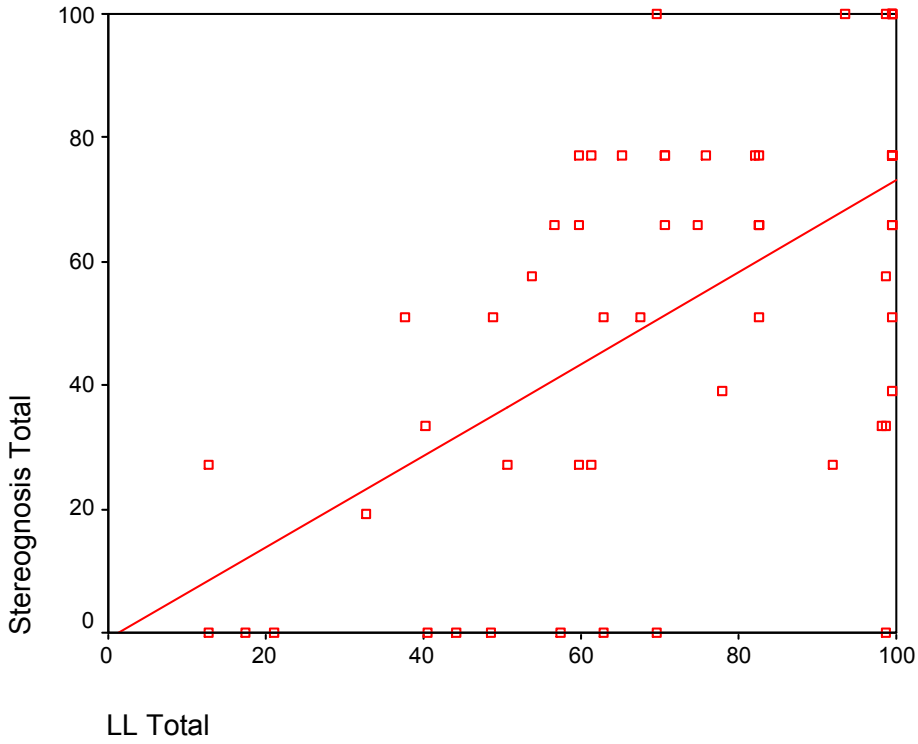
who scored maximum not requiring detailed assessment of upper limb tactile sensations.

The relation between stereognosis total scores and the three other subscales are shown in the graphs below. This confirms that there was a significant relationship between stereognosis total score and the other sensory subscales, though there are more outliers on the lower limb scale compared with the upper limb and proprioception scales.

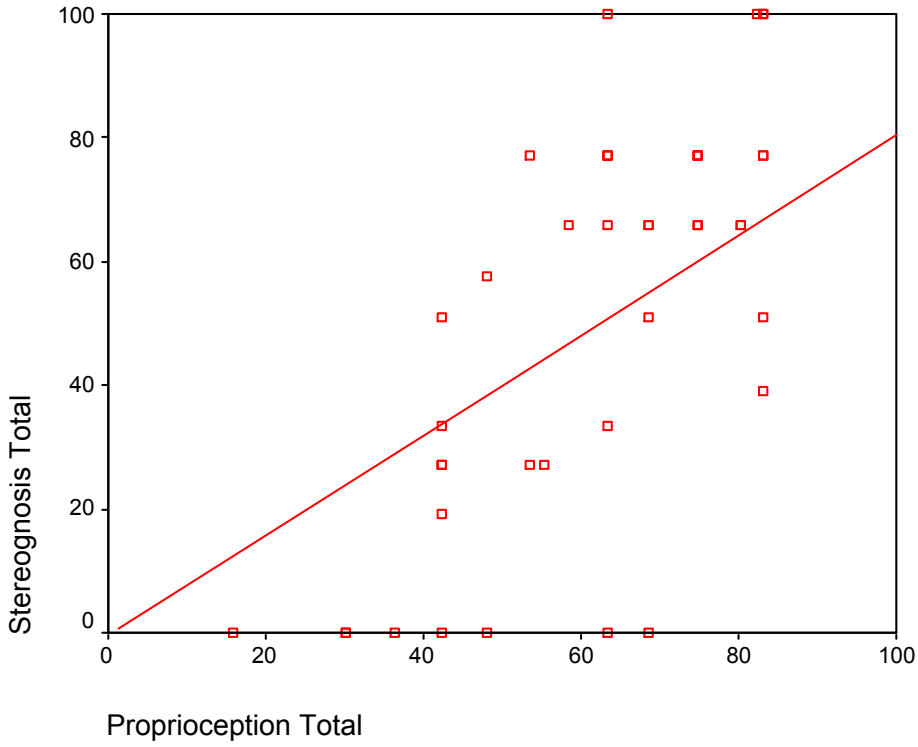
Graph 7: Comparing Total Scores on Stereognosis with Upper Limb Scores



Graph 8: Comparing Total Scores on Stereognosis with Lower Limb Scores



Graph 9: Comparing Total Scores on Stereognosis with Proprioception Scores



5.10 Summary- Sensory Impairment Total Scores

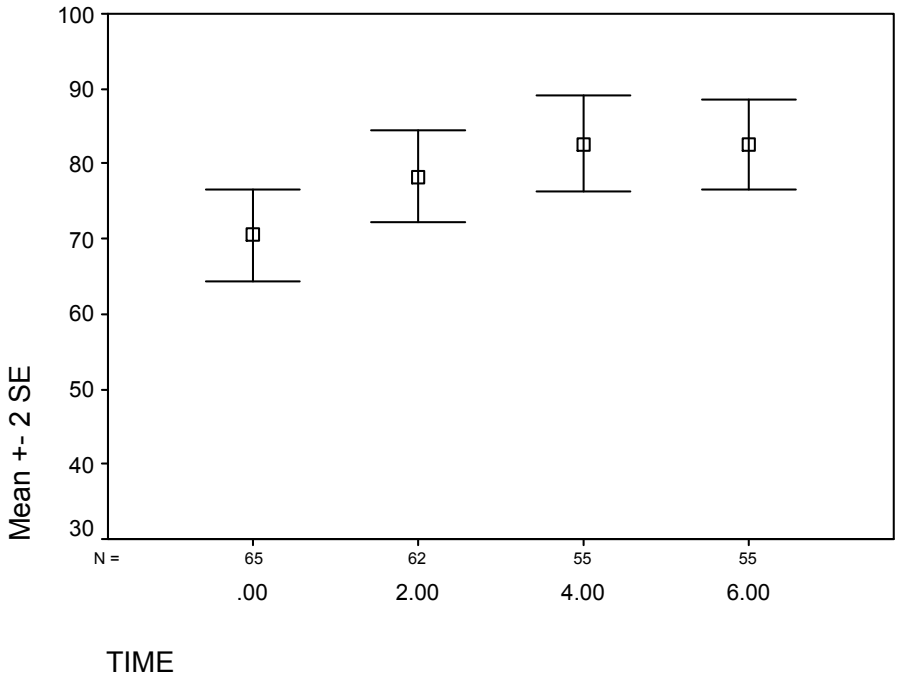
Stereognosis was the most severely impaired sensation. There was a significant correlation between those patients who did well on the stereognosis scale, also scoring highly in the upper limb, lower limb and proprioception subscales. This correlation was the highest for the upper limb total scores.

CHAPTER VI
RESULTS AND DISCUSSION
Sensory Recovery

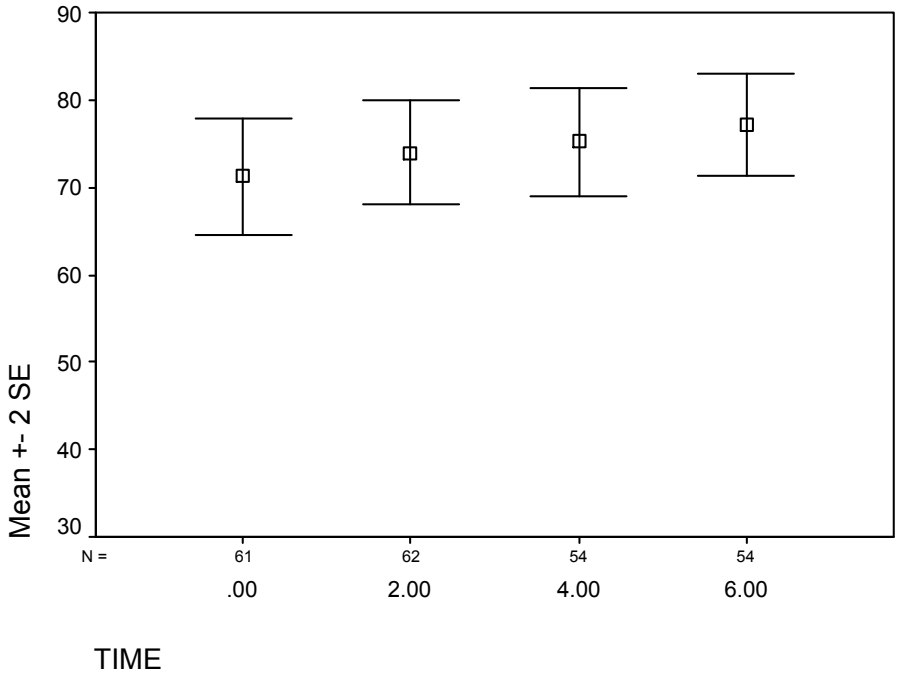
6.1 Hypothesis 7: Recovery of Sensory Impairment

The recovery of sensory impairment, as assessed on the four scales, was evaluated. The mean and standard error scores of the subscale totals over time (baseline and 2, 4 and 6 months) are presented in graphical form below (Graphs 6-9).

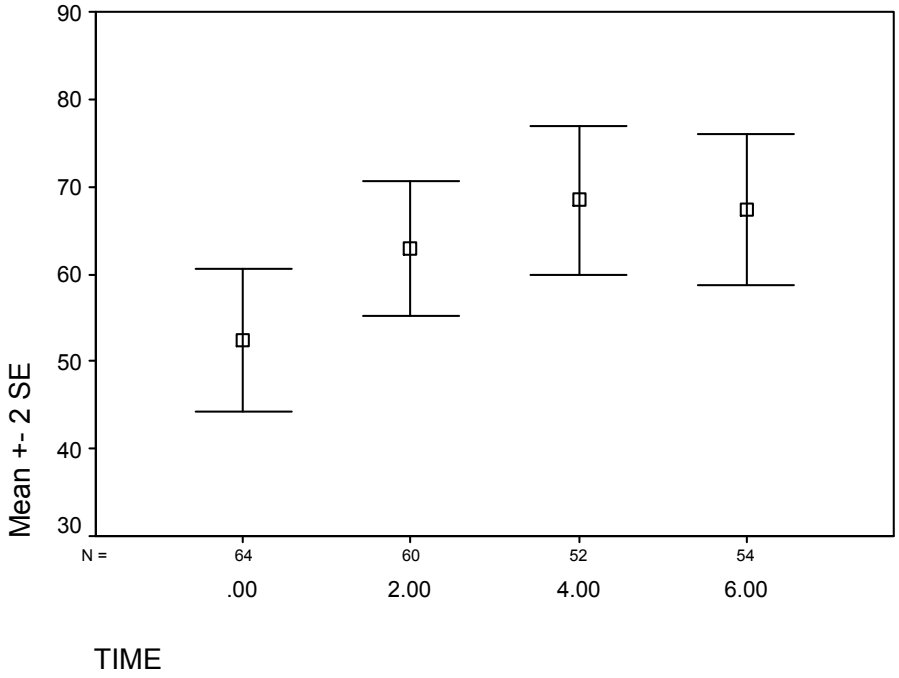
Graph 6: Total scores for the upper limb scale over time



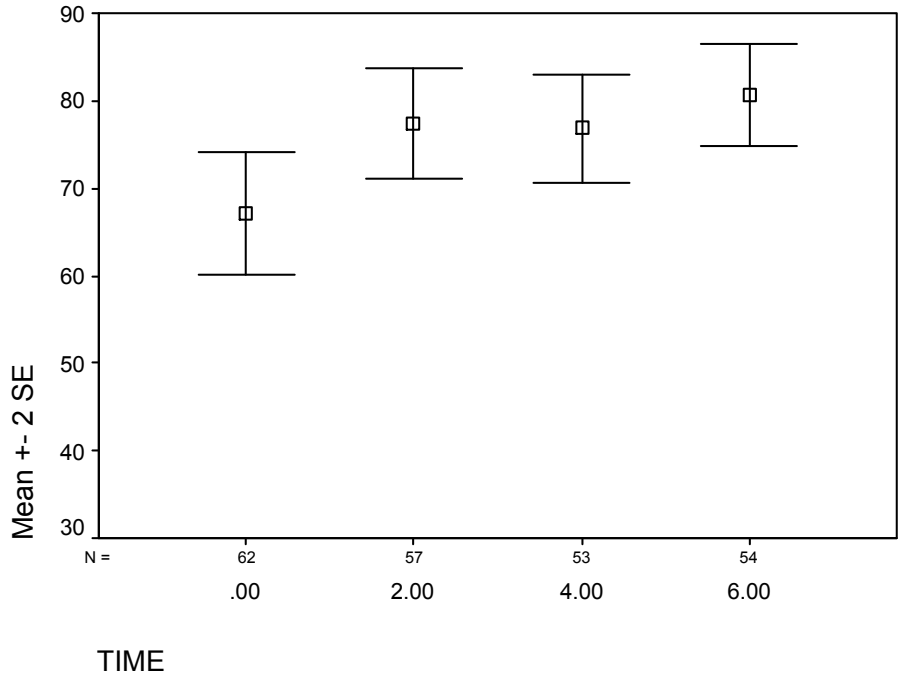
Graph 7: Total scores for the lower limb scale over time



Graph 8: Total scores for the stereognosis scale over time



Graph 9: Total scores for the proprioception scale over time



From the graphs it appears that there was recovery on each of the sensory abilities over time. However there is the possibility that the observed "effect" is nothing more than random variability. Therefore, a one-way analysis of variance (ANOVA) was used to determine whether the means differed significantly over time. The results are given in table 35.

Table 35: Differences between means of the sensory subscales over time

		Sum of Squares	df	Mean Square	F	Sig.
Upper Limb Total	Between Groups Within Groups Total	5928.06 131383.21 137311.27	3 233 236	1976.02 563.88	3.504	**0.016**
Lower Limb Total	Between Groups Within Groups Total	1062.33 125853.57 126915.90	3 227 230	354.11 554.42	0.639	0.591
Stereognosis Total	Between Groups Within Groups Total	9550.77 221086.31 230637.08	3 226 229	3183.59 978.26	3.254	**0.023**
Proprioception Total	Between Groups Within Groups Total	3013.00 129502.87 135515.87	3 222 225	2004.33 583.35	3.44	**0.018**

There were significant differences in the means over time in the upper limb, stereognosis and proprioception scales ($p<0.05$). However the difference between the means of the lower limb scale over time did not reach statistical significance ($p>0.05$).

The ANOVA indicated that the combined differences of means of the upper limb, stereognosis and proprioception scales differed significantly, but not whether any particular time point differed significantly from another. Therefore a Tukey HSD test was used to determine this. Results are reported in table 36.

Table 36: Differences between the means of the sensory subscales at different time points

		Mean Difference	S.E.	Sig.
Upper Limb Total	0 - 2 months	-7.74	4.22	0.259
	0 - 4 months	-12.09	4.35	**0.030***
	0 – 6 months	-12.00	4.35	**0.032***
	2 – 4 months	-4.35	4.40	0.756
	2 – 6 months	-4.26	4.40	0.767
	4 – 6 months	0.09	4.53	1.00
Lower Limb Total	0 - 2 months	-2.75	4.25	0.916
	0 - 4 months	-3.98	4.40	0.802
	0 – 6 months	-5.91	4.40	0.536
	2 – 4 months	-1.23	4.38	0.992
	2 – 6 months	-3.16	4.38	0.888
	4 – 6 months	-1.93	4.53	0.974
Stereognosis Total	0 - 2 months	-10.49	5.62	0.246
	0 - 4 months	-15.98	5.84	**0.034***
	0 – 6 months	-14.87	5.78	0.052
	2 – 4 months	-5.50	5.93	0.790
	2 – 6 months	-4.39	5.87	0.878
	4 – 6 months	1.11	6.08	0.998
Proprioception Total	0 - 2 months	-0.94	0.40	0.095
	0 - 4 months	-0.89	0.41	0.140
	0 – 6 months	-1.22	0.41	**0.017***
	2 – 4 months	0.05	0.42	0.999
	2 – 6 months	-0.28	0.42	0.906
	4 – 6 months	-0.34	0.43	0.860

In summary, this table shows there were significant differences at the 5% level:

- In the upper limb scores between 0 and 4 months
- In the upper limb scores between 0 and 6 months
- In the stereognosis scores between 0 and 4 months
- In the proprioception scores between 0 and 6 months

This indicates that people's sensory deficit in these three domains recovered in the first six months post-stroke. Most significant recovery occurred early after stroke, with significant changes in upper limb sensory ability and stereognosis accruing earlier than change in proprioception.

6.2 Discussion: Recovery of Sensory Impairment

The results showed that upper limb tactile sensation, stereognosis and proprioception sensations all showed significant recovery over six months, but there was no significant improvement in the lower limb tactile sensations.

The upper limb tactile scale showed significant recovery between admission, and assessment at four and six months. This may be because the upper limb is heavily dependent on many sensations to enable efficient movement and to allow interaction with the environment. Upper limb sensorimotor function is fundamental for most activities of daily living, such as washing, dressing, toileting, as well as tasks requiring increased dexterity such as cooking, writing, manipulating tools, eating or drinking etc. A patient receiving routine therapy that is not specifically targeted at sensory recovery may be getting indirect sensory training, and it has been shown sensory training may aid recovery (Cambier et al., 2003, Feys et al., 1998, Yekutiel and Guttman, 1993). It is possible that more specific sensory rehabilitation, targeting impaired sensory abilities may further aid recovery in the upper limb sensations.

The lower limb tactile sensations did not show significant recovery. This may be because in contrast to the upper limbs, the lower limbs are used less in personal activities of daily living and may get less sensory feedback than normal because of decreased mobility. It is recognised that prolonged

experience of altered sensory input results in changes in the sensory representation due to plasticity in the somatosensory cortex (Braun et al., 2001). Motor problems also result in patients sitting in abnormal postures for long periods of time, which may lead to permanent changes in the functional organization of the sensory maps (Sanger and Merzenich, 2000). A review by Teasell and colleagues (2004) stated "the corollary of "use it or lose it" in the motor system is "stimulate it or lose it" in the somatosensory system of the brain". This means a negative cycle can exist, in which patients have motor impairment which leads to decreased afferent input which in turn leads to decreased motor and sensory ability. Therefore the fact that patients can have reduced mobility after stroke means this may negatively impact on sensory recovery of the lower limbs. It is therefore possible that sensory training could be beneficial for the lower limb by providing increased stimulation, therefore promoting recovery.

Stereognosis showed significant recovery between 0 and 4 months. This is consistent with the literature that most recovery occurs early after stroke (Andrews et al., 1981, Jorgensen et al., 1995b). Proprioception took longer to recover, as significant differences only occurred between 0 and 6 months.

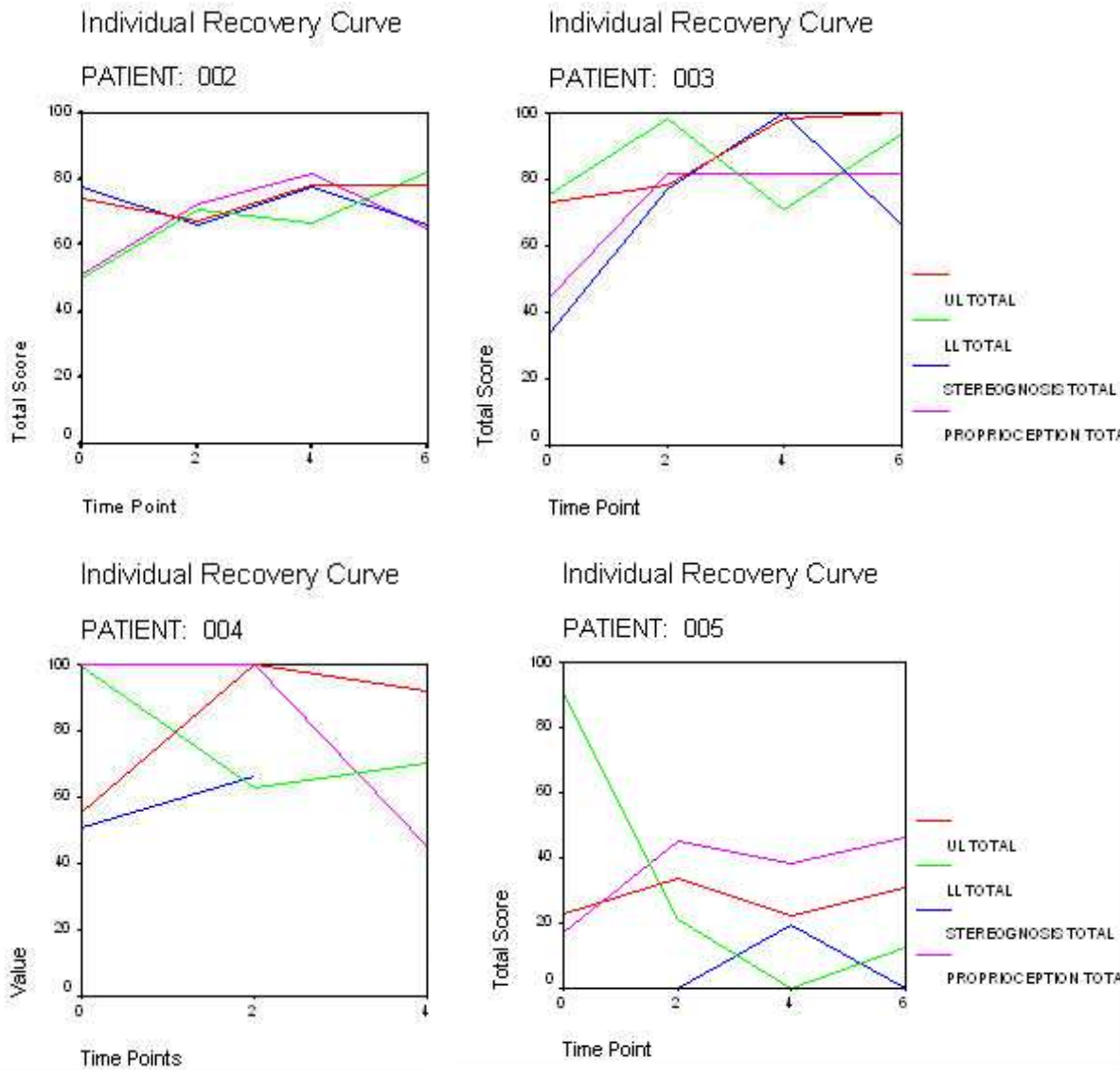
The results showed that recovery occurred up to 6 months after stroke in the upper limb tactile sensations, stereognosis and proprioceptive abilities. There were no significant differences between 4 and 6 months, which suggests the recovery had reached a plateau. Recovery may have continued after six months but this study did not assess beyond six months. This is consistent with

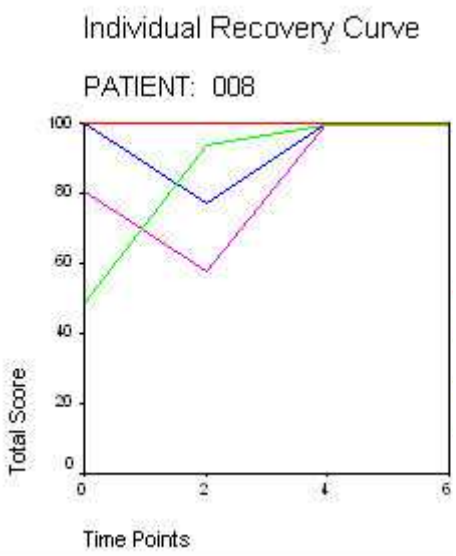
literature suggesting that most recovery occurs within six months after stroke (Andrews et al. 1981; Jorgensen et al. 1995). Although some recovery can be found years after stroke (Jorgensen et al., 1995b, Andrews et al., 1981, Johansson, 2000), recovery is unlikely to be significant (Skilbeck et al., 1983). There has been little detailed research on sensory recovery after six months of stroke onset. It was not possible to determine recovery after six months in this study. Previous research suggested there was generally no significant change after six months (Julkunen et al., 2005), but it would have been useful to check this.

