

Measurement of Upper Limb Motor Recovery following a Stroke

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Summary

Normal movement of the upper limb is very complex. Following a stroke a patient can be left with a non-functional arm. The aim of rehabilitation is to minimise impairments and reduce disability and handicap. Outcome measures are required to guide and evaluate rehabilitation. In this study the impairments of spasticity and/or contracture and muscle weakness were assessed. Spasticity and/or contracture were assessed using the Modified Ashworth Scale. Muscle strength was measured by assessing grip strength with the Standard Jamar dynamometer. Upper limb disability was measured with the Nine Hole Peg Test (a test of manual dexterity) and the Action Research Arm Test (a test of upper limb function with the components of reach and grasp or fine manipulation).

Twenty-two stroke subjects were assessed on five different occasions post stroke. The initial assessment was carried out 2-4 weeks post stroke and then at 4, 8, 20 and 32 weeks following that assessment. The assessment at week 8 was approximately 3 months post stroke and the assessment at week 32 was approximately 6 months post stroke. The aim of the study was firstly, to look at the validity and reliability of the four tests chosen to measure impairment and disability and secondly, to find out if the four tests were able to detect changes in the hemiplegic upper limb over a 6 month period following acute stroke. All the tests did detect change with most of that change occurring in the first 3 months. The most responsive test to change appeared to be grip strength. This study suggests that the tests are suitable outcome measures to use, to guide and evaluate therapeutic intervention after stroke, although there is a need for standardisation of the methodology, equipment, procedure and the scoring used for these tests.

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Pandyan AD, Cameron M, Powell J, Stott DJ, Granat MH. Contractures in the Post Stroke Wrist: A Pilot Study of its Time Course of Development and its Association with Upper Limb Recovery. *Clinical Rehabilitation* 2001 In Press.

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Table of Contents

Contents	Pages
List of Tables	vi
List of Figures	vi
List of Photographs	vii
Chapter One. Introduction	
1.1. Definition of Stroke.....	1
1.2. Circulation of the Brain.....	1
1.3. Aetiology.....	3
1.4. Classification of Stroke.....	3
1.5. Epidemiology of Stroke.....	6
1.5.1. Stroke Mortality.....	6
1.5.2. Incidence of Stroke.....	6
1.5.3. Case-fatality of Stroke.....	6
1.5.4. Prevalence of Stroke.....	7
1.5.5. Cost of Stroke.....	7
1.6. Model of Disablement.....	8
1.6.1. Classification of Pathology.....	8
1.6.2. Classification of Impairment.....	8
1.6.3. Classification of Disability.....	9
1.6.4. Classification of Handicap.....	9
1.7. Rehabilitation Outcomes.....	10
1.8. Measurement.....	10
1.8.1. Validity of Measurement.....	11
1.8.2. Reliability of Measurement.....	12

1.9.	Normal Function of the Upper Limb.....	13
1.10.	Motor Dysfunction of the Upper Limb after Stroke.....	13
1.10.1.	Spasticity	13
1.10.2.	Muscle Weakness	15
1.10.3.	Abnormal Movement Patterns.....	16
1.11.	Recovery of the Upper Limb after Stroke.....	19
1.12.	Aims of Study.....	23

Chapter Two. General Methodology

2.1.	Research Design.....	24
2.2.	Subjects.....	24
2.3.	Inclusion Criteria.....	25
2.4.	Exclusion Criteria.....	25
2.5.	Subject Recruitment.....	26
2.6.	Characteristics of the Study Group.....	27
2.7.	Procedures.....	28
2.8.	Order of Tests.....	30
2.9.	Outcome Measures.....	31
2.9.1.	Measurements of Impairment.....	31
2.9.2.	Measurements of Disability.....	31
2.10.	Statistical Analysis.....	31
2.11.	Reporting of Results.....	32

Chapter Three. The Modified Ashworth Scale

3.1.	Introduction.....	33
3.2.	Validity	34
3.3.	Reliability.....	35

3.4.	Methodology.....	38
3.4.1.	Test Position.....	38
3.4.2.	Procedure.....	38
3.4.3.	Scoring.....	39
3.5.	Results.....	40
3.6.	Discussion.....	44
3.7.	Conclusion.....	46

Chapter Four. Grip Strength

4.1.	Introduction.....	47
4.2.	Validity of Grip Strength	48
4.3.	Validity of the Standard Jamar Dynanometer.....	48
4.4.	Reliability of Grip Strength.....	49
4.5.	Reliability of the Standard Jamar Dynanometer.....	49
4.6.	Methodology.....	51
4.6.1.	Equipment.....	51
4.6.2.	Test Position.....	51
4.6.3.	Procedure.....	52
4.6.4.	Scoring.....	52
4.7.	Results.....	53
4.8.	Discussion.....	57
4.9.	Conclusion.....	59

Chapter Five. The Nine Hole Peg Test

5.1.	Introduction.....	60
5.2.	Validity.....	60
5.3.	Reliability.....	61

5.4.	Methodology.....	63
5.4.1.	Equipment.....	63
5.4.2.	Test Position	64
5.4.3.	Procedure.....	64
5.4.4.	Scoring.....	64
5.5.	Statistical Analysis/Reporting of Results	65
5.6.	Results.....	66
5.7.	Discussion.....	71
5.8.	Conclusion.....	73

Chapter Six. The Action Research Arm Test

6.1.	Introduction.....	74
6.2.	Validity.....	75
6.3.	Reliability.....	76
6.4.	Methodology.....	78
6.4.1.	Equipment.....	78
6.4.2.	Test Position.....	79
6.4.3.	Procedure.....	80
6.4.4.	Scoring.....	82
6.5.	Results.....	83
6.6.	Discussion.....	87
6.7.	Conclusion.....	88

Chapter Seven. General Discussion

7.1.	Discussion.....	90
7.2.	Conclusion.....	96
7.3.	Further Research.....	97

References 98

Appendices

Video of Action Research Arm Test

Back Sleeve

List of Tables

1.1	Cerebral Infarct and Outcome.....	5
2.1.	Characteristics of the Study Group.....	27
3.1.	The Modified Ashworth Scale	34
3.2.	Individual Modified Ashworth Scale Scores	40
3.3.	Modified Ashworth Scale Scores	41
3.4.	Modified Ashworth Scale Scores. Numbers and Percentages	42
3.5.	Changes in Score in the Modified Ashworth Scale	43
4.1.	Individual Mean Grip Strength Scores	53
4.2.	Mean Grip Strength Scores	54
4.3.	Mean Grip Strength Scores. Numbers and Percentages	55
4.4.	Changes in Mean Grip Strength Scores	56
5.1.	Individual Nine Hole Peg Test Scores.....	66
5.2.	Nine Hole Peg Test Scores.....	67
5.3.	Nine Hole Peg Test Scores. Numbers and Percentages.....	68
5.4.	Number of Pegs placed in 120 seconds.....	69
5.5.	Time Taken to place all Nine Pegs.....	69
5.6.	Changes in Nine Hole Peg Test Scores.....	70
6.1.	Individual Action Research Arm Test Scores	83
6.2.	Action Research Arm Test Scores.....	84
6.3.	Action Research Arm Test Scores. Numbers and Percentages.....	85
6.4.	Changes in Action Research Arm Test Scores.....	86

List of Figures

1.1.	Diagram of the Circulation of the Brain.....	2
1.2.	Cerebral Infarct Subtypes and their Clinical Features	4
2.1.	Flow Chart of Subject Recruitment.....	26

3.1.	Boxplots showing Modified Ashworth Scale Scores	41
3.2.	Boxplots showing Changes in Modified Ashworth Scale Scores	43
4.1.	Boxplots showing Mean Grip Strength Scores	54
4.2.	Boxplots showing Changes in Mean Grip Strength	56
5.1.	Boxplots showing Nine Hole Peg Test Scores.....	67
5.2.	Boxplots showing Changes in Nine Hole Peg Test Scores.....	70
6.1.	Boxplots showing Action Research Arm Test Scores.....	84
6.2.	Boxplots showing Changes in Action Research Arm Test Scores....	86
7.1.	Changes in Muscle Tone.....	92
7.2.	Grip Strength in Subjects with Abnormal Muscle Tone.....	94

List of Photographs

1.1.	Flexor Synergy in the Hemiplegic Upper Limb.....	17
1.2.	Flexor Synergy in the Hemiplegic Upper Limb in Supine Lying.....	17
1.3.	Extensor Syergy in the Hemiplegic Upper Limb.....	18
1.4.	Extensor Synergy in the Hemiplegic Upper Limb in Supine Lying.....	18
3.1.	Test Position for the Modified Ashworth Scale.....	39
4.1.	Test Position for measuring Grip Strength	51
5.1.	The Nine Hole Peg Test.....	63
6.1.	The Action Research Arm Test Trolley.....	79
6.2.	Test Position for Action Research Arm Test.....	80

Chapter One

Introduction

1.1. Definition of Stroke

Stroke is synonymous with cerebrovascular accident (CVA), and is a clinical definition (1). Stroke has been defined by the World Health Organisation as a ‘a syndrome 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 of vascular origin’ (2). This definition includes subarachnoid haemorrhages but excludes transient ischaemic attacks, subdural haematomas, and haemorrhage or infarction caused by infection or tumour. It also excludes silent cerebral infarcts (3). Hemiplegia is the paralysis of muscles on one side of the body and is a common neurological impairment after stroke.

1.2. Circulation of the Brain

Blood flows to the brain via four major vessels. The right carotid artery and the left carotid artery pass up the anterior aspect of the neck. Each artery divides into two, the anterior and middle cerebral arteries. These arteries supply the frontal, parietal and temporal lobes. The two anterior cerebral arteries join anteriorly through the anterior communicating artery forming the front of the circle of Willis.

The two other arteries that supply the brain, the vertebral arteries, run up the neck through the foramina in the transverse processes of the cervical vertebrae and anastomose in front of the brainstem to form the basilar artery. Branches of that artery supply the medulla, pons, cerebellum and midbrain. At the top of the midbrain, the basilar artery divides into two posterior cerebral arteries that turn posteriorly to supply the occipital lobes. These two arteries are also joined to the back of the circle of Willis

by small communicating arteries and so an anastomosis occurs between the internal carotids and the vertebral circulation.

The branches of the major cerebral vessels (anterior, middle and posterior cerebral arteries) are termed end arteries as they do not anastomose with each other. If one of these vessels is occluded, damage often occurs in that area.

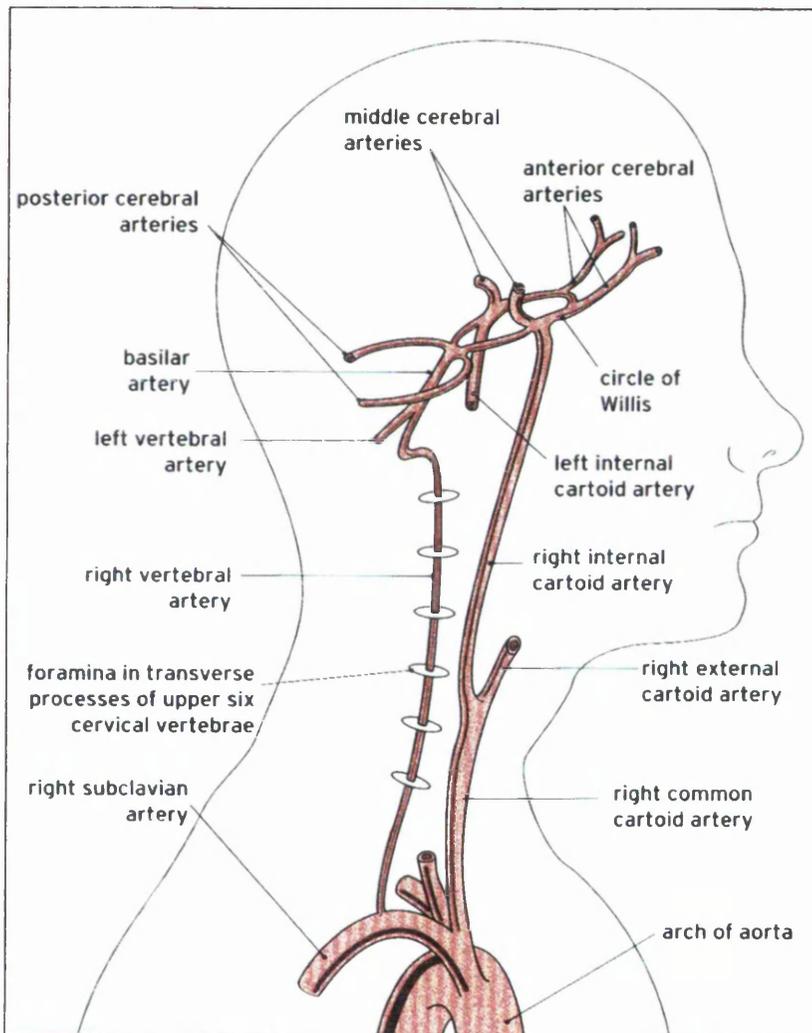


Figure no. 1.1. Diagram of the Circulation of the Brain (1)

1.3. Aetiology of Stroke

The terms stroke or cerebrovascular accident (CVA) are used to describe neurological signs and symptoms that result from diseases involving the blood vessels. Strokes can be caused by either infarction (due to closure of a blood vessel) or haemorrhage (due to bleeding from a vessel). Strokes caused by infarction are due to atherosclerosis and thrombosis or embolus. Most Lacunar strokes are thought to be caused by intrinsic small vessel disease (4). Haemorrhagic strokes are associated with hypertension or underlying lesions such as aneurysm, arteriovenous malformation or amyloid angiopathy (5).

Cerebral infarction is said to be responsible for approximately 80% of all first strokes, intracerebral haemorrhage for about 10% and subarachnoid haemorrhage for about 5% and approximately 5% the cause is unknown (6).

1.4. Classification of Stroke

A computed tomography (CT) brain scan done within 14 days of the onset of symptoms of a stroke will show whether the stroke was caused by a cerebral infarct or haemorrhage. Cerebral infarcts can be classified according to their presenting symptoms and signs. This classification is known as the Oxford Classification (4) in which four subtypes of infarct have been identified. The four subtypes include 1) Total Anterior Circulation Infarction (TACI), 2) Partial Anterior Infarction (PACI), 3) Posterior Circulation Infarction (POCI) and 4) Lacunar Infarction (LACI). This classification of infarction has proved simple and of practical value in establishing diagnosis and in predicting outcome (5).

	Clinical Features
Total Anterior Circulation Infarction (TACI)	motor and sensory deficit, hemianopia and disturbance of higher cerebral function
Partial Anterior Circulation Infarction (PACI)	any two of the above or isolated disturbance of higher cerebral function
Posterior Circulation Infarction (POCI)	signs of brainstem dysfunction or isolated hemianopia
Lacunar Infarction (LACI)	pure motor stroke or pure sensory stroke or pure sensorimotor stroke or ataxic hemiparesis

Figure no. 1.2. Cerebral Infarct Subtypes and their Clinical Features. (5)

Bamford *et al* (1991) (4) developed this subclassification of cerebral infarct following analysis of 543 patients with cerebral infarct. Classifications were based on the area of anatomical involvement. 17% were found to have large anterior cerebral infarcts with both cortical and subcortical involvement; this group was classified as total anterior circulatory infarcts (TACI). 34% had more restricted and predominately cortical infarcts and were classified as partial anterior circulation infarcts (PACI). 24% had infarcts involving vertebrobasilar artery and were called posterior circulation infarcts (POCI); and 25% had infarcts in the territory of the deep perforating arteries and were called lacunar infarcts (LACI). **Table no. 1.1.** shows the outcome of the different cerebral infarct subtypes in Bamford *et al* (1991) study (4) at 30 days, 1 month and 1 year post stroke.

	Cerebral Infarct Subtypes				All Patients
	TACI	PACI	POCI	LACI	
At 30 Days					
Dead	36 (39%)	8 (4%)	9 (7%)	3 (2%)	56 (10%)
Dependent	52 (56%)	73 (39%)	40 (31%)	49 (36%)	214 (39%)
Independent	4 (4%)	104 (56%)	80 (62%)	85 (62%)	273 (50%)
At 6 Months					
Dead	52 (56%)	19 (10%)	18 (14%)	10 (7%)	99 (18%)
Dependent	36 (39%)	64 (34%)	23 (18%)	36 (26%)	159 (29%)
Independent	4 (4%)	102 (55%)	88 (68%)	91 (66%)	285 (52%)
At 1 Year					
Dead	55 (60%)	30 (16%)	24 (19%)	15 (11%)	124 (23%)
Dependent	33 (36%)	52 (29%)	26 (19%)	39 (28%)	150 (28%)
Independent	4 (4%)	103 (55%)	79 (62%)	83 (60%)	269 (49%)

TACI - Total Anterior Circulation Infarction
PACI - Partial Anterior Circulation Infarction
POCI - Posterior Circulation Infarction
LACI - Lacunar Infarction

Dependent = functionally dependent (Modified Rankin Scale (7) Grades 3 - 5)

Independent = functionally independent (Modified Rankin Scale (7) Grades 0 - 2)

Table no. 1.1. Number and (percentages) of stroke subjects following Cerebral Infarct and their outcome at 30 days, 6 months and at 1 year (4).

1.5. Epidemiology of Stroke

1.5.1. Stroke Mortality

Stroke is the third most common cause of death after cancer and myocardial infarction and the most common cause of adult disability in most industrialised countries (8).

Stroke accounts for 10-12 % of all deaths in industrialised countries. 88 % of stroke deaths are in the over 65s. In the western world there has been a decrease in mortality since the early 1900s, particularly in the past 30 years. It is not clear if this reduction is due to a decrease in the incidence of stroke or that survival rates have improved.

1.5.2. Incidence of Stroke

Incidence is the number of first-in-a-lifetime strokes in a population over a defined period of time. The incidence of first-in-a-lifetime stroke is around 2.4 per 1,000 population per year (3). Stroke incidence increases exponentially with age, from 3 per 10,000 in the third and fourth decades to about 300 per 10,000 in the eighth and ninth decade of life (8). Bonita (1992) (8) states that almost 1 in 4 men and 1 in 5 women can expect to have a stroke if they live to the age of 85. Although the risk of having an acute stroke is higher in men than women, the opposite is true for the risk of dying from stroke with 16% of women and 8% of men likely to die from stroke.

1.5.3. Case-fatality of Stroke

Case-fatality measures the proportion of people in a population who die within a specified period of time following stroke. An average of 24% of first-in-a-lifetime strokes die within one month, with approximately 50% of these deaths being caused by

the cerebral lesion itself (3,8). After one year case-fatality has been reported by Bamford et al (1990) (9) at approximately 30%.

1.5.4. Prevalence of Stroke

The best measure of the total burden of stroke on the health service is prevalence, which provides information about the number of stroke sufferers in a population (8). Prevalence of stroke can be estimated through a household survey or calculated on the following relationship $prevalence = incidence \times duration$ (10). Therefore knowing the incidence and the average length of survival, it is possible to calculate an estimate of the prevalence of stroke in the community (10).

There have been very few studies of the prevalence of stroke. Prevalence can be difficult to measure as some patients die soon after onset of stroke and many survivors have no disablement. A typical estimate of prevalence is about 5 per 1000 population but this can depend on factors such as the age of the population in the community (11).

1.5.5. Cost of Stroke

The cost of stroke is approximately 4-5 % of the National Health Service budget (3). Isaard and Forbes (1992) (12) estimated the costs of stroke care in Scotland. The overall costs of inpatient care in 1988 was estimated at £82 million or 5.5 % of total hospital expenditure over one year and this rose to £96 million or 4.3 % of National Health Service budget, when the costs of outpatient, primary and community care were included.

1.6. Model of Disablement

The International Classifications of Impairments, Disability and Handicaps (ICIDH) is a model of disablement published by the World Health Organisation (WHO) 1980 (13). It imposes an order on the effects of disease and enables the clinician to develop a hierarchical list of problems towards which treatment can be directed.

This model of disablement categorises problems according to four levels: pathology, impairment, disability and handicap. Handicap being the worst result of disease.

PATHOLOGY → IMPAIRMENTS → DISABILITY → HANDICAP (13)

1.6.1. Classification of Pathology

Pathology represents a description of the disease or injury process at the organ level (13). Following a stroke it may be possible to establish the site of the lesion by the symptoms and signs presented but not the cause of the lesion.

1.6.2. Classification of Impairment

The ICIDH definition of impairment is 'In the context of a health experience, an impairment is any loss or abnormality of psychological, physiological or anatomical structure or function' (13). In stroke, impairments are the direct neurophysiological consequences of the underlying pathology. Impairments following stroke may include decreased muscle strength and the presence of increased muscle tone (spasticity) for example.

Schenkman (1989) (14) divides impairments into those that are a direct effect of pathophysiology (primary impairments), those that are indirectly effected by pathology (secondary impairments) and those that are effected both directly and indirectly. Secondary impairments are the result of primary impairments, not the pathology itself

e.g. musculo-skeletal contractures develop secondary to decreased muscle strength and immobility (primary impairments).

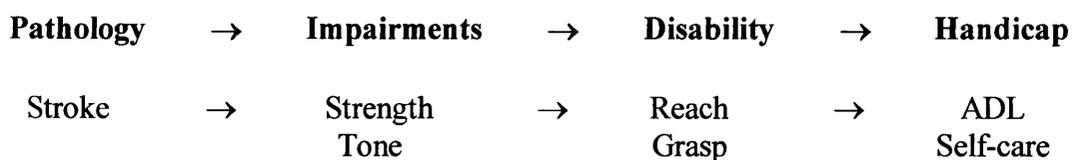
1.6.3. Classification of Disability

The ICIDH definition of disability is ‘In the context of a health experience, a disability is any restriction or lack (resulting from an impairment) of ability to perform an activity in the manner or within the range considered normal for a human being’ (13). Following a stroke disability represents a disturbance in function, such as reaching with the upper limb or manipulating objects with the hand (15).

1.6.4. Classification of Handicap

The ICIDH definition of handicap is ‘In the context of a health experience, a handicap is a disadvantage for a given individual, resulting from an impairment or a disability, that limits or prevents the fulfilment of a role that is normal (depending on age, sex, social and cultural factors) for that individual’ (13). Categories of handicap include physical independence, mobility, orientation, occupation, social integration, and economic self sufficiency (15).

Example of the Model of Disablement for Stroke (15)



1.7. Rehabilitation Outcomes

The ICIDH definition of rehabilitation is ‘Rehabilitation is a problem-solving and educational process aimed at reducing the disability and handicap experienced by someone as a result of disease, always within the limitations imposed both by the available resources and by the underlying disease’ (13).

The process of rehabilitation is to minimise disablement (16). The concepts of impairment, disability and handicap can be regarded as outcome measures for rehabilitation. The goal of acute rehabilitation is to minimise impairment and reduce disability. Once impairments have become stable, the goal of rehabilitation is to maximise functional independence and minimise disability for the given level of impairment. The ultimate goal of rehabilitation is to minimise handicap by integrating the person with the disability back into the community. Therefore, measurement of impairment, disability and handicap are all appropriate outcome measures for rehabilitation.

Measurement of outcome in stroke is becoming increasingly important as stroke care in hospital consumes a large amount of the NHS budget. Outcome measures are also useful for diagnostic and treatment purposes, in research such as trials in the effectiveness of new treatments, or in the study of the natural history and prognosis of the disease (3).

1.8. Measurement

Measurement has been defined as the quantification of an observation against a standard (a measurement tool or scale) (17). Appropriate measures are needed in rehabilitation to discriminate, predict and evaluate treatment interventions or detect change over time. It is important first of all to establish what requires to be measured.

The clinician may wish to measure muscle tone or muscle strength in order to record impairment of a movement dysfunction or measure disability through functional assessment. The next stage is to establish the reason for making the measurement: to describe the problem, to predict the outcome or to evaluate the effect of treatment or change over time. Once clinicians know what they want to measure and why, they require to look for suitable measurement tools that are validated and reliable. When a tool is being used to evaluate treatment or change over time it has to be a responsive measure, that is it has to be able to detect change. Responsiveness is less important if a measure is used to discriminate between individuals. Responsiveness is more important when trying to detect change within individuals (18).