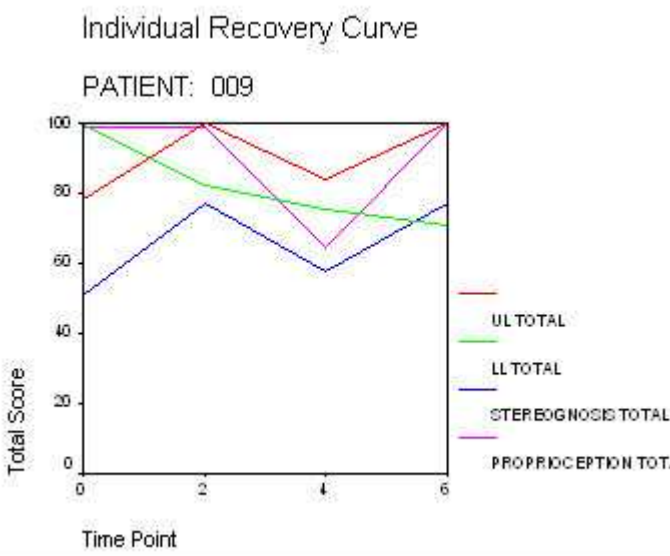
6.3 Results: Individual Recovery

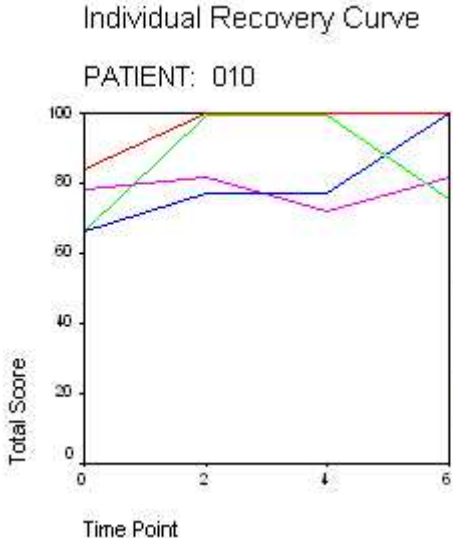
The recovery of individuals' sensory ability was investigated. Graphs of individual recovery curves for the four sensory subscales are shown below.

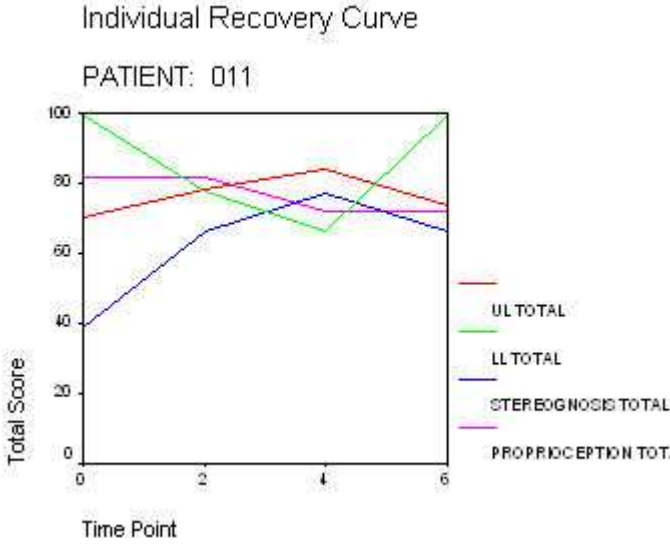
Graphs 10: Individual Recovery Curves

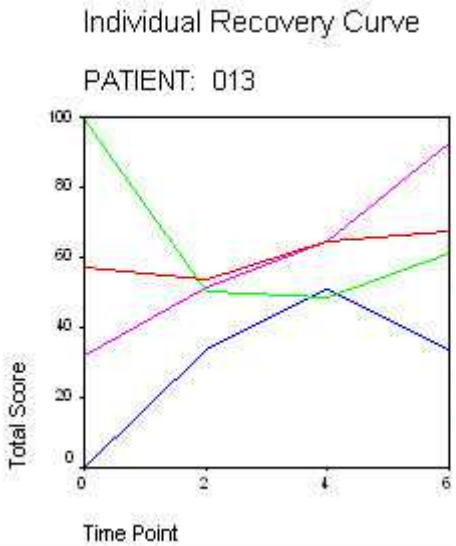


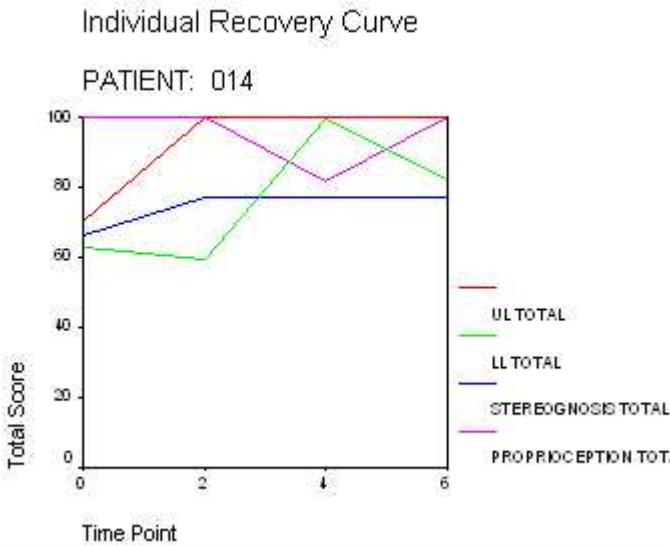

Individual Recovery Curve
PATIENT: 008
Total Score
Time Points

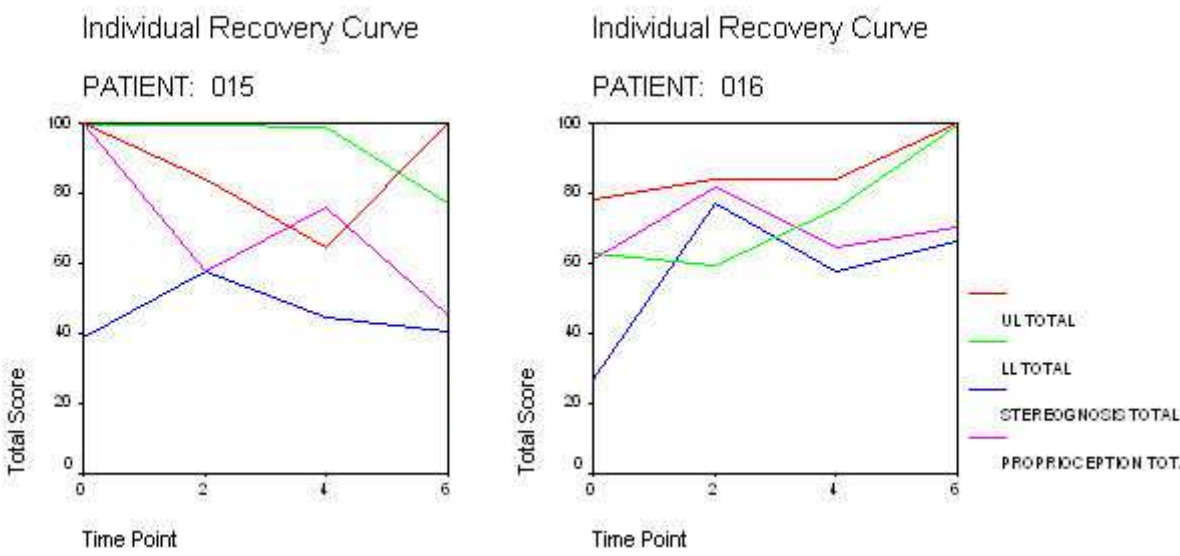

Individual Recovery Curve
PATIENT: 009
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

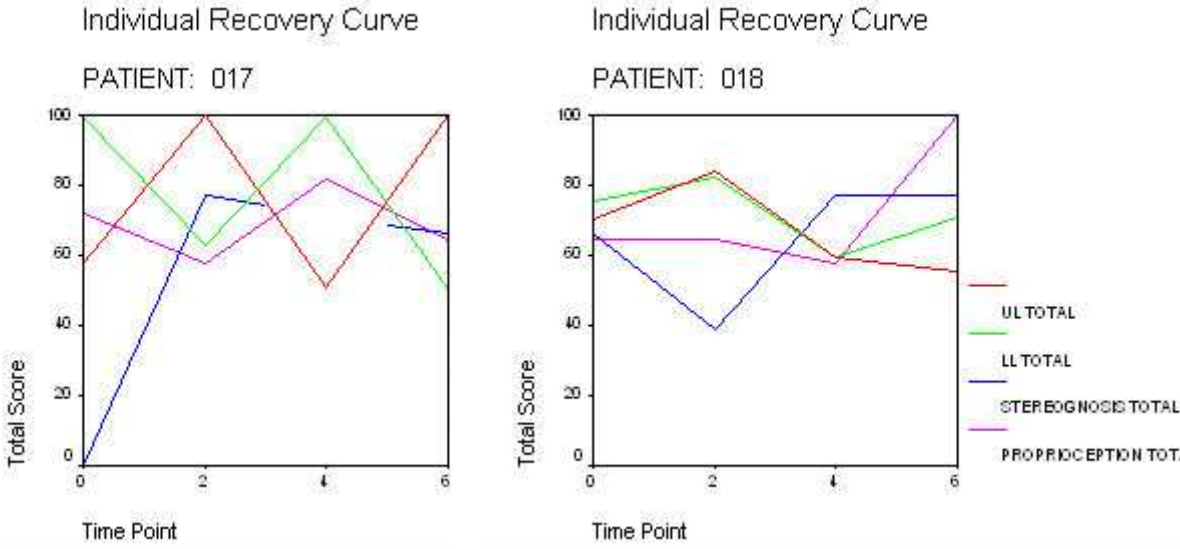

Individual Recovery Curve
PATIENT: 010
Total Score
Time Point

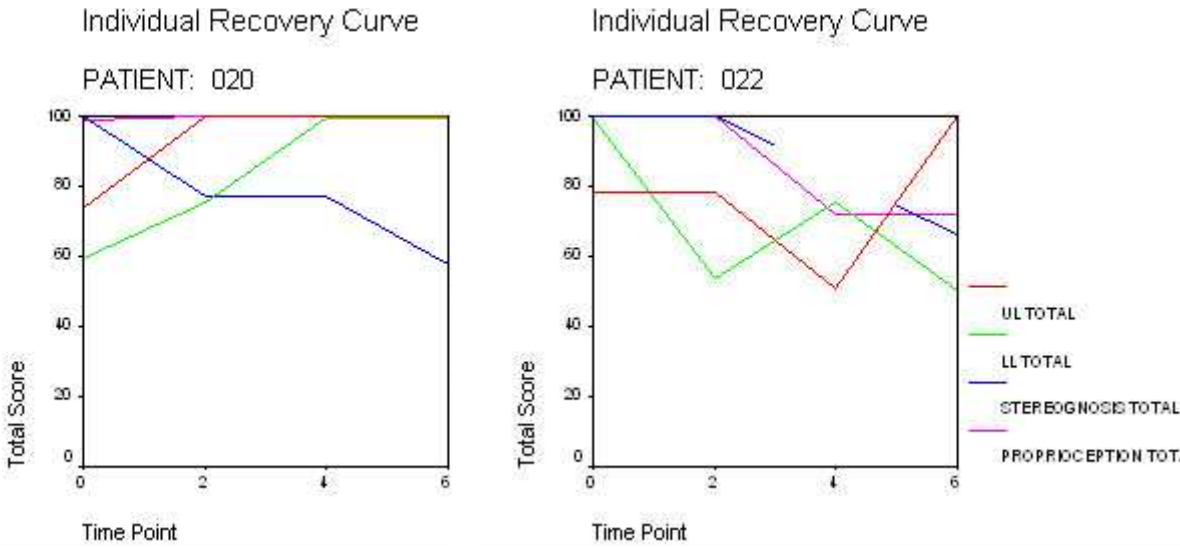

Individual Recovery Curve
PATIENT: 011
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

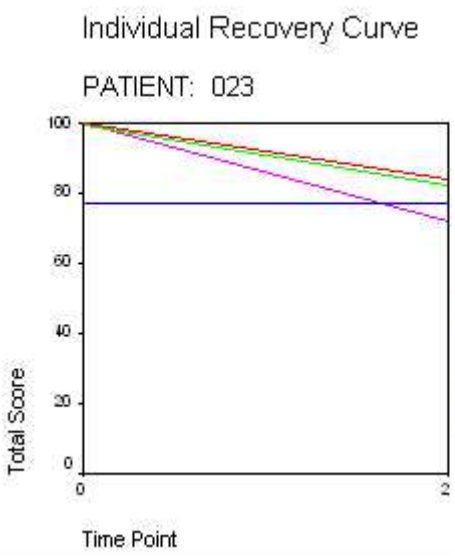

Individual Recovery Curve
PATIENT: 013
Total Score
Time Point

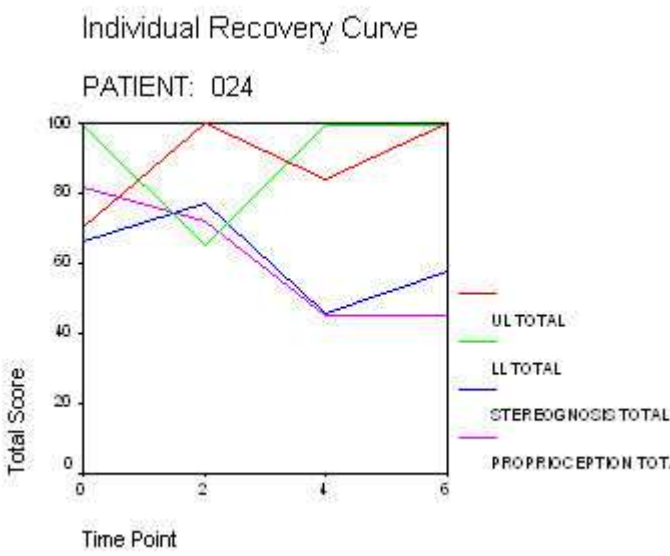

Individual Recovery Curve
PATIENT: 014
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

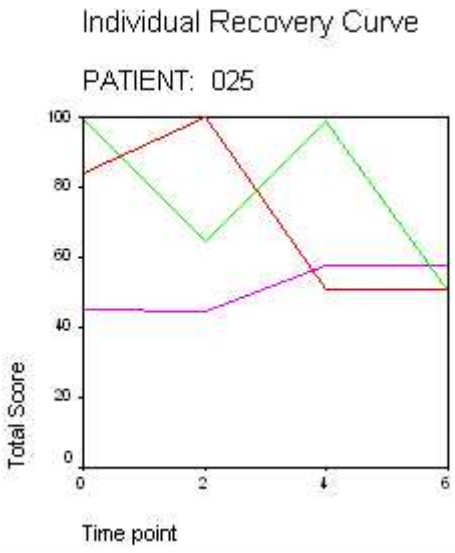

Individual Recovery Curve
PATIENT: 015
Total Score
Time Point
Individual Recovery Curve
PATIENT: 016
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

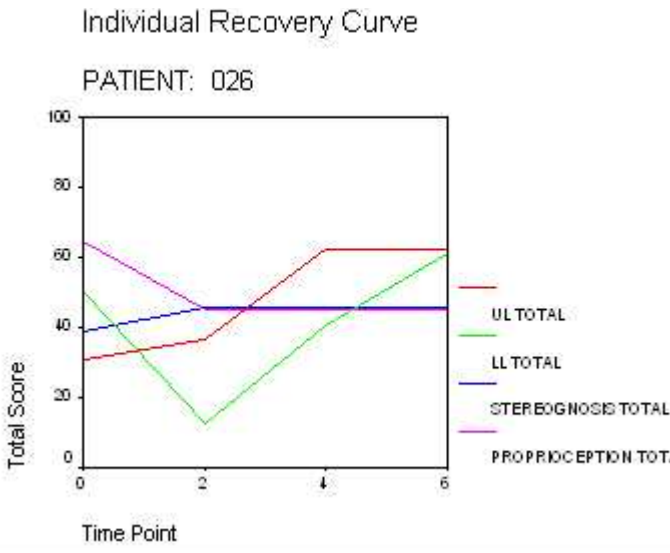

Individual Recovery Curve
PATIENT: 017
Total Score
Time Point
Individual Recovery Curve
PATIENT: 018
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

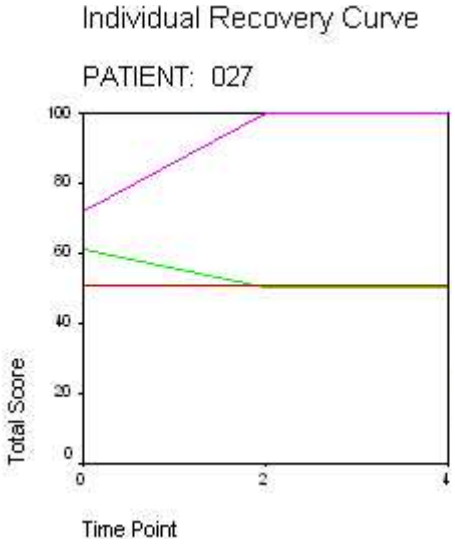

Individual Recovery Curve
PATIENT: 020
Total Score
Time Point
Individual Recovery Curve
PATIENT: 022
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

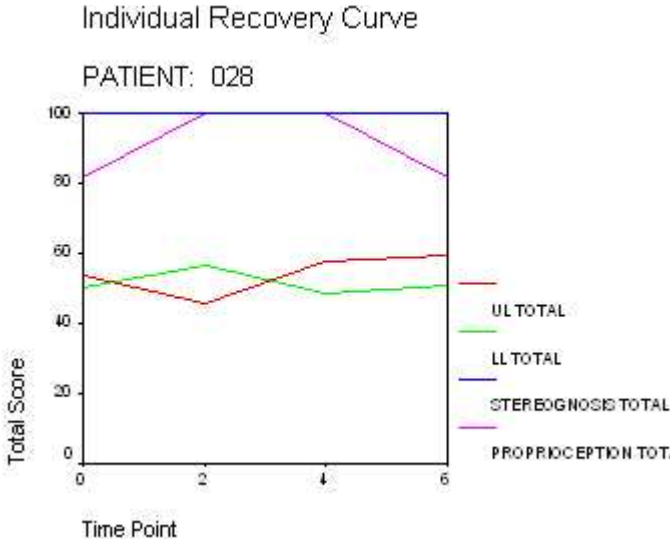

Individual Recovery Curve
PATIENT: 023
Total Score
Time Point

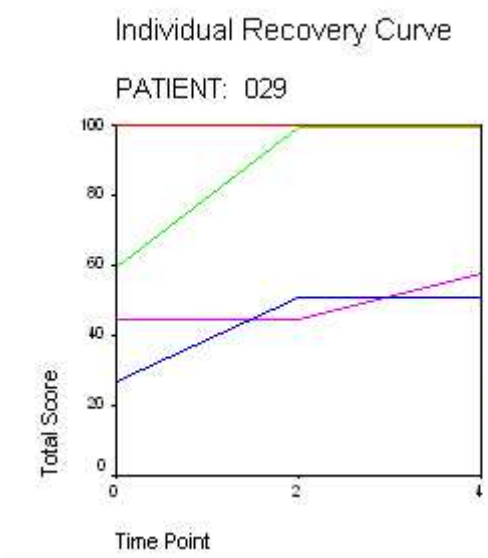

Individual Recovery Curve
PATIENT: 024
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

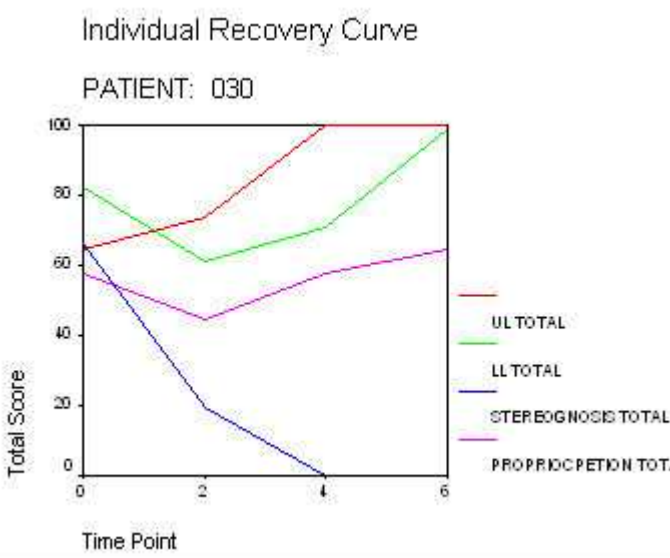

Individual Recovery Curve
PATIENT: 025
Total Score
Time point

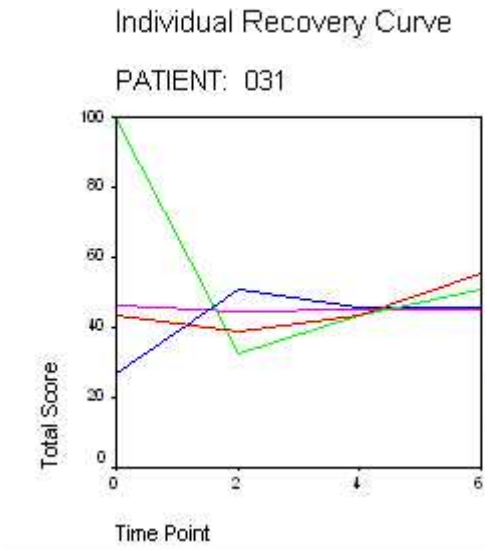

Individual Recovery Curve
PATIENT: 026
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

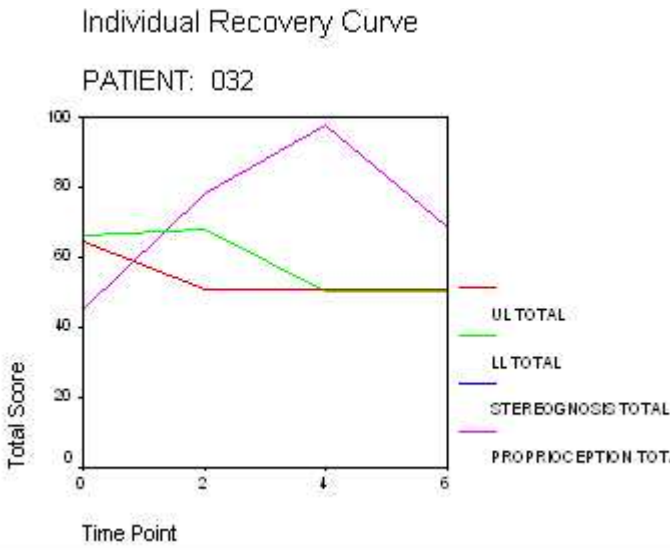

Individual Recovery Curve
PATIENT: 027
Total Score
Time Point

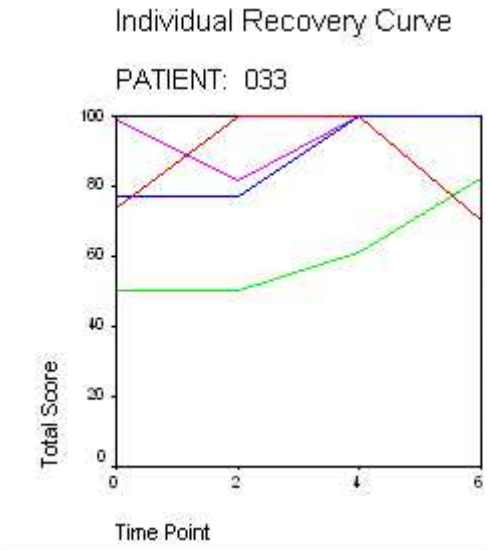

Individual Recovery Curve
PATIENT: 028
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

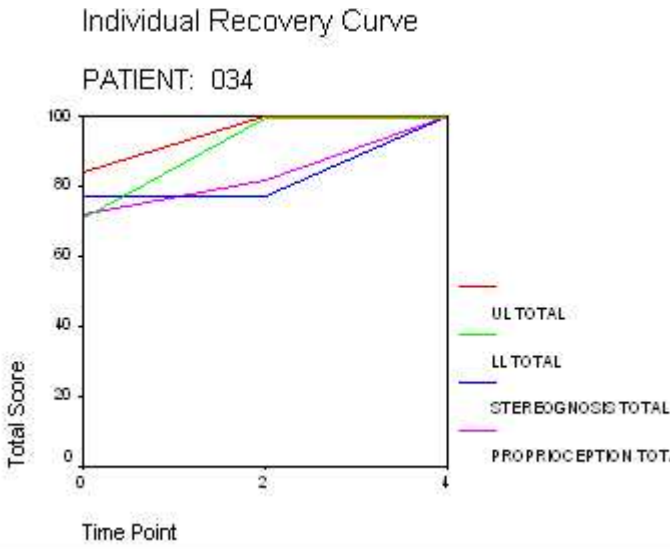

Individual Recovery Curve
PATIENT: 029
Total Score
Time Point

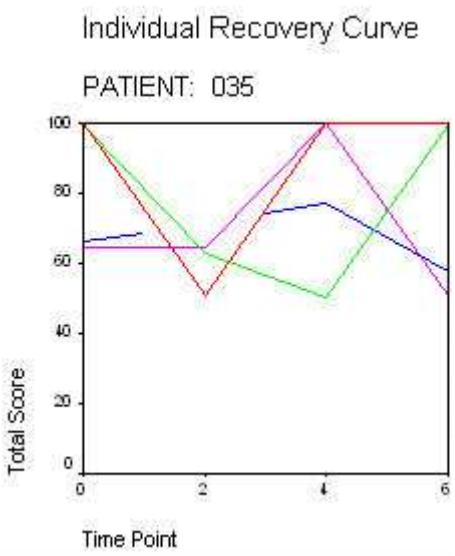

Individual Recovery Curve
PATIENT: 030
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

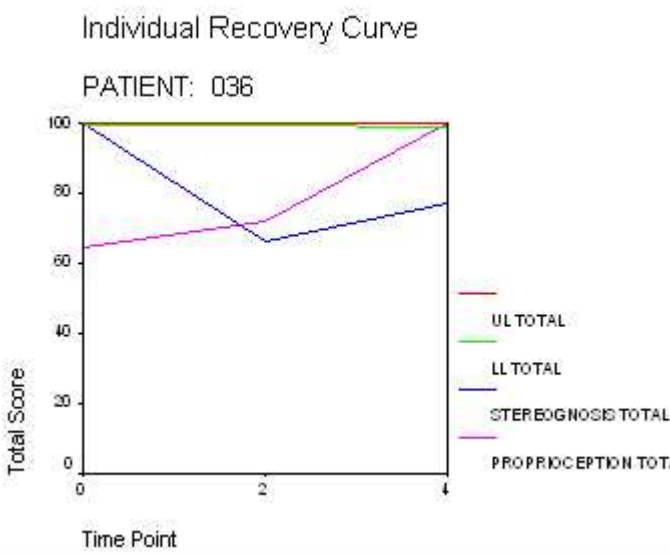

Individual Recovery Curve
PATIENT: 031
Total Score
Time Point

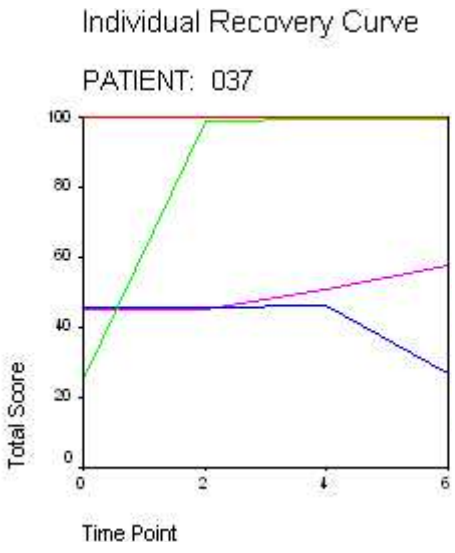

Individual Recovery Curve
PATIENT: 032
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

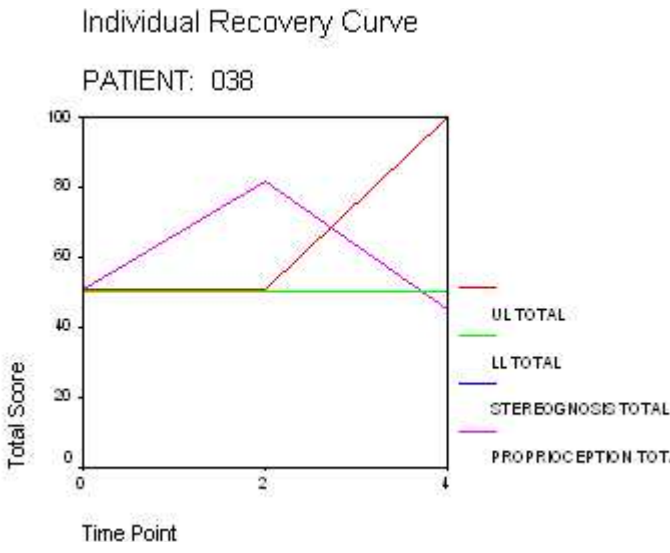

Individual Recovery Curve
PATIENT: 033
Total Score
Time Point

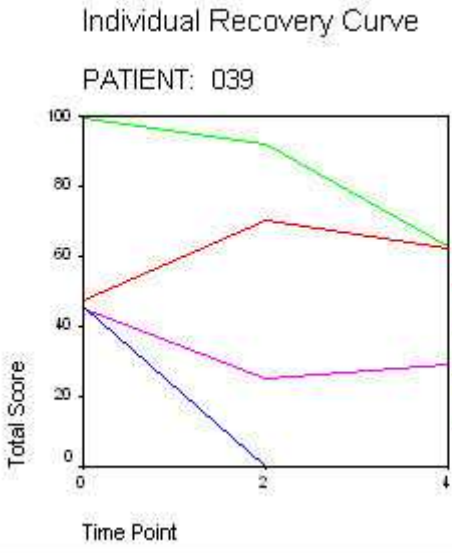

Individual Recovery Curve
PATIENT: 034
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

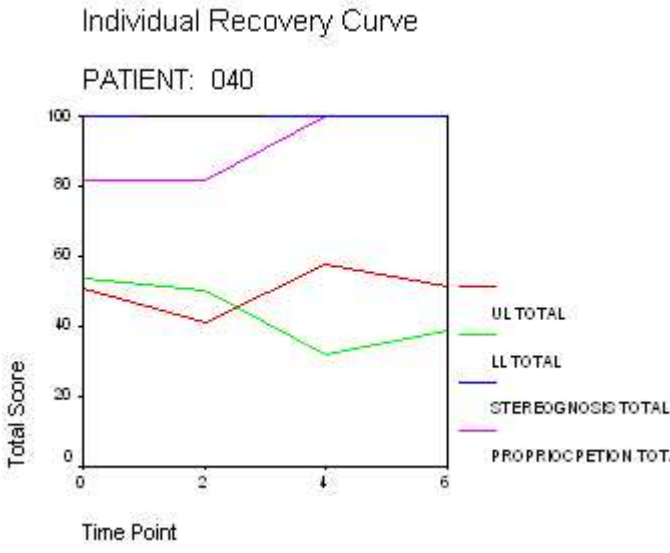

Individual Recovery Curve
PATIENT: 035
Total Score
Time Point

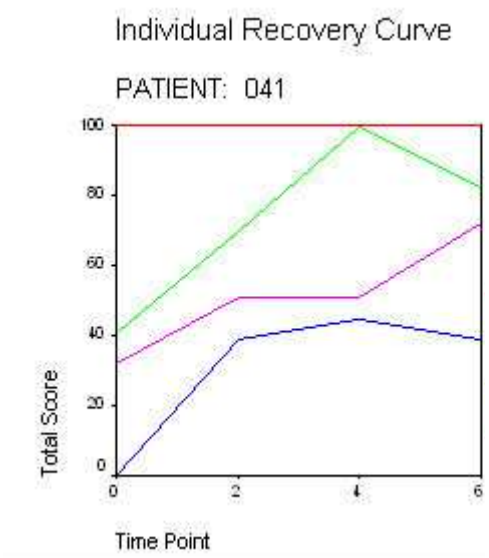

Individual Recovery Curve
PATIENT: 036
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

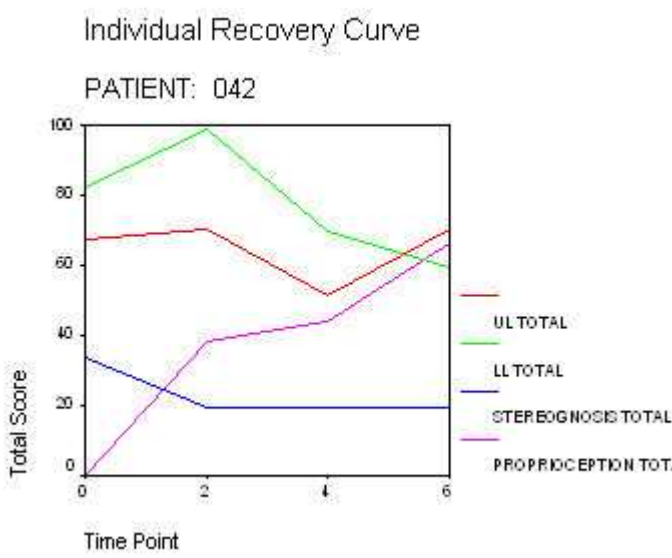

Individual Recovery Curve
PATIENT: 037
Total Score
Time Point

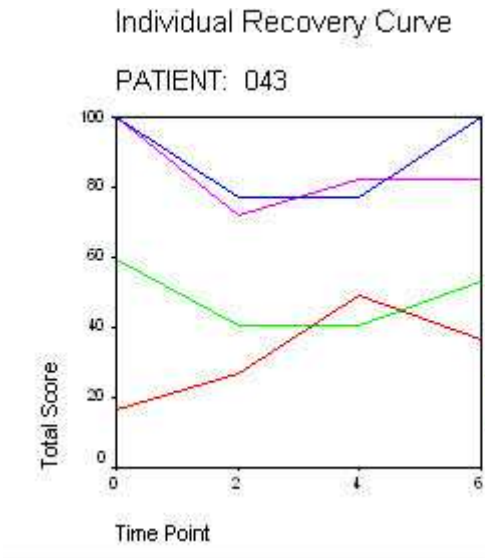

Individual Recovery Curve
PATIENT: 038
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

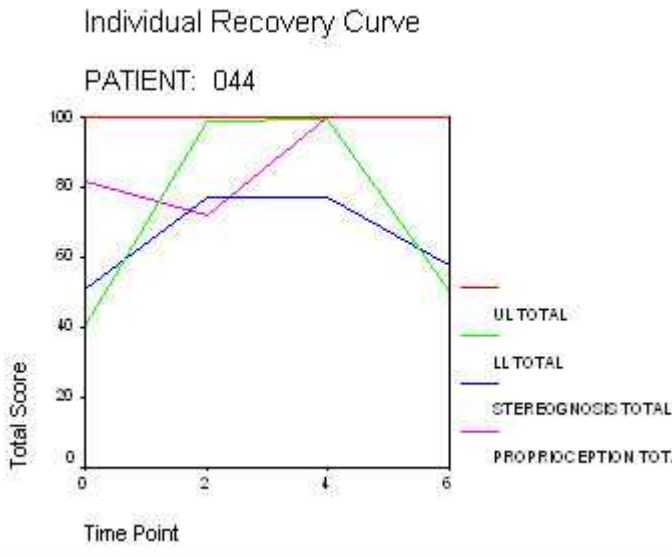

Individual Recovery Curve
PATIENT: 039
Total Score
Time Point

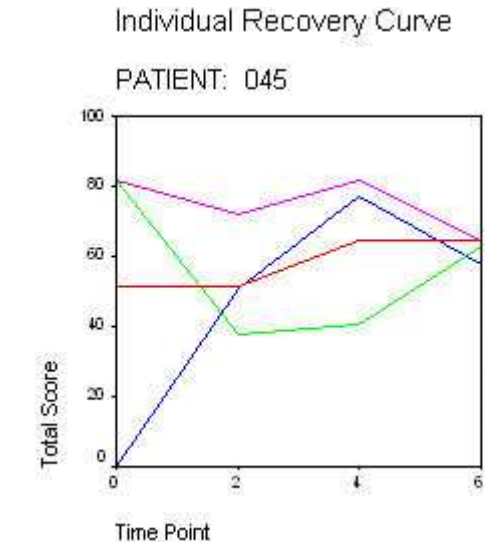

Individual Recovery Curve
PATIENT: 040
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

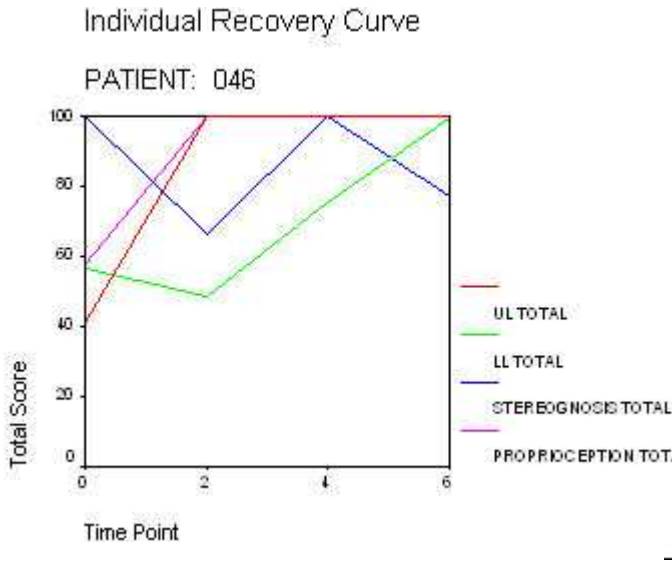

Individual Recovery Curve
PATIENT: 041
Total Score
Time Point

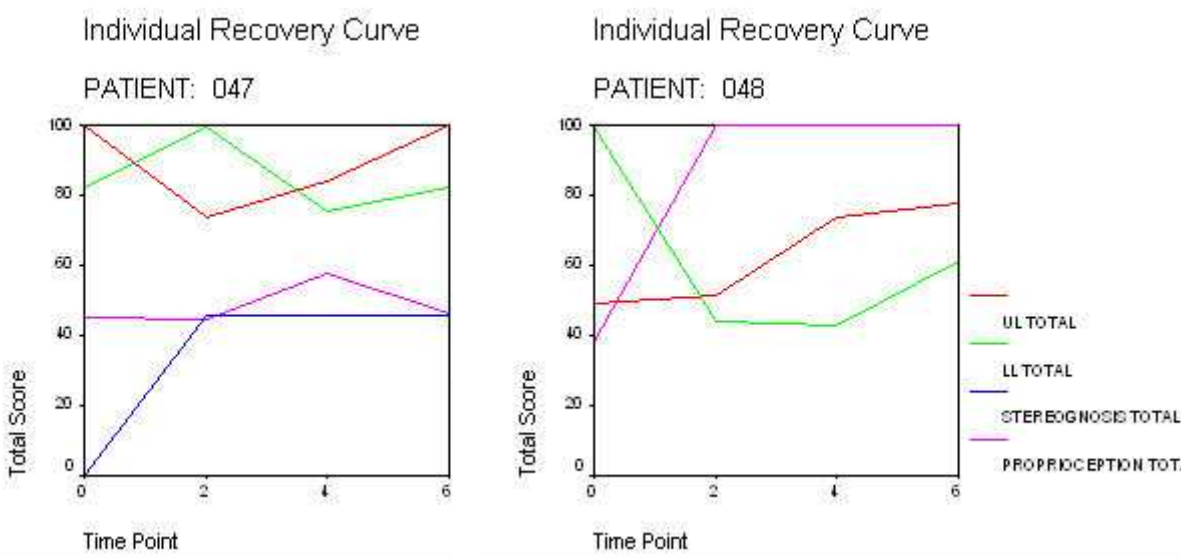

Individual Recovery Curve
PATIENT: 042
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

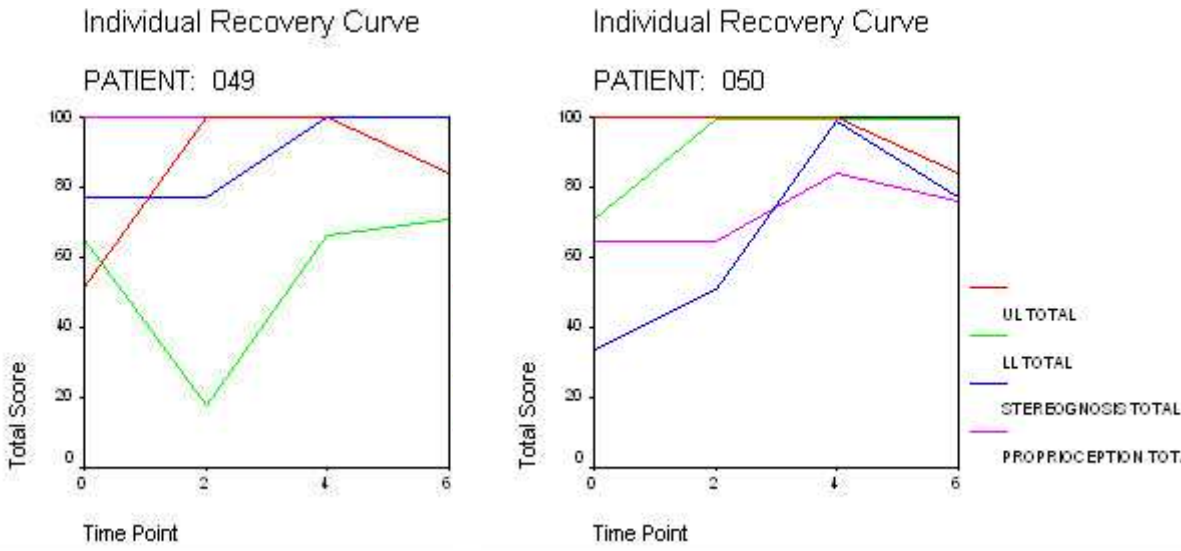

Individual Recovery Curve
PATIENT: 043
Total Score
Time Point

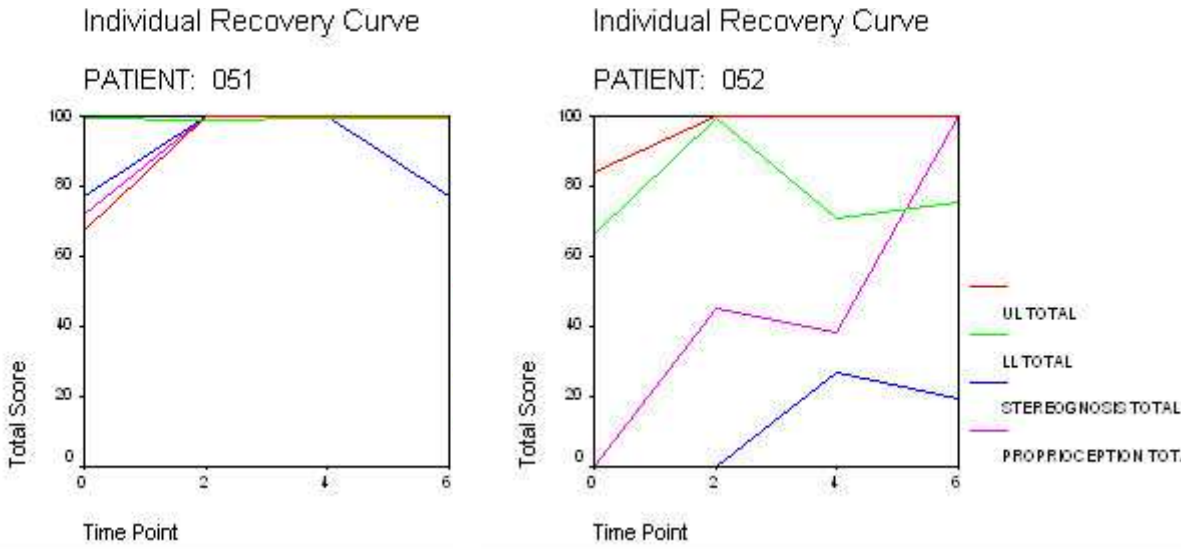

Individual Recovery Curve
PATIENT: 044
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

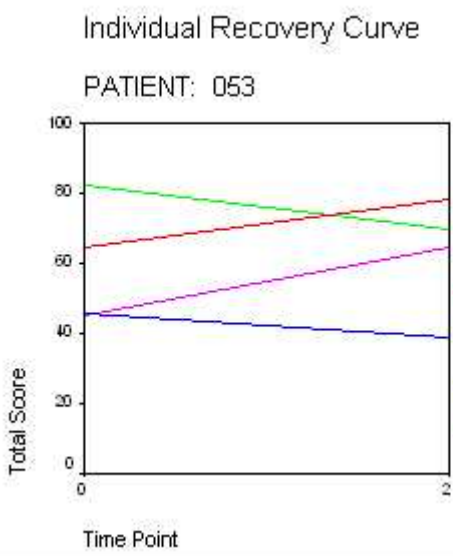

Individual Recovery Curve
PATIENT: 045
Total Score
Time Point

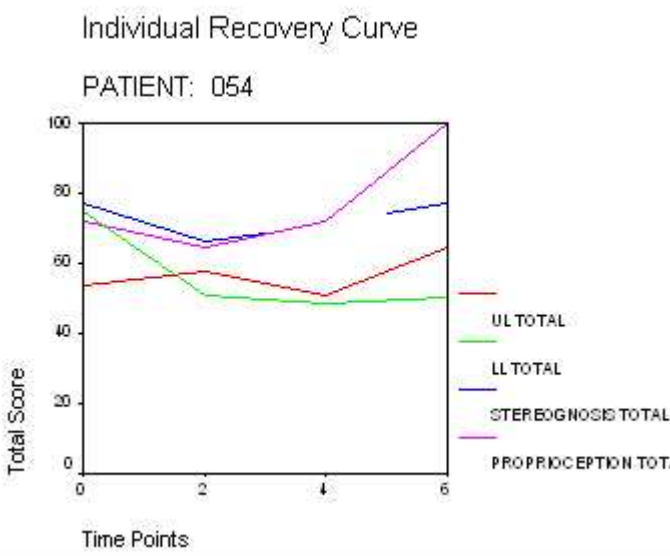

Individual Recovery Curve
PATIENT: 046
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

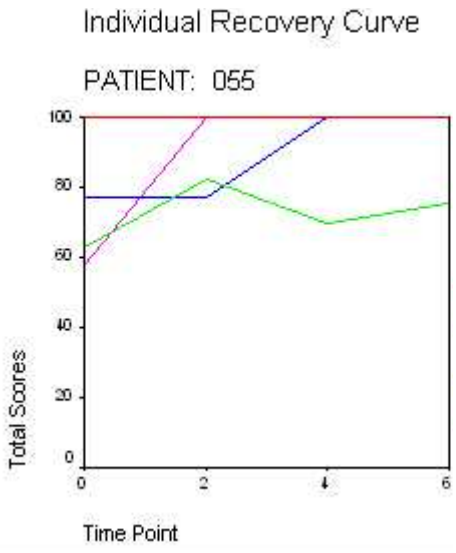

Individual Recovery Curve
PATIENT: 047
Total Score
Time Point
Individual Recovery Curve
PATIENT: 048
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

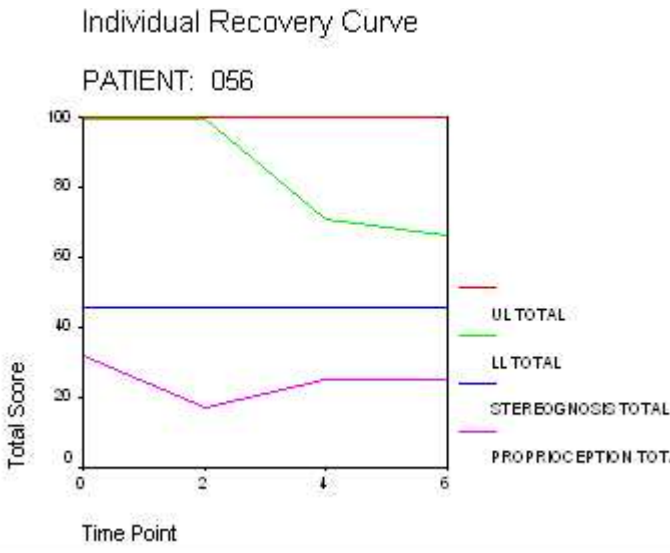

Individual Recovery Curve
PATIENT: 049
Total Score
Time Point
Individual Recovery Curve
PATIENT: 050
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

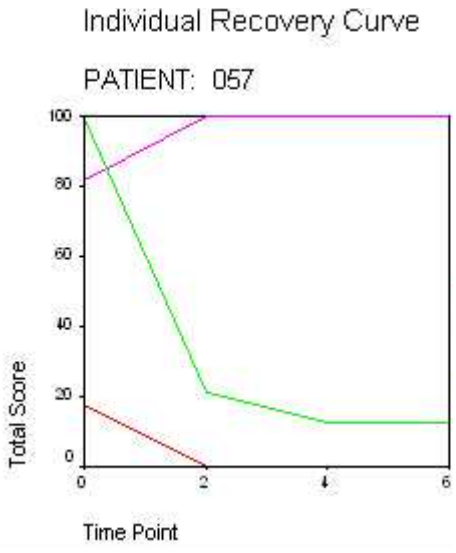

Individual Recovery Curve
PATIENT: 051
Total Score
Time Point
Individual Recovery Curve
PATIENT: 052
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