1.8.1. Validity of Measurement

A test is considered valid if it measures what it claims to measure. Validation therefore is concerned with understanding what a test measures and what inferences can be drawn from the specific scores or findings from the measure, who the test was developed for, which group of subjects it was evaluated on, and why it was developed (1).

Types of Validity Measurement (1,19)

1) **Face Validity** - indicates that an instrument appears to test what it is supposed to.

This is the weakest form of measurement validity.

2) **Content Validity** - refers to the items included in a measure and validation consists of judgement by experts on whether the items in a scale appear appropriate for the intended use.

- 3) **Criterion-related Validity** - indicates that the outcomes of one instrument, the target test, can be used as a substitute measure for an established gold standard criterion test. It can be tested as concurrent or predictive validity.
- a) **Concurrent Validity** - establishes validity when two measures are taken at relatively the same time. Findings are compared for similarity between the measures.
 - b) **Predictive Validity** - compares the findings of a new outcome measure with a predicted outcome
- 4) **Construct Validity** - establishes the ability of an instrument to measure an abstract construct and the degree to which the instrument reflects the theoretical components of the construct.

1.8.2. Reliability of Measurement

Reliability is a test of a scale or instrument to measure something in a reproducible manner (1). The degree to which someone can repeat the measurements he or she has obtained is known as intra-rater or intra-tester reliability. The degree to which more than one tester obtains measures from the same subject that agree is inter-rater or inter-tester reliability. Test reliability can be improved through training and by ensuring the procedure has been clearly defined and standardised. These processes aim for uniformity of administering and scoring the test. Variability of findings from repeated tests may result from differing environmental factors, subjects and procedural differences, or instability of the measure. The user of an outcome measure can also introduce elements of error.

Standardisation is essential for good reliability. Careful documentation, through a manual of how a test should be used, is one recommended way of standardising the test

procedure. A standardised measure should have a manual with specific instructions for both carrying out and scoring the measure, so that all assessors use the measure in exactly the same way.

1.9. Normal Motor Function of the Upper limb

Normal upper limb function is the foundation for fine-motor manipulative skills important to activities such as feeding, dressing, grooming and handwriting (15). The upper limb is involved in a large variety of tasks, which require the limb to produce different joint configurations, and different timing and sequencing of joint movements (20). The arm functions mainly to place the hand in the appropriate position in space, so that it can interact with the surroundings (20). For example the arm requires to reach, to allow the hand to grasp an object. Both reach and grasp involve a complex interaction of neural and non-neural (musculo-skeletal) systems (15). Neural components include muscle strength, muscle tone and co-ordination and the non-neural components include the range of movement at joints, spinal flexibility and muscle properties.

1.10. Motor Dysfunction of the Upper Limb after stroke

This section looks at the motor impairments and movement dysfunctions which can occur following acute stroke. Sensory and cognitive impairments can also affect upper limb function but will not be discussed in this thesis.

1.10.1. Spasticity

The range of abnormal muscle tone found in patients following stroke varies widely. Normal muscle tone can be defined as the muscle's resistance to being lengthened, or its stiffness, and that stiffness or tone is the result of both neural and non-neural

components (20). The non-neural components reflect the mechanical-elastic characteristics of muscle and connective tissue that resist lengthening. The neural basis for muscle stiffness reflects the degree of motor unit activity, most importantly, stretch reflex-generated muscle activity, which resists muscle lengthening. Normal muscle stiffness.

Abnormal tone can range from flaccidity (hypotonicity) to spasticity (hypertonicity). The term spasticity can be used clinically to cover a wide range of abnormal behaviours of movement. It is used to describe a) the hyperactive stretch reflexes, b) abnormal posturing of the limbs, c) excessive co-activation of the antagonist muscles, d) associated movements, e) clonus and f) movement synergies.

Spasticity is defined as 'a motor disorder characterised by a velocity dependent increase in tonic stretch reflexes ('muscle tone') with exaggerated tendon jerks resulting from hyperexcitability of the stretch reflex as one component of the upper motor neurone syndrome' (21). This definition implies that the abnormality underlying spasticity is an adaptation of the stretch reflex. It is assumed that hyperexcitability of the reflex may cause the increased resistance to passive movement found in stroke patients.

The relationship between spasticity and upper limb movement dysfunction, until recently, has been considered to be strong (22,23,24,25) whilst others suggest that what appears clinically as spasticity is a combination of increased muscle stiffness and muscle contracture which can occur due to immobility and muscle weakness (15,20). O'Dwyer and Ada (1996) (26) suggests that there is increasing evidence that spasticity is not connected to upper limb movement dysfunction. They state that after acute stroke what can appear clinically as spasticity is actually increased muscle stiffness and muscle contracture. The belief that spasticity is the dominant impairment after stroke leads to relative passive interventions involving inhibition of the increased muscle tone. Carr

and Shepherd (1998) (20) believe that when clinicians realise that the major impairments after stroke are muscle weakness and inco-ordination, rehabilitation will change to more active exercise and functional training.

Secondary adaptations occurring after stroke, as a result of disuse, include length-associated changes in muscles and other soft tissues. Muscles held short for long periods of immobility shorten and become stiffer and when these muscles shorten they generate tension at shorter lengths.

1.10.2. Muscle Weakness

Muscle strength is defined as the ability to generate sufficient force in a muscle to provide movement or postural stability. Neural aspects of this force production mirror a) the number of motor units recruited, b) the type of units recruited and c) the discharge frequency (15). Muscle strength results from both the properties of muscle and the appropriate recruitment of motor units, and the timing of their activation.

Muscle weakness or the inability to generate force has been described as the major impairment, which contributes to functional disability of the upper limb following acute stroke (20). Muscle weakness is said to be due to a reduction in motor unit recruitment during voluntary movement and a reduction in the firing rate of those motor units, which are recruited (20).

In the recovery stage after stroke or with lesions of gradual onset, the degree of weakness may differ for different muscle groups. There may not be enough descending fibres converging on the motor neurone population either to shape complex movements by graded activation of co-ordinating muscles or to bring motor neurones to the high

frequency discharges necessary for muscle contraction. This results in muscle weakness and loss dexterity.

1.10.3. Abnormal Movement Patterns

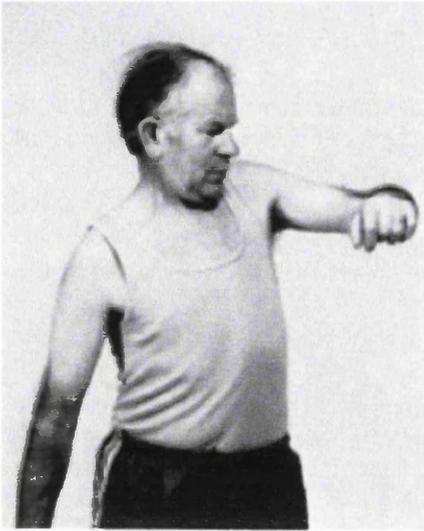
Abnormal movement patterns may be seen following stroke and can limit upper limb function (26,27,28). There are two recognised patterns of movement, the flexion synergy pattern and the extensor synergy pattern (23).

The flexor synergy pattern is seen when the patient attempts to lift up his hemiplegic arm, hold it in the air after it has been lifted, reach for an object or bring his hand to his mouth (23).

Flexor Synergy usually presents with the following pattern of movement (23).

Scapula	Elevates and retracts
Shoulder	Abducts and externally rotates (internally rotates)
Elbow	Flexes
Forearm	Supinates (pronates)
Wrist	Flexes
Fingers	Flex and adduct
Thumb	Flexes and adducts

Due to increased muscle tone the flexor synergy will usually appear with internal rotation of the shoulder and pronation of the forearm.



Photograph no. 1.1.



Photograph no. 1.2.

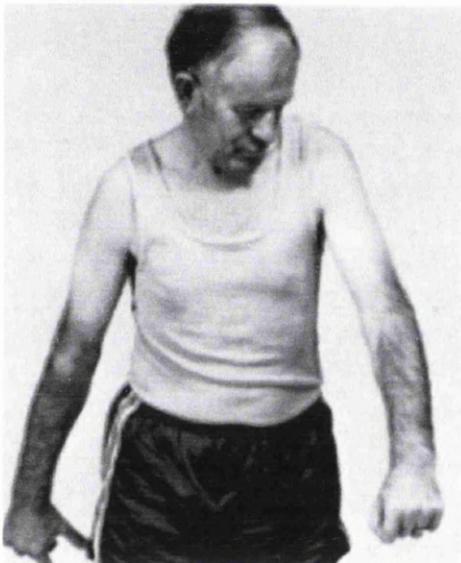
Photograph no. 1.1. Flexor synergy in the hemiplegic left upper limb. The patient is trying to lift his extended left arm. Because the shoulder is abducting (flexor component) the elbow flexes as well, instead of extending. In this case pronation rather than supination occurs with mass flexion. (left hemiplegia) (23)

Photograph no. 1.2. While lying, the patient tries to touch his head. The action of flexing the elbow causes the whole flexor synergy with retraction of the scapula and abduction of the arm. In this instance the shoulder rotates externally. (left hemiplegia) (23)

Extensor synergy usually presents with the following movement pattern (23).

Scapula	Protracts and pushes downwards
Shoulder	Internally rotates and adducts
Elbow	Extends with pronation
Wrist	Extends somewhat
Fingers	Flex with adduction
Thumb	Adducts in flexion

Because of spasticity the wrist is often seen to be flexed.



Photograph no. 1.3.



Photograph no. 1.4.

Photograph no. 1.3. Extensor synergy in the hemiplegic left upper limb - the patient is trying to straighten his elbow. (left hemiplegia) (23)

Photograph no. 1.4. While lying, the patient is trying to extend his left elbow. The shoulder rotates internally and the forearm pronates strongly. (left hemiplegia) (23)

Twitchell (29) states that following a stroke, the recovery of active movement in the upper limb can appear at first as a mass flexion pattern – a flexion synergy. This flexion synergy is usually followed or overlapped by extensor synergy. Davies (23) suggests that the mass patterns of movement or synergies produced may be dependent on the active movement the stroke subject is attempting with their arm.

These patterns of movement could be associated with spasticity or may be due to activation of the stronger muscles. These patterns could also be due to immobility and shortening of soft tissues. For instance the patient who sits most of the day with the shoulder in internal rotation and adduction and the elbow and wrist flexed will probably retain this posture when they stand up (20).

1.11. Recovery of Motor Control in the Upper Limb following a Stroke

Knowledge of the motor recovery of the upper limb following a stroke is important to those working with the stroke patient. It may allow the rehabilitation team to make an early prognosis of the maximum degree of recovery the stroke subject may obtain. It may also help to evaluate different treatment interventions. Spontaneous recovery of voluntary movement may range from none to complete recovery. This range may depend on the site and extent of the cerebral lesion. Early recovery of movement may be due to subsidence of swelling or improved circulation in the brain, while later recovery may be due to reorganisation of nerve pathways (30).

A well referenced study by Twitchell (1951) (29) reports on the spontaneous or “natural” motor recovery of the upper limb following stroke. He was able to observe the motor recovery of the upper limb from the onset of stroke to a stage where the subject had gained their maximum potential of recovery in 25 stroke subjects. He recorded this

motor recovery by observing the stroke patient grasping an object with the affected hand.

Twitchell (29) found that following the onset of a stroke there was initial loss of voluntary movement, with a loss or diminution of the tendon reflexes in the affected limbs. There was also very little resistance to passive movement, the stage of flaccidity. Within 48 hours the tendon reflexes became more active in the paralysed limbs compared to the unaffected limbs and resistance to passive movement began to appear, firstly in the finger and wrist flexors. This resistance gradually increased in strength and more muscle groups became involved, namely the flexors and adductors of the upper limb. This may be referred to as spasticity. Tendon reflexes also become brisker.

The return of voluntary movement in the upper limb usually began with shoulder flexion, followed by elbow, wrist and finger flexion, however, sometimes movement began distally with finger flexion and ascended proximally to the shoulder.

Active movement first appeared as synergistic patterns. In the upper limb it appeared as a mass flexion pattern, that is when a subject attempts to move the affected arm there was gross flexion of the shoulder, elbow, wrist and fingers - a flexion synergy. This flexion synergy is usually followed or overlapped by extensor synergy - the shoulder internally rotates and adducts, the elbow extends, forearm pronates, the wrist may extend and the fingers flex. Davies (23) states that because of spasticity the wrist is often seen to be flexed.

As the power of voluntary movement increased, the increased resistance to movement (spasticity) decreased in a proximal to distal direction. If voluntary movement continued to improve, the next stage of recovery was individual muscle group movement, for example a patient could selectively flex only the shoulder, elbow, wrist or fingers. This selective movement also returned in a proximal to distal direction.

In the final stage of recovery, individual muscle speed, co-ordination and endurance returned. This was the general pattern of recovery seen in the upper limb, however recovery could stop at any stage in the process.

In summary this “natural” pattern of recovery states that motor control normally starts proximally at the shoulder and moves distally to the hand, patterns of movement appear as flexion and extension synergies before more normal functional patterns of movement occur.

Twitchell’s study has been criticised, as it does not consider that the stroke subject’s adapted patterns of movement may be due to either muscle weakness, or the position that an immobile arm may be positioned in during the day (20).

There have been other studies reporting on the amount of recovery seen in the upper limb using different measures (30,31,32,33,34). Voluntary movement has been considered to be an important clinical sign of recovery of motor function (30). This voluntary movement is often measured and recorded. Voluntary movement is not the same as upper extremity function although it is a prerequisite for good motor function.

Bard and Hirschber (1965) (30) studied the recovery of voluntary motion in the upper limb following stroke in 116 subjects. The subjects were examined at weekly intervals for one month, and thereafter monthly up to seven months post stroke. At seven months, 19 of the subjects had no recovery (no observable movement), 47 partial movement (active movement between a 1/4 and 3/4 of the normal range) and 50 full movement (active movement greater than 3/4 of the normal range). This suggests that approximately 50% of the subjects were left with a non-functional arm. They noted that no movement in the first three weeks post stroke suggested that prognosis for full voluntary movement was poor. Therefore upper limb function would also be poor.

Wade *et al* (1983) (31) looked at the recovery of arm function in 92 stroke subjects over a 2 year period using 7 simple clinical tests. Recovery was graded as non-functional, partial recovery and full recovery depending on their score on the seven tests. Improvement in upper limb function was only statistically significant ($p < 0.001$) over the first three months. 56 of the 92 subjects at the initial assessment (within 3 weeks post stroke) had non - functional arms. At the final assessment 2 years later out of those that had non-functional arms initially, 8 had a complete recovery, 14 a partial recovery, leaving 34 with non-functional arms. They found that recovery plateaued at 6 months although some patients showed further recovery.

Another study Parker *et al* (1986) (32) looked at upper limb recovery of 187 stroke subjects and reported that 50% of all stroke survivors had moderate to severe paralysis of the upper limb soon after stroke, that is within 2 weeks of the cerebral vascular incident, and 13% had no paralysis. At 3 months 17% of the 187 patients had severe paralysis, 7% had moderate paralysis and 50% mild paralysis and 26% had no weakness. The subjects were placed in these categories depending on the score they achieved in the arm section of the Motricity Index (35), which is a measure of voluntary motion. They reported that those with no movement initially had a poor prognosis in ability to regain useful arm function.

Heller *et al* (1987) (33) reported the recovery in the upper limb over three months in 56 stroke subjects. They measured upper limb recovery with the Frenchay Arm Test (31), Nine Hole Peg Test (36) and grip strength. They observed that patients that failed to record any grip strength before 24 days post stroke was associated with non-functional arms at 3 months. Sunderland *et al* (1989) (34) assessed arm function in 38 stroke subjects using the Motricity Index (35), the Motor Club Assessment (37), the Nine Hole Peg Test (36), the Frenchay Arm Test (31) and grip strength over a six month

period. This study agreed with Heller *et al* (1987) (33) that no measurable grip strength by one month following stroke indicated poor functional outcome and that the presence of grip strength at one month indicated that there will be some functional recovery at six months.

In conclusion these studies suggest that if there is no recovery of voluntary movement within one month post stroke, the prognosis of recoverable upper limb function was poor. Their results also suggest that most recovery in upper limb voluntary movement and function occurs in the first three months but recovery can still be detected at six months.

1.12. Aims of Study

The aims of this study were to look at two assessments of impairment and two assessments of disability that can occur in the upper limb following stroke. The two impairments assessed were spasticity and/or contracture and grip strength. The two tests of upper limb disability assessed were manual dexterity and upper limb function. Spasticity and/or contracture were assessed using the Modified Ashworth Scale and grip strength was measured using the Standard Jamar dynamometer. Manual dexterity was assessed by the nine hole peg test and upper limb function assessed using the Action Research Arm Test. The validity and reliability of each of the four tests will be explored and then their ability to detect change in the recovery of the upper limb following an acute stroke over a six month period.

Chapter Two

Methodology

2.2. Research Design

This was a prospective longitudinal descriptive study examining changes in upper limb impairment and disability in a cohort of stroke subjects (n = 30 at baseline) who formed the control group of a randomised controlled trial (38). The purpose of the randomised controlled trial was to investigate the effects of electrical stimulation of the wrist extensors on impairment of wrist function and upper limb disability in patients after acute stroke. Twenty-two of the thirty control subjects had complete observations up to the final assessment week, week 32. The purpose of this study was to look at the validity and reliability of four different tests and their ability to detect change in the hemiplegic upper limb over time. Therefore, it was important to look at the twenty-two subjects that had complete observations over the assessment period. The eight subjects that had incomplete data were excluded from this study, as the emphasis of this study was to examine the responsiveness of the tests and not to compare one group of subjects with another, when missing data would need to be included. Assessments were carried out at five different time intervals, at week 0 (2-4 weeks post stroke) and at weeks 4, 8, 20 and 32 after the initial baseline assessment at week 0.

2.2. Subjects

The twenty-two subjects used in this study were hemiplegic stroke sufferers that had been admitted to Glasgow Royal Infirmary following an acute stroke. **Section 2.5. Subject Recruitment** shows the progress of subjects from recruitment to completion of study. Each subject received a computed tomography (CT) brain scan to determine whether the stroke was due to an infarct or haemorrhage. Stroke type was classified

using the Oxford Community Stroke Project (O.C.S.P.) classification (4) by a Consultant Physician. To establish subjects suitability for the randomised controlled trial from which this study was based, they were screened for the following inclusion and exclusion criteria.

2.3. Inclusion Criteria

1. 2-4 weeks after stroke (CVA incident)
2. Able to undergo informed consent
3. Wrist extension of grade 4 or less, on the MRC Scale (39).
4. No previous loss of function at the wrist
5. No pace-maker in situ
6. Able to co-operate with the assessment and intervention

2.4. Exclusion Criteria

1. No wrist extensor power loss
2. Unwell/medical issues
3. Cognitive problems
4. Dysphasia
5. Previous functional problems of the wrist and hand
6. Diagnosis uncertain
7. Overtime period of one month
8. Living outside catchment area
9. Other e.g. poor social circumstances
10. Refused

All subjects gave written informed consent for the randomised controlled trial from which this study was taken. The study was approved by the local hospital ethical committee. Consent Forms and Research Project Information (the randomised controlled trial) can be found in Appendix One pages a - c.

2.5. Subject Recruitment

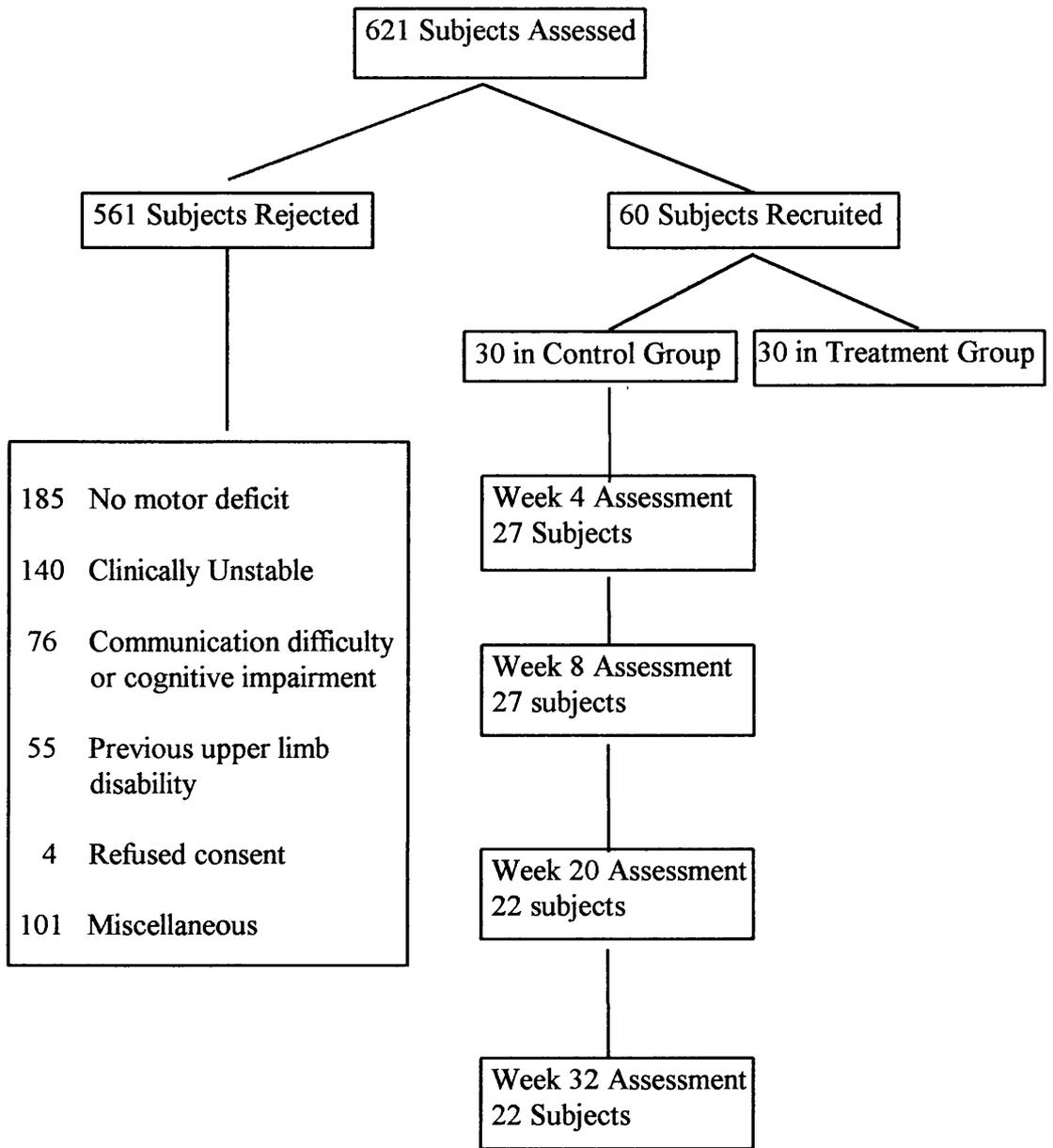


Figure no. 2.1. Flow Chart of Subject Recruitment. Progress of Subjects from Recruitment to Completion.

22 subjects in the control group completed the study. Eight subjects were lost to follow up - four declined follow up, two died, one had a further neurological event and one had an incomplete series of observations.

2.6. Characteristics of the Study Group

	Control Group	
	Group (n = 30)	Group (n = 22)
Male : Female (ratio)	14 : 16	12 : 10
Age (years) mean (SD), range (years).	66 (12) years, range (40 - 93) years	65 (11) years range (40 - 93) years
OCSP Classification of Infarcts		
PACI	16	11
TACI	5	5
LACI	7	4
Intracerebral Haemorrhage	2	2
Left : Right Hemiparesis (ratio)	20 : 10	14 : 8
Time after stroke to study entry (days) mean (SD), range.	23 (5) days, range (14 - 34) days	23 (6) days, range (14 -34) days
Premorbid Rankin Score median, (range)	1, (0 - 3)	1, (0 - 2)
Premorbid Barthel Score median, (range)	20, (16 - 20)	20, (18 - 20)

Table no. 2.1. Characteristics of the Study Group

Control Group (n = 30) represents all subjects in the control group of the randomised controlled trial (38)

Control Group (n = 22) represents a subgroup of the control group with complete observations to week 32

O.C.S.P. - Oxford Community Stroke Project (4)

PACI - Partial Anterior Circulatory Infarct

TACI - Total Anterior Circulatory Infarct

LACI - Lacunar Circulatory Infarct

General baseline information included premorbid Modified Barthel ADL Index (40) and premorbid Modified Rankin Scale (7) scores. These scores were obtained by the Research Therapist involved in the recruitment and intervention therapy in the randomised controlled trial. The Modified Barthel ADL index can be found in Appendix Two pages d-f and the Modified Rankin Scale can be found in Appendix Three page g. Information to obtain these scores was obtained from the subjects or their relatives.