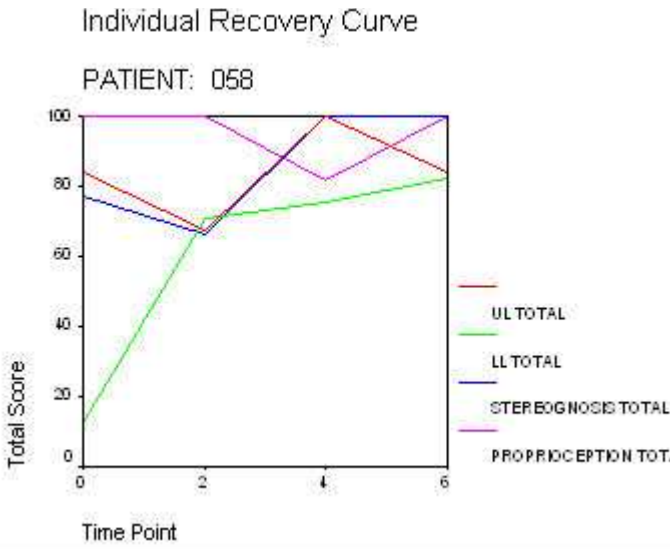

Individual Recovery Curve
PATIENT: 053
Total Score
Time Point

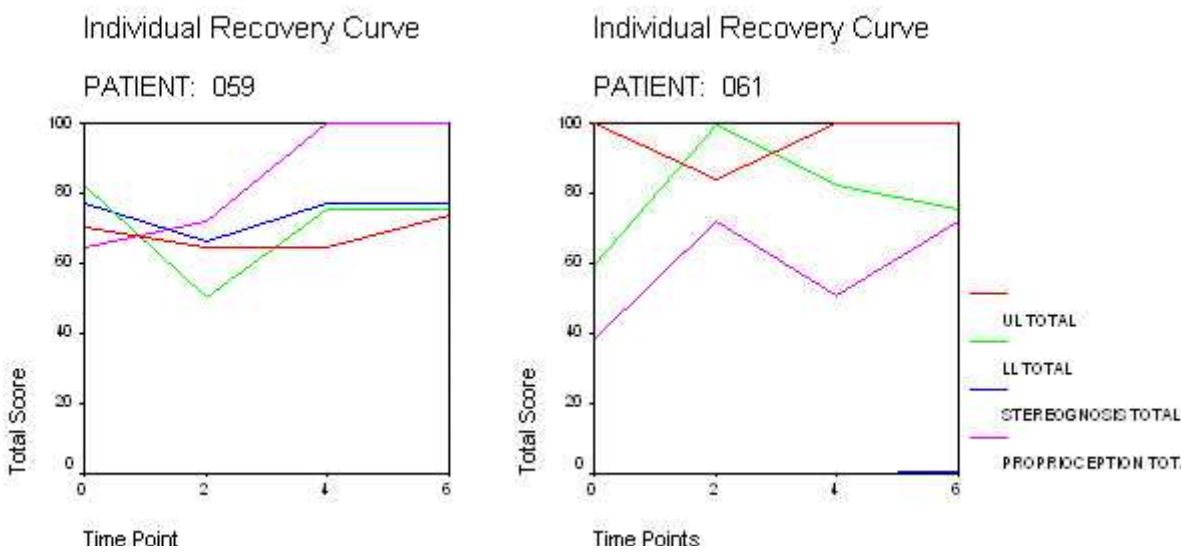

Individual Recovery Curve
PATIENT: 054
Total Score
Time Points
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT


Individual Recovery Curve
PATIENT: 055
Total Scores
Time Point

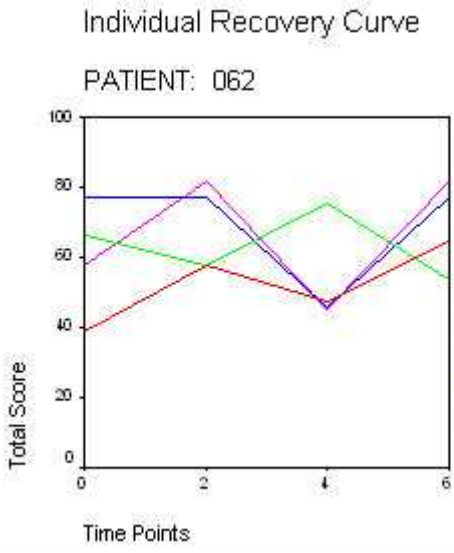

Individual Recovery Curve
PATIENT: 056
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

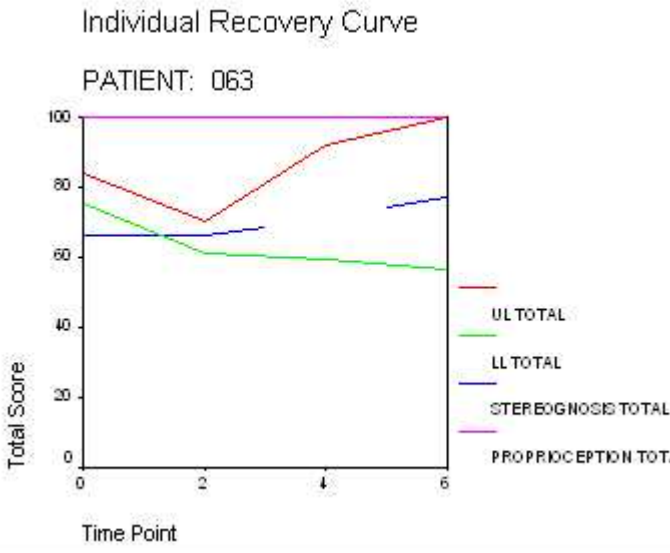

Individual Recovery Curve
PATIENT: 057
Total Score
Time Point

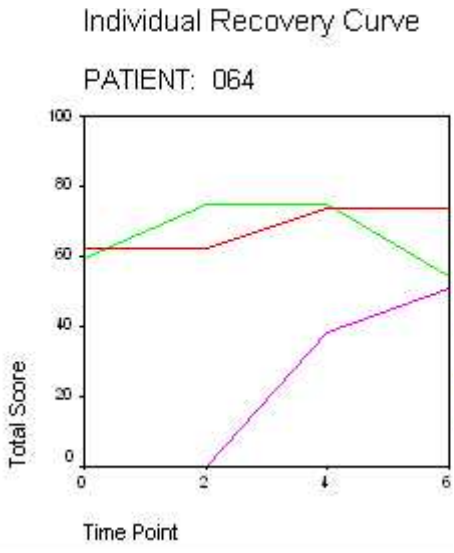

Individual Recovery Curve
PATIENT: 058
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

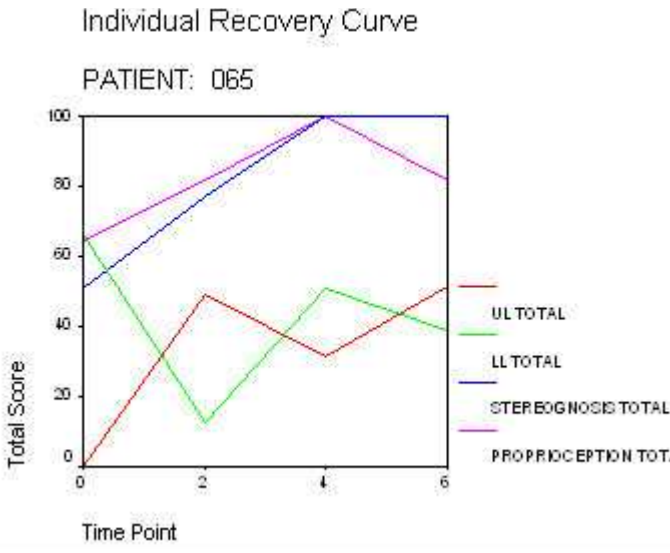

Individual Recovery Curve
PATIENT: 059
Total Score
Time Point

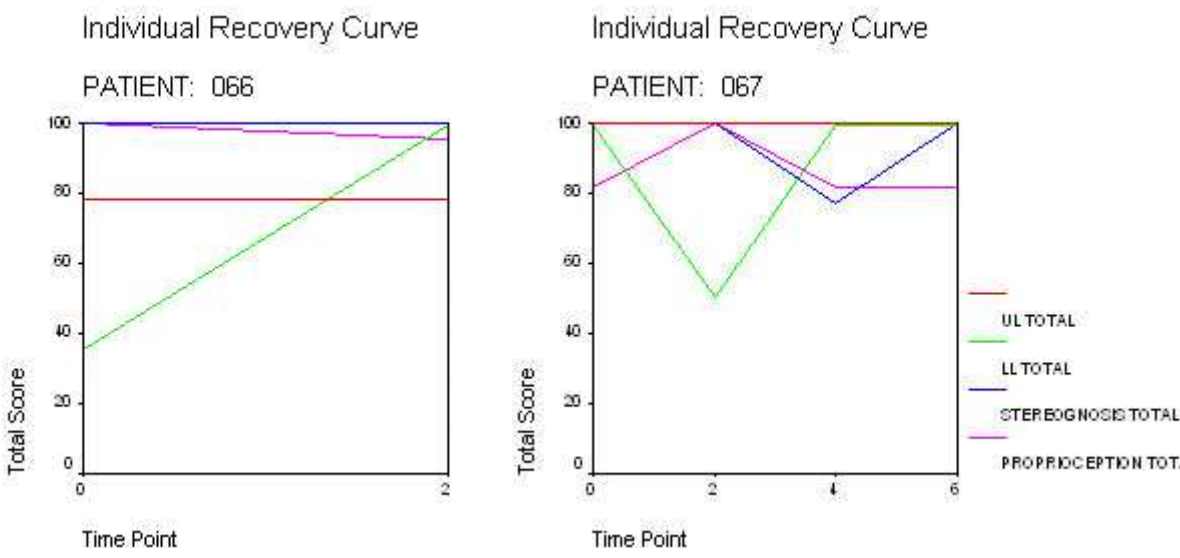
Individual Recovery Curve
PATIENT: 061
Total Score
Time Points
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

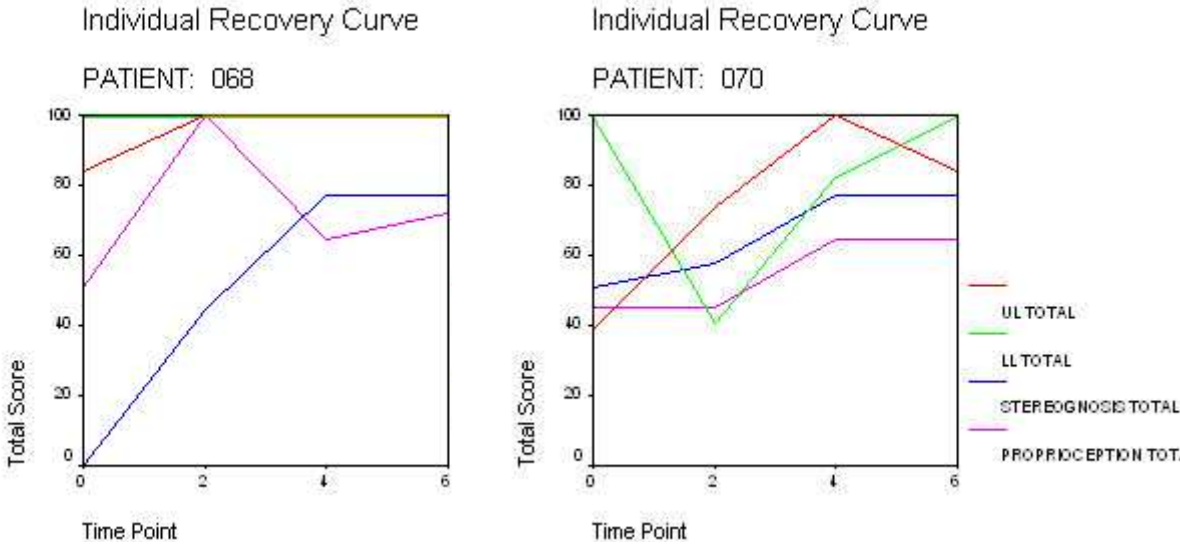

Individual Recovery Curve
PATIENT: 062
Total Score
Time Points

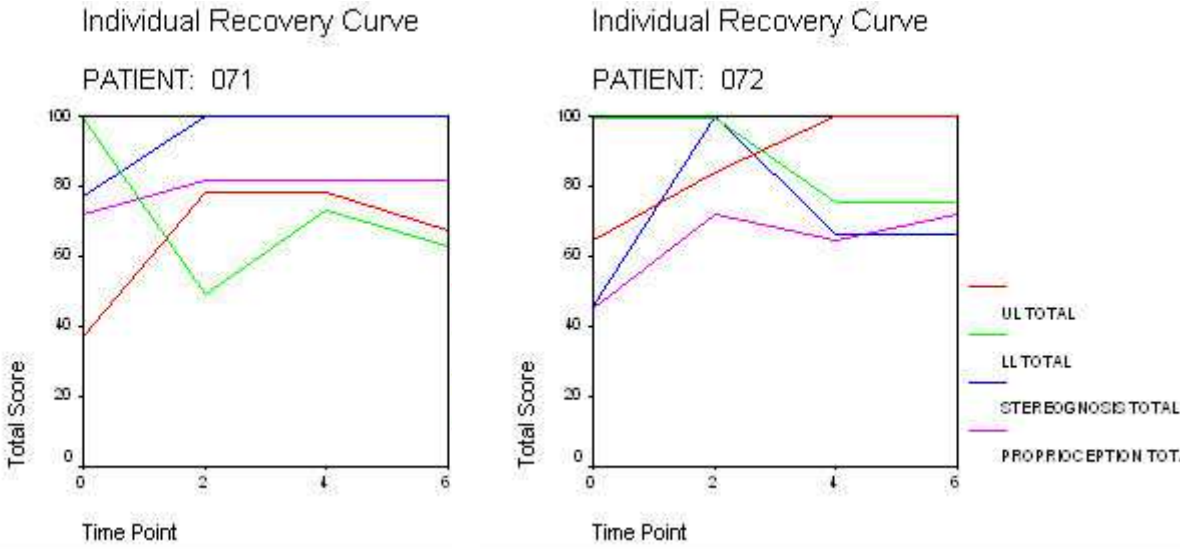

Individual Recovery Curve
PATIENT: 063
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT

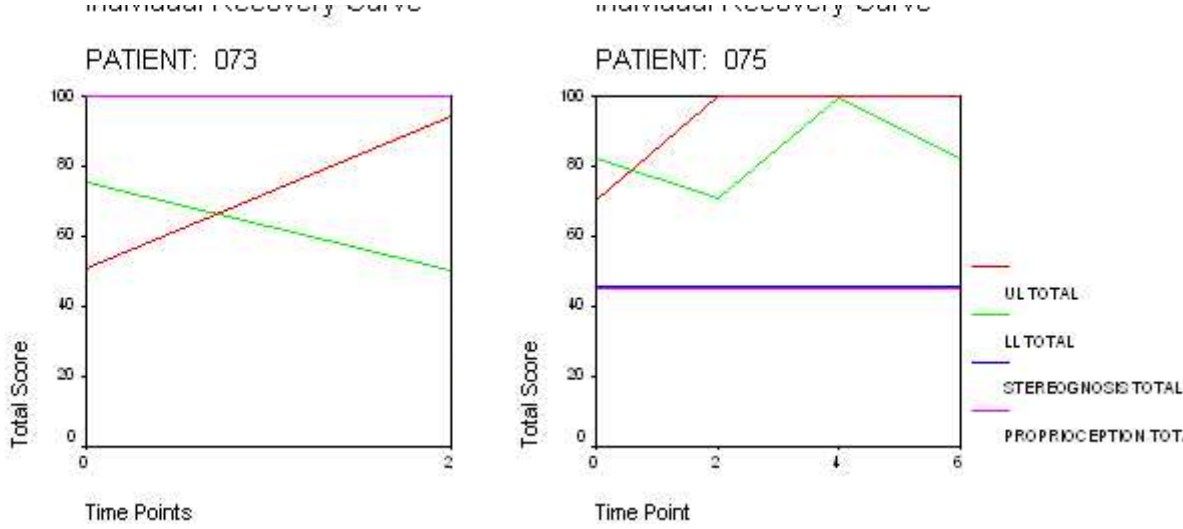

Individual Recovery Curve
PATIENT: 064
Total Score
Time Point


Individual Recovery Curve
PATIENT: 065
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT


Individual Recovery Curve
PATIENT: 066
Total Score
Time Point
Individual Recovery Curve
PATIENT: 067
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT


Individual Recovery Curve
PATIENT: 068
Total Score
Time Point
Individual Recovery Curve
PATIENT: 070
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT


Individual Recovery Curve
PATIENT: 071
Total Score
Time Point
Individual Recovery Curve
PATIENT: 072
Total Score
Time Point
UL TOTAL
LL TOTAL
STEREOGNOSIS TOTAL
PROPRIOCEPTION TOT



These graphs show considerable variation for individuals' performances; some showed improvement, some deterioration and many patients showed variable performance. Some patients had similar recovery curves for the four sensory subscales e.g. patients 002, 034, 051. Others had very different curves for each of the sensory subscales e.g. patients 013, 015, 030. The steepest slopes, both positive and negative, were found between 0 and 2 months. There are several patients who show marked deterioration in lower limb scores between 0 and 2 months (e.g. patients 005, 013, 031, 048, 049, and 057). However the subscales had relatively few items (particularly the shortened stereognosis scale, consisting of six items) and the total scores have been transformed on to a 100-point interval scale. Therefore a change in the slope in clinical terms may only mean a small change in performance, and therefore the graphs need to be interpreted with caution. To investigate the change scores between 0 and 2 months, 2 & 4 months and 4 & 6 months for each patient were calculated. Descriptive statistics of these changes scores are shown in table 36.

Table 36: Descriptive Statistics for the Change Scores for the Four Sensory Subscales

Sensory Subscale	Change Between	N	Minimum	Maximum	Mean	S.D.
Upper Limb	0 & 2 months	66	-50	59	8.6	20.0
	2 & 4 months	62	-50	50	2.3	17.9
	4 & 6 months	55	-30	50	2.7	12.6
Lower Limb	0 & 2 months	66	-78	73	-7.3	34.3
	2 & 4 months	62	-29	49	4.2	20.8
	4 & 6 months	55	-49	49	0.8	18.7
Stereognosis	0 & 2 months	57	-47	77	7.2	25.2
	2 & 4 months	50	-34	48	6.7	18.6
	4 & 6 months	47	-34	31	-2.9	13.5
Proprioception	0 & 2 months	66	-42	62	7.5	20.5
	2 & 4 months	62	-55	42	1.2	19.3
	4 & 6 months	54	-49	62	3.7	18.1

This table reflects the large variation in scores. Some people deteriorated and others improved. All sensations showed most variable change between admission and 2 months, with higher standard deviations at this time point compared with between 2 and 4 months, and 4 and 6 months. The lower limb scale showed a mean negative change indicating many patients deteriorated between admission and 2 months. It also has the largest standard deviation showing there was a wide range of change scores. There was also a small negative value (-2.9) for the mean change score in stereognosis between 4 and 6 months.

Those patients who showed significant recovery (i.e. improved by more than 2 s.d. of change score) or deterioration (worsened by more than 2 s.d. of change score) were investigated to determine factors relating to significant change in individuals. Their change scores are reported in the table below. Those showing significant changes are highlighted (yellow if improved, red if deteriorated).

Key

Significant improvement

Significant deterioration

Table 37: Change Scores For All Patients For The Four Sensory Subscales

Patient	Upper Limb Change Score			Lower Limb Change Score			Stereognosis Change Score			Proprioception Change Score		
	0 & 2 mths	2 & 4 mths	4 & 6 mths	0 & 2 mths	2 & 4 mths	4 & 6 mths	0 & 2 mths	2 & 4 mths	4 & 6 mths	0 & 2 mths	2 & 4 mths	4 & 6 mths
1	.	.	.	.	.	.	.	.	.	.	.	.
2	-6	11	0	21	-4	16	-11	11	-11	21	9	-17
3	5	20	2	23	-28	23	44	23	-34	37	0	0
4	44	-8	.	-36	7	.	15	.	.	0	-55	.
5	11	-11	8	-70	-21	13	0	19	-19	28	-7	8
6	.	.	.	.	.	.	.	.	.	.	.	.
8	0	0	0	45	6	0	-23	23	0	-23	42	0
9	22	-16	16	-17	-7	-5	26	-19	19	0	-34	35
10	16	0	0	33	0	-24	11	0	23	4	-9	9
11	8	6	-10	-22	-11	33	27	11	-11	0	-9	0
12	.	.	.	.	.	.	.	.	.	.	.	.
13	-4	11	3	-49	-2	13	33	17	-17	20	13	28
14	30	0	0	-3	40	-17	11	0	0	0	-18	18
15	-16	-19	35	0	-1	-22	19	-13	-4	-42	18	-31
16	6	0	16	-3	16	24	50	-19	8	20	-17	6
17	42	-50	15	-36	36	-35	77	23	.	-15	-8	.
18	14	-24	-4	7	-23	11	-27	38	0	0	-7	42
20	26	0	0	16	24	0	-23	0	-19	1	0	0
22	0	-28	50	-46	22	-26	0	.	.	0	-28	0
23	-16	.	.	-17	.	.	0	.	.	-28	.	.
24	30	-16	16	-34	34	0	11	-31	12	-9	-27	0
25	16	-50	0	-35	34	-49	.	.	.	-1	13	0
26	5	26	0	-37	28	21	7	0	0	-19	0	0
27	0	0	.	-11	0	.	.	.	.	28	0	.
28	-8	12	2	7	-8	3	0	0	0	18	0	-18
29	0	0	.	40	0	.	24	0	.	0	13	.
30	9	26	0	-21	10	28	-47	-19	0	-13	13	7
31	-4	4	12	-67	11	8	24	-5	0	-2	1	0
32	-14	0	0	1	-18	0	.	.	.	33	20	-29
33	26	0	-30	0	11	21	0	23	0	-17	18	0
34	16	0	.	29	0	.	0	23	.	9	18	.
35	-50	50	0	18	0	0	.	.	-19	0	35	0
36	0	0	.	0	-1	.	-34	11	.	8	28	.

37	0	0	0	73	1	0	0	1	-19	0	6	7
38	0	50	.	0	0	.	.	.	.	31	-36	.
39	23	-8	.	-8	-29	.	-46	0	.	-20	4	.
40	-9	17	-6	-4	-18	7	.	.	0	0	18	0
41	0	0	0	29	30	-17	39	6	-6	19	0	21
42	3	-19	19	16	-29	-10	-14	0	0	38	5	23
43	11	22	-13	-20	0	13	-23	0	23	-28	10	0
44	0	0	0	58	1	-49	26	0	-19	-9	28	0
45	0	13	0	-44	3	22	51	26	-19	-9	9	-17
46	59	0	0	-8	27	24	-34	34	-23	42	0	0
47	-26	10	16	17	-24	7	46	0	0	-1	13	-11
48	2	22	4	-55	-1	18	.	.	.	62	0	0
49	49	0	-16	-48	49	4	0	23	0	0	0	0
50	0	0	-16	29	0	0	17	48	-22	0	20	-8
51	33	0	0	-1	1	0	23	0	-23	28	0	0
52	16	0	0	33	-29	5	0	27	-8	45	-7	62
53	13	.	.	-13	.	.	-7	.	.	19	.	.
54	4	-7	14	-24	-2	2	-11	.	.	-8	8	28
55	0	0	0	20	-13	6	0	23	0	42	0	0
56	0	0	0	0	-29	-4	0	0	0	-15	8	0
57	-18	0	0	-78	-8	0	.	.	.	18	0	0
58	-17	33	-16	58	5	7	-11	34	0	0	-18	18
59	-6	0	9	-32	26	0	-11	11	0	8	28	0
60	.	.	.	.	.	.	.	.	.	.	.	.
61	-16	16	0	40	-17	-7	0	0	1	34	-21	21
62	19	-10	17	-9	18	-22	0	-31	31	24	-36	36
63	-14	22	8	-15	-2	-3	0	.	.	0	0	0
64	0	12	0	15	0	-21	0	0	0	0	38	13
65	49	-18	20	-54	38	-12	26	23	0	17	18	-18
66	0	.	.	64	.	.	0	.	.	-4	.	.
67	0	0	0	-49	49	0	0	-23	23	18	-18	0
68	16	0	0	0	0	0	45	32	0	49	-35	8
70	35	26	-16	-59	42	17	7	19	0	0	19	0
71	41	0	-11	-50	24	-10	23	0	0	9	0	0
72	19	16	0	0	-24	0	54	-34	0	27	-8	8
73	44	.	.	-26	.	.	.	.	.	0	.	.
74	.	.	.	.	.	.	.	.	.	.	.	.
75	30	0	0	-12	29	-17	0	0	0	0	0	0

Overall the table shows that marked changes in ability were scattered across patients and across time points, indicating there were no patients who overall showed very marked changes across sensory abilities. Although on inspection, it appeared that several patients showed deterioration in lower limb sensation between 0 & 2 months, this was only significant in 2 patients (due to a large S.D.). Overall 24 patients showed significant recovery in 30 areas, as some patients showed significant improvement in more than one score or at more than one time point. Ten patients showed significant deterioration. It was hypothesised that sensory ability would recover with time, therefore significant deterioration was not expected. People who deteriorated were investigated further to determine whether there was real deterioration or whether extrinsic factors might account for it. It was possible to find reasons for 7 of the 10 patients' deterioration when the raw data and patients' records were cross-checked. These were:

Patient 4 On mental health ward at 4 months, limited concentration may have lowered scores

Patient 5 Not able to assess all lower limb areas at intake and 2-month assessment as wearing TEDS therefore total scores were calculated though maximum possible total score was less

Patient 17 Different assessor at 4 months suggesting a potential problem with inter-rater reliability.

Patient 25 Tearful at 4-month assessment, therefore not fully attentive

Patient 35 Unable to assess some of upper limb and proprioception at admission therefore total scores were calculated though maximum possible total score was less

Patient 44 Fractured tibia/fibula at 6 months

Patient 57 Inconsistent communication at admission, with the patient having difficulty comprehending intructions with some possible false positive responses at intake (responding yes when she was not aware of the stimulus)

For the remaining 3 patients, 1 patient (patient 3) had deterioration in stereognosis between 4 and 6 months. This was due to the patient guessing similar objects but not the exact item at six months. For the other 2 patients (patients 15 and 33), they had a decrease in RMA & Barthel scores respectively suggesting some other event may have occurred. Therefore it seems the reasons for significant deterioration can be explained, and that the assessment is accurately reflecting sensory ability.

For analysis, those who deteriorated for factors unrelated to their sensory ability could have been removed. However it was decided not to since these problems are likely to occur in clinical practice and many are subjective. For example how it was decided if the patient was fully attentive or not was subjective and therefore commented on by the assessor. Therefore a decision was made to include all patients who were assessed in the analysis.

The lower limb scale particularly did not show a significant recovery pattern. There were no significant differences between scores at different time points. However a few did improve therefore the patients whose lower limb total score positively improved between 0 and 2 months were compared with those who deteriorated in order to identify factors associated with recovery of lower limb sensation. Mann-Whitney U tests were used to compare sensory ability to performance on the NIHSS, Barthel, RMA and EADL between those who improved and those who did not. These results are shown in table 38.

Table 38: Comparison of the stroke severity, motor and ADL ability for those patients whose lower limb score improved with those who deteriorated

		Score Improved n=23	Score deteriorated n=34	Mann-Whitney Statistic	
NIHSS	Median IQR	4 4	8 6.75	U value p	172.5 <0.001*
RMA Gross Function at admission	Median IQR	6 7	1 4.25	U value p	185.0 0.001*
RMA Gross Function at 2 months	Median IQR	9 5	5 7.5	U value p	193.0 0.001*
RMA Leg & Trunk at admission	Median IQR	8 3	3 5	U value p	230.0 0.008*
RMA Leg & Trunk at 2 months	Median IQR	7 7	6 7.5	U value p	212.5 0.003*
RMA Upper Limb at admission	Median IQR	9 10	1 5	U value p	190.0 0.001*
RMA Upper Limb at 2 months	Median IQR	13 6	2.5 10.25	U value p	162.0 <0.001*
Barthel at admission	Median IQR	75 35	37.5 51.25	U value p	172.5 <0.001*
Barthel at 2 months	Median IQR	95 15	75 51.25	U value p	181.0 0.001*
EADL at 2 months	Median IQR	13 12	4 8	U value p	229.0 0.012*

This showed significant differences ($p<0.05$) for the NIHSS total, RMA gross function, upper limb and leg and trunk sections on admission and 2 months, Barthel at 0 and 2 months, and EADL score at 2 months. Patients who deteriorated in lower limb sensory ability had more severe strokes, worse

motor ability and less independence in activities of daily living ability compared with those who improved.

6.4 Discussion: Individual Sensory Recovery

Although most sensations showed recovery, there was a lot of individual variation in the pattern of recovery and some patients showed deterioration. Possible reasons for significant deterioration have been speculated such as other medical events, inconsistent communication or attention. In some cases, other medical factors may have caused deterioration. However some medical problems were recorded and when sensory assessment was still possible, it seemed not to affect sensory performance. One patient had a myocardial infarction and two patients had chest infections during the follow-up period, though not near to the time of their assessment and this did not seem to influence their performance. Two people had further strokes. One of these patients (Patient 53) then withdrew from the study, and it did not seem to affect sensory performance in the other. It is recognised that other medical events, including further strokes, that were not identified could have influenced sensory recovery and explain some of the variation in the sensory scores.

The fact that when a different assessor assessed one patient (patient 17) there was a discrepancy in scores suggested there may be a problem with the inter-rater reliability of the scale. Therefore this was investigated, and is detailed in the appendix 7. This showed the inter-rater reliability of the shortened NSA to be good.

To fit the sensory subscales to the Rasch model, items were removed from each scale. This meant the shortened scales from which total scores were derived included fewer items. However the scales had increased sensitivity, as the

results from fewer items were transformed on to a 0-100 scale. The smallest scale is the stereognosis scale with six items. Therefore a small difference in the actual assessment (e.g. incorrectly naming one object) may make a big difference in total score and appear as a large change on the individual recovery graphs. This is why it was important to investigate significant change as defined by a change as greater than two standard deviations.

Some patients had variable performance on the NSA throughout the six months. Reasons for this included patients' mood, concentration and attention at the time of assessment. Although every effort was made to assess patients when they were alert and at the time of day that was best for them, this was not always possible. Some patients found the length of the NSA hard to tolerate, particularly at the initial assessment. It was also difficult to assess whether concentration was maintained when the patient was blindfolded. Though steps were taken to minimize distraction, such as testing in a quiet area, ideal testing conditions were difficult to control completely. The distractions differed dependent on the constraints of the environment where testing was done e.g. interruptions from other staff on the stroke units, telephone ringing while at patient's home. These might all have affected the results of the NSA, as it is known that attention affects performance of the somatosensory system (Hamalainen et al., 2002, Hsiao et al., 2002). Other reasons for variation included how tired patients were, and their interest in their performance. During the six-month follow-up period, some patients became disinterested in the assessment and found it monotonous, whereas some viewed the assessment as a challenge and were eager to know if their performance had improved since

their last assessment. Therefore this could impact on sensory performance on the NSA.

Although there was little variation in lower limb sensory scores over time, the fact that there were significant differences between those who improved and those who deteriorated suggests the NSA was detecting differences between patients groups, as opposed to being inconsistent or indicative of an unreliable tool.

Overall this analysis indicated that the NSA was sensitive to change in abilities over time, did detect sensory impairment and that some sensory abilities showed significant recovery over time.

6.5 Results: Factors Relating to Stereognosis Impairment

It was recognised that cognitive impairment may affect stereognosis ability. Cognitive factors were recorded on the NIHSS. Therefore the relationship between stereognosis impairment and cognitive factors, including inattention, orientation in time, aphasia, dysarthria, visual field problems and the ability to follow commands was examined. Cross tabulations and chi-squares were calculated for stereognosis ability on admission and the other factors on the NIHSS. The patients were divided into two groups (above and below the 50^{th} percentile) according to their total scores on the stereognosis scale.

Table 39: Cross tabulations for cognitive factors with stereognosis impairment

		Inattention	
		No	Yes
Stereognosis	<50	5	8
	>50	30	12

		Orientation in Time	
		Present	Absent
Stereognosis	<50	11	2
	>50	37	5

		Aphasia	
		No	Yes
Stereognosis	<50	12	1
	>50	33	9

		Dysarthria	
		No	Yes
Stereognosis	<50	7	6
	>50	33	9

		Visual field problems	
		No	Yes
Stereognosis	<50	9	4
	>50	38	4

		Ability to follow commands	
		Present	Absent
Stereognosis	<50	12	1
	>50	42	0

Table 40: The Difference in Stereognostic Ability by Cognitive Related Factors

Factors	χ^2
Inattention	0.04*
Orientation in Time	0.74
Aphasia	0.25
Dysarthria	0.09
Visual Field Problems	0.08
Ability to follow commands	0.07

The results showed no significant difference between the groups for the presence of aphasia, dysarthria, visual field problems and ability to follow commands, with impairment in these not associated with worse stereognostic ability. However the presence of dysarthria, visual field problems and ability to follow commands were approaching significance. There was a significant difference in stereognosis between those with and without inattention (χ^2 $p<0.05$).

6.6 Discussion: Factors Relating to Stereognosis Impairment

Stereognosis ability was significantly different between those patients with and without inattention. No other cognitive factors, including orientation in time, aphasia, dysarthria, visual field problems and ability to follow commands showed significance. However relatively few patients actually showed cognitive related problems (e.g. 8 had visual field problems, 10 had aphasia). Therefore it is probably due to the lack of sensitivity of the NIHSS assessment

that fewer factors were not significant. This is supported by the observation that dysarthria, visual field deficits and ability to follow commands were approaching significance. This is because the NIHSS is a gross measure of stroke severity and not specifically a test of cognition. Therefore conclusions must be taken with caution.

Inattention was detected using the NIHSS, and included visual, tactile, auditory, spatial, or personal inattention or extinction to bilateral simultaneous stimulation in one of the sensory modalities. This is assessed rather subjectively using information obtained during the prior testing of the NIHSS. Patients were classified as having profound hemi-inattention or extinction to more than one modality if they did not recognize their own hand or oriented to only one side of space. Therefore it included many different forms of inattention but was assessed rather crudely. Inattention occurs as a result of damage to the posterior parietal cortex, frontal lobe, cingulate gyrus, striatum, thalamus, or specific brain-stem nuclei, with the neural network for attention an example of how different anatomic areas work together to produce a specific behaviour (Swan, 2001). Stereognosis is regarded as a complex sensation requiring the integration of many abilities, and has cognitive components such as integrating the sensory information and naming the object (Roland, 1976a), as with all sensory tasks it has a decision-making element (Romo et al., 2002). These different components of stereognosis call upon many different anatomical areas of the brain. Stereognosis impairment has been seen following lesions of sensory hand areas, contralateral postcentral gyrus, parietal lobes, non-parietal areas and ipsilateral hemisphere (Roland, 1976). As both stereognosis and attention require large neural networks, with

stereognosis requiring the person to attend to the object recognition task, it is not surprising that impairment in attention impacts on stereognosis ability. It has been shown that object recognition requires a highly specific integration across different cortical areas (Kang et al., 1985). If someone is unable to attend to the contralateral side of their body, it is logical to assume that they will not be able to recognise an object placed in their contralateral hand. It may be that impairments of stereognosis and manifestations of sensory inattention, as patients were not excluded from stereognosis assessment if inattention was detected. Previous researchers have suggested that it is necessary to distinguish between sensory impairment and neglect (Carey, 1995). This is a limitation of this study.

Previous literature supports the fact that inattention impacts on stereognosis ability. It has been speculated that increased blood flow in the frontal region during stereognosis tasks reflects an attentional component (Roland, 1976). In people with multiple sclerosis, correlation has been found between stereognosis and other neuropsychological measures when sensory deficits were controlled for (Beason-Hazen et al., 1993), with stereognosis impairment related to worse performance in cognitive domains. Using fMRI attention-related changes have been shown in somatosensory areas(Hamalainen et al., 2002, Hsiao et al., 2002), although there was individual variability in these changes and these were directed at tactile stimulation and orientation tasks as opposed to stereognosis.

The results in this study seem consistent with previous research, that stereognosis has a cognitive component. However, this was not the main focus

of this thesis, and it would be useful to investigate this further using more sensitive cognitive measures, particularly those of inattention.

6.7 Results: Factors Relating to Sensory Impairment and Recovery

Many patients had some form of sensory impairment and this recovered over time. It was then investigated whether stroke severity, motor and ADL ability and age related to this sensory impairment and to sensory outcome at six-months. Prior to analysis, data were screened for fit with the assumptions of multivariate analysis. Normality was examined using the Kolmogorov Smirnov (K-S) Lilliefors test, and bivariate scatter graphs examined for linearity and homoscedasticity. Bivariate scatterplots of the variables showed that relationships between the variables were linear, and mostly homoscedastic, indicating that multivariate analysis was appropriate. Score distributions, skew values and significance levels are shown in Table 41.

Table 41: Descriptive statistics and skew values for the sensory scores and measures of function of severity

			Skew	K-S Lilliefors	Significance
Upper Limb sensory score	mean SD Range	71.89 24.41 0-100	-0.702	0.156	0.001
Lower Limb sensory score	mean SD Range	73.10 25.197 13-99	-0.737	0.175	<0.001
Stereognosis score	mean SD Range	53.75 31.617 0-100	-0.404	0.176	<0.001
Proprioception score	mean SD Range	66.88 27.256 0-100	-0.692	0.114	0.062
NIHSS	median Range IQR	6 0-23 6.25	0.929	0.130	0.018
RMA Gross function	median Range IQR	2 0-10 5.25	0.388	.0185	<0.001
RMA Leg & Trunk	median Range IQR	4 0-10 6.25	-0.95	0.156	0.001
RMA Upper Limb	median Range IQR	4 0-15 11	0.271	0.167	<0.001
Barthel	median Range IQR	50 0-100 55	-0.103	0.117	0.018
Age at intake assessment	mean SD Range	71.18 9.888 44-85	-0.706	0.106	0.165

The sensory subscales were all negatively skewed because many people achieved high scores. The upper limb, lower limb and stereognosis scales also significantly deviated from a normal distribution. Transformation using reflection and square root or logarithm made no difference with scores still negatively skewed. Transformations complicate the interpretation of the results, and should be used deliberately and in an informed manner (Osborne

and Waters, 2002), and as they did not improve normality were not used in this analysis. The majority of the dependent variables, with exception of age and the Barthel and NIHSS total scores also significantly deviated from normal. However it has long been established that moderate violations of parametric assumptions have little or no effect on substantive conclusions in most instances (Cohen, 1969). Therefore it was decided to use Pearson correlations and multiple regression as opposed to logistic regression to explore relationships between the measures of function and ADL ability. Although logistic regression makes no assumptions regarding distributions, categorising the dependent variables into dichotomous variables as is required for logistic regression would have resulted in loss of information.

The relationships between subjects' performance on the NSA subscales and performance on other assessments were explored using Pearson correlations.

Table 42: Pearson correlations to show the relationship between sensory impairment and other impairments

Patient characteristics		Sensation			
		Upper Limb	Lower Limb	Stereognosis	Proprioception
Age	r p	-0.73 0.56	-0.24 0.06	0.01 0.95	0.04 0.76
NIHSS	r p	-0.60 <0.01**	-0.55 <0.01**	-0.61 <0.01**	-0.474 <0.01**
RMA Gross Function	r p	0.20 0.10	0.24 0.06	0.39 0.01**	0.29 0.02*
RMA Leg & Trunk	r p	0.29 0.02	0.29 0.02*	0.45 <0.01**	0.32 0.01*
RMA Upper Limb	r p	0.38 0.02**	0.33 0.009**	0.59 <0.01**	0.42 0.01**
Barthel Index	r p	0.35 0.05**	0.35 0.005**	0.512 <0.01**	0.43 <0.01**

** Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

The results indicate significant relationships between stroke severity, motor and ADL ability and the sensory subscales. For the upper limb scale, the

significant correlations were with the NIHSS, RMA upper limb section, and Barthel Index. The variables that significantly correlated with sensory impairment of the lower limb were the NIHSS, RMA leg and trunk and upper limb sections, and Barthel Index. Impairment of stereognosis was significantly correlated with the NIHSS, Barthel Index and all the sections of the RMA. The proprioception subscale was significantly correlated with the NIHSS, all sections of the RMA and the Barthel Index. Spearman's rho correlations were calculated to check whether results would have been different if the data were treated as non-parametric. This showed no difference.

Other medical factors that are related to prognosis after stroke were also investigated to see whether they affected sensory impairment. These were type of stroke, presence of swallowing problems and urinary incontinence. Since the data were categorical and there were more than two categories, the Kruskal-Wallis test was used and is reported in table 43.

The NIHSS total score was significantly correlated with performance on the sensory subscales. Individual components of the NIHSS were investigated, these being the presence of ataxia, aphasia, dysarthria and inattention, to determine whether there was a statistically significant difference in sensory ability between these patients. This was calculated by the Kruskal-Wallis test and is also reported in table 43.

Table 43: Comparison of sensory impairment according to scores on NIHSS subscales and prognostic factors

Patient characteristics		Sensation			
		Upper Limb	Lower Limb	Stereognosis	Proprioception
Type of Stroke	Chi-square P value	10.80 0.01**	12.04 0.01**	9.90 0.02*	7.95 0.05*
Urinary incontinence	Chi-square P value	7.79 0.02*	8.25 0.02*	7.91 0.02*	6.09 0.05*
Swallowing Problems	Chi-square P value	2.27 0.32	2.18 0.34	3.59 0.17	1.94 0.38
Visual field deficit	Chi-square P value	4.94 0.08	1.92 0.38	6.38 0.04*	4.87 0.09
Presence of ataxia	Chi-square P value	2.43 0.30	2.60 0.27	2.43 0.30	0.20 0.91
Presence of aphasia	Chi-square P value	2.54 0.28	5.14 0.08	0.16 0.92	0.54 0.76
Presence of dysarthria	Chi-square P value	1.98 0.16	1.73 0.19	2.93 0.09	1.18 0.28
Presence of inattention	Chi-square P value	8.69 0.01**	7.38 0.03*	7.19 0.03*	6.74 0.03*

**Difference is significant at the 0.01 level
*Difference is significant at the 0.05 level

This table shows that type of stroke, incontinence and inattention were significantly related to sensory impairment.

Mann-Whitney U tests were used to determine whether there were significant differences in sensory ability dependent on gender. There were no statistically significant differences in sensory ability in any of the subscales between men and women (U values 321.0 to 484.0, $p>0.05$). Therefore gender was not included as a variable in regression analysis.

6.8 Multiple Regression Analysis

By calculating correlation coefficients it was established that there was a significant relationship between sensory impairment and stroke severity, motor and ADL ability. Kruskal-Wallis tests also showed that type of stroke, urinary incontinence and inattention were significantly related to sensory ability. Regression analysis was then used to describe the relationship between these

variables, and to indicate to what extent sensory impairment was related to these factors accounting for their relationships with each other.

Multiple linear regression analyses were conducted to determine whether there was a linear relationship between performance on the subscales of the NSA and the variables that were significantly related to the presence of sensory impairment.

6.8.1 Regression Analysis – Upper Limb Scale

For regression analysis, the total score for the upper limb sensory scale at recruitment was the dependent variable, with possible independent variables those that were statistically significantly related. These were the Barthel Index, type of stroke, NIHSS total score, inattention as detected on the NIHSS, the RMA upper limb scale, and urinary incontinence. For the purpose of regression analysis, urinary incontinence was recoded as a dichotomous variable (continent = 0, incontinent or catheterised = 1). This was because including polytomous variables would have meant creating dummy variables. For multiple regression the number of cases must substantially exceed the number of independent variables, therefore it was decided only to include dummy variables for type of stroke and inattention.

Using the enter method, a significant model emerged ($F_{1, 63} = 36.050$, $p<0.001$)

Adjusted $R^2 = 0.354$

Significant variables are shown below:

Predictive variable: NIHSS Beta: -0.603, $p<0.001$

The main determinant of sensory impairment in the upper limb was overall stroke severity. This shows that the NIHSS, a scale that quantifies the degree of neurological dysfunction, accounts for 35% of the variance of the upper limb sensory score at recruitment. Upper limb motor function (as determined by the RMA upper limb section) was not significantly related to the upper limb sensory abilities. Overall the model only accounted for approximately a third of the variance of the upper limb sensory impairment. RMA upper limb section, Barthel, urinary incontinence, inattention and type of stroke were not significant predictors in the model.

6.8.2 Lower Limb Scale

Regression analysis was undertaken, using the total score for the lower limb sensory scale as the dependent variable. The independent variables were those that were statistically significantly correlated; the Barthel Index, type of stroke, NIHSS (total score and presence of inattention), the RMA upper limb and leg and trunk sections, the type of stroke and urinary incontinence.

Using the enter method, a significant model emerged ($F_{2,58} = 15.917$, $p<0.001$)

Adjusted $R^2 = 0.332$

Significant variables are shown below:

Predictive variable: NIHSS Beta: -0.435, $p<0.001$

Type of stroke: TACS Beta: 0.260, $p=0.031$

The main predictors of lower limb sensory impairment were stroke severity and type of stroke. RMA upper limb and leg and trunk sections, urinary incontinence, inattention and Barthel Index were not significant predictors in the model. This model, though significant, again only accounted for approximately a third of the variance of lower limb sensory impairment.

6.8.3 Stereognosis Scale

For regression analysis, the total score of the stereognosis scale on admission was the dependent variable, with independent variables those which were statistically significantly correlated; the Barthel Index, type of stroke, NIHSS (total score and the presence of inattention and visual field deficits), urinary incontinence and the RMA gross function, upper limb and leg and trunk sections.

Using the enter method, a significant model emerged ($F_{2,61} = 22.554$, $p<0.001$)

Adjusted $R^2 = 0.406$

Significant variables are shown below:

Predictive variable:	NIHSS	Beta: -0.376, p=0.007
	RMA Upper Limb	Beta: 0.332, p=0.017

The determinants for stereognosis impairment were overall stroke severity and motor ability of the upper limb. RMA gross function and leg and trunk sections, urinary incontinence, type of stroke, inattention and Barthel were not significant predictors in the model. This shows that the NIHSS and upper limb motor ability accounted for almost 41% of the variance of stereognosis impairment.

6.8.4 Proprioception Scale

For regression analysis the total scores of the proprioception scale was the dependent variable, with independent variables those which were statistically significantly correlated; the Barthel Index, urinary incontinence, type of stroke, NIHSS (total score and presence of inattention), and the RMA gross function, upper limb and leg and trunk sections.

Using the enter method, a significant model emerged ($F_{1, 60} = 17.395$, $p<0.001$)

Adjusted $R^2 = 0.212$

Significant variables are shown below:

Predictive variable: NIHSS Beta: -0.474, $p<0.001$

Overall stroke severity was the main predictor of proprioceptive impairment. The RMA, Barthel Index, urinary incontinence, inattention and type of stroke were not significant predictors in the model. This model, though the best available with the variables collected, only accounted for 21% of the variance of proprioceptive impairment.

6.8.5 Summary of Results of Regression Analysis

In summary, multiple linear regressions were undertaken to investigate the relation between stroke severity, motor and ADL ability and sensory impairment. Significant models emerged for the sensory subscales (upper limb, lower limb, stereognosis and proprioception) at recruitment, but accounted for a relatively small amount of the variance, ranging from 21-41%. The main factor that explained the variance in impairment was stroke severity.

6.9 Discussion: Factors Relating to Sensory Impairment

The results show significant correlations between sensory impairment and stroke severity, type of stroke, motor ability, ADL ability and urinary incontinence. However it is impossible to say from the correlations whether these factors were only significantly related because of their relationships with each other, as opposed to being independently related to sensory impairment. Therefore multiple linear regressions were undertaken. These indicated that these associations were largely accounted for by other variables being associated with each other. Incontinence is a marker for stroke severity because of its association with death and disability and its influence on the place of discharge of stroke survivors (Benbow et al., 1991, Khan et al., 1981, Nakayama et al., 1997). Ability to undertake activities of daily living is also negatively associated with stroke severity. It has been demonstrated that the NIHSS was related to ADL ability (De Haan et al., 1993). The fact that ADL ability and incontinence although significantly correlated with sensory ability were not included in the regression models, suggests they were a reflection of stroke severity and not independent markers.

The main determinant of sensory impairment was the NIHSS total score, a global measure of stroke severity. This is consistent with previous literature, as it is known that the severity of somatosensory loss is partially dependent upon the extent of the lesion (Barnett et al., 1986, Carey, 1995, Lamotte and Mountcastle, 1979, Roland, 1984). Sensory processing is highly complex, involving many somatosensory pathways and many areas of the brain. Sensory impairment can result from a lesion anywhere from the brainstem to the cortex

(Yekutiel, 2000), with more extensive damage increasing the likelihood of sensory areas and pathways being affected.

For the lower limb, type of stroke was also a factor. The type of stroke using the Bamford classification that was significant was the presence of a total anterior circulation stroke (TACS). Patients were classified using clinical criteria only and those with TACS, by definition, presented with the triad of hemiparesis or hemisensory loss, dysphasia (or other new higher cortical dysfunction) and homonymous hemianopia, therefore many would be expected to have sensory impairment. The Bamford classification correctly predicts the site and size of infarct in about three quarters of patients (Anderson et al., 1994, Lindgren et al., 1994, Mead et al., 2000, Wardlaw JM et al., 1996). The anterior cerebral artery passes below the anterior cerebral hemisphere on each side and supplies the cortical surface at the front of the brain, including the sensory cortices. It is therefore surprising that type of stroke was only a predictive factor for lower limb sensory impairment and not impairment on the other sensory scales. This suggests that it is not just the size of stroke which affected sensory impairment, as if this was the case the type of stroke would have been a predictive variable in more than one model.

The stereognosis model included the variables NIHSS score and RMA upper limb score. Motor ability of the hand is required to manipulate objects, which will affect stereognostic ability as it will impair the haptic exploration of objects. Object recognition relies on purposive manual exploration to derive perceptions of the properties of an object (Klatzky and Lederman, 1995). Therefore the results of this study support that motor activity serves to enhance

the sensory system in stereognosis (Lederman and Klatzky, 1987), or that motor ability is needed in order to detect that patients have stereognosis ability.

Significant models emerged for the scales, but accounted for a relatively small amount of the variance, ranging from 21-41%. However approximately two-thirds of the variance was not accounted for, meaning that other factors were involved. The model for proprioception had the lowest adjusted R^2 value, accounting for only 21% of the variance of proprioceptive impairment. Other possible reasons include cognitive and perceptual factors. Also, use of the inattention component in the NIHSS may not be a sensitive enough method to detect impairment, therefore a more thorough assessment of inattention would have been worthwhile.