The **Table no. 2.1.** page 19 demonstrates that the twenty-two subjects used in this study had similar characteristics to the thirty subjects in the control group of the randomised controlled trial.

Baseline measurements of the tests (the Modified Ashworth Scale, Grip Strength, the Nine Hole Peg Test and the Action Research Arm Test) used in this study also showed that the twenty-two subjects were representative of the thirty control subjects as the difference between the two groups were not statistically significant. A table of results can be found in Appendix Four page h. The table also gives Modified Barthel ADL Index and Modified Rankin Scale Scores at the Baseline Assessment Week 0.

2.7. Procedures

The assessments took place at Glasgow Royal Infirmary or Lightburn Hospital (Care of the Elderly Rehabilitation Hospital) in a screened area of the physiotherapy department. The place of assessment whether it be at Glasgow Royal Infirmary or Lightburn Hospital was kept constant for each subject throughout the study. All assessments took place in the morning before any therapeutic intervention. The control group in the randomised controlled trial received standard stroke therapy, plus a visit from the intervention physiotherapist to discuss their progress in rehabilitation during the 8 week intervention period (assessment weeks 0 to 8). The time spent with the control

group by the intervention therapist was similar to the contact time given to the intervention group. This contact may have stimulated patients to perform better in their rehabilitation.

2.8. Order of Tests

The tests were carried out in the following order in the randomised controlled trial (41). An assessor blinded to the intervention therapy carried out these measurements.

1. Handicap - Modified Rankin Scale
2. Activities of Daily Living - Modified Barthel ADL Index
3. Unilateral Visual Neglect - Star Cancellation Test
4. Oedema - Finger Circumference Measurements
5. Wrist pain at rest - Visual Analogue Scale and Descriptive Rating Scale
- 6. Spasticity - Modified Ashworth Scale**
7. Pain on movement into wrist extension - Visual Analogue Scale and Descriptive Rating Scale
- 8. Grip Strength – Standard Jamar Dynamometer**
- 9. Hand Dexterity - Nine Hole Peg Test**
- 10. Upper Limb Function - Action Research Arm Test**
11. Oedema - Volumeter
12. Resting Wrist Angle
13. Passive extension of the Wrist
14. Active extension of the Wrist
15. Wrist extension moment at 0 degrees
16. Wrist extension moment at 15 degrees
17. Wrist extension moment at 30 degrees

Tests 12 to 16 were measured using a specially constructed table designed by the Bioengineering Department at Strathclyde University (41).

Tests in bold text **6, 8, 9 and 10** will be reported on in this thesis.

2.9. Outcome Measures

The following outcome measures were used in this thesis and will be reported on separately.

2.9.1. Measurements of Impairment

- 1. Spasticity.** This was measured using the Modified Ashworth Scale (**Chapter 3**).
- 2. Grip Strength.** This was measured using the Standard Jamar Dynamometer (**Chapter 4**).

2.9.2. Measurements of Disability

- 1. Manual Dexterity.** This was measured using the Nine Hole Peg Test (**Chapter 5**).
- 2. Upper Limb Function.** This was measured using the Action Research Arm Test (**Chapter 6**).

The subjects sat in a chair or wheelchair at a table for the above tests, except for the Action Research Arm Test. The same chair and table were used for all assessments. A specially constructed trolley was used for the Action Research Arm Test.

2.10. Statistical Analysis

For all the tests, results were analysed using the Statistical Package for Social Sciences (S.P.S.S.) Version 7. The data collected for each test was non-parametric. The Wilcoxon signed-ranks test, a non-parametric test for two related samples, was used to determine whether the change of scores between assessment weeks 0 and 8, weeks 0 and 32 and weeks 8 and 32 were significant. Results were accepted as statistically significant at $p \leq 0.05$.

2.11. Reporting of Results

1. A table with individual subjects total scores for each test, for each assessment week.
2. Boxplots were used to show the scores of each test over the assessment period.
3. A table showing the median, the interquartile range, the minimum and the maximum scores for each test, for every assessment week.
4. Test scores number and percentages of subjects.
5. Boxplots were used to show the change of score between weeks 0 and 8, weeks 0 and 32 and weeks 8 and 32.
6. Table showing the median, the interquartile range, the minimum and the maximum change of scores between weeks 0 and 8, weeks 0 and 32 and weeks 8 and 32 and the p -value of the statistical change in scores.

For some tests extra data was supplied to explain the results.

Change in test scores are reported between week 0, the initial assessment which was approximately 2 to 4 weeks post stroke, and week 8 which is approximately 3 months after the onset of stroke. Most recovery following stroke is suggested to occur within in the first 3 months (31,32,33,34). Changes in test scores are also reported between week 0 and week 32 (week 32 is approximately 6 months after subjects have achieved most of their recovery at 3 months) and between weeks 8 and 32.

Chapter Three

The Modified Ashworth Scale

3.1. Introduction

Spasticity can be a problem following stroke and chronic spasticity can be associated with varying degrees of contracture, which decreases the available range of movement at joints and therefore restricts functional activity (42). It is important to measure spasticity and monitor the development of contractures in order to evaluate the effects of treatment (42). One characteristic of muscle spasticity is an increased resistance to passive stretch. Clinicians have often assessed the severity of spasticity by applying a manual stretch to a muscle group and subsequently describing the resistance encountered (43). Rating scales appear to be the easiest way to assess spasticity (44) and are the present yardstick against which newer, more exact methods must be compared (45). Ashworth (1964) (46) originally presented a five-point ordinal scale to categorise the severity of spasticity based on standardised descriptions of the encountered resistance.

Spasticity is described as being velocity dependent (21) and it has been suggested that movements slower than approximately 20° per second would not excite stretch reflexes in most stroke patients (47). Ashworth's original scale was modified slightly by Bohannon and Smith (1987) (48) by incorporating the angle at which resistance appeared and controlling the speed of passive movement with a deliberate 1-sec. count. The modifications consisted of the inclusion of an additional level (1+) for continuous resistance and making ranks 1,1+, and 2 dependant on where in the range of passive movement the resistance appears.

The Modified Ashworth Scale has been described as having face validity (48) and has been tested for reliability (48,49,50,51). There have been many studies on the reliability of the M.A.S. but there is a question as to whether the scale has been used to measure

spasticity over time in the recovery of the upper limb following acute stroke. Sunderland *et al* (1989) (34) measured spasticity using another rating scale which graded spasticity into absent, mild or severe but this scale is described as unreliable with large interrater errors (52). Spasticity was measured using the M.A.S. in our randomised controlled trial as it was looking at the effects of electrical stimulation on wrist flexor spasticity (38).

Grade	Description
0 (0)	no increase in muscle tone
1 (1)	slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of range of motion when the affected part(s) is moved in flexion or extension
2 (1+)	slight increase in muscle tone, manifested by a catch, followed by minimal resistance throughout the remainder (less than half) of the ROM
3 (2)	more marked increase in muscle tone through most of the ROM, but affected part(s) easily moved
4 (3)	considerable increase in muscle tone, passive movement difficult
5 (4)	affected part(s) rigid in flexion or extension

Table no. 3.1. The Modified Ashworth Scale

For the purposes of calculating the grading of the Modified Ashworth Scale using S.P.S.S., the scale 0 to 5 was used.

3.2. Validity

The Modified Ashworth Scale (M.A.S.) is said to have face validity (48). Face validity suggests that the ordinal scale appears to test what it is supposed to and that it is a convincing method for doing so. However resistance to passive movement may be due to changes in the properties of muscle as well as due to spasticity (45,53), therefore the results of the M.A.S. are likely to be affected by the development of shortening in

muscles as well as spasticity. The M.A.S. is a subjective test and therefore could be described, as been scientifically weak (19). The validity of assessing and treating disturbances in tone are open to question (54), as more recent literature puts more importance on weakness as the primary impairment in stroke (26,55).

3.3. Reliability

The Modified Ashworth Scale (M.A.S.) has been tested for inter-rater reliability (48,49,50). Inter-rater as well as intra-rater reliability has also been tested by Allison *et al* (1996) (51).

Bohannon and Smith (1987) (48) used the M.A.S. to measure spasticity in the elbow flexors of 30 subjects (24 of which had suffered from a stroke). The elbow was extended from maximal flexion to maximal extension in approximately one second 5 to 8 times by two examiners. There was a break of several minutes between each examiner's assessment. The raters agreed on 86.7% of their ratings. The Kendall's tau correlation between examiners was $\tau = 0.847$ ($p < 0.001$).

Bodin and Morris (1991) (49) used the M.A.S. to assess 18 subjects with demonstrable wrist flexor spasticity following a stroke. Each subject was graded by two examiners under three different test conditions: following a 10 minute rest period, following a 90 second stretch of the wrist flexors and following a 90 second stretch of the wrist extensor muscles as part of a larger study (56). To test for wrist flexor spasticity, the wrist was extended from maximal flexion to maximal extension over a duration of one second, 3 to 5 times by each rater. A break of 2 minutes was given between the two examiners. There was 76% agreement between raters on the gradings. The Kendall's correlation coefficient indicated a high degree of reliability between raters

$\tau = 0.857$ ($p < 0.05$).

Inter-rater reliability was also tested by Sloan *et al* (1992) (50). Four raters assessed 34 hemiplegic subjects (31 of which had suffered from a stroke). They tested the spasticity of the elbow flexors (from maximal elbow flexion to maximal elbow extension), elbow extensors (from maximal elbow extension to maximal elbow flexion) and the knee flexors (from maximal knee flexion to maximal knee extension). Each movement was of one second duration and repeated four times by each rater. No indication is given to how much rest was given between each rater's assessment. They found Spearman's rank difference correlation coefficients to be acceptable for elbow flexors and elbow extensors, mean correlations ranged from 0.67 to 0.74 ($p < 0.001$) but they showed poorer correlation for knee flexion spasticity 0.45 ($p < 0.01$). From their study the M.A.S. appears to be a satisfactory clinical measure for upper limb spasticity in terms of its inter-rater reliability but appeared not so reliable when testing lower limb spasticity.

Allison *et al* (1996) (51) tested inter-rater, intra-rater and temporal (between days) reliability of the M.A.S. on plantar flexor muscle spasticity in 30 subjects with traumatic brain injury. Two examiners tested each subject for plantar flexor spasticity by taking the ankle from maximal plantarflexion to maximal dorsiflexion over a period of approximately half a second. This was repeated 5 to 8 times. Each ankle was tested twice by both examiners. Temporal reliability was tested by the examiner with the highest intra-rater reliability when 21 subjects returned on the following days to be retested. Spearman's correlation coefficients were 0.73 for inter-rater reliability, 0.74 and 0.55 for intra-rater reliability 0.82 for temporal reliability. The M.A.S. was considered reliable to measure plantar flexor spasticity although it is weak.

Correlation statistics have limited use in assessing reliability of a measurement. Modern statistical methods that are more widely accepted are the use of the kappa statistic for categorical data and Bland and Altman plots for continuous data (57).

When a measure is based in categories such as the Modified Ashworth Scale, the correct test to compare two or more ratings is a kappa statistic. Kappa measures the agreement among ratings beyond that expected by chance, and is therefore superior to reporting simple agreements (58). A weakness of the kappa statistic is that it does not take into account the degree of disagreement - all disagreements are treated equally. Where the categories are ordered, as is often the case e.g. the Modified Ashworth Scale, it may be preferable to give different weights (weighted kappa) to disagreements according to the size of the discrepancy. Observations representing a difference of only one category, are considered less serious than those where the discrepancy is two or three categories. It therefore would be of interest to look at the kappa statistic and the weighted kappa in reliability studies of the Modified Ashworth Scale.

3.4. Methodology

Twitchell (29) suggests that resistance to passive movement in the upper limb appears initially in the wrist and finger flexors. Measuring resistance to passive extension of the wrist joint may indicate the potential development of increasing muscle tone (spasticity) or contracture in other joints of the upper limb. Hence, in this study increased resistance to passive extension at the wrist joint was measured. This was also the joint of interest in the randomised controlled trial (38). The measurement of resistance to passive wrist extension was assessed before the measurement of grip strength as the action of gripping involves flexion of the fingers and may influence the grades obtained on the M.A.S.

3.4.1. Test Position

The subject was sat upright on a chair with no arms or a wheelchair with the arm rest removed for the assessment of spasticity. The chair each subject sat on remained constant throughout the study. The arm to be tested was held by the examiner, in shoulder adduction and in neutral rotation, the elbow flexed at 90° and the forearm in neutral, with one hand holding the forearm in neutral (midway between pronation and supination) just proximal to the wrist joint and the other hand holding the palmar aspect of the hand.

3.4.2. Procedure

The wrist is passively moved into extension from maximal wrist flexion to the maximal wrist extension over a duration of one second. The movement is demonstrated to the subject being assessed on their unaffected wrist before the affected wrist is tested. The subject is asked to let their hand go heavy before the movement is performed.



Photograph no. 3.1. Test Position for the Modified Ashworth Scale

3.4.3. Scoring

The test is performed once only on the affected arm. The examiner notes the range of movement and the resistance felt during movement and applies it to the Modified Ashworth Scale see introduction page 34. The scale ranges from a score of 0 to a score of 5, the higher the score the greater the resistance to passive stretch and an increase in spasticity and contracture.

3.5. Results

Subject Number	Modified Ashworth Scores				
	Week 0	Week 4	Week 8	Week 20	Week 32
1	1	2	2	2	2
2	0	1	1	1	1
3	0	1	0	0	0
4	0	0	0	0	0
5	2	2	2	1	1
6	2	2	3	3	3
7	1	2	3	3	3
8	3	0	1	4	4
9	1	1	1	3	3
10	1	1	1	3	2
11	3	4	4	4	4
12	1	1	2	2	2
13	0	2	3	2	2
14	0	0	1	0	0
15	2	3	3	3	3
16	1	1	1	1	2
17	0	0	0	0	0
18	3	3	3	3	4
19	2	3	3	3	3
20	0	0	0	0	0
21	1	1	1	1	1
22	1	1	0	0	0

Table no. 3.2. Individual Modified Ashworth Scale Scores

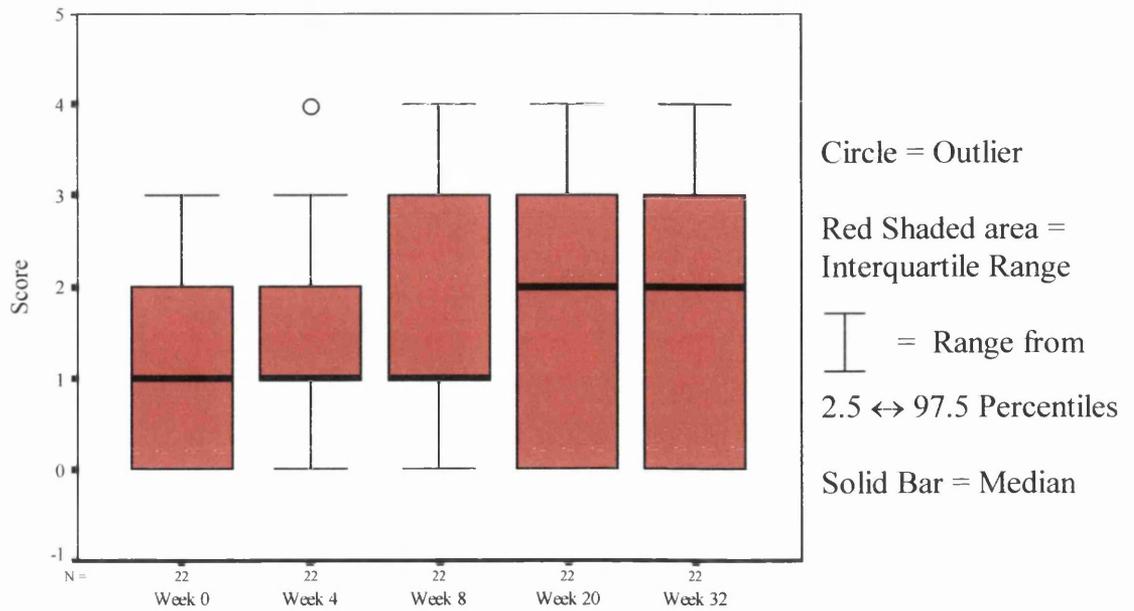


Figure no. 3.1. Boxplot showing Modified Ashworth Scale Scores over 32 weeks.

Week	Median	I.Q.R.	Minimum	Maximum
0	1	2.00	0	3
4	1	1.25	0	4
8	1	2.25	0	4
20	2	3.00	0	4
32	2	3.00	0	4

Table no. 3.3. Modified Ashworth Scale Scores over 32 weeks.

Figure no. 3.1. and Table no. 3.3. show that over 20 weeks there is a trend for muscle tone to increase as indicated by an increase in the Modified Ashworth Scale score.

Between weeks 20 and 32 results remain the same.

Score	Week 0	Week 4	Week 8	Week 20	Week 32
0	7 (31.8%)	5 (22.7%)	5 (22.7%)	6 (27.3%)	6 (27.3%)
1	8 (36.4%)	8 (36.4%)	7 (31.8%)	4 (18.2%)	3 (13.6%)
2	4 (18.2%)	5 (22.7%)	3 (13.6%)	3 (13.6%)	5 (22.7%)
3	3 (13.6%)	3 (13.6%)	6 (27.3%)	7 (31.8%)	5 (22.7%)
4	-----	1 (4.5%)	1 (4.5%)	2 (9.1%)	3 (13.6%)
5	-----	-----	-----	-----	-----

Table no. 3.4. Numbers and (Percentages) of Subjects and Scores in the Modified Ashworth Scale.

At week 0, 7 subjects (31.8%) had no increase in muscle tone. This decreases to 6 subjects (27.3%) by week 32. Throughout the study no subjects scored 5 on the Modified Ashworth Scale, that is there were no subjects that had a wrist that was unable to be moved passively.

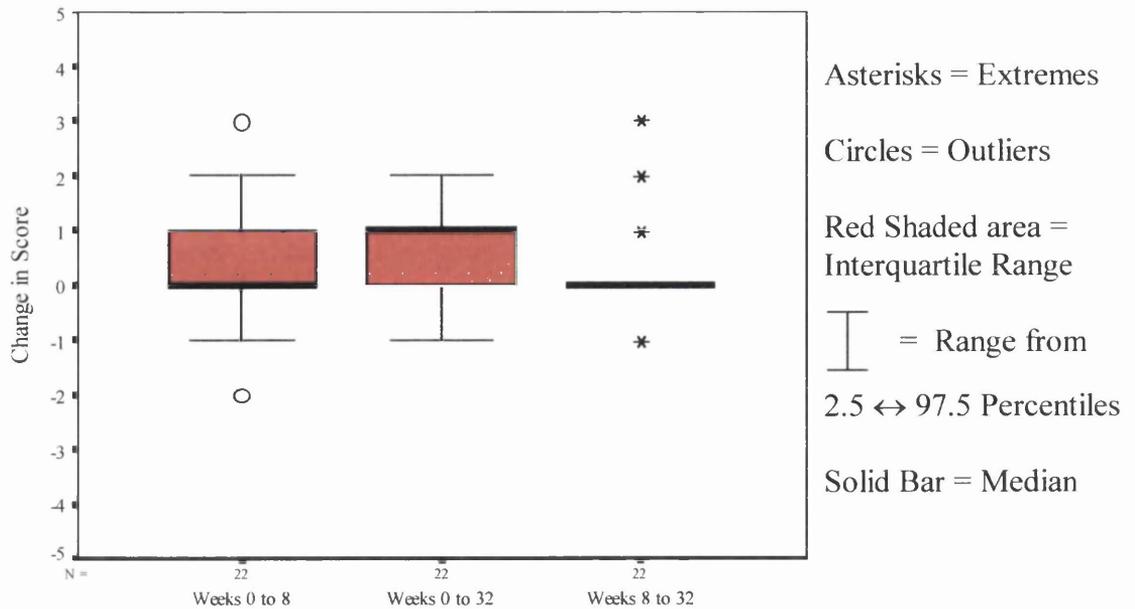


Figure no. 3.2. Boxplots showing Changes in Score in the Modified Ashworth Scale between assessment weeks 0, 8 and 32.

Weeks	Median	I.Q.R.	Minimum	Maximum	<i>p</i> - value
0 to 8	0.0	1	-2	3	0.053
0 to 32	1.0	1	-1	2	0.003*
8 to 32	0.0	0.25	-1	3	0.272

* significant change

Table no. 3.5. Changes in Score in the Modified Ashworth Scale between assessment weeks 0, 8 and 32.

Figure no. 3.2. and Table no. 3.5. indicates that over the 32 week study period there is a significant change ($p = 0.003$) in the Modified Ashworth Scale suggesting that there is an increase in muscle tone.

3.6. Discussion

The results indicate that the Modified Ashworth Scale (M.A.S.) did detect changes in muscle tone in the wrist flexors over the period of the study. Muscle tone (spasticity) appeared to increase over the period of the study, particularly over the first 3 months after stroke. It can also be said that as the M.A.S. does not only measure changes in muscle tone but also changes in soft tissue. There is shortening of soft tissue over the period of the study and consequently a reduction in range of movement. This shortening is seen mainly in the wrist flexors and therefore there is a decreased range of wrist extension. The majority of our subjects presented with increased muscle tone and/or soft tissue shortening throughout the study which suggests that our subjects had marked impairment and therefore disability. **Table no. 3.3.** demonstrates that at week 0 (2-4 weeks post stroke), 7 (31.8%) out of the 22 subjects had no increase in muscle tone and at the end of the study, week 32 (6 months post stroke) this had decreased by 1 to 6 (27.3%) out of 22 subjects presenting with no increase in muscle tone. Therefore 15 (68.2%) out of 22 subjects presented with increased muscle tone at assessment week 0 which increased to 16 (72.7%) of the 22 subjects by assessment week 32 (6 months post stroke). Throughout the study no subjects scored 5 on the Modified Ashworth Scale, that is no subjects developed a wrist that could not be moved. **Figure no. 3.2. and Table no. 3.5.** show that there a significant increase in muscle tone (spasticity) and/or an increase in muscle or joint stiffness over the period of the study ($p = 0.003$). **Figure no. 3.2. and Table no. 3.5.** suggest there is a trend for these changes to occur in the first three months. **Figure 3.1. and Table 3.3.** show that changes in M.A.S. scores appeared between week 0 and assessment week 20 and suggests that there was no change between week 20 and week 32. A trend is seen in those subjects that had an increase in muscle

tone at assessment week 0 (2-4 weeks post stroke), for that tone (spasticity) to increase

Table no. 3.4.

The Modified Ashworth Scale has been tested for reliability on stroke subjects (61,62,63), but the literature suggests that it has not been used to detect changes in muscle tone over a period of 6 months. Sunderland *et al* (1989) (34) measured spasticity by passive movement of the shoulder, elbow and wrist. Abnormal resistance to passive movement or increased muscle tone was rated as absent, mild or severe spasticity at each joint. There was no indication as to the methodology they used to measure for increased muscle tone (spasticity). They reported that at their initial assessment (within 3 weeks of onset of stroke) 12 (31%) of their 31 subjects had abnormal resistance to passive movement at the shoulder, elbow and wrist. Amongst the 31 subjects followed over 6 months, 7 (22%) showed increasing resistance to passive movement, therefore an increase in muscle tone (spasticity) and/or soft tissue shortening. These results suggest that our subjects had greater impairment and therefore disability in their upper limbs compared to their subjects, although they used a different scale to measure an increase in muscle tone and their methodology is not clear.