Sensation is a complex ability and is a problem in its own right. Sensory impairment was a reflection of stroke severity but low variance indicates other factors were involved. Therefore there is a need to assess sensory impairment after stroke, as not all problems will be detected if only the NIHSS is used.

6.10 Results: Factors Relating to Sensory Outcome

To determine whether stroke severity, motor and ADL ability related to sensory outcome at six months, the relationships between performance on the NSA subscales at 6 months and performance on other assessments at recruitment were explored using Pearson correlations and are reported in table 44. If variables are found that predict outcome, this may have implications for provision of rehabilitation.

Table 44: Relationships between impairment at recruitment and sensory impairment at 6 months

Characteristics at recruitment		Sensation at 6 months			
		Upper Limb	Lower Limb	Stereognosis	Proprioception
Age	r	0.07	0.07	-0.05	0.23
	p	0.60	0.61	0.75	0.10
NIHSS	r	-0.57	-0.95	-0.73	-0.72
	p	<0.01**	<0.01**	<0.01**	<0.01**
Upper Limb Sensation	r	0.76	0.64	0.69	0.69
	p	<0.01**	<0.01**	<0.01**	<0.01**
Lower Limb Sensation	r	0.62	0.47	0.47	0.51
	p	<0.01**	<0.01**	<0.01**	<0.01**
Stereognosis	r	0.49	0.49	0.75	0.63
	p	<0.01**	<0.01**	<0.01**	<0.01**
Proprioception	r	0.56	0.52	0.72	0.65
	p	<0.01**	<0.01**	<0.01**	<0.01**
RMA Gross Function	r	0.23	0.44	0.43	0.33
	p	0.09	<0.01**	<0.01**	0.02*
RMA Leg & Trunk	r	0.29	0.47	0.44	0.40
	p	0.03*	<0.01**	<0.01**	<0.01**
RMA Upper Limb	r	0.33	0.46	0.54	0.54
	p	0.02*	<0.01**	<0.01**	<0.01**
Barthel Index	r	0.41	0.57	0.58	0.45
	p	<0.01**	<0.01**	<0.01**	<0.01**

** Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

This shows that sensory impairment at recruitment was significantly correlated with sensory outcome at six months. The NIHSS and Barthel Index were

correlated significantly with all sensory outcome scores, as were most sections of the RMA. Age did not correlate significantly with performance on any of the sensory subscales.

Other categorical factors that may have affected sensory outcome were type of stroke, presence of swallowing problems, and urinary incontinence and were investigated using the Kruskal-Wallis test. The whole NIHSS scale at recruitment was significantly related to sensory outcome. Some of the individual components of the scale were investigated to determine whether they were also related to sensory outcome using the Kruskal-Wallis test. These results are reported in table 45 below.

Table 45: Comparison of sensory outcome according to scores on NIHSS subscales and prognostic factors

Characteristics at recruitment		Sensation at 6 months			
		Upper Limb	Lower Limb	Stereognosis	Proprioception
Type of Stroke	Chi-square P value	17.42 0.001**	10.402 0.02*	7.02 0.07	7.92 0.05*
Urinary incontinence	Chi-square P value	13.59 0.001**	11.22 0.004**	11.20 0.004**	5.15 0.08
Swallowing Problems	Chi-square P value	5.97 0.05*	7.32 0.03*	3.05 0.22	3.92 0.14
Visual field deficit	Chi-square P value	6.02 0.05*	3.14 0.21	13.03 0.001**	11.53 0.003**
Presence of ataxia	Chi-square P value	2.62 0.27	2.62 0.27	1.72 0.42	1.34 0.51
Presence of aphasia	Chi-square P value	8.45 0.02*	3.24 0.20	0.36 0.84	5.98 0.05*
Presence of dysarthria	Chi-square P value	3.27 0.07	4.56 0.03*	8.45 0.02*	3.58 0.06
Presence of inattention	Chi-square P value	9.93 0.007**	2.76 0.25	10.29 0.006**	11.46 0.003**

**Difference is significant at the 0.01 level
*Difference is significant at the 0.05 level

This shows that type of stroke, urinary incontinence, swallowing problems and the presence of visual field deficits, aphasia, dysarthria and inattention at recruitment all significantly related to aspects of sensory ability at six months. Sensory outcome did not differ according to gender. There were no statistically significant differences in sensory ability at six months in any of the subscales between men and women (U values 311.5 to 366.0, $p>0.01$). Therefore gender was not included as a variable in regression analysis.

6.11 Results of Multiple Regression Analysis – Sensory Outcome

The factors that were significantly related to sensory outcome at six months were identified. Regression analysis was then used to describe the relationship between these variables, and to specify to what extent sensory outcome was related to these factors accounting for their relationship with each other. For this analysis, dummy variables were created for the individual components of the NIHSS and type of stroke, and urinary incontinence was recoded as a dichotomous variable.

6.11.1 Upper Limb Scale

For regression analysis, the total score for the upper limb sensory scale at six months was the dependent variable, with independent variables those that were statistically significantly related. These were all of the sensory scales at recruitment, the RMA upper limb and leg and trunk section, the Barthel Index, the NIHSS (the total score and the presence of visual field deficits, aphasia and inattention), type of stroke and urinary incontinence.

Using the enter method, a significant model emerged ($F_{1, 44} = 56.991$, $p<0.001$)

Adjusted $R^2 = 0.554$

Significant variable is shown below:

Predictive variable:	Upper Limb sensation at recruitment	Beta: 0.751, $p<0.001$

The main predictor of upper limb sensory ability at six months was upper limb sensory ability on recruitment. The other variables were not significant predictors in the model. Impaired upper limb sensation at recruitment had the largest impact in upper limb sensory outcome at six months, accounting for over half of the variance.

6.11.2 Lower Limb Scale

For regression analysis, the lower limb sensory scores at six months was the dependent variable, with the independent variables those that were statistically significantly related. These were all of the sensory scales at recruitment, all sections of the RMA, the Barthel Index, the NIHSS (the total score and the presence of dysarthria), the type of stroke, swallowing problems and urinary incontinence.

Using the enter method, a significant model emerged ($F_{2, 42} = 20.041$, $p<0.001$)

Adjusted $R^2 = 0.464$

Significant variable is shown below:

Predictive variable:	Upper Limb sensation at recruitment	Beta: 0.494, $p<0.001$

	Barthel Index	Beta: 0.330, p=0.010

The main determinant of lower limb sensory ability at six months was upper limb sensory ability at recruitment and the Barthel Index at recruitment. The other variables were not significant predictors in the model. Impaired upper limb sensation and ability in personal ADLs at recruitment had the largest impact on lower limb sensory outcome at six months, accounting for almost half of the variance.

6.11.3 Stereognosis Scale

For regression analysis, the dependent variable in this analysis was the stereognosis total scores at six months, with the independent variables those that were statistically significantly related. These were all of the sensory scales at recruitment, all of the sections of the RMA, the Barthel Index, the NIHSS (the total score and the presence of visual field deficits, dysarthria and inattention), and urinary incontinence.

Using the enter method, a significant model emerged ($F_{3, 46} = 40.813$, $p<0.001$)

Adjusted $R^2 = 0.709$

Significant variable is shown below:

Predictive variable:	Stereognosis at recruitment	Beta: 0.407, p<0.001
	Proprioception at recruitment	Beta: 0.347, p=0.002
	Urinary Incontinence	Beta: -4.028, p<0.001

The main predictors of stereognosis ability at six months were stereognosis and proprioception ability at recruitment, and the presence of urinary incontinence, accounting for over 70% of the variance. The other variables were not significant predictors in the model.

6.11.4 Proprioception Scale

For regression analysis, proprioception score at six months was the dependent variable in this analysis, with the independent variables those that were statistically significantly related. These were all of the sensory scales at recruitment, all sections of the RMA, the Barthel Index, the NIHSS (the total score and the presence of visual field deficits, aphasia and inattention), and type of stroke.

Using the enter method, a significant model emerged ($F_{2, 42} = 23.939$, $p<0.001$)

Adjusted $R^2 = 0.510$

Significant variables are shown below:

Predictive variable:	Proprioception at recruitment	Beta: 0.420, p=0.004
	Upper Limb sensation at recruitment	Beta: 0.382, p=0.009

This shows that the degree of upper limb sensory impairment and proprioception at recruitment was the greatest predictor of proprioceptive ability, accounting for over half of the variance. The other variables were not significant predictors in the model.

6.11.5 Summary of Results of Regression Analysis for Sensory Outcome

In summary, multiple linear regressions were undertaken to investigate how stroke severity, motor and ADL ability impacted on sensory outcome at six-months. Significant models were found for each sensory subscale six months after stroke. The main factor that explained sensory outcome was initial sensory impairment.

6.12 Discussion: Factors Relating to Sensory Outcome

Factors were investigated to see if they had prognostic value, in terms of whether assessments early after stroke were related to sensory ability at six months. Correlations showed that stroke severity, sensory, motor and ADL ability at recruitment, type of stroke and urinary incontinence at recruitment were all significantly related to sensory ability at six months. Multiple regression analysis indicated sensory problems at recruitment were the main determinant of sensory outcome. Models accounted for a higher percentage of the variance of sensory outcome than for sensory impairment (46-71%).

The main predictor of outcome was sensory ability at recruitment possibly as this reflects the extent to which sensory pathways were affected. Initial stroke severity is known to be the most powerful predictor of outcome (Fullerton et al., 1988), with the severity of the initial deficit inversely proportional to the prognosis for recovery (Teasall and Bitensky, 2004). Jorgensen (1995b) found the time course of neurological and functional recovery was strongly related to stroke severity and functional disability. This study shows that this is also true for sensory recovery. Given that the NIHSS is a measure of stroke severity, it is surprising that this is not a predictor, unlike with sensory impairment. However this only accounted for some of the variation, and it was not possible to predict accurately which patients will recover, who will deteriorate and to what extent they will recover. This is consistent with previous literature investigating outcome, as though severe initial impairment is a poor prognostic indicator, there is variable recovery and some patients do have a good outcome (Jorgensen et al., 1995b, Jorgensen et al., 1999).

Sensory impairment was not always predictive for the same area of the body. For example, upper limb sensory impairment significantly predicted lower limb sensory ability at six months, whereas lower limb sensory impairment at recruitment was not a predictive factor. This may be because upper limb and lower limb sensory impairment were highly correlated and the upper limb sensory scale was more sensitive.

However there was still a considerable amount of variability unaccounted for. Therefore it should not be presumed that a patient who has marked impairment initially does not have the possibility to recover. Other non-measured factors must have an impact.

The Barthel Index at recruitment was a significant predictor of lower limb sensory recovery. The Barthel Index is a measure of ADL ability, showing that the independence in patients' ability to do personal tasks at recruitment was related to lower limb sensory outcome at six months. The Barthel Index grossly reflects ability to move and to transfer and therefore is a general guide to a persons' activity level. It reflects that people can walk or have better lower limb movement if they score highly, and hence have better sensory outcome. Therefore increased activity seems to enhance sensory recovery. This may be a justification for sensory re-education, as patients with decreased ability and therefore receiving less afferent input are at an increased risk of having sensory impairment at six months. However if this were the case it would be expected that there would be a relationship with the lower limb section of the Rivermead Motor Assessment. The model only accounts for approximately half the variability, meaning other factors are involved.

The significant factors for stereognosis outcome in the model were stereognosis and proprioceptive ability at recruitment and presence of urinary incontinence at recruitment. Initial stereognosis impairment was a predictor of outcome as it reflects the extent to which sensory pathways are affected. Stereognosis is a combined sensation that requires the integration of many modalities, including proprioceptive information and solving of the perceptual problem of object recognition (Klatzky et al., 1985). Therefore if areas of the brain required for proprioception were damaged this seems to have affected stereognosis outcome. The fact that presence of urinary incontinence at recruitment affected stereognosis ability at six months does seem incongruous, however it has been shown to be a prognostic factor in another study of outcome of ADL ability (Kwakkel et al., 1996). It may be that incontinence is an indicator of stroke severity because of its association with death and disability and its influence on the place of discharge of stroke survivors (Benbow et al., 1991, Khan et al., 1981, Nakayama et al., 1997).

Proprioception outcome was predicted by upper limb sensory impairment and proprioception sensory score at recruitment. The extent to which a patients' sensory ability is affected at intake will impact on outcome. The fact that upper limb sensory impairment was a significant predictor may be as proprioception is dependent on activity and disorganised sensation results in disorganised movement (DeSouza, 1983). However motor ability of the upper limb was not a significant factor. It should be reinforced that almost half of the variance was again unaccounted for, so other factors must impact on outcome.

The variability of sensory impairment and outcome not accounted for may be due to factors such as the patients' cognitive and perceptual ability, motivation and attention. The number of factors involved is a reflection of the highly complex and individual nature of damage following stroke. Sensation and perception are inseparably linked (Yekutiel, 2000). Stereognosis has cognitive components e.g. to integrate all the sensory information, to name the object (Roland, 1976a). It is known that factors such as an enriched environment and active participation facilitate recovery (Damiano et al., 2001, DeSouza, 1983, Teasall and Bitensky, 2004). However these factors were not addressed in this study. This is because it was impractical to include any more outcome measures as administration time would have affected patient compliance. The fact not all of the variation could be accounted for is similar to the findings for functional outcome, as the cumulative impact of functional deficits such as somatosensory and hemianopia deficits were greater than for motor severity alone (Patel et al., 2000). The lack of ability to predict the outcome suggests there other factors are involved, one of which it may be possible to treat and therefore improve outcome.

CHAPTER VII

OVERALL DISCUSSION

7.1 Introduction

This chapter includes general discussion regarding the research and clinical implications of this study, identifies the contributions to knowledge and the strengths and weaknesses of the work, and suggests ideas for further research.

7.2 Analysis of the NSA

Rasch analysis identified items within the NSA that were not internally valid, enabling removal of these items to produce a shortened assessment. A new scoring form for this shortened version was produced (see Appendix 6). The items remaining in the shortened NSA seem reasonable clinically, and although on inspection may seem to exclude some body areas it can be argued there is little point gathering redundant information. To develop the shortened NSA for practical use, some items had to be included, e.g. knee pressure as a precursor to testing knee bilateral simultaneous touch. However if the person location score is to be calculated from the shortened assessment, these extra items should be removed before scoring. The shortened NSA is therefore a sensory assessment that satisfies the requirements of an outcome measure in terms of standardisation, validity and reliability. Use of Rasch analysis was helpful in this study to ensure internal validity of the NSA, and to enable calculations of total scores to investigate sensory recovery. A limitation is that it lacks the face validity of the full scale. However it is recognised that in a clinical setting it is unlikely that a therapist would have the knowledge, time or appropriate software to calculate total scores for individual patients. Nevertheless this

study presents clinicians with an assessment tool that is short and has internal construct validity. Researchers also have a potential outcome measure for use in intervention studies.

Since this study was undertaken, other researchers have attempted to modify the NSA. Stork-Hornsveld and colleagues (2006) attempted to further standardise the instructions of the NSA, defining points of contact for the tactile sensations and stating starting positions and handgrip for testing proprioception. They also removed the assessment of temperature, as this was the least reliable item in the revised NSA (Lincoln et al, 1998). They included 21 patients with intracranial disorders, not only stroke patients, and excluded patients with a mini-mental state of less than 15 points. The further standardisation improved the reproducibility of the majority of the test items such that they had predominantly good to excellent inter-rater and intra-rater reliability. However the NSA has not been used on patients other than those who have had stroke before, and the overall level of sensory impairment in the sample was low. The small sample size including patients with varied intracranial disorders means the results should be taken with caution. However the fact that further standardisation of the revised NSA improved reliability may be a reason why the inter-rater reliability in this study was improved, as further guidelines and a body chart were included in the instructions.

7.3 Research Implications

The development of a scoring method for the NSA that allowed total scores to be calculated improved the interpretation of the results. Previously much information about sensory ability for each body area and each modality was recorded. As a total score could not be calculated due to the data being of

ordinal level, it was difficult to compare patients against each other and over time. The Rasch analysis enabled total scores to be calculated. This means the NSA is a measure that is well placed to be used in further research of sensory recovery and in studies on the effectiveness of an intervention to improve sensory ability.

The information in this study provides a basis from which an intervention study for sensory rehabilitation can be undertaken to determine whether sensory recovery can be enhanced. This could be in terms of fewer patients deteriorating, and more patients achieving a higher sensory ability at six months. Previous studies have used inappropriate outcome measures (Chen et al., 2005, Smania et al., 2003, Yekutiel and Guttman, 1993) or summated ordinal scores (Cambier et al., 2003). If sensory recovery is influenced by intervention, the impact of this on motor and ADL ability needs to be investigated. This is as because motor and sensory ability are closely linked. It has been established that sensory impairment is detrimental to motor recovery (Kuffofsky et al., 1982, Aglioti et al., 1996), and conversely enhanced sensory recovery may improve motor recovery.

There was variation in sensory outcome. Several factors could be responsible, including treatment given, whether sensation was targeted and the skill of the therapist. This study was an observation study that simply recorded patients' sensory ability over time. Though an intervention for sensory problems was not specifically given in this study, all patients received rehabilitation including physiotherapy and occupational therapy. Sensory representation is affected by patients' experiences. The content of physiotherapy and occupational therapy

treatment was recorded in the CERISE project (De Wit et al., 2006). Thirty individual physiotherapy and occupational therapy session were videotaped and the content explored. Neither physiotherapists nor occupational therapists recorded any treatments specifically for sensory impairments. However these may have been treated indirectly during interventions, as though not specifically targeted, the motor, sensory and perceptual systems are inextricably linked. For example sit to stand practice involves getting patients to be more aware of their body position and how they are completing the task, therefore increasing their proprioceptive awareness.

The literature on sensory rehabilitation refers to the importance of involving the patient in the treatments and maintaining concentration (DeSouza, 1983, Yekutiel, 2000, Yekutiel and Guttman, 1993). Some therapists may have been more aware of this or may have been more skilled than others. Interaction skills of the "expert" physiotherapist are thought to lead to a positive patient outcome (Gyllensten et al., 1999). This is another reason for individual variation in sensory performance, and may affect recovery.

Therefore the results presented for sensory recovery will have been affected by other factors. Ethically and practically it is not possible to observe patients without them receiving any rehabilitation or having sensory experiences, therefore these results indicate what happens with rehabilitation with no targeting of sensory impairment. The lack of a standardised usable outcome measure may have been a contributing factor for the sparse attention given to the treatment of sensory impairments in the past. This study has provided a basis from which an intervention study can be undertaken.

7.4 Clinical Implications

Rasch analysis enabled the calculation of total scores that aided analysis, but also importantly allowed the scale to be shortened. The shortened NSA is valid and showed good inter-rater reliability. It is quicker to administer than the full version, does not require specialised training or equipment and is easily transportable. This should aid its implementation into clinical practice.

Sensory assessment is not only of interest to physiotherapists, but occupational therapists are often involved in sensory rehabilitation and information on sensory impairment is also useful for the nursing and medical team. For example sensory impairment may affect a patients' ability to wash and dress, and has implications on pressure care. Therefore the clinical application of the shortened NSA will be useful for other members of the multi-disciplinary team.

7.5 Limitations of the study

Though this is one of the larger studies to date on sensory impairment after stroke, it still includes a relatively small sample. Some patients were lost to follow-up leaving 58 patients at the six-month assessment. This means caution should be taken with the generalisation of the results to the stroke population and a larger study would be of benefit. This may show lower limb recovery and enable other factors to be examined.

The selection criteria used in this study were determined by the Collaborative Evaluation of Rehabilitation In Stroke across Europe (CERISE), as this study was undertaken in collaboration and under the same ethical approval. This meant that the sample was limited to those between the ages of forty and eighty-five years old. This limitation should be recognised as it is known that

somatosensory function decreases with age (Kenshalo, 1986, Kaplan et al., 1985, Desrosiers et al., 1996), and the nature of sensory impairment and recovery in those stroke patients outside this age range needs to be investigated. However it is unlikely that the findings do not apply to the extremes. The recruitment procedure also meant that only patients who were admitted to stroke units were included in the study. Therefore stroke patients who were not admitted to hospital or who were discharged straight from the acute unit were excluded. 22–60% of patients who have a stroke remain in the community (Robinson, 1983), meaning a large number of patients were not included. The study also only included patients with a first stroke as the aim was to investigate the impact of a stroke on sensory ability and recovery, not the cumulative impact of several strokes. As risk of suffering a recurrence after stroke has been shown to be 30% by 5 years (Burn et al., 1994), about nine times the risk of stroke in the general population, in clinical practice many patients seen have more than one stroke and therefore this patient group warrants investigation. The impact of more than one stroke has not yet been evaluated and is a possibility for further research.

Time constraints meant that patients were only followed up for six months, and assessed at four different time points. To gain a clearer picture of the pattern of recovery it would have been useful to have followed up patients more frequently. This may have meant inaccuracies in sensory assessment when other factors may have affected sensory performance e.g. attention may have been easier to detect. However more frequent follow-up assessments were not possible, as the time taken to administer the assessments, especially using the

full version of the NSA, meant more follow-up appointments may have affected patients' compliance.

It would also have been ideal to continue with assessments for a longer time to see if sensory recovery had reached a plateau as the results suggested or continued to improve. Previous research has found some recovery can continue longer after stroke onset (Liepert et al., 1998, Steinberg and Augustine, 1997), particularly with patients who are severely impaired initially (Duncan et al., 1992, Wade et al., 1983, Wadell et al., 1987, Wade et al., 1987). Therefore follow up of patients in this study up to 2 years would have helped confirm these observations.

Some factors that may have affected sensory assessment were not assessed, such as aphasia and mood; therefore the effect of these on sensory impairment and recovery could not be evaluated. The presence of inattention or neglect was not assessed in detail in this study, only by one item in the NIHSS. The NIHSS total score and the attention item individually were both included in the regression analyses, though the inattention item was not a significant predictor of either sensory impairment or sensory outcome at six months. Specific measures of inattention, such as the star cancellation test (Halligan et al., 1990) which has been shown to be a sensitive measure of inattention (Halligan et al., 1990) were not used, so it is unknown whether these would be significant predictors of sensory ability.

Attention and sensation are closely linked, and inattention could present as sensory impairment since a patient with inattention may not acknowledge

sensory stimuli if they were unaware of one side of their body. This means some patients may have been classified as having sensory problems when they had deficits in attention or a combination of sensory and attention problems. This limitation should be recognised and for future research it would be useful to investigate the relationship between sensory impairment and sensory attention.

Other limitations include the fact that two assessors were involved. Although the interrater reliability was high it was not perfect (see Appendix). The assessors were not blind to previous scores and therefore could be biased e.g. if a patient scored highly on their initial assessment they may be inclined to think they should score highly when re-assessed. Also patients were included only if they gave consent, and therefore may under represent patients who were depressed, cognitively impaired or aphasic.

7.6 Implications for Further Research

One problem with defining the frequency of sensory impairment was the lack of information on healthy age-matched controls. It is known that somatosensory ability decreases with age (Kenshalo, 1986, Kaplan et al., 1985, Desrosiers et al., 1996), and the lack of normative standards for clinical measures has been highlighted in the past (Carey et al., 1997). This means it is difficult to distinguish "impairment" from what is typical of an age-matched population. It would be useful for the NSA to be assessed on age-matched controls to identify a normal range from which impairment can be defined. This information would be useful to develop cut-offs, which distinguish

sensory impairment in stroke patients and to indicate which other factors, such as age and peripheral neuropathy, affect results. However, rates of impairment were very low on the "unaffected" side therefore it is unlikely there would be many with problems.

A study measuring other factors that may have affected sensory impairment would be beneficial. In this study several potential factors that may have affected sensory ability were recorded, including stroke severity, motor ability and ADL ability. The length of the full NSA and time constraints meant more outcome measures were not included in the assessment battery. The regression analyses showed these factors alone did not fully predict the initial sensory impairment or outcome at six months. Therefore a further study assessing the impact of cognitive factors, perceptual ability, mood and inattention should be undertaken. These could then be included in regression analyses to see which, if any factors are significant predictors of sensory impairment or outcome.

The information on the natural recovery of sensation is a useful basis for an intervention study. There have been mixed results regarding the benefits of sensorimotor rehabilitation (Teasall and Bitensky, 2004) though this is a term that covers a range of interventions. Those which are specific to training sensation show a positive effect (Cambier et al., 2003, Yekutiel and Guttman, 1993, Smania et al., 2003, Carey et al., 1993). However problems with methodology, outcome measures used and determining what recovery is spontaneous and what is due to an intervention means the question of whether sensory rehabilitation is effective still needs further clarification. There is a need for better trials to evaluate outcome. The shortened NSA could be used as

the primary outcome measure, as it provides an interval level of measurement and has demonstrated reliability and validity, in a study investigating the effectiveness of a sensory rehabilitation programme.

It is not known which patients will have the best outcome in terms of sensory ability, and what it is that enables better outcomes. The fact that sensory and hence motor ability may deteriorate as a result of abnormal afferent input (Musa, 1986, DeSouza, 1983) may support the use of passive and active/ active-assisted movements as an intervention, and may support the use of patient involvement in treatment as opposed to their being merely passive participants on whom therapy is carried out. However this is speculative and an intervention study needs to test this hypothesis.