The methodology used for assessing muscle tone has varied when using the Modified Ashworth Scale from study to study. The number of times a joint has been moved from maximal flexion to maximal extension ranges from three to eight times. Bohannon and Smith (1987) (48) moved the elbow from maximal flexion to maximal extension from five to eight times, Bodin and Morris (49) moved the wrist from maximal flexion to maximal extension three to five times, Allison *et al* (51) moved the ankle from maximal plantarflexion to maximal dorsiflexion five to eight times but Sloan *et al* (1992) (50) who looked at three different muscle groups and tested them for increased muscle tone repeated each movement four times. In this study the wrist flexors were tested for

increased tone (spasticity) by moving the wrist joint from maximal flexion to maximal extension once only as it was thought that moving the joint through full range movement up to eight times could be considered as mobilising or stretching the soft tissue surrounding the joint and therefore the recording of the grading on the M.A.S. would be more difficult. It may also be considered difficult and subject to error for an examiner to make a subjective assessment of the resistance to passive movement by moving the wrist only once from maximal flexion to maximal extension. Repeated movement may be considered more accurate as the examiner has a longer period of time to grade the resistance to passive movement on the Modified Ashworth Scale.

3.7. Conclusion

The Modified Ashworth Scale is a subjective scale for measuring muscle tone. The scale did detect changes in muscle tone throughout the study. However the validity of the measurement has been criticised because it is considered that it does not only measure muscle tone but shortening of soft tissue which results in muscle and joint stiffness which could be due to muscle weakness and positioning of the limb that cannot be actively moved by the stroke subject.

The reliability of the Modified Ashworth Scale has been tested although methodology has varied and there is a need for this to be standardised. The M.A.S. has not been widely used to detect change in muscle tone over a period of time. More research is required to evaluate this scale, firstly what does it actually measure and secondly what is the usefulness of this measure. Could it be used to detect potential shortening of soft tissues and guide therapists to the appropriate rehabilitation for their stroke subjects or could it be used as a prognostic indicator.

Chapter Four

Grip Strength

4.1. Introduction

The assessment of grip strength in stroke patients has been criticised in the past as it involves flexion of the fingers which could be considered encouragement of the typically spastic pattern which may develop following an acute stroke and therefore increased grip strength may indicate increased spasticity rather than increased muscle strength (23,24). Weakness, however is one of the most common impairments following stroke which improves with functional recovery (15,20), therefore it is important to measure strength (59,60,61,62).

The measurement of grip strength has been described as a valid and reliable measure of upper limb function in acute strokes (17,33,34,54). Grip strength is also considered as one of the most sensitive measures of upper limb recovery, detecting early recovery and recovery at 3 (33,34) and 6 months post stroke (34). It has also proved a useful prognostic indicator as increases are paralleled with increases in arm function (34). Grip strength has been used as one of a battery of tests to measure recovery in the upper limb recovery following stroke (33,34) and in randomised controlled trials (38,63).

The tools to measure grip strength vary widely (64). The Standard Jamar dynamometer is probably the most commonly used, due to its accuracy (65,66,67). The Standard Jamar dynamometer has been tested for validity and reliability (67,68). Normative data has been published without (69,70) and with the recommended standardised procedure of measurement (71,72). The standardised method recommended for measuring grip strength will be described in more detail in the methodology section of this chapter.

4.2. Validity of Grip Strength

Concurrent validity of grip strength has been established by Sunderland *et al* (1989) (34). They measured grip strength using an electric dynamometer (two flat padded bars mounted in parallel to each other 2 cm. apart which when squeezed together produce a reading in Newtons on a digital display) on 38 stroke patients admitted to hospital on four different occasions 1) within 3 weeks of admission, 2) one month after initial assessment, 3) three months and 4) at six months. They recorded grip strength as the mean of three trials on the affected side as a percentage of the mean of three trials on the unaffected side. As well as measuring grip strength four other tests of arm function were measured 1) the Motricity Index (35), 2) the Motor Club Assessment (37), 3) the Frenchay Arm Test (31) and 4) the Nine Hole Peg Test (36). At the first assessment percentage grip showed good correlation with the Motricity Index ($r = 0.87$), the Frenchay Arm Test ($r = 0.86$), the Motor Club Assessment ($r = 0.81$) and the Nine Hole Peg Test ($r = 0.71$). Correlation at the final 6 month assessment between percentage grip strength and the other measurements were; the Motricity Index ($r = 0.83$), the Frenchay Arm Test ($r = 0.90$), the Motor Club Assessment ($r = 0.86$) and the nine Hole Peg Test ($r = 0.79$).

4.3. Validity of the Standard Jamar Dynamometer

One form of measuring validity is checking the accuracy of the measurement tool. Grip strength instruments have been checked for accuracy by using known weights suspended from its handle (65,66). Mathiowetz *et al* (1984) (67) compared the Standard Jamar dynamometer the one used in this study, with the digital Jamar dynamometer and the Preston dynamometer using this method. They reported that the Standard Jamar dynamometer had the highest calibration accuracy of ± 3 percent. It has also been

recommended that the same Standard Jamar dynamometer should be used throughout when measuring grip strength. This accuracy prompted the use of the Standard Jamar dynamometer in this study.

4.4. Reliability of Grip Strength

Inter-rater and test re-test reliability for grip strength has been tested on stroke subjects (33). Two assessors measured grip strength using a dynamometer (a bulb connected to an aneroid dial) on both the affected and unaffected sides of ten stroke patients whom had had their stroke more than eighteen months previously and had reduced arm function. As well as measuring grip strength they also measured arm function with the Frenchay Arm Test (31), finger tapping and the Nine Hole Peg Test (36). Grip strength was recorded in mm. of Hg. The ten patients were tested on three different occasions at weekly intervals. The first and third measurements by one assessor and the second by the other assessor. Test re-test Spearman rho correlations were calculated for the total score on the Frenchay Arm Test, grip strength and finger tapping on the affected and unaffected sides and the Nine Hole Peg Test. The results were 0.83-0.99 between assessor one/measurement one and assessor two/measurement two; 0.68-0.90 between assessor one/measurement one and assessor one/measurement three; and 0.75-0.99 between assessor two/measurement two and assessor one/measurement three. All correlations were statistically significant ($p > 0.025 - p < 0.001$); the strength of the correlations suggest good inter-rater and test re-test reliability for each test.

4.5. Reliability of the Standard Jamar Dynamometer

Inter-rater and test re-test reliability has been tested on normal subjects (67) using the Standard Jamar dynamometer but it's reliability has not been tested on stroke patients.

Mathiowetz *et al* (1984) (67) measured grip strength using the Standard Jamar dynamometer on twenty seven occupational therapy students. The Standard Jamar dynamometer was calibrated before the study. The standardised procedure to measure grip strength was followed (73). Two trained examiners measured both hands independently, alternating between left and right hand. The mean of three measurements was recorded for each hand. Very high inter-rater reliability was established using the Pearson product-moment correlation coefficient (right hand $r = 0.996$, left hand $r = 0.999$). To establish test-retest reliability grip strength was measured by one examiner within one week following the initial assessment. Test-retest reliability was assessed using the Pearson product-moment correlation coefficient. They looked at correlations for one trial, mean of two trials, mean of three trials and the highest score of three trials. The mean of three trials presented the highest correlation (right hand $r = 0.883$, left hand $r = 0.929$). Mathiowetz *et al* (1984) (67) recommends that the mean of three trials is the most reliable method of measuring grip strength which supports the recommendation of American Society Hand Therapists (A.S.H.T.) (73), therefore the mean of three trials is used in this study.

4.6. Methodology

4.6.1. Equipment

Grip strength was measured using a standard adjustable handle Jamar dynamometer. The second handle position was used for all subjects throughout the study as recommended by A.S.H.T. (American Society of Hand Therapists) (73). The Jamar dynamometer was calibrated at the factory and the instructions suggest that re-calibration is not necessary within two years of purchase, therefore the dynamometer was not checked for calibration during the study.



Photograph no. 4.1. Test Position for measuring Grip Strength.

4.6.2. Test Position

The subject is sat upright on a chair with no arms or a wheelchair for the assessment of grip strength. The chair each participant sat on remained constant throughout the study. The standardised arm position recommended by the American Society of Hand

Therapists (A.S.H.T.) (73) was utilised as follows: shoulder adducted and in neutral rotation, elbow flexed at 90°, forearm in neutral (midway between pronation and supination), wrist between 0-30° extension and 0-15° of ulnar deviation. The Standard Jamar dynamometer is a heavy instrument, therefore it was supported by the examiner.

4.6.3. Procedure

Before testing grip strength the examiner demonstrates the action required by the subject. The Standard Jamar dynamometer is placed in the subject's affected hand. The maximum hand on the dial is turned anti-clockwise to zero. The dynamometer is supported by the examiner and then the subject is asked to squeeze the handles as hard as they can. No other verbal encouragement is given. The Standard Jamar dynamometer automatically records the maximum grip force applied by the subject. This measurement was repeated three times with a natural break between measurements when each score was recorded by the examiner and the dial returned to zero. The grip strength of the affected hand was measured only.

4.6.4. Scoring

Grip strength was measured in kilogrammes of force and the mean of the three trials was used in the results.

The Standard Jamar dynamometer was purchased from Camp Ltd, Northgate House, Staple Gardens, Winchester, Hants. SO23 8ST.

4.7. Results

Subject Number	Mean Grip Strength Scores (kilogrammes of force)				
	Week 0	Week 4	Week 8	Week 20	Week 32
1	0	0	0	2	0
2	0	2	2	4	6
3	4	2	5	7	7
4	9	12	16	18	18
5	0	0	0	0	0
6	0	0	0	5	5
7	0	0	0	0	0
8	0	0	0	0	0
9	8	9	7	6	8
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	14	23	21	30	28
15	0	5	3	8	9
16	2	2	4	5	6
17	12	15	24	23	28
18	0	0	0	0	0
19	0	0	0	4	4
20	14	24	26	32	31
21	3	7	5	13	14
22	18	29	25	24	27

Table no. 4.1. Individual mean Grip Strength Scores (mean of three trials) for each assessment week for the hemiplegic hand of all 22 stroke subjects

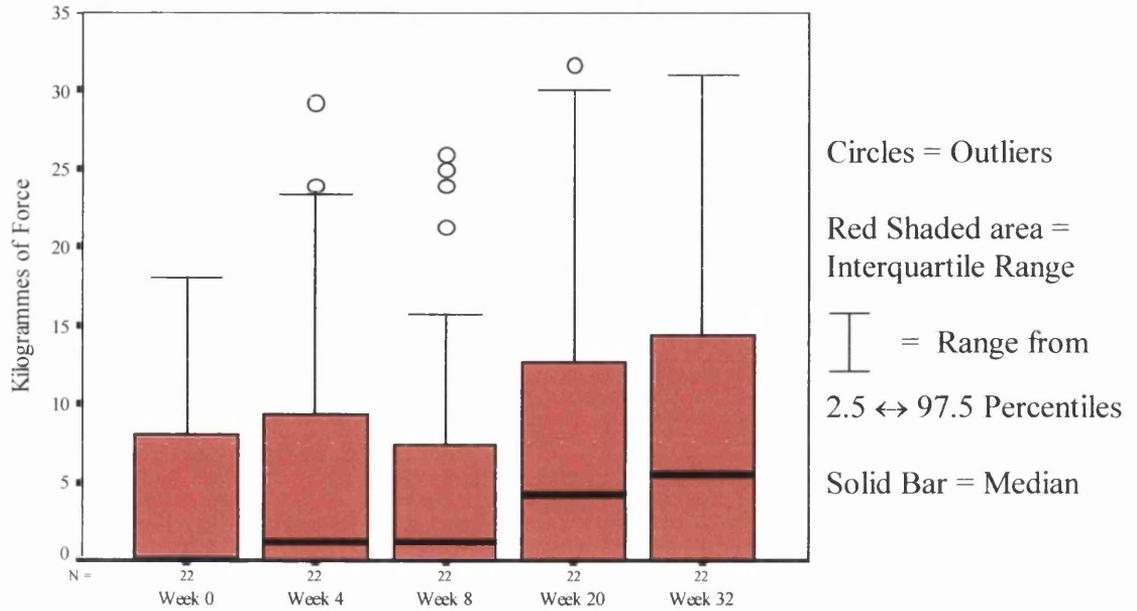


Figure no. 4.1. Boxplots showing mean Grip Strength (mean of three trials) of the hemiplegic hand over 32 weeks.

Week	Median	I.Q.R.	Minimum	Maximum
0	0.0	8.25	0	18
4	1.17	10.08	0	29
8	1.17	9.42	0	26
20	4.17	13.92	0	32
32	5.50	15.33	0	31

Table no. 4.2. Mean Grip Strength (mean of three trials) of the hemiplegic hand over 32 weeks.

Figure no. 4.1. and Table no. 4.2. show that there is an improvement in mean grip strength (mean of three trials) over 32 weeks.

Grip Strength (kgs.)	Week 0	Week 4	Week 8	Week 20	Week 32
0 (kgs.)	13 (59.1%)	10 (45.5%)	11 (50.0%)	8 (36.4%)	9 (40.9%)
1 - 10 (kgs.)	5 (22.7%)	7 (31.8%)	6 (27.3%)	8 (36.4%)	7 (31.8%)
11 - 20 (kgs.)	4 (18.2%)	2 (9.1%)	1 (4.5%)	2 (9.1%)	2 (9.1%)
21 - 30 (kgs.)	-----	3 (13.6%)	4 (18.2%)	3 (13.6%)	3 (13.6%)
31 - 40 (kgs.)	-----	-----	-----	1 (4.5%)	1 (4.5%)

Table no. 4.3. Numbers and (Percentages) of subjects and mean Grip Strength (mean of three trials) of the hemiplegic hand over 32 weeks.

At week 0, 13 (59.1%) of the 22 subjects were unable to record a grip strength. This decreased to 9 subjects (40.9%) by week 32. Those subjects that could record a grip strength showed an increase in strength over the 32 week period.

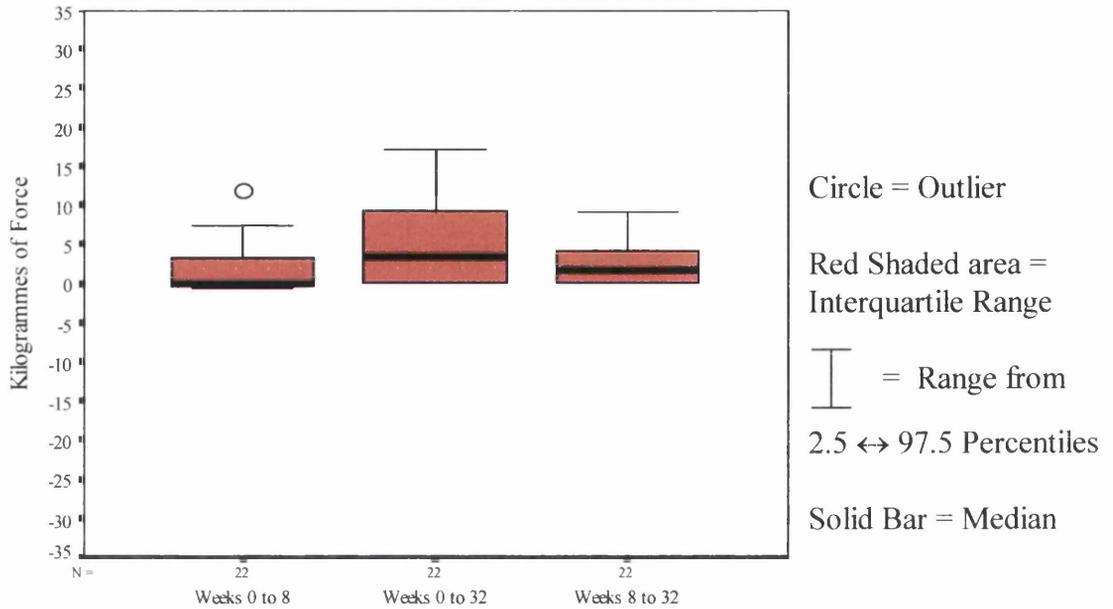


Figure no. 4.2. Boxplots showing Changes in mean Grip Strength (mean of three trials) between assessment weeks 0, 8 and 32.

Weeks	Median	I.Q.R.	Minimum	Maximum	<i>p</i> - value
0 to 8	0.0	4.17	-1	12	0.004*
0 to 32	3.33	9.33	0	17	0.002*
8 to 32	1.67	4.25	0	9	0.001*

* significant change

Table no. 4.4. Changes in mean Grip Strength (mean of three trials) between weeks 0, 8 and 32.

There is a significant change in mean grip strength (mean of three trials) between weeks 0 and 8 ($p = 0.004$), weeks 0 and 32 ($p = 0.002$) and weeks 8 and 32 ($p = 0.001$).

4.8. Discussion

The results show that the measurement of grip strength with the Standard Jamar dynamometer detected change of grip strength over the period of the study. Approximately half the number of subjects were unable to produce any recording of grip strength suggesting that the subjects used in this study had noticeable impairment in strength and therefore presumably poor recovery in arm function. Grip strength has been reported to show good sensitivity to change, detecting early recovery as well as later changes at 3 (33) and 6 months (34). Absent grip strength at one month post stroke has been shown to indicate poor functional outcome in the upper limb (34).

At week 0, **Table no. 4.3.**, 13 (59.1%) of the 22 subjects were unable to record any grip strength, by week 32 this had decreased to 9 (40.9%) subjects. Therefore only 4 subjects who were unable to produce grip strength at week 0 (2-4 weeks post stroke) were able to record grip strength at week 32. **Figure no. 4.2. and Table no. 4.4.** demonstrate that changes in grip strength were statistically significant between weeks 0 and 8 ($p = 0.004$), weeks 0 and 32 ($p = 0.002$) and weeks 8 and 32 ($p = 0.001$). This is comparable with other studies which have shown improvement in grip strength in the first 3 months post stroke (weeks 0 and 8) (28,29). Sunderland *et al* (1989) (34) reported statistically significant changes in grip strength in the first three months post stroke $p < 0.01$ and also between 3 and 6 months $p < 0.01$.

The measurement tool used to assess grip strength in stroke studies has varied. Heller *et al* (1987) (33) used a dynamometer which consisted of a bulb connected to an aneroid dial which recorded grip strength in mm of Hg. Sunderland *et al* (1989) (34) used an electric dynamometer (MIE Medical Research, Digital Pinch/Grip Analyser) which consisted of two flat padded bars mounted parallel to each other 2 cm. apart. The maximum grip force was measured in newtons. This tool was also used in a randomised

controlled trial (63). The results of my studies with the Standard Jamar dynamometer measuring grip strength in kilogrammes of force suggest that it is also sensitive in detecting changes in grip strength over time after stroke.

The recording of grip strength is also variable. The Standard Jamar dynamometer has been well researched in normal subjects and normative data collected. The American Society of Hand Therapists (ASHT) (73) which has recommended the Standard Jamar dynamometer as the instrument of choice when assessing grip strength also suggests that recording the mean of three trials as the most reliable measure. In this study the mean of three trials was recorded and in the randomised controlled trial (38) the best of three trials was recorded. In both these studies only the affected hand of the stroke subject was measured. Heller *et al* (1987) (33) looked at 63 age matched normal controls in their study. The tool they used to measure grip strength had a maximum reading of 300 mm. of Hg. It is unclear how many trials were given. Alternate subjects were asked to start with the dominant and non dominant hand. Grip strength was recorded as a percentage of the other side, however these results could be criticised because of the ceiling effect of the measuring instrument as 36 out of 59 scored 300 mm. of Hg. on the dominant side and 34 out of 59 on the non dominant side. For their study of grip strength on stroke subjects they took the score of 75% of the other side as a cut off for normal. Those below 75% were considered to have abnormal grip strength. Sunderland *et al* (1989) (34) measured grip strength three times with each hand, alternating between the affected and unaffected side. They looked at the best way to analyse the scores and found that the least variable score was recording the average strength of grip on the affected side as a percentage of the average grip of the unaffected side. Like Heller *et al* (1987) (33) they used 75% of the other side as the cut-off for normal.

The position of the upper limb for the measurement of grip strength could effect the reliability of results. The American Society of Hand Therapists (ASHT) (73) has recommended a standard position for measuring grip strength and that position was used in this study. In one study the test position is not described (33) and in another study (34) the test position is standardised for all subjects but is different to that recommended by A.S.H.T. (73), the stroke subject rests the hand being measured on their lap.

4.9. Conclusion

The measurement of grip strength is an easy and quick test to perform. Significant improvement in grip strength measured by the Standard Jamar dynamometer occurred throughout the study. Changes in grip strength were detected in the first three months and between three and six months.

Grip strength in acute stroke has been measured with various different tools and procedures. Results have also been reported in several ways. All reported methods have been sufficiently sensitive to detect changes in grip strength. It is important, however, that the instrument used, the procedure and the recording of results are standardised for the measurement of grip strength in stroke subjects so that it can be more accurately used to evaluate rehabilitation of the upper limb.

Chapter Five

The Nine Hole Peg Test

5.1. Introduction

Peg tests are used to measure manual dexterity (54). Subjects are required to pick up pegs and place them into corresponding holes in a board. The time taken is recorded. The Nine Hole Peg Test (N.H.P.T.) is one of several peg tests. As its name suggests the subject has to pick up nine pegs, one at a time, and place them into nine holes. It has been reported as the simplest peg test as it is easy to use. It is portable and takes a short time to carry out. Some studies have timed the placing and removal of the pegs (69,74) whilst others have timed only the placing of the nine pegs (32,33,34,63). Results are usually expressed as the number of pegs placed per second. Results can also be recorded as the time taken to place nine pegs or the number of pegs placed in the board in a set time. The N.H.P.T. has been tested for validity (32,74) and reliability (33,74). Normative data has been published (33,69,74). The N.H.P.T. has been used to measure upper limb recovery following a stroke (32,33) and in randomised controlled trials (38,63). Research suggests that it is a more sensitive measurement at the upper range of upper limb recovery (33).

5.2. Validity

Concurrent validity has been established (32,74). Mathiowetz *et al* (1985) (74) compared the nine hole peg test with the purdue peg board (75). They reported a significant inverse correlation between the time taken for completion of the N.H.P.T. (placing and removing the nine pegs) and the Purdue Peg score (the combined total number of pegs placed by the left hand, then the right hand and then both hands together in 30 seconds) (for the right hand, $r = - 0.61$; for the left hand, $r = - 0.53$). This validity

was questioned as they used a sample size of only 26 whom were all female occupational therapy students who would have knowledge regarding hand function (76). Parker *et al* (32) compared the N.H.P.T. with the Frenchay arm test (F.A.T.) (31). They assessed 187 stroke subjects (93 men:94 women with a mean (SD) age of 71.8 (10.8) years) at three months after stroke. They reported that at three months the F.A.T. score had a linear correlation co-efficient of + 0.71 with the Barthel ADL index (77) and + 0.90 with the motricity index (35), whereas the N.H.P.T. score had a linear correlation co-efficient of + 0.68 with the Barthel ADL index and + 0.82 with the motricity index. Both Mathiowetz *et al* (1985) (74) and Parker *et al* (1986) (32) established concurrent validity timing the placing of the nine pegs.

5.3. Reliability

Inter-rater and test-retest reliability for the N.H.P.T. has been tested on normal subjects (74) as well as on stroke subjects (33). Both used different methods of administering the N.H.P.T.