Investigation in to the concurrent validity of the NSA could be undertaken. Investigation into how the NSA relates with other more specialised tests, such as the tactile discrimination test (Carey et al., 1997), the joint position sense test (Carey, 1993) and the touch-pressure sensation tests (Dannenbaum et al., 2002) should be undertaken. The relationship between results on the NSA and the Rivermead Assessment of Somatosensory Performance (RASP) (Winward et al., 2002) could also be investigated. This would show which is more sensitive to change, which is shorter, easier to undertake and how they relate to outcome. These studies would involve assessing a sample of stroke patients on the shortened NSA and other measures of sensation. The relationship between the measures and the sensitivity and specificity of the NSA could then be explored.

The question of how somatosensory performance and rehabilitation affects performance needs to be addressed. The current outcome measures used in studies of sensation, such as the NSA, are at an impairment level. This is how therapists have traditionally measured outcome, whilst patients mostly measure outcome in terms of their ability (Grimmer et al., 2004). Therefore the relevance of the outcome measures used in future studies of sensation need to be considered, with the inclusion of an outcome that detects changes of functional ability. The functional outcome measures that are currently available do not specifically include functions that are heavily reliant on somatosensory ability and may be insufficient to detect changes in function due to somatosensory recovery. Smania et al. (2003) attempted to use visual analogue scales reported by patients' relatives to evaluate the amount of use of the affected arm in ADLs and also ten functional tests, including closing a zip and putting on and removing a bottle cap, to assess the impact of sensory ability on function. Although these showed significant improvement following an intervention they have not been validated or standardised and the study only included four patients. However when investigating the effectiveness of sensory rehabilitation the impact it has on function needs to be addressed, though this may require the development of an outcome measure first.

In addition to quantitative information on sensory impairment, a qualitative study would be of interest to obtain patients views on the impact of sensory impairment and to gain detailed information on how they felt it affected their function. Anecdotally in this study some patients found sensory deficit extremely debilitating and it made some everyday tasks, such as carrying hot

drinks and putting on clothing, practically impossible. This has not been investigated before but the importance of involving consumers in research is recognised (Hanley et al., 2003). This would allow the patients' perspectives to be studied, and importantly whether they felt sensory impairment was relevant to them. This information would also be important in terms of devising a sensory rehabilitation programme, and giving information on what tasks should be included in a functional outcome measure.

A study of sensory recovery specifically restricted to stroke patients with sensory deficits would be useful. It would be a more efficient use of time and resources and would give a larger proportion of patients with sensory problems. This would allow impairment and recovery of the ipsilateral side to be investigated. It would also allow differences between patients with a bilateral lesion, and between left and right lesions to be investigated further. Sterzi and colleagues (Sterzi et al., 1993) suggested that there was a difference between patients with a left and right lesion in terms of incidence of sensory impairment, in that patients with a right lesion often had left spatial neglect that concurred with the sensory disorder resulting in contralateral hemi anaesthesia. However this was a retrospective study that used non-standardised methods to assess deficits of pain and position sense. It therefore warrants further investigation.

CHAPTER VIII: CONCLUSION

8.1 Hypotheses

Hypothesis 1

It was confirmed that a high proportion of patients had sensory impairment following first stroke

Hypothesis 2

There was a higher proportion of problems in the more complex sensations particularly stereognosis, compared with the tactile sensations.

Hypothesis 3

There were no significant relationships between sensory impairment in different modalities in the same body areas.

Hypothesis 4

There were significant differences in the frequency of sensory problems according to the part of the body assessed, though high agreements were found between body areas in close proximity to each other e.g. hand and wrist.

Hypothesis 5

Following Rasch analysis, the items of the NSA could be combined to provide overall scores.

Hypothesis 6

The scoring of the Nottingham Sensory Assessment (NSA) showed no significant differences between raters. For the majority of items there was at least a substantial agreement between assessors.

Hypothesis 7

There was significant recovery in all sensory modalities over six months except lower limb sensory ability.

Hypothesis 8

There was individual variation in the amount of sensory recovery, with some patients showing recovery, some deterioration and others varying over time.

Hypothesis 9

Sensory outcome at six months was related to initial level of sensory impairment.

8.2 Conclusion

Sensory impairment was common in stroke patients. Stereognosis was the most frequently impaired sensation and the most severely impaired. The different sensations showed only slight agreement between impairment in the same body areas, supporting the hypothesis that the different sensory modalities were independent of each other. High agreements were found in different body areas between impairments within each sensory modality.

Significant recovery was shown over the six-month period after stroke for upper limb tactile sensations, stereognosis and proprioception sensations. Lower limb sensations did not show significant recovery.

There was some individual variation, with some patients showing recovery, some showing deterioration and some patients' performance varying over time. However this occurred across patients and at different time points. For those patients that showed significant deterioration, this could be explained by other factors, such as further stroke. The group of patients that significantly improved in their sensory ability had less severe strokes.

Sensory impairment in the lower limb did not show significant recovery for the group as a whole and did not have a consistent recovery pattern in individuals. Patients that deteriorated between admission and 2 months had more severe strokes, motor impairment and less independence in activities of daily living, than those patients who improved. This supports the fact that though there is little variation in lower limb sensory scores those that occur are reflecting changes in sensory ability.

There was a significant difference in stereognosis at admission between those with and without inattention. However there was no significant difference between those patients with problems following commands, orientation in time, aphasia, dysarthria, or visual field problems and those without as measured by the NIHSS. This is possibly due to the lack of sensitivity of the NIHSS to detect these problems. As inattention was a significant factor, it warrants further investigation to explore its effect on stereognosis. Detailed cognitive assessments were not completed in this study as the focus was on sensory recovery in general and not specifically stereognosis. There were also

practical limitations in the number of assessments that each patient could complete.

The severity of the stroke, initial sensory impairment and activities of daily living ability were significantly related to sensory recovery. However these factors together accounted for 46-71% of the variance, indicating that other factors such as cognitive and perceptual ability may affect outcome. This has implications for future research, as it is not yet possible to predict which patients will show good recovery and which will deteriorate.

8.3 Research Implications

The development of a scoring method for the NSA that allowed total scores to be calculated improved the interpretation of the results. Previously much information about sensory ability for each body area and each modality was recorded. As a total score could not be calculated due to the data being of ordinal level, it was difficult to compare patients against each other and over time. The Rasch analysis enabled total scores to be calculated. This means the NSA is a measure that is well placed to be used in further research of sensory recovery and in studies on the effectiveness of an intervention to improve sensory ability. It is now possible to undertake a randomised controlled trial to evaluate treatment of sensory problems.

8.4 Clinical Implications of the Study

Sensation is a complex ability and is a problem in its own right. Sensory impairment was a reflection of stroke severity but low variance indicates other factors were involved. Therefore there is a need to assess sensory impairment

after stroke, as not all problems will be detected if only measures of stroke severity are used.

Sensory outcome at 6 months could not be accurately predicted. It was not possible to predict accurately which patients would recover and to what extent they would recover, and who would deteriorate. Therefore it should not be presumed that a patient who has marked impairment initially does not have the potential to recover. The lack of ability to predict outcome suggests there other factors are involved, one of which it may be possible to treat and therefore improve outcome.

Rasch analysis enabled the calculation of total scores that aided analysis, but also importantly allowed the scale to be shortened. The shortened NSA is valid and showed good inter-rater reliability. It is quicker to administer than the full version, does not require specialised training or equipment and is easily transportable. This should aid its implementation into clinical practice.

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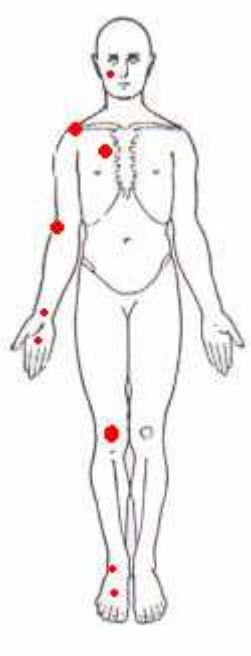
APPENDIX 1

NOTTINGHAM SENSORY ASSESSMENT
Instructions

The patient should be assessed in sitting and in a suitable state of undress (ideally in shorts & underwear, without TED stockings). It should be ensured the patient is comfortable and in a quiet area with no distractions. Each test is described and demonstrated to the patient before he or she is blindfolded. The blindfold is removed regularly throughout the test to avoid the patient becoming disorientated.



The body area to be tested is as marked on the body chart. Apply the test sensation to the test area, to the left and right side in a random order. The patient is asked to indicate, either verbally or by a body movement, whenever he or she feels the test sensation.

Each part of the body is assessed three times for each of the tests.

Presence of a reflex does not count as awareness of sensation, though this should be commented on in the comment box.

Tactile Sensation

If the patient has problems communicating begin testing light touch, pressure and pinprick sections.

Scoring criteria

0 *Absent* Fails to identify the test sensation on three occasions
1 *Impaired* Identifies the test sensation, but not on all three occasions in each region of the body or feels duller
2 *Normal* Correctly identifies the test sensation on all three occasions
9 Unable to test

Light Touch Touch, not brush, the skin lightly with a cotton wool ball.

Pressure Press the skin just enough to deform the skin contour using the index finger.

Pinprick Prick the skin with a neurotip, maintaining even pressure.

Temperature Touch the skin with the side of one of two test tubes, one filled with hot water, one filled with cold water (use the sides, not the bases of the test tubes). Apply hot and cold tubes in random order.

Tactile localisation Only test those areas on which the patient has scored 2 on the pressure section.
Record all others as 9.
Repeat the pressure test with the index fingertip coated with talcum powder to mark the spot touched and ask the patient to point to the exact spot that has been touched. If communication permits, the test may be combined with the pressure test. 2cm of error are allowed.

Bilateral Simultaneous Touch Touch corresponding sites on one or both sides of the body using the fingertips and ask the patient to indicate if both or one (and which) have been touched. Only test those items on which patient has scored 2 on pressure section. Record all others as 9.

Equipment required: Blindfold, cotton wool ball, Neurotip, two test tubes, hot and cold water, talcum powder.

Kinaesthetic Sensations

All three aspects of movement are tested: appreciation of movement, its direction and accurate joint position sense are assessed simultaneously. The limb on the affected side of the body is supported and moved by the examiner in various directions but movement is only at one joint at a time. The patient is asked to mirror the change of movement with the other limb. Three practice movements are allowed before blindfolding.

The upper limb is tested in sitting, and the lower lying supine.

Scoring

0 *Absent* No appreciation of movement taking place.

1 *Appreciation of movement taking place* Patient indicates on each movement that a movement takes place but the direction is incorrect.

2 *Direction of movement sense* Patient is able to appreciate and mirror the direction of the test movement taking place each time, but is inaccurate in its new position.

3 *Joint Position sense* Accurately mirrors the test movement to within 10°of the new test position

9 *Unable to test*

Equipment required: Blindfold.

Stereognosis

The object is placed in the patient's hand for a maximum of 30 seconds. Identification is by naming, description or by pair-matching with an identical set. Affected side of the body is tested first. The object may be moved around the affected hand by the examiner.

Scoring for each object

2 *Normal* Item is correctly named or matched.

1 *Impaired* Some features of object identified or attempts at descriptions of objects.

0 *Absent* Unable to identify the object in any manner.

9 *Unable to test*

Equipment required: Blindfold, 2p coin, 10p coin, 50p coin, biro (score 2 if labelled "pen"), pencil, comb, scissors, sponge, flannel (score 2 if labelled "cloth" or "face cloth"), cup, glass (score 2 if labelled "beaker").

REVISED NOTTINGHAM SENSORY ASSESSMENT

Name ……. Examiner …….

Patient code …….. Side of body affected: RIGHT / LEFT / BOTH / NEITHER

Date of Stroke …….. Date of Assessment ..……

TACTILE SENSATION												PROPRIOCEPTION
Regions of the body	Light touch		Temperature		Pinprick		Pressure		Tactile Localisation		Bilateral simultaneous touch	
	L	R	L	R	L	R	L	R	L	R		
Face												
Trunk												
Shoulder												
Elbow												
Wrist												
Hand												
Hip												
Knee												
Ankle												
Foot												

STEREOGNOSIS

10p Coin		Biro		Comb		Sponge		Cup	
2p Coin		Pencil		Scissors		Flannel		Glass	
50p Coin									

COMMENTS: e.g. oedema or bruising present, TEDS, presence of reflexes

KEY

0 Absent
1 Impaired
2 Normal
9 Unable to test

KEY - Proprioception

0 Absent
1 Appreciation of Movement (wrong direction)
2 Direction of movement (>10 degrees)
3 Joint Position Sense (< 10 degrees)
9 Unable to test

APPENDIX 2

The National Institutes of Health Stroke Scale

Record performance in each category after each subscale exam. Do not go back and change scores. Follow directions provided for each exam technique. Scores should reflect what a patient does, not what you thinks the patient can do. The order may be changed: first all items in sitting, than all items in lying (order of items: 1a+b+c, 2, 3, 4, 5, 6, 7 and 11, 8 and 11, A, 9 and 10).
You should record answers while administering the exam and work quickly. Except where indicated, the patient should not be coached. (i.e. repeated requests to patient to make a special effort).

IF ANY ITEM IS LEFT UNTESTED, A DETAILED EXPLANATION MUST BE CLEARLY WRITTEN DOWN. QUESTIONS 5, 6,7 AND 10 HAVE ALLOWED SCORES OF 9. DO NOT ADD THE 9' s INTO THE TOTAL SCORE.

Equipment required:
- Eye patch.
- Pin prick.
- Aphasia and dysarthria: picture, standard set of words and sentences.

1.a. Level of consciousness
0= Alert, keenly responsive.
1= Not alert, but arousable with minimal stimulation to obey, answer or respond.
2= Not alert, requires repeated stimulation to attend, or is obtunded and requires strong or painful stimulation to make movements (not stereotyped).
3= Responds only with reflex motor or autonomic effects or totally unresponsive, flaccid, areflexic.

1.b. Ask patient the month and their age
Must be exactly right
0= Answers both questions correctly.
1= Answers one question correctly.
2= Answers neither question correctly.

1.c. Ask patient to open and close eyes and then grip and release non-paretic hand
The first attempt on verbal command is scored. If patient does not understand verbal commands, you may use pantomime and touch the non-paretic hand.
0= Performs both tasks correctly.
1= Performs one task correctly.
2= Performs neither correctly.

2. Best gaze (only horizontal eye movement)

Explain exercise to patient and demonstrate if necessary.Patient should follow pencil or your face with eyes.
When there is no voluntary eye movement, check reflexive oculo-cephalic eye movement by moving the patients head from one side to the other.
To distinguish between partial gaze palsy and forced deviation, turn the head alternatively to both sides. Check whether eyes are maintained in forced position to one side. If you notice that the patient has a nystagmus, this does not influence your score.
0= Normal
1= Partial gaze palsy. This score is given when gaze is abnormal in one or both eyes, but where forced deviation or total gaze paresis are not present.
2= Forced deviation, or total gaze paresis not overcome by the oculocephalic maneuver.

3. Visual field testing
This test should be performed while patient is sitting.
Test each eye separately (use an eye patch).
To distinguish between partial and complete hemianopia, follow the next instructions:
Start movement of your fingers in the peripheral field of vision. If patient sees this movement, he scores '0'.
If patient can't see the movement of your fingers, move your hand towards the mid-line. Test again if the patient can see this movement. If yes he/she scores '1'.
If you have to move over the mid-line before he/she notices the movement, the score is '2'.
Patient must not be able to count fingers, only be able to recognise the start of finger movements.
Don't forget to test the visual extinction as part of Item 11.

If one eye can not be assessed (e.g. blindness), the score on item 3 refers to the eye that can be assessed. Only in case of hemianopia => score '1' on item 3.
E.g. patient is blind in right eye, hemianopia in left eye => score '1' on item 3.
E.g. patient is blind in right eye, left eye is normal (no visual loss, no hemianopia) => score '0' on item 3.
Note: Make a note in the comments sheet if one eye can not be assessed or in case of other problems.

0= No visual loss
1= Partial hemianopia
2= Complete hemianopia
3= Bilateral hemianopia (blind including cortical blindness)

4. Facial Paresis (Ask patient to show teeth or raise eyebrows and close eyes
tightly)

0= Normal symmetrical movement
1= Minor paralysis (flattened nasolabial fold, asymmetry on smiling)
2= Partial paralysis (total or near total paralysis of lower face)
3= Complete paralysis of one or both sides (absence of facial movement in the upper and lower face)

5. Motor function - Arm (right and left)
Patient is on the plinth in supine lying with one or two pillows under head and shoulders.
To distinguish between score '3' or '4': ask for a specific movement if patient doesn't understand the order: 'Move your arm'. You may place arm in the appropriate start position.

0= No drift , limb hold 90 (or 45) degrees for full 10 seconds
1= Drift, limb hold 90 (or 45) degrees, but drifts down before full 10 seconds;
does not hit bed or other support
2= Some effort against gravity, limb cannot get to or maintain (if cued) 90 (or 45)
degrees, drifts down to bed, but has some effort against gravity
3= No effort against gravity, limb falls
4= No movement

If the score is '9', give an explanation:
9= Untestable (Joint fused or limb amputated)

6. Motor function- Leg (right and left)
Patient is on the plinth in supine lying with one or two pillows under head and shoulders.
To distinguish between score '3' or '4': ask for a specific movement if patient doesn't understand the order: 'Move your leg'. You may place leg in the appropriate start position.

0= No drift, leg holds 30 degrees position for full 5 seconds.
1= Drift, leg falls by the end of the 5 second period but does not hit bed.
2= Some effort against gravity; leg falls to bed by 5 seconds, but has some
effort against gravity.
3= No effort against gravity, leg falls to bed immediately.
4= No movement

If the score is '9', give an explanation:
9= Untestable (Joint fused or limb amputated)

7. Limb ataxia
Test with eyes open.

Finger-to-nose test: finger must be in the visual field and maintain same position.

0= No ataxia
1= Present in one limb
2= Present in two limbs

If present, is ataxia in right arm
1= Yes
0= No

Left arm
1= Yes
0= No

If the score is '9', give an explanation:
9= Untestable (Joint fused or limb amputated)

Right leg
1= Yes
0= No

Left leg
1= Yes
0= No

If the score is '9', give an explanation:
9= Untestable (Joint fused or limb amputated)

8. Sensory (Use pinprick to test arms, legs , trunk and face -- compare side to side)

Standard test position is supine lying. If the patient is more comfortable in the sitting position, this position is also allowed.
Test with eyes closed.
Score 2: 'Severe to total sensory loss; patient is not aware of being touched at the face, arm and leg'.
*Pin prick: 10 cm above and under elbow and knee **on lateral side**.*
If patient feels something on affected side, test than whether the sensation is less sharp or duller when compared with the unaffected side.
Vary the rhythm of touching the patient.
Test tactile extinction. If the patient feels the 'touch' tested separately on the left and right side, than verify if he/she feels the 'touch' on both sides if the stimulation is given simultaneously left and right.

0= Normal, no sensory loss.

1= Mild to moderate sensory loss; patient feels pinprick is less sharp or is dull on
the affected side; or there is a loss of superficial pain with pinprick but patient is
aware he/she is being touched.
2= Severe to total sensory loss; patient is not aware of being touched in the face,
and leg.

9. Best language (describe picture, name items, read sentences)
If patient wears glasses, he should use these during this test.
If patient has visual field loss, make sure you show him/her the picture in his visual field.

0= No aphasia, normal.
1= Mild to moderate aphasia; some obvious loss of of fluency or facility of
comprehension, without significant limitation on ideas expressed or form of
expression. Reduction of speech and/or comprehension, however, makes
conversation about provided material difficult or impossible. For example in
conversation about provided materials examiner can identify picture or naming
card from patient's response.
2= Severe aphasia; all communication is through fragmentary expression; great
need for interference, questioning, and guessing by the listener. Range of
information that can be exchanged is limited; listener carries burden of
communication.
Examiner cannot identify materials provided from patient's response.
3= Mute, global aphasia; no usable speech or auditory comprehension.

10. Dysarthria (read several words)
If patient wears glasses, he should use these for this test.
If a patient has visual field loss, make sure you show him/her the picture in his/her visual field (E.g. you can hand the pictures over to the patient).

0= Normal articulation
1= Mild to moderate; patient slurs at least some words and, at worst, can be
understood with some difficulty.
2= Severe; patient's speech is so slurred as to be unintelligible in the absence of
or out of proportion to any dysphasia, or is mute/anarthric.

If the score is '9', give an explanation:
9= Intubated or other physical barrier, explain:

11. Extinction or inattention
If the patient has no visual or tactile extinction, but you found evidence for neglect, score a '1'.
If the patient has a severe sensory loss preventing meaningful simultaneous sensory stimulation, and the visual stimuli are normal, the score is normal.
Inattention in one modality= score '1'; inattention in more than one modality= score '2'.

0= No abnormality.
1= Visual, tactile, auditory, spatial, or personal inattention or extinction to bilateral
simultaneous stimulation in one of the sensory modalities.
2= Profound hemi-inattention or hemi-inattention to more than one modality.
Does not recognize own hand or orients to only one side of space.

TOTAL SCORE _____

Additional item, not a part of the NIH Stroke Scale score.

A. Distal Motor function
If not all fingers can be extended, score a '1'.
If the extension is incomplete, score a '1'.
No strength at all, score a '2'.

0 = Normal (no flexion after 5 seconds)
1= At least some extension after 5 seconds, but not fully extended. Any movement
of the fingers which is not command is not scored.
2= No voluntary extension after 5 seconds. Movements of the fingers at another time are not scored.

APPENDIX 3

Rivermead Motor Assessment

General Instructions:

Go through the items in order of difficulty. Three tries are allowed for each item. The best performance is scored. Score '1' if patient can perform activity, ' 0' if he cannot. If the patient refuses to perform the item, for example, due to anxiety, then score "0". In the 'Gross Function' and 'Arm' section you may stop that the test after 3 consecutive '0' scores. In the 'Leg and Trunk' section all actions should be tested, even if there are three consecutive '0' scores.

Give no feedback of whether correct or incorrect, just give general encouragement. Repeat instructions and demonstrate them to the patient if necessary. All exercises should be carried out independently unless otherwise stated. All arm tests refer to the affected side unless otherwise stated. Whenever a stroke patient has impairments of both sides (left and right), the items of the RMA that refer to ‘the affected side’ are performed with the side that is the most impaired.

This "Gross Function" section does not evaluate quality of movement. The end position must be reached and must be safe, but the way the exercise is performed does not matter except if otherwise stated. It can be assessed simply by asking, which makes it a rapid measure. If it is not possible to assess the gross function section by asking, then it is assessed practically. It is allowed to start the assessment at the estimated level that the patient can perform and then check that they were able to do the three previous items. Then continue with the assessment until the patient has three consecutive failures.

A. Gross function

1. Sit unsupported

Without holding on, on edge of bed/ plinth, feet unsupported.

2. Lying to sitting on side of bed

Using any method. "Bed" can also be a "plinth" depending on circumstances. The patient is allowed to choose over which side of the bed he/she comes up into the sitting position.

3. Sitting to standing

May use hands to push up. Must stand up in 15 sec and stand for 15 sec, with an aid if necessary. The height of bed or plinth should be adjusted so that the patient's feet were flat on the ground with approximately 110 degrees of knee flexion.

4. Transfer from wheelchair to chair towards unaffected side

The assessor is allowed to position the wheelchair perpendicular to the chair, with the brakes on and foot plates removed. No further help or advice was given. The patient may use their hands. If the patient usually used an aid e.g. frame or sliding board to transfer from wheelchair to chair, they were also allowed to use it in this test. If they performed the transfers independently (with or without an aid), they still scored a '1'.

The usual principle of the gross function section is that provided they can do the task independently then how they do it doesn't matter. Provided they are independent and need no external help it is adequate. On that basis using a frame, or sliding board was acceptable.

5. Transfer from wheelchair to chair towards affected side

As in Item 4.

6. Walk 10 m indoors with an aid

Any walking aid can be used. No stand-by help. If when performing the assessment the patient has not yet been supplied with a walking aid, the patient can choose him/herself any walking aid to perform the test. If the environment of the assessment e.g. home visits does not have a suitable space for a 10m walk in a straight line, the patient can change directions.

7. Climb stairs independently

Any method may be used. May use banister and aid though must be a full flight of stairs, defined as 8 to 12 steps. No stand-by help is allowed meaning that the patient can walk safely without supervision of the therapist.

8. Walk 10 m indoors without an aid

No stand-by help. No calliper, splint or walking aid can be used.

9. Walk 10m, pick up beanbag from floor, turn and carry back

Bend down any way, may use aid to walk if necessary. No stand-by help. May use either hand to pick up beanbag.

10. Walk outside 40 m

May use walking aid, calliper or splint. No stand-by help. It is allowed to ask the patient, family or therapist to assess this item.

11.Walk up and down four steps

Patient may use an aid if he would normally use one, but may not hold on to rail. This is included to test ability to negotiate curb or stairs without a rail. The patient is allowed to walk down the four steps backwards. If no steps are available e.g. in the patient's home, this item can be assessed by asking whether he/she uses stairs in public buildings, without using rails. If the patient does not know the answer or answers that he/she never uses stairs then they scored "0" on this item.