Mathiowetz *et al* (1985) (74) gave their subjects (26 female Occupational Therapy students) a practice attempt at the test followed by the actual test. They tested both hands, timing the placing and removal of the nine pegs. Very high inter-rater reliability was established using the Pearson correlation coefficient (right hand $r = 0.97$, left hand $r = 0.99$). This showed that the independent assessors carried out the test in a similar way. To establish test-retest reliability, the initial test was carried with a follow up test within one week. Test-retest reliability was high ($r = 0.69$) for the right hand and moderate ($r = 0.43$) for the left hand. Using the same test-retest reliability data, a two-tailed, paired data t test was used to measure the practice effect between the two assessment sessions

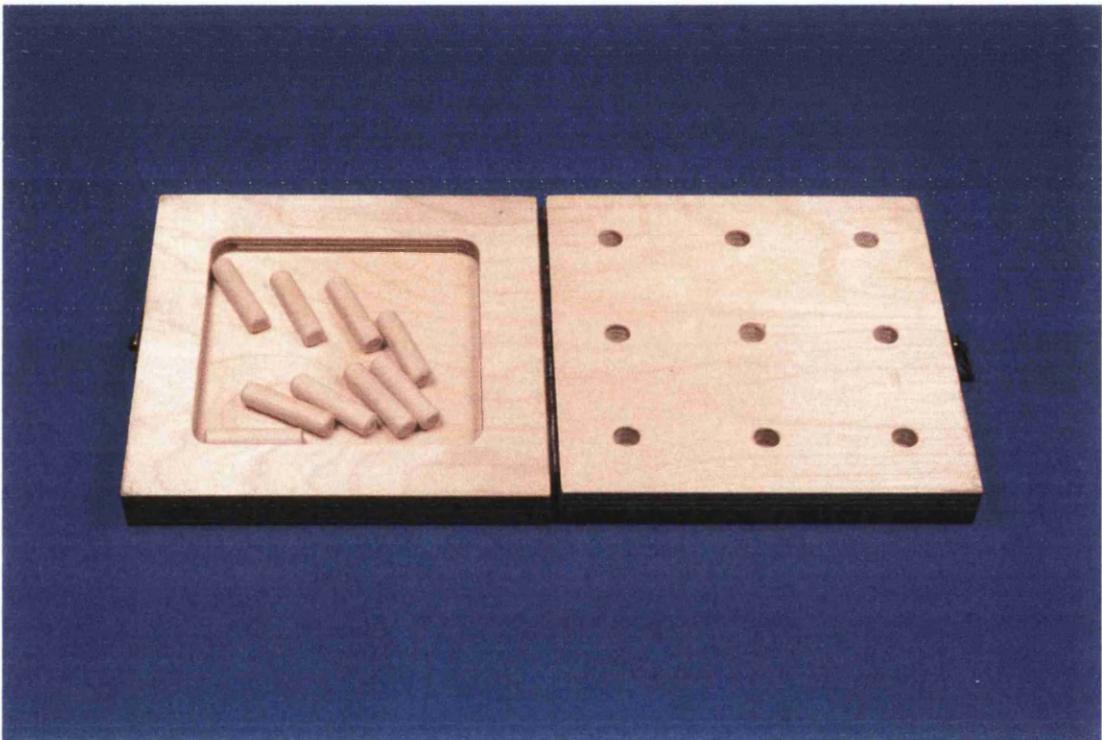
for each hand. A significant difference was noted for the right hand ($p < 0.001$) and for the left hand ($p < 0.05$).

Heller *et al* (1987) (33) tested reliability on ten stroke subjects (age and gender not reported) all of whom had decreased upper limb function and had their stroke more than eighteen months previously. They tested the subjects affected hand once giving them fifty seconds to attempt to place the pegs. Results were expressed in pegs per second. Inter-rater and intra-rater test-retest reliability for the N.H.P.T. was assessed by two observers. Subjects were tested on three occasions at weekly intervals. The first and third tests were carried out by one observer and the second by the second observer. Test-retest Spearman correlations were calculated. Correlations were all ≥ 0.68 , with statistical significance $p \leq 0.025$. This was interpreted as showing good inter-observer and intra-rater test-retest reliability.

5.4. Methodology

5.4.1. Equipment

The nine hole peg test consists of a wooden 150mm. square hinged box with a clip fastener. Each half of the hinged box has a depth of 17.5mm. The base has a 100 mm. square tray with curved corners and is 8mm. deep which holds the nine pegs. The lid has nine holes with a diameter of 10 mm. and a depth of 10 mm. spaced 50 mm. apart in three rows of three holes. The nine wooden dowels (pegs) are 32 mm. long and have a diameter of 9 mm. See scaled drawing page Appendix Five page i.



Photograph no. 5.1. The Nine Hole Peg Test

The Nine Hole Peg Test was purchased from Dr. D. T. Wade, Rivermead Rehabilitation Centre, Abingdon Road, Oxford OX1 4XD, UK.

5.4.2. Test Position

The subject is seated in a chair or wheelchair at a table. The chair and table are standard throughout the assessments. The box was centred on the table in the sagittal mid-plane of the patient's head and trunk. The tray with the nine pegs loosely placed was situated on the affected side of the body.

5.4.3. Procedure

The subject is asked to place the pegs one at a time, with the affected hand, in the holes of the peg board, in no specific order. They are given 120 seconds to complete the task. The task is completed once only. No verbal encouragement is given to go faster during the test as some patients were flustered by the test and this only increased their anxiety. The patient is not made aware that the test is timed.

5.4.4. Scoring

The examiner sits opposite the subject and times the task with a watch with a second hand (a stop watch can be used). Time recorded is the time taken from when the subject touches the first peg to pick it up to the time the last peg is placed (when released) in the board. Either the number of pegs placed in 120 seconds or the time taken to place all 9 pegs is recorded and the result expressed in the number of pegs placed per second.

A score of 0.075 pegs/ sec. = all 9 pegs placed in exactly 120 seconds.

A score greater than 0.075 pegs/sec. = all 9 pegs placed in less than 120 seconds.

A score less than 0.075 pegs/sec. = less than 9 pegs placed in 120 seconds.

5.5. Statistical Analysis/ Reporting of Results

As well as the statistical analysis applied to all other tests see methodology chapter page 32. Results also show the number of pegs placed in 120 seconds, the time taken for those who could place all nine pegs and number of pegs placed per second for all 22 subjects at each assessment week.

5.6. Results

Subject Number	Nine Hole Peg Test Scores (Pegs per Second)				
	Week 0	Week 4	Week 8	Week 20	Week 32
1	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.008
3	0.017	0.033	0.033	0.106	0.129
4	0.180	0.214	0.273	0.237	0.360
5	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000
9	0.000	0.008	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000
13	0.000	0.000	0.000	0.000	0.000
14	0.150	0.300	0.300	0.360	0.257
15	0.000	0.000	0.000	0.000	0.000
16	0.000	0.025	0.033	0.067	0.082
17	0.050	0.300	0.450	0.180	0.321
18	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000
20	0.042	0.196	0.200	0.257	0.200
21	0.000	0.092	0.214	0.214	0.300
22	0.115	0.257	0.310	0.409	0.429

Table no. 5.1. Individual Nine Hole Peg Test Scores (pegs per second)

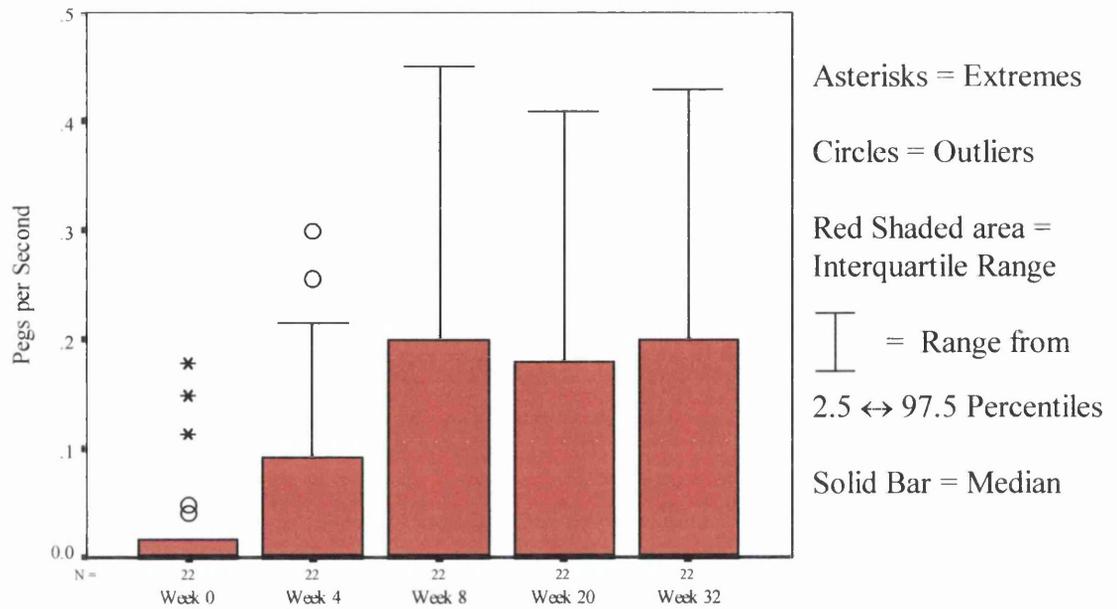


Figure no. 5.1. Boxplots showing Nine Hole Peg Test Scores (pegs per second) over 32 weeks.

Week	Median	I.Q.R.	Minimum	Maximum
0	0.000	0.023	0.000	0.180
4	0.000	0.118	0.000	0.300
8	0.000	0.204	0.000	0.450
20	0.000	0.189	0.000	0.409
32	0.000	0.214	0.000	0.429

Table no. 5.2. Nine Hole Peg Test Scores (pegs per second) over 32 weeks.

Figure no. 5.1. and **Table no. 5.2.** show that there is an increase in Nine Hole Peg Test from weeks 0 to 8. The median is 0.000 at each assessment week.

Pegs per Second	Week 0	Week 4	Week 8	Week 20	Week 32
0.000	16 (72.7%)	13 (59.1%)	14 (63.6%)	14 (63.6%)	13 (59.1%)
0.001 - 0.074	3 (13.6%)	3 (13.6%)	2 (9.1%)	1 (4.5%)	1 (4.5%)
0.075 - 0.100	-----	1 (4.5%)	-----	-----	1 (4.5%)
0.101 - 0.200	3 (13.6%)	1 (4.5%)	1 (4.5%)	2 (9.1%)	2 (9.1%)
0.201 - 0.300	-----	4 (18.2%)	3 (13.6%)	3 (13.6%)	2 (9.1%)
0.301 - 0.400	-----	-----	1 (4.5%)	1 (4.5%)	2 (9.1%)
0.401 - 0.500	-----	-----	1 (4.5%)	1 (4.5%)	1 (4.5%)

Table no. 5.3. Numbers and Percentages of Subjects and Nine Hole Peg Test Scores over 32 weeks.

Pegs per second = 0.075 (9 pegs placed in 120 seconds)

Pegs/sec. > 0.075 (9 pegs placed in less than 120 seconds)

Pegs/sec. < 0.075 (fewer than 9 pegs are placed in 120 seconds)

At week 0, 16 subjects (72.7%) failed to score in the Nine Hole Peg Test. This decreased to 13 (59.1%) by week 32. Those that could attempt the Nine Hole Peg Test showed most improvement in scores between weeks 0 and 4 and weeks 4 and 8.

No. of pegs placed in 120 seconds	Week 0	Week 4	Week 8	Week 20	Week 32
0 (no pegs)	16 (72.7%)	13 (59.1%)	14 (63.6%)	14 (63.6%)	13 (59.1%)
1 - 4 pegs	1 (4.5%)	3 (13.6%)	2 (9.1%)	-----	1 (4.5%)
5 - 8 pegs	2 (9.1%)	-----	-----	1 (4.5%)	-----
9 pegs	3 (13.6%)	6 (27.3%)	6 (27.3%)	7 (31.8%)	8 (36.4%)

Table no. 5.4. Number and Percentages of Subjects and the Number of Pegs they could place in 120 seconds.

At week 0,16 subjects (72.7%) failed to place any pegs. This decreased to 13 subjects (59.1%) by week 32. At week 0, 3 subjects (13.6%) placed all nine pegs. This increased to 8 subjects (36.4%) by week 32.

Time in Seconds to place 9 pegs	Week 0	Week 4	Week 8	Week 20	Week 32
0 - 18 seconds	-----	-----	-----	-----	-----
19 - 29 seconds	-----	-----	2 (9.1%)	2 (9.1%)	3 (13.6%)
30 - 59 seconds	1 (4.5%)	5 (22.6%)	4 (18.2%)	4 (18.2%)	3 (13.6%)
60 - 89 seconds	2 (9.1%)	-----	-----	1 (4.5%)	1 (4.5%)
90 - 120 seconds	-----	1 (4.5%)	-----	-----	1 (4.5%)

Table no. 5.5. Number and Percentages of Subjects and the Time Taken to place all 9 Pegs in the Nine Hole Peg Test.

At week 0, 1 subject (4.5%) could place all nine pegs in under 60 seconds (1 minute). This increased to 6 subjects (27.3%) by week 8 and remained at 6 subjects (27.3%) at assessment weeks 20 and 32.

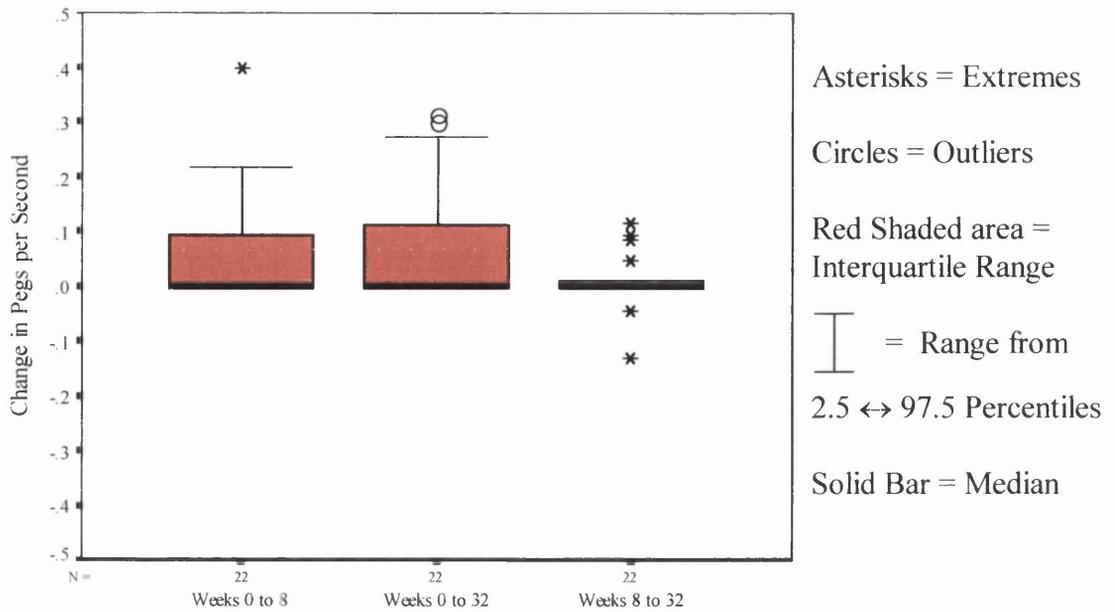


Figure no. 5.2. Boxplots showing Changes in Nine Hole Peg Test Scores (pegs per second) between assessment weeks 0, 8 and 32.

Weeks	Median	I.Q.R.	Minimum	Maximum	<i>p</i> - value
0 to 8	0.000	0.107	0.000	0.400	0.012*
0 to 32	0.000	0.124	0.000	0.313	0.008*
8 to 32	0.000	0.018	-0.129	0.118	0.263

* significant change

Table no. 5.6. Changes in Nine Hole Peg Test Scores (pegs per second) between assessment weeks 0, 8 and 32.

Figure no. 5.2. and Table no. 5.6. show that there is a significant change in Nine Hole Peg Test scores between weeks 0 and 8 ($p = 0.012$) and weeks 0 and 32 ($p = 0.008$). There is not a significant difference between weeks 8 and 32.

5.7. Discussion

From the results it can be seen that the nine hole peg test (N.H.P.T.) did detect change with improvements over the first 3 months after stroke but only a minority of subjects were able to attempt it. This shows that the subjects used in this research study had marked disability with reduced function of the upper limb. It has been noted that the nine hole peg test is a more sensitive test in measuring change in subjects with less severe disability (33).

At week 0, **Table no. 5.3.**, 16 (72.7%) of the 22 stroke subjects were unable to attempt the N.H.P.T., by week 32 this had reduced to 13 (59.1%) subjects. Thus, only three who were unable to attempt the test at the initial assessment (week 0) could attempt it by week 32. Of the six subjects that managed to score at week 0 only three could place all nine pegs with only one managing to place all nine pegs within one minute (**Table no. 5.5.**). By week 8 the number able to place all nine pegs had increased to 8 (36.4%) out of the 22 subjects, six of whom could place all the pegs under one minute. The number of subjects placing nine pegs under one minute remained the same between assessment weeks 8 and 32. **Figure no. 5.1. and Table no. 5.2.** show that there is an improvement in N.H.P.T. scores between weeks 0 and 8 and then scores plateau. A significant improvement was seen between week 0 and 8 ($p = 0.012$) (**Figure no. 5.2. and Table no. 5.6.**). There is also a trend for slight improvement in scores between weeks 8 and 32 but this was not statistically significant. The improvement shown in the first 3 months (assessment weeks 0 to 8) is similar to other studies (33,34). One study (32) has reported no significant improvement in N.H.P.T. scores between 3 and 6 months (assessment weeks 8 and 32), another (34) reported a significant improvement $p < 0.01$.

Studies using the Nine Hole Peg Test, have little data on the apparatus used. Dimensions are given for the dowels and the size of the holes and their distance apart on the peg board, but there is a lack of information on where the pegs are picked up from, a round dish (36), a rectangular box (74), the table top (33), a tray (34). This variation may affect results.

Not only do studies using the N.H.P.T. have variations in the equipment used for the test but there are also variations in the timing, the number of trials, the reporting of the results and the instructions given to the subjects.

Normative data has been collected in two different ways. One method (74) was timing the subjects placing and removing the nine pegs. These subjects were given a practice attempt before the timed trial. The dominant hand tested first, then the non-dominant hand. Verbal encouragement was given to subjects to go faster during the test. The other study measuring norms (33) gave subjects a maximum of 50 seconds to place all nine pegs. Only one trial was given. Alternate subjects were asked to use the dominant and non-dominant hands. Little difference was found in the scores between dominant and non-dominant hands. Results were expressed in number of pegs placed per second. This study concluded that a 'normal' score was to place all nine pegs in 18 seconds or less. None of the subjects in our study were able to place nine pegs in 18 seconds or less at any of the assessment weeks **Table no. 5.5.**

Stroke studies (32,33,34,63) where the N.H.P.T. has been used, have given their subjects 50 seconds to complete the test. The number of trials has varied from one trial where the affected hand only was tested (32,33) to three trials with each hand alternating between affected and unaffected hands (34,63). From these stroke studies, it is not clear if subjects had verbal prompting to go as fast as they can during the test. Results have been expressed as the time taken to place all nine pegs (32), the number of pegs placed in

50 seconds (32), pegs per second (33,34,63) and as a percentage of the unaffected hand (63).

In order to improve the sensitivity of the N.H.P.T. with our subjects, a time of 120 seconds was given to complete the test. This longer time was also given for two other reasons. One, the N.H.P.T. was one of several assessments our subjects had to complete, the total assessment time taking approximately one hour. Secondly, it was noted that some subjects took longer to discover the easiest method to pick up the pegs, once they had found the best way to pick up the pegs their time quickened. Each subject was given one trial with the affected hand. No verbal encouragement was given during the test as some subjects required to concentrate hard whilst performing the test and any distraction may have disturbed that concentration. Results were expressed in pegs per second for statistical analysis. **Table no. 5.4.** shows how many pegs were placed in 120 seconds and **Table no. 5.5** shows the time taken for those subjects whom could place all nine pegs.

5.8. Conclusion

Maximum improvement in Nine Hole Peg Test Scores occurred in the first 3 months. The Nine Hole Peg Test has a relatively high floor level of performance as subjects have to have some motor recovery to be able to attempt it.

Nine Hole Peg Test literature is confusing as there are a variety of different methods of administrating the test and reporting the results. The equipment used for testing also varies. There is a need to standardise the test in order that it can be used to evaluate rehabilitation or in stroke outcome studies.

Chapter Six

The Action Research Arm Test

6.1. Introduction

One of the first published batteries used to measure upper extremity function following stroke was developed by Carroll (1965) (78,79). This battery consisting of 33 different tasks is known as the Upper Extremity Function Test (U.E.F.T.) and assesses proximal and distal strength and dexterity in the upper limb. The U.E.F.T. was modified by Lyle (80) by using Guttman Scale analysis (81) and is known as the Action Research Arm Test (A.R.A.T.). There are 19 different tasks in the A.R.A.T. which are placed in four sub-tests, 1) Grasp, 2) Grip, 3) Pinch and 4) Gross Movement. The first three sub-tests assess manual dexterity as well as upper limb control. The sub-test Gross Movement assesses control of the upper limb without manual dexterity. Guttman Scale analysis allowed Lyle to place each sub-test into a hierarchical order of difficulty. Subjects are tested on the hardest item of each sub-test first and if they were given full marks, they automatically received full marks for that sub-test. If they failed the hardest item, they were then given the easiest item in that sub-test and if they failed that, they scored 0 for that sub-test. Those that pass the easiest item having failed the hardest have to perform all the task items within that sub-test. A score between 0 and 3 can be given for each test item. The maximal score that can be achieved in the A.R.A.T. is 57 for one upper limb or 114 for both upper limbs. Some studies measure the hemiplegic limb only (82,83), while others measure both upper limbs (80,84). The A.R.A.T. has been tested for validity (82,84) and reliability (80,83,84). The A.R.A.T. has been used to measure recovery in the upper limb following stroke (82) and in randomised controlled trials (38,85,86).

6.2. Validity

Concurrent validity has been established (82,84). De Weerd *et al* (1985) (82) assessed 53 hemiplegic subjects (25 male:28 female, mean (SD) age 68.6 (9.3) years) using the Brunnstrom-Fugl-Meyer test (B-FM) (87) and the Action Research Arm test (A.R.A.T.) on two occasions, at two and eight weeks following the onset of their stroke. Only the hemiplegic arm was tested. The Spearman rank correlation co-efficient was used to determine the association between the B-FM and the A.R.A.T. The correlation was 0.91 at two weeks and 0.94 at eight weeks. These correlation coefficients were significant at the 0.01 level of significance.

Hsieh *et al* (1998) (84) observed 50 stroke subjects (30 male:20 female, mean (SD) 65(13) years), 20 of whom had a right hemiparesis, 23 had a left hemiparesis and 5 with bilateral paresis. The subjects assessed had been admitted to a Physical Medicine and Rehabilitation Department over a 5 month period. As this was not an acute setting the range in days after onset of stroke and assessment was wide median 55 days, range 8-535 days. Hsieh *et al* (1998) (84) compared the A.R.A.T. with the upper limb sections of three other well validated scales, 1) the Motor Assessment Scale (88,89), 2) the Motricity Index (35) and 3) the Modified Motor Assessment Chart (87). Both upper limbs were assessed. The standard, Pearson product-moment correlation was employed to examine the relationship between the scores in the A.R.A.T. and the other three scales. There was a close association between the A.R.A.T. and upper limb sections of 1) the Motor Assessment Scale $r = 0.96$, 2) the Motricity Index $r = 0.87$ and 3) the Modified Motor Assessment Chart $r = 0.94$.

6.3. Reliability

Inter-rater and test-retest reliability of a modified U.E.F.T. has been tested by Lyle (80) which is often quoted as reliability of the A.R.A.T. These reliability studies were undertaken before Lyle applied Guttman Scale analysis (81) to the U.E.F.T. 20 subjects (13 male:7 female, mean age 53 years, age range 26 to 72 years) with hemiplegia following cortical damage from various causes (days after onset of stroke ranged from one month to 42 years, mean time 46 months) were assessed by two teams of two examiners. Both upper limbs were assessed. After assessing 10 subjects inter-rater reliability was found to be very high using the Pearson correlation co-efficient, $r = + 0.99$ ($p < 0.001$). Test-retest reliability was established by reassessing all 20 subjects within a mean (SD) of 7.5 (6.5) days, Pearson correlation co-efficient $r = + 0.98$ ($p < 0.001$).

Inter-rater reliability of the A.R.A.T. was examined by Hsieh *et al* (1998) (84). They assessed the same 50 stroke subjects as they used for their validity study. Each subject was assessed by three different Occupational Therapists within a three day period. Both upper limbs were tested. The intra-class correlation coefficient (ICC) was used to examine the degree of agreement between raters for the total A.R.A.T. score as well as for the four different sub-tests. For the total score the ICC was 0.98 ($p < 0.0001$), for the four sub-tests the ICC varied from 0.95 to 0.98.