12. Run 10 m

Must be symmetrical.

13. Hop on affected leg five times on the spot

Must hop on ball of foot without stopping to regain balance. No help with arms. "On the spot" means a circle with a diameter of approximately 50cm.

B. <u>Leg and trunk</u>

1. Roll to affected side

Starting position should be lying, not crook lying. It should be ensured the patient is positioned on the plinth in such a way that there is suitable space on the plinth for he/she to role in the required direction. The patient is not allowed to pull him or herself up using the side of the bed but is allowed to use their hands to push. The end position should be stable

2. Roll to unaffected side

As Item 1.

3. Half-bridging

The starting position is half-crook lying. Therapist may position leg, but patient must maintain position even after movement is completed. Patient must put some weight through affected leg to lift hip on affected side, assessed by the therapist placing their hand under the affected heel.

4. Sitting to standing

The patient may not use their arms to push off. Their feet must be flat on floor, with weight going through both feet.

5. **Half-crook lying: lift affected leg over side of bed and return it to the same position.**

Affected leg in half-crook position. Lift leg off bed on to support; for example, box, stool, floor, so that hip is in neutral and knee at 90 degrees while resting on support. Must keep affected knee flexed throughout movement. Do not allow external rotation at hip. This tests control of hip and knee.

6. **Standing, step unaffected leg on and off block**

A solid block of 20cm should be used. There should not be retraction of pelvis or hyperextension of knee. This tests knee and hip control while weight bearing through the affected leg. This item is not scored depending on speed, therefore if the patient completes the item but very quickly due to lack of balance, they are still scored as being able to complete the activity".

7. **Standing, tap ground lightly five times with unaffected foot**

Without retraction of pelvis or hyperextension of knee. Weight must stay on affected leg, with the unaffected foot coming fully off the ground between each tap. May tap ground only with foot tip, not with the whole foot. This again tests knee and hip control while weight bearing through the affected leg but is more difficult than in 6.

8. **Lying, dorsiflex affected ankle with leg flexed**

Physiotherapist may hold affected leg in position, knee at 90 degrees. Do not allow

inversion. Must have half range of movement of unaffected foot. The patient should not be wearing shoes. The exercise should be demonstrated and performed initially on the unaffected side. This allowed the therapist to check the patient understood the task and also allowed them to observe their range of movement on the unaffected side to allow a comparison.

8. Lying, dorsiflex affected ankle with leg extended

Same condition as in 8, with leg extended. Do not allow inversion or knee flexion. Foot must reach plantigrade (90°).

10. Stand with affected hip in neutral position, flex affected knee

Therapist may not position leg. This is extremely difficult for most hemiplegic patients, but is included to assess minimal dysfunction.

C. Arm

1. Lying, protract shoulder girdle with arm in elevation

Arm may be supported. The starting position is with the shoulder in 90 degrees of flexion. The therapist should place one hand on the medial border of the scapula to feel for protraction. However if only a contraction is felt, the patient still scores "0- unable", movement must occur for a score of "1" to be given.

2. Lying, hold extended arm in elevation (some external rotation) for at least 2 sec

Therapist should place arm in position, with shoulder at 90 degrees of flexion.The patient must maintain the position with some external rotation. Do not allow pronation. Elbow must be held within 30 degrees of full extension.

3. Flexion and extension of elbow, with arm as in 2 above

Starting position with shoulder in 90 degrees of flexion. Elbow must extend to at least 20 degrees full extension. Palm should not face out during any part of movement. The elbow is not supported, and the palm of the patient's hand must touch their face before the elbow is then extended for the patient to be scored as able to complete the activity ("1").

4. Sitting, elbow into side, pronation and supination

Three-quarters range is acceptable, with elbow unsupported and at right angles.

5. Reach forward, pick up large ball with both hands and place down again

Ball should be on table so far in front of patient that he has to extend arms fully to reach it, not reach forward with their trunk. The patient must have reached forward with both arms without any support of, for example, the table or their unaffected side. Shoulders must be protracted, elbows extended, wrist neutral or extended, and fingers extended throughout movement. Palms should be kept in contact with the ball on the lateral sides.

6. Stretch arm forward, pick up tennis ball from table, release on affected side, return to table, then release again on table. Repeat five times

Shoulder must be protracted, elbow extended and wrist neutral or extended during each phase. The patient must release the ball next to their affected thigh by removing the hand off the ball. The patient must perform the exercise correctly five times after another.

7. Same exercise as in 6 above with pencil

Patients must use thumb and fingers to grip. A palmar grip or lateral pinch is not acceptable.

8. Pick up a piece of paper from table in front and release five times

The patient must use their thumb and fingers to pick up paper and not pull it to edge of table. Arm position as in 6 above. The paper should be picked up and released on the same spot. They may not pick up the paper by wrinkling it.

9. Cut putty with a knife and fork on plate with non-slip mat and put pieces into container at side of plate

The patient can chose which hand he/she wants to use the knife with, and with which he/she wants to use the fork. They must however picked up the knife or fork with their affected hand, without help from their unaffected hand. It must be a bimanual activity, with at least 3 pieces of the putty being cut into bite-size pieces.

10. Stand on spot, maintain upright position, pat large ball on floor with palm of hand for 5 continuous bounces

The patient may try first with their unaffected arm.

11. Continuous opposition of thumb and each finger more than 14 times in 10 sec

Must do movement in consistent sequence. Do not allow thumb to slide from one finger to the other. *Visual control is allowed.*

12. Supination and pronation on to palm of unaffected hand 20 times in 10 sec

Arm must be away from body, the full palm and the full dorsum of the affected hand (not only the ulnar side of the hand) must touch the palm of the unaffected hand. Each tap counts as one. This is similar to 4 above, but introduces speed

13. Standing, with affected arm abducted to 90 degrees with palm flat against wall. Maintain arm in position. Turn body towards wall and as far as possible towards arm, i.e. rotate body beyond 90 degrees

Do not allow flexion at elbow, and wrist must be extended with palm of hand fully in contact with wall.

14. Place string around head and tie bow at back

Do not allow neck to flex. Affected hand must be used for more than just supporting string. This tests function of hand without help of sight. It is ensured the patient ties a bow, not a knot. However the bow does not have to be in the centre of the patient's head, it is allowed to be

asymmetrical (e.g. due to restricted shoulder movement). However extreme neck flexion is not allowed.

15. 'Pat- a-cake' seven times in 15 sec

Initially demonstrate this to the patient face to face. Then mark crosses on wall at shoulder level. Clap both hands together (both hands touch crosses.) Each sentence counts as one. Give patients three tries. This is a complex pattern which involves co-ordination, speed,and memory, as well as good arm function.

Barthel Index

Item 5: Feeding: If the patient ate independently but only when the food was cut or mixed then on the Barthel Index a score of 1 (needs help cutting, spreading butter etc.) was given.

Item 10: Bathing**:** If the patient never had a bath, only a shower, they still scored 1 if they showered independently. The principal is about 'being able to wash yourself (whole body) independently' and not the method in which this is done.

APPENDIX 4

The Barthel ADL Index: guidelines

1. This index should be used as a record of what a patient does, not as a record of what a patient could do.

2. The main aim is to establish degree of independence from any help, physical or verbal, however minor and for whatever reason.

3. The need for supervision renders a patient not independent.

4. A patient's performance should be established using the best available evidence. Asking the patient, friends/relatives and nurses are the usual sources, but direct observation and common sense are also important. However direct testing is not needed.

5. Usually the patient's performance over the preceding 24-48 hours in important, but occasionally longer periods will be relevant.

6. Middle categories imply that the patient supplies over 50 percent of the effort.

7. Use of aids to be independent is allowed.
(Wade, 1992)

1. Bowels
0= incontinent (or needs to be given enema)
5= occasional accident (once a week)
10= continent

2. Bladder
0= incontinent, or catheterized and unable to manage alone
5= occasional accident (maximum once per 24 hours)
10= continent

3. Grooming
0= needs help with personal care
5= independent face/hair/teeth/shaving (implements provided)

4. Toilet use
0= dependent
5= needs some help, but can do something alone
10= independent (on and off, dressing, wiping)

5. Feeding
0= unable
5= needs help cutting, spreading butter, etc.
10= independent

6. Transfer (bed to chair and back)
0= unable, no sitting balance

5= major help (one or two people, physical), can sit
10= minor help (verbal or physical)
15= independent

7. Mobility
0= immobile
5= wheelchair independent, including corners
10= walks with help of one person (verbal or physical)
15= independent (but may use any aid; for example, stick)

8. Dressing
0= dependent
5= needs help but can do about half unaided
10= independent (including buttons, zips, laces, etc.)

9. Stairs
0= unable
5= needs help (verbal, physical, carrying aid)
10=independent

10. Bathing
0= dependent
5= independent

APPENDIX 5

Nottingham Extended Activities of Daily Living

The following questions are about everyday activities. Please answer by ticking ONE box for each question. Please record what you have ACTUALLY done in the last few weeks.

DID YOU…….	Not at all	With help	On your own with difficulty	On your own
1. Walk around outside?	☐	☐	☐	☐
2. Climb stairs?	☐	☐	☐	☐
3. Get in and out of a car?	☐	☐	☐	☐
4. Walk over uneven ground?	☐	☐	☐	☐
5. Cross roads?	☐	☐	☐	☐
6. Travel on public transport?	☐	☐	☐	☐
7. Manage to feed yourself?	☐	☐	☐	☐
8. Manage to make yourself a hot drink?	☐	☐	☐	☐
9. Take hot drinks from one room to another?	☐	☐	☐	☐
10. Do the washing up?	☐	☐	☐	☐
11. Make yourself a hot snack?	☐	☐	☐	☐

12. Manage your own money when you were out?				
13. Wash small items of clothing?				
14. Do your own housework?				
15. Do your own shopping?				
16. Do a full clothes wash?				
17. Read newspapers or books?				
18. Use the telephone?				
19. Write letters?				
20. Go out socially?				
21. Manage your own garden?				
22. Drive a car?				

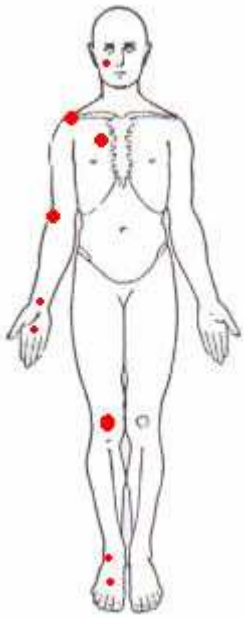
APPENDIX 6

SHORTENED NOTTINGHAM SENSORY ASSESSMENT (2005)

Instructions

The patient should be assessed in sitting and in a suitable state of undress (ideally in shorts & underwear, without TED stockings). It should be ensured the patient is comfortable and in a quiet area with no distractions. Each test is described and demonstrated to the patient before he or she is blindfolded. The blindfold is removed regularly throughout the test to avoid the patient becoming disorientated.

The body area to be tested is as marked on the body chart. Apply the test sensation to the test area, to the left and right side in a random order. The patient is asked to indicate, either verbally or by a body movement, whenever he or she feels the test sensation.



Each part of the body is assessed three times for each of the tests.

Presence of a reflex does not count as awareness of sensation, though this should be commented on in the comment box.

Tactile Sensation

If the patient has problems communicating begin testing light touch, pressure and pinprick sections.

Scoring criteria

0	*Absent*	Fails to identify the test sensation on three occasions
1	*Impaired*	Identifies the test sensation, but not on all three occasions in each region of the body or feels duller
2	*Normal*	Correctly identifies the test sensation on all three occasions
10	*Unable to test*	

Light Touch Touch, not brush, the skin lightly with a cotton wool ball.

Pressure Press the skin just enough to deform the skin contour using the index finger.

Pinprick Prick the skin with a neurotip, maintaining even pressure.

Temperature Touch the skin with the side of one of two test tubes, one filled with hot water, one filled with cold water (use the sides, not the bases of the test tubes). Apply hot and cold tubes in random order.

Tactile localisation Only test those areas on which the patient has scored 2 on the pressure section.
Record all others as 9.
Repeat the pressure test with the index fingertip coated with talcum powder to mark the spot touched and ask the patient to point to the exact spot that has been touched. If communication permits, the test may be combined with the pressure test. 2cm of error are allowed.

Bilateral Simultaneous Touch Touch corresponding sites on one or both sides of the body using the fingertips and ask the patient to indicate if both or one (and which) have been touched. Only test those items on which the patient has scored 2 on pressure section.
Record all others as 9.

Equipment required: Blindfold, cotton wool ball, Neurotip, two test tubes, hot and cold water, talcum powder.

Kinaesthetic Sensations

All three aspects of movement are tested: appreciation of movement, its direction and accurate joint position sense are assessed simultaneously. The limb on the affected side of the body is supported and moved by the examiner in various directions but movement is only at one joint at a time. The patient is asked to mirror the change of movement with the other limb. Three practice movements are allowed before blindfolding.

The upper limb is tested in sitting, and the lower lying supine.

Scoring

0	*Absent*	No appreciation of movement taking place.
1	*Appreciation of movement taking place*	Patient indicates on each movement that a movement takes place but the direction is incorrect.
2	*Direction of movement*	Patient is able to appreciate and mirror the direction of the test movement taking place each time, but is *sense* inaccurate in its new position.
3	*Joint Position*	Accurately mirrors the test movement to within *sense* 10°of the new test position
10	*Unable to test*	

Equipment required: Blindfold.

Stereognosis

The object is placed in the patient's hand for a maximum of 30 seconds. Identification is by naming, description or by pair-matching with an identical set. Affected side of the body is tested first. The object may be moved around the affected hand by the examiner.

Scoring for each object

2	*Normal*	Item is correctly named or matched.
1	*Impaired*	Some features of object identified or attempts at descriptions of objects.
0	*Absent*	Unable to identify the object in any manner.
10	*Unable to test*	

Equipment required: Blindfold, 2p coin, 10p coin, 50p coin, biro (score 2 if labelled "pen"), pencil, comb, scissors, sponge, flannel (score 2 if labelled "cloth" or "face cloth"), cup, glass (score 2 if labelled "beaker").

SHORTENED NOTTINGHAM SENSORY ASSESSMENT FORM

Name …… Assessor ……

Side of body affected: RIGHT / LEFT / BOTH Side of body assessed: RIGHT / LEFT

Date of Stroke …… Date of Assessment ……

TACTILE SENSATION

Light Touch

Face ☐ Trunk ☐ Shoulder ☐ Wrist ☐ Hand ☐

Temperature

Face ☐ Trunk ☐ Elbow ☐ Wrist ☐ Hand ☐

Knee ☐ Ankle ☐ Foot ☐

Pinprick

Face ☐ Trunk ☐ Shoulder ☐ Elbow ☐ Hand ☐ Ankle ☐ Foot ☐

Pressure

Face ☐ Trunk ☐ Shoulder ☐ Elbow ☐ Wrist ☐

Knee ☐ Ankle ☐ Foot ☐

Tactile Localisation

Face ☐ Trunk ☐ Ankle ☐ Foot ☐

Bilateral Simultaneous Touch

Face ☐ Trunk ☐ Shoulder ☐ Elbow ☐ Knee ☐ Ankle ☐ Foot ☐

STEREOGNOSIS Help given manipulating object Y / N

50p coin ☐ Pencil ☐ Comb ☐ Sponge ☐ Glass ☐

PROPRIOCEPTION

Shoulder ☐ Elbow ☐ Hand ☐ Hip ☐ Knee ☐

COMMENTS: e.g. oedema or bruising present, TEDS, performance on ipsilateral side

KEY
0 Absent
1 Impaired
2 Normal
9 Unable to test

KEY - Proprioception
0 Absent
1 Appreciation of Movement (wrong direction)
2 Direction of movement (>10^{o})
3 Joint Position Sense (< 10^{o})
9 Unable to test

APPENDIX 7

Inter-Rater Reliability of the Shortened NSA

In the main study the internal validity of the NSA was checked. As a result of deleting those items which lacked validity, a shortened version was produced and a new assessment form created (see Appendix 6). The inter-rater reliability of this shortened NSA was then tested.

Method

Patients were recruited from those involved in the main study, following the same inclusion and exclusion criteria and under the same ethical approval. A convenience sample of twenty-one patients was included. These were determined by those patients, which were due for assessment on the day the observer was available. For these patients the inter-rater reliability of the shortened NSA between two assessors was examined. One of the researchers (LC) was familiar with the NSA and trained the other researchers (BS & SA) in the assessment to ensure standardisation. Pilot assessments were carried out prior to data collection.

Each patient was assessed on the NSA by an assessor (LC, BS or SA) following the procedure in the main study. A second assessor (LC, BS, or SA) observed each assessment and independently rated the patient on the NSA. Assessor 1 remained constant (LC) and was paired with either assessor 2 (BS) or assessor 3 (SA) dependent on availability. The assessment forms of each assessor were kept separate so it was not possible for the assessors to see how each other had scored.

Data collected were entered into the SPSS package for collation of information into a suitable format for analysis. Reliability of the assessment was examined

using the kappa coefficient of agreement (Cohen, 1960), which measures the amount of agreement that exists beyond chance.

Results

Demographic Details

The demographic details of the twenty-one patients included are shown in table below.

Appendix Table 1: Demographic Details of the Patients

Gender	men women	10 11
Age	Mean SD range	73 11 41-85
Time since onset (days)	median IQR	19 14-36
Side of lesion	right left no clear lateralisation	9 11 1
Ward	F20 (QMC*) Beeston (NCH*)	7 14
Post-stroke Barthel	Median IQR	35 20-65
Rivermead Motor Assessment at recruitment	Gross Motor Function: Median IQR	8 5-13
NIHSS	Median IQR	2 1-5

*QMC = Queens Medical Centre, NCH= Nottingham City Hospital

The level of agreement between assessors was calculated using Cohen's kappa coefficient. Results are shown in the table below. Where no Kappa value is given, this is because it could not be calculated as no patients scored one of the categories.

Table 2 : Level of agreement between two assessors for each item

Sensation		Kappa Value		
		Assessor 1 & 2	Assessor 1&3	Assessor 1 & Assessor 2 &3
	n	11	10	21
Light Touch	Face	0.83	0.80	0.81
	Trunk	1.00	1.00	0.92
	Shoulder	0.76	1.00	0.92
	Wrist	1.00	1.00	1.00
	Hand	1.00	1.00	1.00
Temperature	Face	0.81	-	0.80
	Trunk	1.00	1.00	1.00
	Elbow	0.80	0.82	0.81
	Wrist	1.00	0.83	0.91
	Hand	0.83	0.80	0.82
	Knee	0.73	-	0.76
	Ankle	1.00	1.00	1.00
	Foot	1.00	1.00	1.00
Pinprick	Face	1.00	1.00	1.00
	Trunk	0.51	1.00	0.73
	Shoulder	1.00	1.00	1.00
	Elbow	1.00	1.00	1.00
	Hand	1.00	1.00	1.00
	Ankle	0.82	1.00	0.91
	Foot	1.00	1.00	1.00
Pressure	Face	1.00	1.00	1.00
	Trunk	**0.21**	**0.57**	**0.42**
	Shoulder	**0.26**	**-**	**0.43**
	Elbow	**0.53**	0.82	0.67
	Wrist	1.00	1.00	1.00
	Foot	1.00	**0.63**	0.80
Tactile Localisation	Face	1.00	1.00	1.00
	Trunk	1.00	0.71	0.85
	Ankle	**-0.17**	**0.33**	**0.16**
	Foot	1.00	**0.55**	0.75
Bilateral Simultaneous Touch	Face	-	1.00	1.00
	Trunk	**0.59**	1.00	0.83
	Shoulder	1.00	1.00	1.00
	Elbow	1.00	1.00	1.00
	Knee	1.00	1.00	1.00
	Ankle	-	-	-
	Foot	1.00	1.00	1.00
Stereognosis	50p coin	1.00	1.00	1.00
	Pencil	1.00	1.00	1.00
	Comb	1.00	1.00	1.00
	Sponge	1.00	1.00	1.00
	Glass	1.00	1.00	1.00
Proprioception	Shoulder	-	1.00	0.67
	Elbow	**0.56**	1.00	0.76
	Hand	**0.55**	1.00	0.75
	Hip	-	-	-
	Knee	0.83	0.84	0.83

KEY: Interpretation of Kappa values (Landis, 1977)

< 0	Agreement weaker than chance
0 - 0.2	Slight
0.2 - 0.4	Fair
0.4 - 0.6	Moderate
0.6 - 0.8	Substantial
0.8 - 1.0	Almost Perfect

The results show that for the majority of items there was at least a substantial agreement between assessors. The items which showed less agreement were detection of pressure of the trunk and shoulder, and tactile localisation of the ankle. These were low between both assessor 1 and 2, and assessor 1 and 3. However the pressure items were still within acceptable limits, showing moderate agreement between all assessors. Ankle tactile localisation only showed slight agreement for all assessors, and there was particularly poor agreement between assessors 1 and 2.

Discussion

The results show that as a whole the shortened NSA has good inter-rater reliability. Assessment of pressure in the shoulder and trunk was less reliabile although still acceptable. This may be because of the method used in this study (both assessors scored patients simultaneously, one carried out the assessment while the other simply observed). This means the person carrying out the assessment had more interaction with the patient and provided the sensory stimulus. On occasions the scorer may have been less well placed to see the patients' response to the stimulus and was also unable to obtain clarification or re-assess an item if they were unsure. Getting a clear view may have been difficult for the scorer on areas such as the trunk which require the examiner to be in close contact with the patient. However this is not supported by the fact that substantial agreement between assessors was found for the shoulder and trunk for other tactile sensations.

Tactile localisation of the ankle showed only slight agreement between assessors, and may have been due to differences in the assessors' perception of the accuracy required of the localisation for the different categories. However

the other areas of the body showed high agreement, so it is unclear as to why agreement was so poor for the ankle. The agreement between assessor 1 and 3 was fair, whereas the agreement between assessor 1 and 2 was worse than one might have expected by chance. This lack of reliability means that the inclusion of this item in the shortened NSA should be questioned, and suggest that the ankle is a very unreliable area for sensory assessment.

Previous inter-rater reliability work on the NSA has shown less agreement than the present study. On the original NSA (Lincoln et al., 1991) inter-rater reliability was found to be poor, and the revised version (Lincoln et al., 1998) had acceptable but not good inter-rater reliability. However both of these studies examined reliability between assessors on different assessment occasions. The first study compared a physiotherapist and a doctor, with the time between these assessments unspecified. The second study compared two physiotherapists assessing patients within three days of each other. Therefore the lack of reliability in these studies may have been due to changes in sensory ability or environmental factors e.g. temperature, light, between assessments, variability of performance or factors such as poor concentration and low mood. It was suggested that the reliability of the NSA needed to be investigated using simultaneous recording of responses from two assessors (Lincoln et al., 1998). This was addressed in this study, which showed that the shortened NSA had good inter-rater reliability under these conditions. This means that the NSA has high reliability and results from two assessors in this study could be combined.

Inter-rater reliability of the Rivermead Assessment of Somatosensory Performance (RASP) (Winward et al., 2002) has also been determined. This

was determined by comparing different therapists assessing the same patient within 5 days of each other. Although the RASP had good inter-rater reliability, only the agreement between total scores as opposed to the individual items was checked. The RASP is less likely to be used in clinical practice than the NSA since it requires purchase of an assessment manual and specific equipment, and assesses fewer body areas. Its internal validity remains to be investigated. Therefore the shortened NSA is a practical and reliable sensory assessment that is used in clinical practice within the UK.

This study only included a small sample of patients. Therefore impairment on some items was not observed. It would have been beneficial to examine the reliability on a larger number of patients. This would ensure that every item had been observed in people who were unimpaired on the item as well as impaired on the item.

Conclusion

The shortened NSA has been found to have good inter-rater reliability. This means it is a sensory assessment suitable for clinical use that is standardised, reliable and valid. It now warrants further use with stroke patients in both clinical and research settings.

APPENDIX 8

Publications/Presentations

- Physiotherapeutic Research Group Seminar
  Presentation of PhD preliminary results
  February 2004

- Presentation of Abstract: Sensory Impairment and Patterns of Recovery: Preliminary Results.
  Stroke Association Scientific Meeting,
  Aston University, Birmingham Sept 2003

- Presentation of Abstract: Rasch Analysis of the Nottingham Sensory Assessment
  Society for Research in Rehabilitation Summer Meeting
  Glasgow, June 2004

  Awarded Verna Wright prize for best oral presentation

  Abstract published
  Connell, L.A., Lincoln, N.B., Radford, K. (2004) Rasch Analysis of the Nottingham Sensory Assessment. *Clinical Rehabilitation* **18** p930

- Poster abstract: Rasch Analysis of the Nottingham Sensory Assessment
  Stroke Association Scientific Meeting,
  Churchill College, Cambridge Sept 2004

- Presentation of Abstract: Sensory Impairment and Recovery After Stroke
  Society for Research in Rehabilitation Winter Meeting
  Sheffield, February 2007