The above study was criticised by Van der Lee *et al* (2001) (83), as it calculated the sum score in an unusual way, combining the scores of both arms. By doing this the reliability of the A.R.A.T. could be higher as the score of the unaffected limb will probably be maximal, thus reducing the degree of inter-rater disagreement. Van der Lee *et al* (2001) (83) assessed 20 chronic stroke subjects (9 men, 11 women; median age 62 years with a median time since stroke of 3.6 years) with a history of a single stroke, at

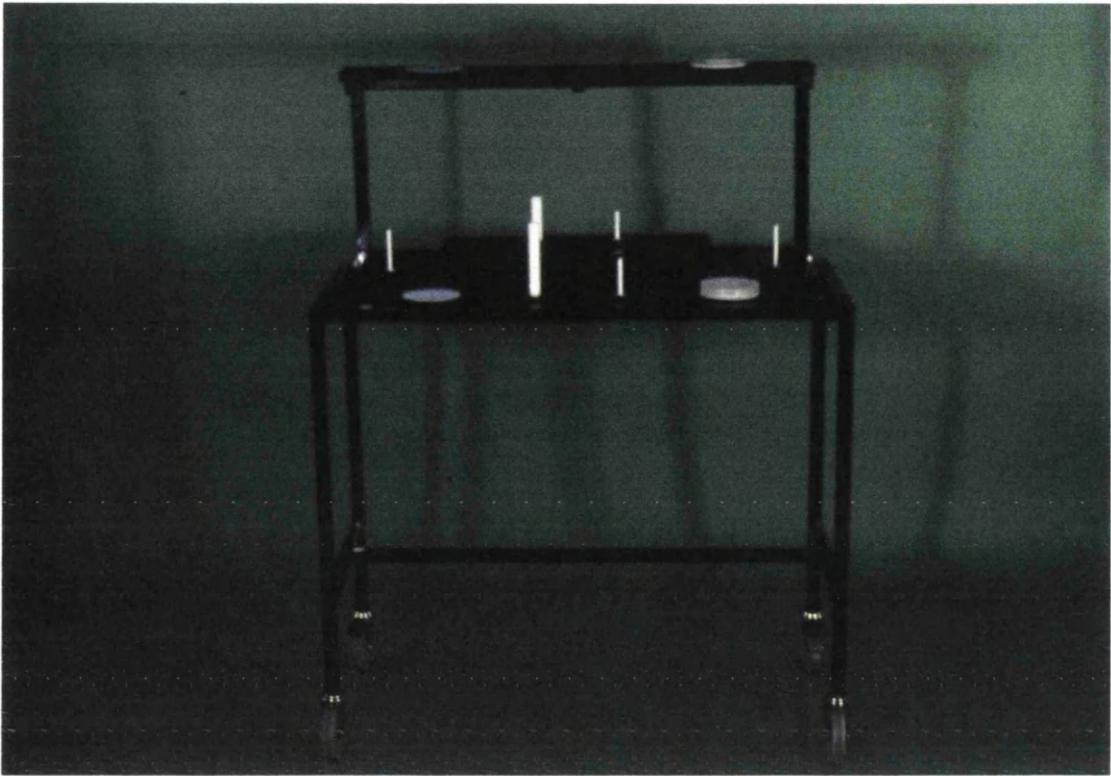
least one year previously. The affected upper limb only, was assessed. Intra-rater reliability of the sum scores and of individual items was assessed by comparing (1) the ratings of the laboratory measurements of 20 patients with the ratings of the same measurements recorded on videotape by the original rater, and (2) the repeated ratings of videotaped measurements by the same rater. Inter-rater reliability was assessed by comparing the ratings of the videotaped measurements of two raters. Their results showed all intra- and interrater Spearman's rho and ICC values were higher than 0.98. They concluded that intra- and inter-rater reliability was high for the A.R.A.T. in a population of Chronic Stroke. The mean difference between ratings was highest for the inter-rater pair (.75; 95% confidence interval, .02 - 1.48), suggesting a small systemic difference between raters. Intra-rater limits of agreement -1.66 to 2.26; inter-rater limits of agreement were -2.35 to 3.85. median weighted kappas exceeded .92 for the total score in the A.R.A.T. The lowest agreement was found in the sub-test gross movement but the difference between ratings was never greater than one point on the four point scale.

6.4. Methodology

6.4.1. Equipment

The equipment required for the A.R.A.T. includes a specially constructed trolley, which was built by the Bioengineering Department, Strathclyde University, Glasgow following the specifications described by Lyle (90). The trolley was constructed of wood and slotted angle iron and the wheels had brakes to keep the trolley in position. The trolley is almost mirrored for left and right upper limb assessment. Scaled drawings can be found in Appendix Six pages j-l.

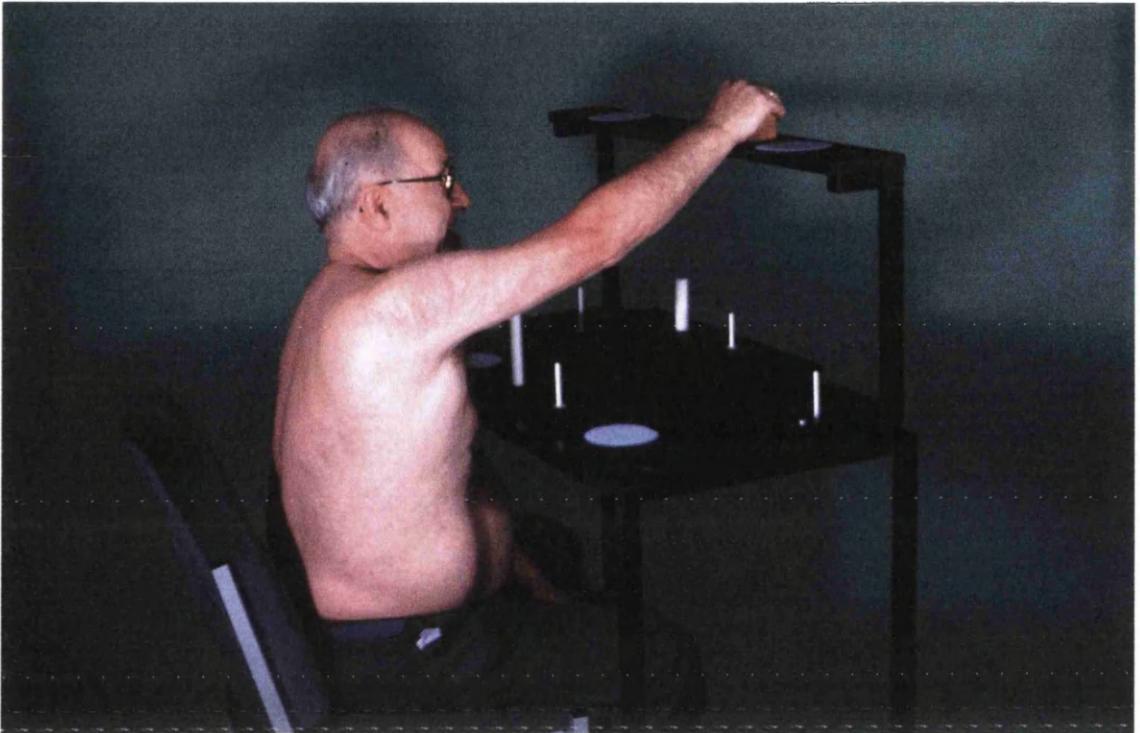
A chair with no arm supports is also required. The chair used in this study had a seat height of 43 centimetres. For each sub-test apart from the sub-test Gross Movement, further equipment is required. For the sub-test Grasp, four wooden cubes of different sizes, a cricket ball and a sharpening stone are required. For the sub-test Grip, two perspex tumblers, two perspex tubes of different sizes and a washer are required and for the sub-test Pinch, a marble, a ball-bearing and two 10 centimetre dishes with an inside depth of 1 centimetre (dishes are secured in place with 10 centimetre diameter velcro to the trolley for the pinch sub-test only) are required. Photographs and dimensions for all the equipment required can be found in the Appendix Seven pages m-0.



Photograph no. 6.1. The Action Research Arm Test Trolley.

6.4.2. Test Position

For the first sub-test Gross Movement, the subject has to sit on the chair with no arm supports. For the other three sub-tests the subject being assessed remains seated and the trolley is wheeled in, in front of the subject, as close to the subject's chest as possible and the brakes applied. The middle of the trolley being opposite the subject's mid-sagittal plane. The subject is not allowed to rise from the chair during the test.



Photograph no. 6.2. Test Position for Action Research Arm Test.

6.4.3. Procedure

In this study, the hierarchical order was not followed, therefore each subject was tested on each test item. The hemiplegic arm only, was tested. As gross movement tends to return before more dextrous movement, the gross movement sub-test was assessed first, followed by the sub-tests grasp, grip and pinch in that order. The order of the test items in the sub-test gross movement was reversed from Lyle's order with the easiest being performed first. The order of the test items in the other three sub-tests were followed as per Lyle's order. There was no time limit to the test and each test item was demonstrated to the subject before their attempt.

Sub-test Gross Movement

During this test the subject is asked to sit with their head upright and still

- 1 __ Lift hand to mouth
- 2 __ Place hand on top of head
- 3 __ Place hand behind head

Sub-test Grasp

This sub-test involves lifting each of the six items with the affected hand from the trolley top and placing them on the top shelf in turn.

- 1 __ Pick up 10cm. cube, block of wood
- 2 __ Pick up 2.5cm. cube, block of wood
- 3 __ Pick up 5cm. cube, block of wood
- 4 __ Pick up 7.5cm. cube, block of wood
- 5 __ Pick up cricket ball, 7.5cm. diameter
- 6 __ Pick up sharpening stone 10x2.5x1 cm.

Sub-test Grip

- 1 __ Pour water from glass to glass (plastic tumbler half full (100 mls. of water)).
- 2 __ Lift tube 2.25cm.in diameter from peg on trolley top to another peg on the lower shelf
- 3 __ Lift tube 1cm. in diameter from peg on trolley top to another peg on the lower shelf
- 4 __ Lift washer 3.5cm. in diameter and place it over bolt on trolley top

Sub-test Pinch

This sub-test involves lifting either the marble or the ball bearing from the dish on the trolley top and placing it in the dish on the top shelf using the tips of each of the first three fingers and the tip of the thumb. The dishes are fixed to the trolley top with 10 centimetre diameter velcro.

- 1 __ Pick up 6mm. ball bearing between 3rd. finger and thumb.
- 2 __ Pick up 1.5cm. marble between first finger and thumb
- 3 __ Pick up ball bearing between 2nd finger and thumb
- 4 __ Pick up ball bearing between 1st finger and thumb
- 5 __ Pick up marble between 3rd finger and thumb
- 6 __ Pick up marble between 2nd finger and thumb

6.4.4. Scoring

The nineteen test items were graded on the four point scale shown below. The scores are added together. The higher the score the less disabled the upper limb. The maximum score that can be obtained is 57.

Score	Description
3	Performs test normally
2	Completes test, but takes an abnormally long time or has great difficulty
1	Performs test partially
0	Can perform no part of test

A video of the A.R.A.T. can be found at the back of this thesis, which shows a subject going through the test and receiving a score for each test item. The script for the video can be found in Appendix Eight page p-r.

6.5. Results

Subject Number	Action Research Arm Test Scores				
	Week 0	Week 4	Week 8	Week 20	Week 32
1	0	0	0	0	0
2	0	15	26	36	32
3	40	40	52	51	44
4	51	54	57	57	57
5	0	0	0	0	0
6	0	0	0	3	1
7	0	0	0	0	0
8	0	0	0	0	0
9	9	25	29	9	7
10	0	0	0	0	2
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	1	0
14	50	54	50	57	57
15	0	1	2	2	1
16	10	29	32	40	40
17	34	46	49	55	57
18	0	1	1	1	1
19	0	0	0	0	0
20	41	54	57	57	57
21	19	32	39	55	57
22	46	51	56	57	57

Table no. 6.1. Individual Action Research Arm Test Scores.

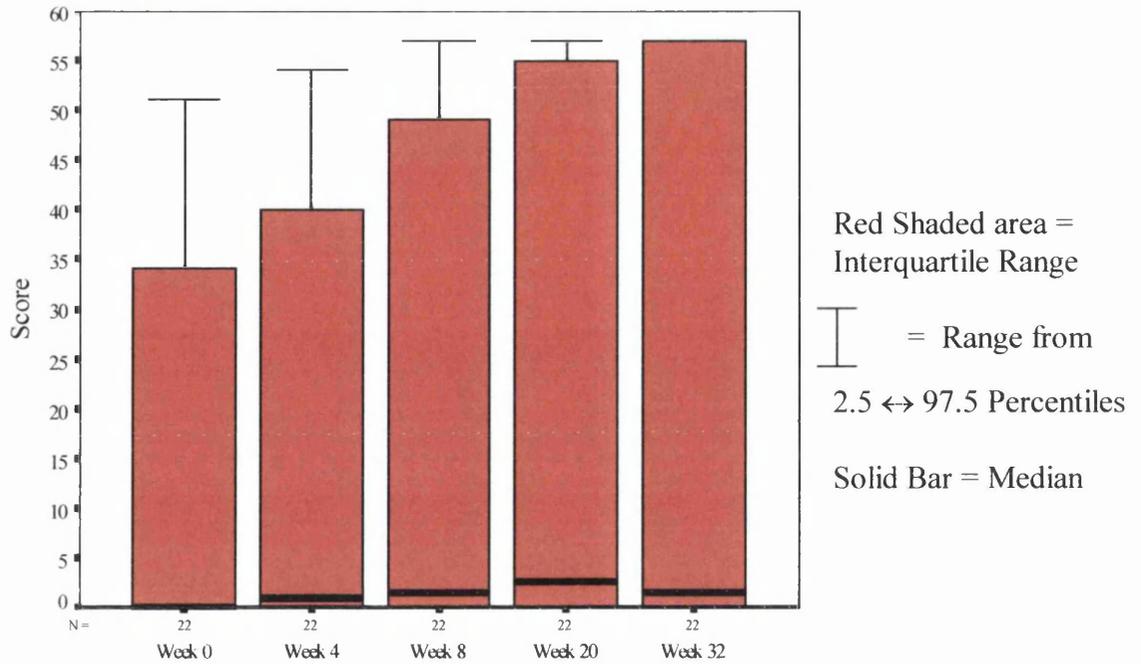


Figure no. 6.1. Boxplot showing Action Research Arm Test Scores over 32 weeks.

Week	Median	I.Q.R.	Minimum	Maximum
0	0.0	35.50	0	51
4	1.0	41.50	0	54
8	1.5	49.25	0	57
20	2.5	55.00	0	57
32	1.5	57	0	57

Table no. 6.2. Action Research Arm Test Scores over 32 weeks.

Figure no. 6.1. and Table no. 6.2. show that over a 32 week period there is an improvement in Action Research Arm Test scores.

Score	Week 0	Week 4	Week 8	Week 20	Week 32
0	13 (59.1%)	10 (45.5%)	10 (45.5%)	8 (36.4%)	8 (36.4%)
1 - 10	2 (9.1%)	2 (9.1%)	2 (9.1%)	5 (22.6%)	5 (22.6%)
11 - 20	1 (4.5%)	1 (4.5%)	-----	-----	-----
21 - 30	-----	2 (9.1%)	2 (9.1%)	-----	-----
31 - 40	2 (9.1%)	2 (9.1%)	2 (9.1%)	2 (9.1%)	1 (4.5%)
41 - 50	3 (13.6%)	1 (4.5%)	2 (9.1%)	-----	2 (9.1%)
51 -56	1 (4.5%)	4 (18.2%)	2 (9.1%)	3 (13.6%)	-----
57	-----	-----	2 (9.1%)	4 (18.2%)	6 (27.3%)

Table no. 6.3. Number and (Percentages) of Subjects and Total Scores in the Action Research Arm Test.

At week 0, 13 of the 22 subjects (59.1%) failed to score in the A.R.A.T. This decreased to 8 out of 22 (36.4%) at week 32. At week 0 and week 4 none of the subjects could achieve full marks. By week 32, 6 subjects (27.3%) achieved full marks.

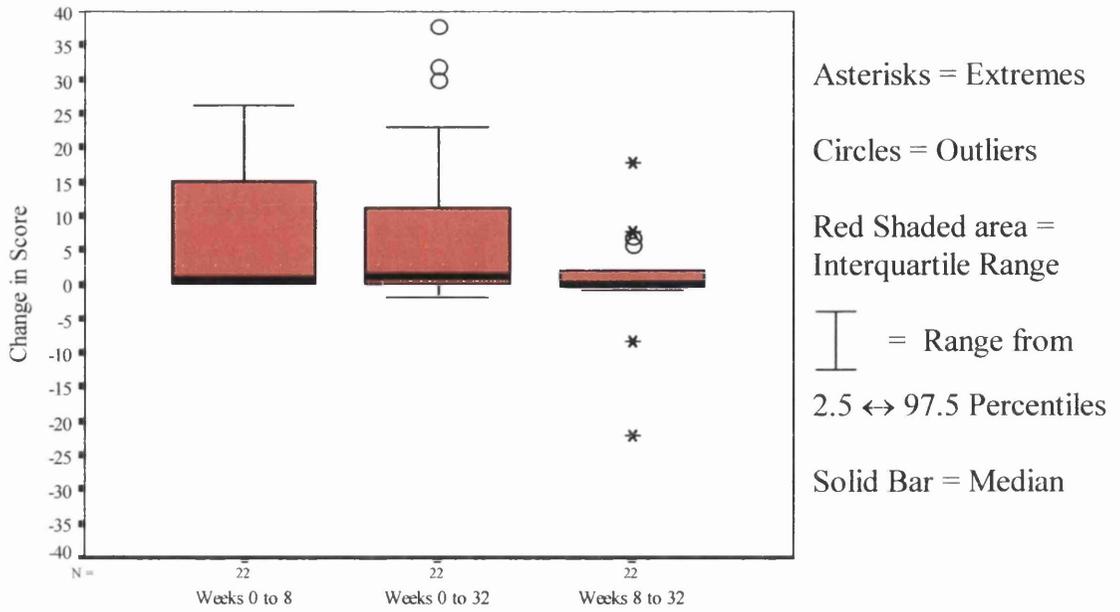


Figure no. 6.2. Changes in Action Research Arm Test Scores between assessment weeks 0,8 and 32.

Weeks	Median	I.Q.R.	Minimum	Maximum	<i>p</i> - value
0 to 8	0.5	15.25	0	26	0.003*
0 to 32	1.0	12.25	-2	38	0.003*
8 to 32	0.0	3.00	-22	18	0.284

* significant change

Table no. 6.4. Changes in Action Research Arm Test Scores between assessment weeks 0,8 and 32.

There is a significant change in Action Research Arm Test scores between weeks 0 and 8 ($p = 0.003$) and weeks 0 and 32 ($p = 0.003$) but there is not a significant change between weeks 8 and 32 ($p = 0.284$).

6.6. Discussion

The results show that the Action Research Arm Test (A.R.A.T.) did detect change with approximately 60% of subjects being able to attempt it by assessment week 32. Most improvement in Action Research Arm Test scores occurred in the first three months.

At week 0, **Table no. 6.3.**, 13 (59.1%) of the 22 stroke subjects were unable to attempt the A.R.A.T., by week 32 this had reduced to 8 (36.4%) subjects. Only five subjects who were unable to attempt the initial assessment (week 0) could attempt it by week 32. **Figure no. 6.1. and Table no. 6.2.** show that there is a trend for continual improvement over the 32 week period. A significant improvement in scores was seen between weeks 0 and 8 ($p = 0.003$) and weeks 0 and 32 ($p = 0.003$) (**Figure no. 6.2. and Table no. 6.4.**). A continual improvement in scores can be seen between weeks 0 and 32 (**Table no. 6.1 and Table no. 6.3.**). The improvement in A.R.A.T. scores in the first three months (assessment weeks 0 to 8) is similar to one other study (82). The A.R.A.T. has been used mainly in randomised controlled trials evaluating modes of treatment such as electromyographic (EMG) biofeedback (85), electrical stimulation (38) and increased intensity of physiotherapy treatment to the upper limb (86) rather than measuring the recovery of the upper limb following a stroke. Therefore there is little data on the A.R.A.T. and its ability to measure change overtime.

The literature describing the dimensions, weight and surface characteristics of the equipment used in the A.R.A.T. are limited. The approximate dimensions of the smaller equipment used are described (90), however the trolley design is more vague. Referral to Lyle's thesis (90) does give you more information with drawings of the trolley but they are not to scale. Another limitation that may affect comparison of results from study to

study, is the lack of information on the weight and surface characteristics of the smaller objects that are picked up and moved during the test. The height of the chair and the trolley were not adjustable, therefore subjects that were of smaller stature could find the test more difficult when trying to reach up to higher shelf with some attempting to stand as they stretched. It was also noticed that when some subjects had to lift smaller objects such as the marble or ball bearing the length of their nails may help or hinder their ability. Those subjects with smaller hand spans appeared to have more difficulty lifting the largest block in the grasp sub-test, although this could also be due to its weight. The literature also fails to give us any indication as to how long an examiner should allow a subject to attempt a test, this being left to their own clinical judgement. Timing may help with scoring a subject's performance and may increase the test's sensitivity.

The four point ordinal scale used to grade the stroke subject's ability to perform a test item in the A.R.A.T. is subjective and is prone to disagreement. In this study and in Van der Lee *et al* (2001) (83) reliability study there was some difficulty grading some subjects performance. This could be resolved perhaps by having more explicit descriptions for grading the scores.

6.7. Conclusion

The Action Research Arm Test (A.R.A.T.) did detect change over time in our stroke subjects, with significant improvement in scores in the first three months post stroke.

The A.R.A.T. can be used to measure one or both limbs. If you are evaluating a specific treatment technique on the hemiplegic limb perhaps just measuring that upper limb suffices. If you are measuring ADL as well as arm function measuring both limbs may be more applicable. The hierarchical order may or may not be followed. If there are time constraints the hierarchical order described by Lyle (80) will save time, especially if

both upper limbs are to be measured. The test may be more sensitive if a subject is asked to attempt all test items in the A.R.A.T. and this method may be of more value when evaluating modes of treatment.

There is a need to further standardise the test with more accurate recording of the dimensions, weight and surface characteristics of the equipment used as the test is not commercially available. The lack of detailed information is a major problem in setting up the A.R.A.T. for use in research. In this thesis scale drawings and the weight of the objects are made available. Grading the surface characteristics of the objects is more difficult.

Chapter Seven

General Discussion

7.1. Discussion

This was a study of twenty-two of the thirty acute stroke subjects who were recruited as part of the control group in our randomised controlled trial ‘electrical stimulation of the wrist extensors in post stroke hemiplegia’ (38). Subjects were only recruited if they demonstrated impairment of the upper limb, that is wrist extension of the affected arm had to have a score of grade 4 or less on the MRC scale (39). The twenty-two subjects appeared to be a small but representative sample of acute stroke subjects with upper limb impairment and disability.

Four tests were chosen from the battery of tests used in the randomised controlled trial which can be found in the Methodology Chapter Page 30. Each of the four tests, the Modified Ashworth Scale, Grip Strength, the Nine Hole Peg Test and the Action Research Arm Test, have already being discussed and conclusions drawn in previous chapters on the merits of each individual test. This general discussion will look at the results overall and compare the findings with other literature looking at the motor recovery of the upper limb following a stroke.

An impairment, which is important in the recovery of motor control in the upper limb is abnormal muscle tone and the development of increasing spasticity (hypertonicity). The ordinal rating scale that was used in this study to measure muscle tone was the Modified Ashworth Scale. There is considerable debate as to whether this scale actually measures muscle tone or the development of soft tissue shortening due to the stroke subject’s inability to move their affected limb. Perhaps the fact that it could be measuring two different impairments does not matter as long as it can detect change, and guide therapeutic intervention to either inhibiting the developing spasticity or stretching the

shortening soft tissue. In this study the wrist flexor group of muscles were tested for abnormal muscle tone.

There was a significant increase in muscle tone (spasticity) or shortening of the soft tissues reducing the range of wrist extension over the six months of the study with most change occurring in the first three months which was almost statistically significant. There are few studies that have measured spasticity over time. Sunderland *et al* (1989) (34) assessed spasticity over a period of six months and reported that 12 (31%) of their 38 subjects had abnormal resistance to passive movement at the initial assessment, with 7 (22%) out of 31 subjects showing an increase to passive movement by six months. However the scale they used has been considered unreliable (52). In our study 15 (68.1%) of the 22 subjects were rated as having abnormal resistance to passive movement at the initial assessment, with 14 (63.6%) of the 22 subjects showing an increase in resistance to passive movement at the final assessment (these results were calculated from the tables in Appendix Nine pages s and w. These results may suggest that our stroke population were more impaired by spasticity and/or soft tissue shortening, contracture. These results may also suggest that the Modified Ashworth Scale may be more reliable and sensitive scale to changes in resistance to passive movement than the scale used by Sunderland *et al* (1989) (34).

Assessment Week 0

Assessment Week 32

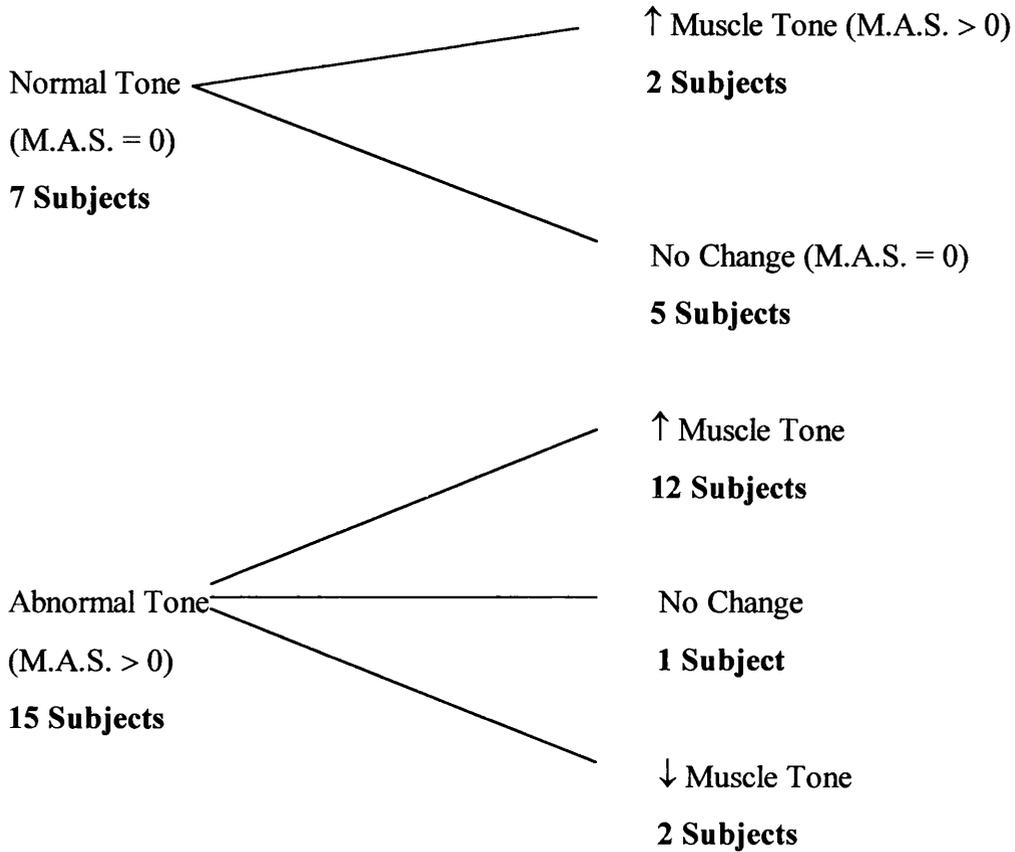


Figure No.7.1. Changes in Muscle Tone

Muscle weakness is considered the most important impairment following stroke (15,20,59). The measurement of muscle strength was assessed by measuring grip strength using the Standard Jamar dynamometer. Grip strength was chosen as the ability to grip is fundamental when using the hand for functional activities. Grip strength has already been used in the measurement of upper limb recovery following stroke (33,34) and it has been suggested that it a good prognostic indicator of upper limb functional

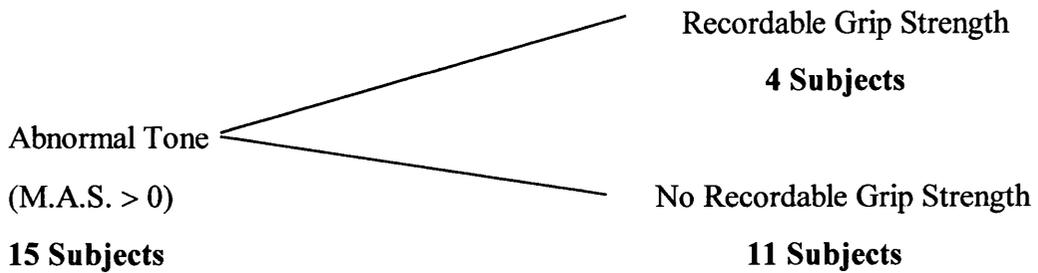
outcome (34). At the initial assessment (2-4 weeks post stroke), 9 (40.1%) of our 22 subjects could record a grip strength. The number of subjects that could record a grip strength rose to 11 (50%) of the 22 subjects at assessment week 8 (three months post stroke), and increased further to 13 (59.1%) to of the 22 subjects at the final assessment (six months post stroke). Despite the number of subjects that could not record grip strength, the measurement of grip strength appeared to be the most sensitive of our measures in detecting changes in motor control recovery with significant increases in grip strength occurring within the first three months, and between three and six months following stroke. These findings are similar to other studies which used grip strength as a measure of recovery of the upper limb (33,34), although they did not use the Standard Jamar dynamometer to assess grip strength. There is no upper limit to the recording of grip strength using the Standard Jamar dynamometer.

Scale may be more reliable and sensitive scale to changes in resistance to passive movement than the scale used by Sunderland *et al* (1989) (34).

Sunderland *et al* (1989) (34) assessed spasticity over a period of six months and looked at the relationship between grip strength and spasticity. They reported that 4 out of their 12 subjects, that had abnormal resistance to passive movement at the initial assessment, had measurable grip strength. At six months, 3 out of 7 subjects that showed increasing resistance to passive movement had measurable grip strength. If we look at that relationship in this study do we find the same results? The following results were calculated from the tables in Appendix Nine pages s and w. At week 0, 15 (68.1%) of the 22 subjects were rated as having abnormal muscle tone, 4 of which had measurable grip strength. At six months 14 (63.6%) of the 22 subjects showed increasing resistance to passive movement, 8 of these subjects had no measurable grip strength at six months. This left 6 subjects with measurable grip strength despite an increase in muscle tone or

developing contracture, although their grip strengths were less than 9 kilogrammes of force. Of these 6 subjects only 2 subjects achieved a score in the Nine Hole Peg Test and 5 subjects achieved a score in the Action Research Arm Test (A.R.A.T.). 2 of the subjects had a score of 1 out of a possible score of 57 in the A.R.A.T. which suggests very little active movement.

Assessment Week 0



Assessment Week 32

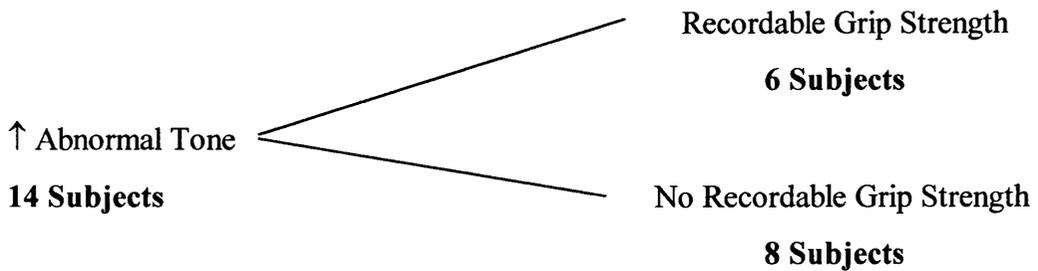


Figure No. 7.2. Grip Strength in Subjects with Abnormal Muscle Tone.

In order that the upper limb can function normally, the arm has to be able to reach and the hand grasp or manipulate objects. The two measurements of disability used in this study were the Nine Hole Peg Test and the Action Research Arm Test.

The Nine Hole Peg Test (N.H.P.T.) assesses manual dexterity. This is a difficult test and the stroke subjects had to have a reasonable amount of motor recovery to be able to attempt it. Only 6 (27.3%) of the 22 subjects could record a score at the initial assessment. This increased to 8 (36.4%) at three months and increased to 9 (40.9%) out of the 22 subjects at six months. Although less than 41% of our subjects were able to attempt the N.H.P.T., the test detected improvement in manual dexterity over the six month period with significant improvement occurring in the first three months. These results compare favourably with Sunderland *et al* (1989) (34). Timing a test improves its sensitivity and this test can be used when patients have reached the ceiling of other tests of arm function.

The Action Research Arm Test (A.R.A.T.) looks at the components of reaching with the arm and the finer manipulation of the hand together, that is it assesses the upper limb as one unit. At the initial assessment 9 (40.9%) of the 22 stroke subjects were able to score in the A.R.A.T., this increased to 12 (54.5%) subjects at assessment week 8 and this number increased further to 14 (63.6%) subjects by the final assessment. The Action Research Arm Test detected improvement in upper limb function over the six month period with most improvement occurring in the first three months. At three months 2 (16.6%) of the 12 subjects who scored in the A.R.A.T. achieved the maximum score obtainable in the A.R.A.T. and by the final assessment 6 (42.8%) of the 14 subjects who scored in the A.R.A.T. achieved the maximum score which suggests there is a ceiling effect to the test.

The absence of grip strength at one month has been suggested as a reliable predictor of poor recovery of upper limb function at six months post stroke (34). In our study 13 (59.1%) of our 22 subjects had no recordable grip strength at the initial assessment (2-4 weeks post stroke). Of those 13 subjects, only one subject scored in the Nine Hole Peg

Test and had a reasonable score of 32 out of 57 for the Action Research Arm Test (A.R.A.T.) suggesting some degree of return of upper limb function. A further 3 subjects scored in the A.R.A.T. despite no grip strength at the initial assessment, however two scored 1 out of a possible score of 57 and one subject scored 2. These scores cannot be considered as functional. Our results are very similar to Sunderland *et al* (1989) (34), and we can agree that the absence of grip strength at one month post stroke suggests poor functional outcome for the upper limb at six months.

In summary, our study suggests that recovery of motor control in the upper limb following stroke occurs mainly in the first three months but further recovery can be seen up to six months post stroke. These findings are in agreement with other studies (31,32,33,34). It could be argued that improvement in scores in the tests that measured strength, manual dexterity and upper limb function could be due to practise as the patients repeated the same tests at each assessment week. These tests may also not only improve due to motor recovery but could also be due to improvements in cognition, visual neglect and sensation.

7.2 Conclusion

Normal movement of the upper limb is very complex. Following stroke an individual can be left with a non-functional arm. The aim of rehabilitation is to minimise impairments and reduce disability and handicap. Outcome measures are required to guide and evaluate rehabilitation. In this study the impairments of abnormal muscle tone and muscle weakness were assessed. Abnormal muscle tone (spasticity) and/or contracture were assessed using the Modified Ashworth Scale. Muscle strength was measured by assessing grip strength with the Standard Jamar dynamometer. Upper limb disability was measured by the Nine Hole Peg Test (a test of manual dexterity) and the Action

Research Arm Test (a test of upper limb function with the components of reach and grasp or fine manipulation). All four tests did detect change and therefore they can be used to assess recovery of the upper limb and evaluate different therapeutic interventions. The most responsive test to change was grip strength. This study suggests that the four tests are suitable outcome measures, although there is a need to standardise the tests.

7.3. Further Research

In this study four tests were investigated for their sensitivity in detecting change in motor recovery of the upper limb following stroke. All the tests had been tested for validity and reliability. From the literature search there was evidence that there was no standardisation of the methodology, equipment, procedure and scoring of these tests. There is a need to develop standardised outcome measures in physiotherapy in order to chart recovery after stroke or evaluate therapeutic intervention.

Further research is required to find out if the tests in this study could detect changes in the upper limb after stroke beyond the six month period.

Motor recovery of the upper limb following stroke may depend on the site and extent of the lesion therefore it may help rehabilitation if a pattern of recovery could be established for the different stroke subtypes.

Absence or lack of grip strength at one month has been seen to be a reliable indicator of a poor functional outcome in the upper limb. Increasing spasticity and contracture could also be a sign that could predict a poor functional outcome although further investigation is required.

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Appendix One

Greater Glasgow Health Board

Glasgow Royal Infirmary Unit - Research Ethics Committee

Patient Information and Consent Form

N.B. This form should detail the purpose of the study, nature of the procedure, any discomfort and possible risks in terms which this patient can understand.

Title of Project:

The use of electrical stimulation for the prevention of wrist contractures in post-stroke hemiplegia.

Patient's Summary

After a stroke, many people are left with a stiff and weak hand. It has been suggested that electrical stimulation of the muscles of the forearm may help to reduce stiffness and encourage recovery of movement at the wrist after stroke. If you agree to take part in this study you will be allocated to receive either standard physiotherapy, or standard physiotherapy plus electrical stimulation. Those who receive electrical stimulation will have this for 30 minutes 3 times a day for up to 8 weeks or until discharge from hospital (if this occurs within 8 weeks). Electrical stimulation can cause minor local discomfort, but the strength of the current will be adjusted so that you are comfortable. Before the study, and at one, two, five and eight months very careful measurements will be made of movements at your wrist and how well you are able to use your arm.

If you do not wish to participate in this study, or at any stage wish to withdraw, your care will in no way be affected. Your General Practitioner will be informed of your participation in this study. Your participation in this study may not be of direct benefit to yourself, however hopefully it should help us in our treatment of future patients with stroke.

CONSENT

I, (Name).....of (Address).....

.....

agree to take part in the Research Project / Study Programme described above.

Dr / Mr.....has explained to me what I have to do, how it might affect me and the purpose of the Research Project / Study Programme.

Signed..... Date.....

Witness..... Date.....

Academic Section Address

I, ----- consent to having photographs, slides and video tape as part of the electrical stimulation study which I took part in, for the use in published and unpublished material and for the teaching of medical and paramedical staff and students.

Signed----- Date-----

Name (in BLOCK LETTERS)-----

Signature of Witness----- Date-----

Name (in BLOCK LETTERS)-----

Research Project Information

Thank you for taking time to consider taking part in our project. This should hopefully help you to discuss the project with your family or friends.

The project aims to look at a new way of treating your wrist. This uses Electrical Stimulation to produce movement at your wrist which at the moment you are unable to do. We are interested in seeing how this helps your wrist and hand to work.

If you enter the study you will be either given the treatment or not. This is in addition to your normal therapy. It is not possible to know which group you will be in.

If you enter the study you will have regular, detailed assessments of your wrist and arm. If you are at home we will arrange for you to attend the hospital for these assessments.

The Electrical Stimulation is an odd sensation which some people describe as like pins and needles, most people get used to it quickly. If you are chosen to be in the treatment group you will find considerable time is taken to ensure that the stimulation is correct and that you are happy with it.

Your family are welcome to be involved in the stimulation, this is especially important if you go home during the time when you are using the stimulator.

You are free to leave the study at any stage, this will not affect your continuing treatment in any way.

I am happy to answer any questions you may have.

Signed by the Research Physiotherapist.

Appendix Two

The Modified Barthel ADL Index

Bowels

0 = incontinent (or needs to be given enemata)

1 = occasional accident (one a week)

2 = continent

Bladder

0 = incontinent, or catheterised and unable to manage alone

1 = occasional accident (maximum once per 24 hours)

2 = continent

Grooming

0 = needs help with personal care

1 = independent face/hair/teeth/shaving (implements provided)

Toilet Use

0 = dependent

1 = needs some help, but can do something alone

2 = independent (on & off, dressing, wiping)

Feeding

0 = unable

1 = needs help cutting, spreading butter etc.

2 = independent

Transferring (bed to chair and back)

0 = unable, no sitting balance

1 = major help (one or two people, physical), can sit

2 = minor help (verbal or physical)

3 = independent

Mobility

0 = immobile

1 = wheelchair independent, including corners

2 = walks with help of one person (verbal or physical)

3 = independent (but may use aid, e.g. stick)

Dressing

0 = dependent

1 = needs help, but can do about house unaided

2 = independent (including buttons, zips, laces etc.)

Stairs

0 = unable

1 = needs help (verbal, physical, carrying aid)

2 = independent

Bathing

0 = dependent

1 = independent (or in shower)

Maximum Score = 20

The Modified Barthel ADL Index Guidelines

Bowels

(preceding week)

If needs enema from nurse, then incontinent *.

Occasional * = once a week.

Bladder

(preceding week)

Occasional = less than once a day.

A catheterised patient who can completely manage the catheter alone is registered as continent.

Grooming

(preceding 24-48 hours)

Refers to personal hygiene: doing teeth, fitting false teeth, doing hair, shaving, washing face.

Implements * can be provided by helper.

Toilet Use

Should be able to reach toilet / commode, undress sufficiently, clean self, dress and leave.

With help = can wipe self, and do some other of above *.

Feeding

Able to eat any normal food (not only soft food*).

Food cooked by and served by others. But not cut up.

Help = food cut up, patient feeds self.

Transfers

From bed to chair and back.

Dependent = no sitting balance (unable to sit); two people to lift.

Major help = one strong / skilled, or two normal people. Can sit up.

Minor help = one person easily OR needs any supervision for safety.

Mobility

Refers to mobility about house or ward, indoors. May use aid. If in wheelchair must negotiate corners / doors unaided.

Help = by one, untrained person, including supervision / moral support.

Dressing

Should be able to select and put on all clothes, which may be adapted.

Help = help with buttons, zips etc. (check!) but can put on some garments alone.*

Stairs

Must carry any walking aid used to be independent.

Bathing

Usually the most difficult activity.

Must get in / out unsupervised, and wash self.

Independent in shower = "independent" if unsupervised/ unaided.*

* = items added or modified after study ; asterisk at end, whole item added; asterisk in middle phrase added or clarified.

The Modified Barthel ADL Index - Guidelines

In General

The index should be used as a record of WHAT A PATIENT DOES, NOT as a record of WHAT A PATIENT COULD DO.

The main aim is to establish DEGREE OF INDEPENDENCE FROM ANY HELP, physical or verbal, however minor and for whatever reason.

The need for SUPERVISION renders the patient, NOT INDEPENDENT.

A patient's performance should be established USING THE BEST AVAILABLE EVIDENCE . Asking the patient, friends/relatives and nurses will be the usual source, but direct observation and common sense are also important. However, DIRECT TESTING IS NOT NEEDED.

Usually the performance over the preceding 24 - 48 hours* is important, but occasionally longer periods will be relevant.

UNCONCIOUS PATIENTS SHOULD SCORE "0" throughout, even if not yet incontinent.

Middle categories imply that the patient supplies OVER 50% OF THE EFFORT.

USE OF AIDS to be independent is ALLOWED.

* = items added or modified after study; asterisk at end, whole item added; asterisk in middle, phrase added or clarified.

The Barthel Score is an Activities of Daily Living (ADL) score.

The Score range is 0 - 20.

The higher the score the more independent the patient.

Appendix Three

The Modified Rankin Scale

Grade	Description
0	No symptoms at all.
1	No significant disability, despite symptoms; able to carry out all usual duties and activities.
2	Slight disability; unable to carry out all previous activities but able to look after own affairs without assistance.
3	Moderate disability; requiring some help, but able to walk without assistance.
4	Moderately severe disability; unable to walk without assistance and unable to attend to own bodily needs without assistance.
5	Severe disability; bedridden, incontinent, and requiring constant nursing care and attention.

The higher the score the more handicapped the subject.

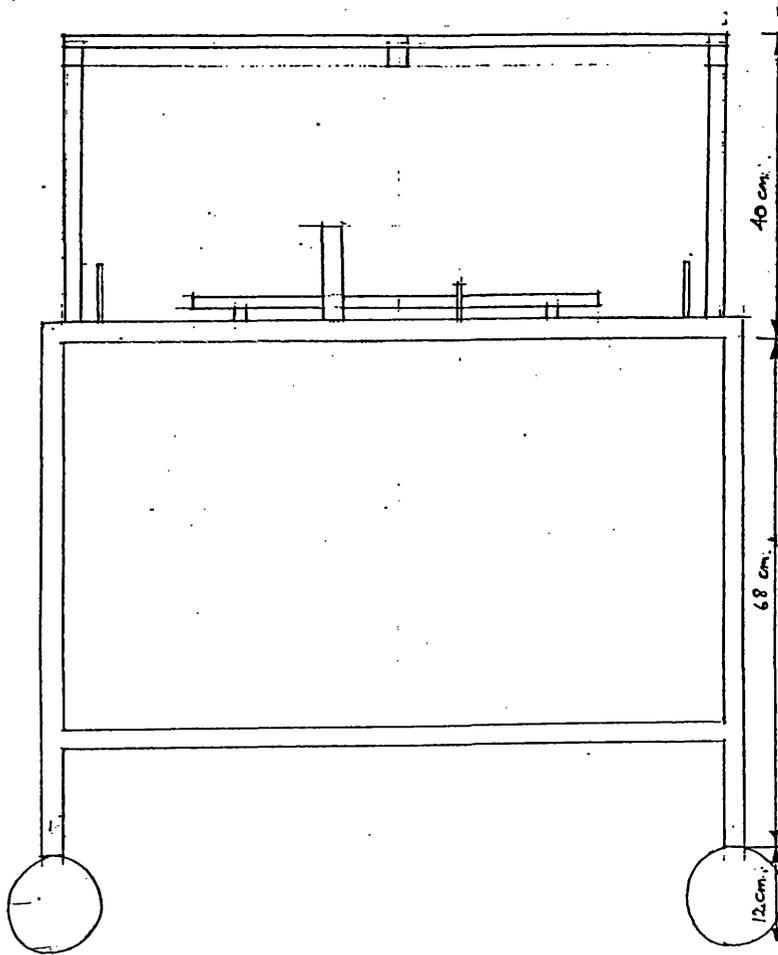
Appendix Four

Baseline Test Measurements. Comparison between the whole Control Group (n = 30) and Subgroup of Controls (n = 22) who completed assessments to the end of the study.

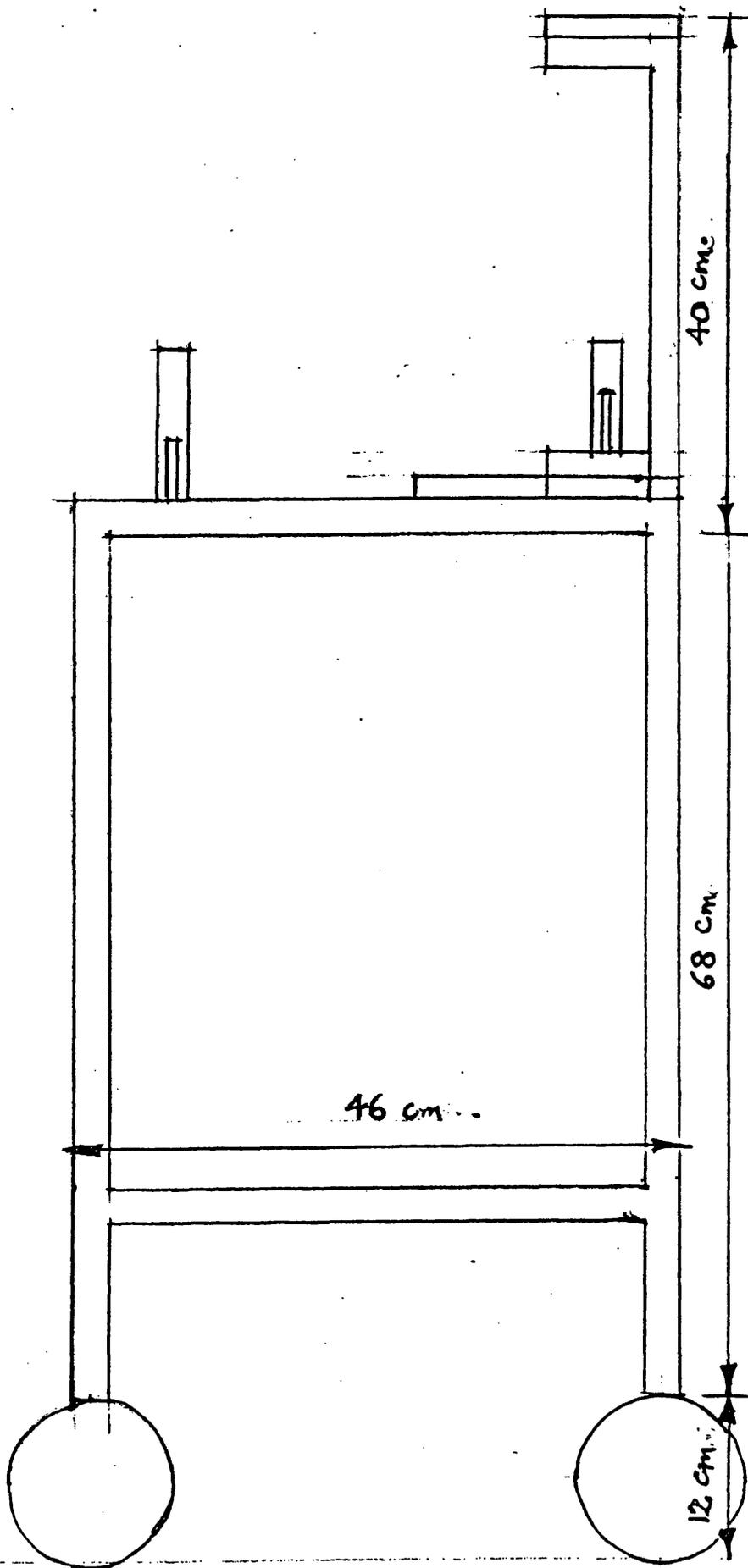
Test	Control Group (n = 30)				Control Group (n = 22)				p - value
	Median	I.Q.R.	Min	Max	Median	I.Q.R.	Min	Max	
Ashworth	1	2	0	3	1	2	0	3	0.539
Grip Strength	0.00	8.25	0	29	0.00	8.25	0	18	0.752
NHPT	0.00	0.04	0.00	0.39	0.00	0.02	0.00	0.18	0.817
ARAT	0.00	39.25	0	54	0.00	35.50	0	51	0.805
Barthel	7	8.25	2	19	7.5	7.25	2	19	0.772
Rankin	4	2	2	5	4	1.25	2	5	0.882

Using the non-parametric Mann Whitney U-Test for two unrelated samples shows that there is no significant difference between the two control groups for each test at week 0.

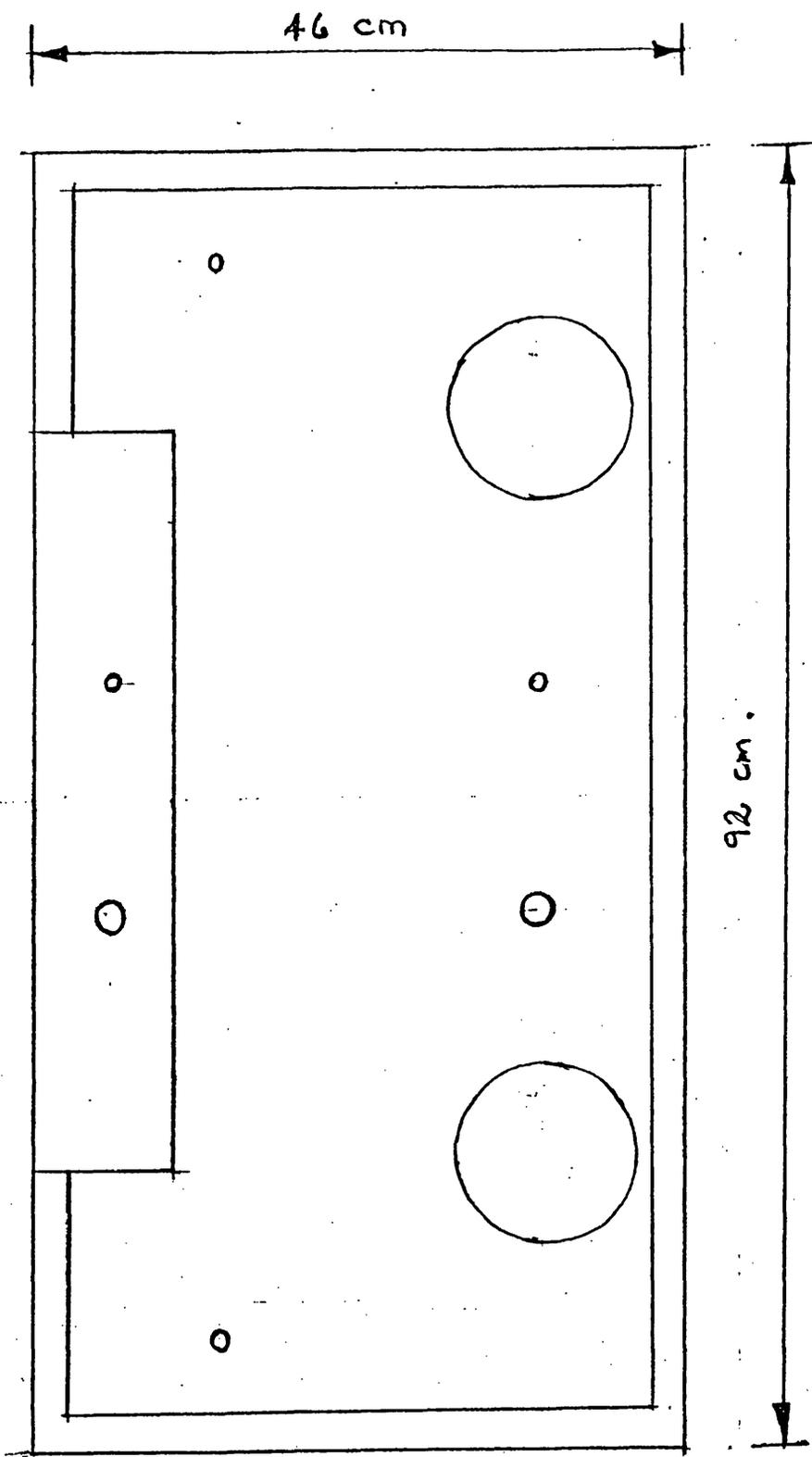
Appendix Six



TROLLEY FOR ACTION RESEARCH ARM TEST
SCALE 1:10



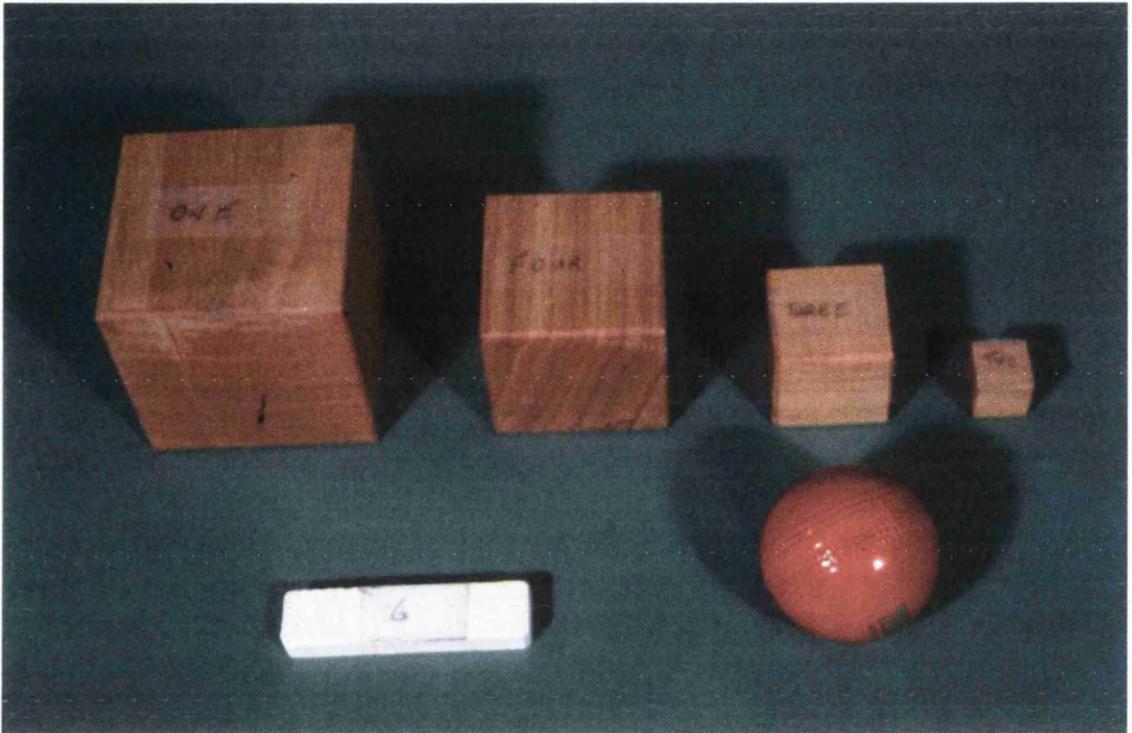
SECTION OF TROLLEY
FOR ACTION RESEARCH
ARM TEST
SCALE 1:5^k



TROLLEY TOP FOR ACTION RESEARCH ARM TEST

SCALE 1 : 5

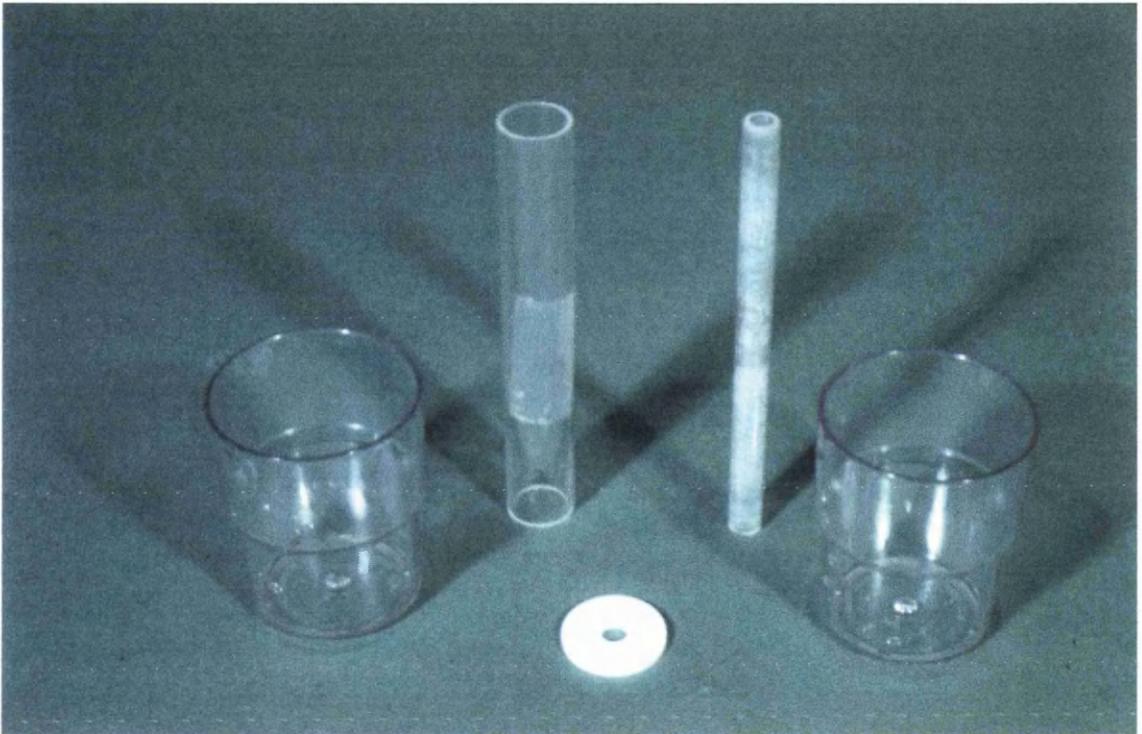
Appendix Seven



Photograph of the Equipment required for the Sub Test Grasp of the Action Research Arm test.

Sub - test	Description	Dimensions	Weight
Grasp	Wooden Block	10 cm. cubed	420 grammes
	Wooden Block	7.5 cm. cubed	200 grammes
	Wooden Block	5 cm. cubed	50 grammes
	Wooden Block	2.5 cm. cubed	10 grammes
	Cricket Ball	7.5 cm. diameter	200 grammes
	Sharpening Stone	10 × 2.5 × 1 cm.	40 grammes

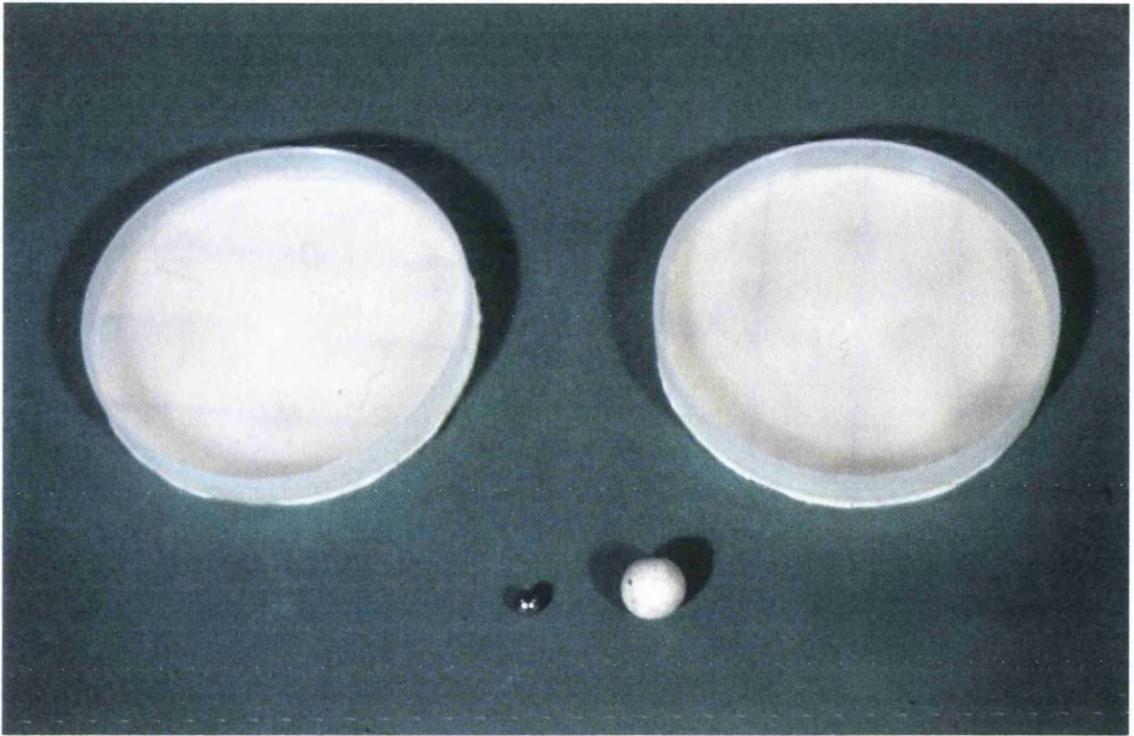
Dimensions of the Equipment required for the Sub Test Grasp of the Action Research Arm Test.



Photograph of the Equipment required for the Sub Test Grip of the Action Research Arm Test.

Sub - test	Description	Dimensions	Weight
Grip	2 perspex tumblers	7 cm. diameter 9 cm. height	30 grammes each
	Perspex tube	2.5 cm. diameter 16.5 cm. length	30 grammes
	Perspex tube	1 cm. diameter 16.5 cm. length	10 grammes
	Washer	3.5 cm. diameter 0.4 cm. depth	Negligible

Dimensions of the Equipment required for the Sub Test Grip of the Action Research Arm Test



Photograph of the Equipment required for the Sub Test Pinch of the Action Research Arm Test.

Sub - test	Description	Dimensions	Weight
Pinch	Marble	1.5 cm. diameter	Negligible
	Ball Bearing	0.6cm. diameter	Negligible
	2 plastic dishes	10 cm. diameter 1 cm. inside depth	30 grammes each

Dimensions of the Equipment required for the Sub Test Pinch of the Action Research Arm Test.

Appendix Eight

Script Plan For Video

Title

Action Research Arm Test
(A.R.A.T.)

The ACTION RESEARCH ARM TEST is a quantitative test of upper limb function. It has been designed to measure the recovery of the upper limb following a stroke. The test consists of FOUR sub-tests, GROSS MOVEMENT, GRASP, GRIP and PINCH.

Each is given a sub-score which when added together gives a total Action Research Arm Test (A.R.A.T.) score.

The sub-tests are further broken down.

Each item in the sub-test receives a score between 0 and 3.

Scoring can be subjective especially when a score of 1 or 2 is given.

All scoring should be based on this ranking.

The equipment required for the Action Research Arm Test (A.R.A.T.) includes a trolley and a chair.

For the sub-test GRASP, four wooden cubes of different sizes, a cricket ball and a sharpening stone are required.

For the sub-test GRIP, two perspex tumblers, two perspex tubes of different sizes and a washer are required.

For the sub-test PINCH, a marble, a ball bearing and two dishes are required.

The trolley is constructed of wood and slotted angle iron and is made to exact specifications.

The trolley wheels all have brakes.

The chair has no arm rests and the seat height is forty three centimetres.

The subject sat comfortably in the chair for the first sub-test GROSS MOVEMENT.

The trolley was not required for this sub-test.

During this test the subject was asked to sit with their head upright and still.

ITEM ONE

The subject was asked to lift their affected hand to their mouth.

A score of 2 was given for this item.

ITEM TWO

The subject was asked to lift their affected hand and place it on top of their head.

A score of 2 was given for this item.

ITEM THREE

The subject was asked to place their affected hand behind their head.

A score of 1 was given for this item

Giving a total of 5 for this sub-test.

The subject remains seated and the trolley is wheeled in, in front of the subject, as close to the subject's chest as possible.

The middle of the trolley opposite the subject's mid-sagittal plane.

The subject was not allowed to rise from the chair during the test.

GRASP

This sub-test involves lifting each of the six items with the affected hand and placing them on the top shelf in turn.

ITEM ONE

Is a 10 centimetre wooden cube weighing 420 grammes.

A score of 1 was given for this item

ITEM TWO

Is a 2.5 centimetre cube weighing 10 grammes.

A score of 3 was given for this item.

ITEM THREE

Is a 5 centimetre cube weighing 50 grammes.

A score of 3 was given for this item.

ITEM FOUR

Is a 7.5 centimetre cube weighing 200 grammes.

A score of 3 was given for this item.

ITEM FIVE

Is a 7.5 centimetre diameter cricket ball weighing 200 grammes.

A score of 3 was given for this item.

ITEM SIX

Is a 10 5 2.5 5 1 centimetre sharpening stone weighing 40 grammes.

A score of 3 was given for this item.

Giving a total score 16 for this sub-test.

GRIP

ITEM ONE

Involves pouring 100 millilitres of water from one tumbler into another tumbler.

A score of 2 was given for this item.

ITEM TWO

Involves lifting a 2.5 centimetre diameter tube weighing 30 grammes from a peg at the front of the trolley and placing it over a peg on the lower shelf at the back of the trolley.

A score of 3 was given for this item.

ITEM THREE

Involves lifting a 1 cm. diameter tube weighing 10 grammes from a peg at the front of the trolley and placing it over a peg on the lower shelf at the back of the trolley.

A score of 3 was given for this item.

ITEM FOUR

Involves lifting a washer 3.5 centimetres in diameter and a depth of 0.4 centimetres from the trolley top to a peg at the back of the trolley top.

A score of 2 was given for this item.

Giving a score of 10 for this sub-test.

PINCH

Two ten centimetre dishes with an inside depth of one centimetre are required for this test.

One is placed on the trolley top and the other on the shelf (the side of the affected arm). The dishes are secured in place with a ten centimetre diameter circular patches of velcro.

A rough textured 1.5 centimetre marble and a smooth textured 6 millimetre ball bearing are also required for the test.

the test involves lifting either the marble or the ball bearing from the dish on the trolley and placing it in the dish on the top shelf using the tips of each of the first three fingers and the tip of the thumb.

ITEM ONE

The ball bearing is picked up between the third finger and thumb.

A score of 1 was given for this item.

ITEM TWO

The marble is picked up between the first finger and thumb.

A score of 3 was given for this item.

ITEM THREE

The ball bearing is picked up between the second finger and thumb.

A score of 1 was given for this item.

ITEM FOUR

The ball bearing is picked up between the first finger and thumb.

A score of 3 was given for this item.

ITEM FIVE

The marble is picked up between the third finger and thumb.

A score of 1 was given for this item.

ITEM SIX

The marble is picked up between the second finger and thumb.

A score of 1 was given for this item.

A total of 10 was given for this sub-test.

The subscores are added together to give a total ARAT score of 41 out of a possible score of 57.

Appendix Nine

Subject Number	Assessment Week 0			
	M.A.S.	Grip Strength	N.H.P.T.	A.R.A.T.
1	1	0	0.000	0
2	0	0	0.000	0
3	0	4	0.017	40
4	0	9	0.180	51
5	2	0	0.000	0
6	2	0	0.000	0
7	1	0	0.000	0
8	3	0	0.000	0
9	1	8	0.000	9
10	1	0	0.000	0
11	3	0	0.000	0
12	1	0	0.000	0
13	0	0	0.000	0
14	0	14	0.150	50
15	2	0	0.000	0
16	1	2	0.000	10
17	0	12	0.050	34
18	3	0	0.000	0
19	2	0	0.000	0
20	0	14	0.042	41
21	1	3	0.000	19
22	1	18	0.115	46

Individual Scores for each test at Assessment Week 0

M.A.S. - Modified Ashworth Scale

N.H.P.T. - Nine Hole Peg Test

A.R.A.T. - Action Research Arm Test

Subject Number	Assessment Week 4			
	M.A.S.	Grip Strength	N.H.P.T.	A.R.A.T.
1	2	0	0.000	0
2	1	2	0.000	15
3	1	2	0.033	40
4	0	12	0.214	54
5	2	0	0.000	0
6	2	0	0.000	0
7	2	0	0.000	0
8	0	0	0.000	0
9	1	9	0.008	25
10	1	0	0.000	0
11	4	0	0.000	0
12	1	0	0.000	0
13	2	0	0.000	0
14	0	23	0.300	54
15	3	5	0.000	1
16	1	2	0.025	29
17	0	15	0.300	46
18	3	0	0.000	1
19	3	0	0.000	0
20	0	24	0.196	54
21	1	7	0.092	32
22	1	29	0.257	51

Individual Scores for each test for Assessment Week 4

M.A.S. - Modified Ashworth Scale

N.H.P.T. - Nine Hole Peg Test

A.R.A.T. - Action Research Arm Test

Subject Number	Assessment Week 8			
	M.A.S.	Grip Strength	N.H.P.T.	A.R.A.T.
1	2	0	0.000	0
2	1	2	0.000	26
3	0	5	0.033	52
4	0	16	0.273	57
5	2	0	0.000	0
6	3	0	0.000	0
7	3	0	0.000	0
8	1	0	0.000	0
9	1	7	0.000	29
10	1	0	0.000	0
11	4	0	0.000	0
12	2	0	0.000	0
13	3	0	0.000	0
14	1	21	0.300	50
15	3	3	0.000	2
16	1	4	0.033	32
17	0	24	0.450	49
18	3	0	0.000	1
19	3	0	0.000	0
20	0	26	0.200	57
21	1	5	0.214	39
22	0	25	0.310	56

Individual Scores for each test for Assessment Week 8

M.A.S. - Modified Ashworth Scale

N.H.P.T. - Nine Hole Peg Test

A.R.A.T. - Action Research Arm Test

Subject Number	Assessment Week 20			
	M.A.S.	Grip Strength	N.H.P.T.	A.R.A.T.
1	2	2	0.000	0
2	1	4	0.000	36
3	0	7	0.106	51
4	0	18	0.237	57
5	1	0	0.000	0
6	3	5	0.000	3
7	3	0	0.000	0
8	4	0	0.000	0
9	3	6	0.000	9
10	3	0	0.000	0
11	4	0	0.000	0
12	2	0	0.000	0
13	2	0	0.000	1
14	0	30	0.360	57
15	3	8	0.000	2
16	1	5	0.067	40
17	0	23	0.180	55
18	3	0	0.000	1
19	3	4	0.000	0
20	0	32	0.257	57
21	1	13	0.214	55
22	0	24	0.409	57

Individual Scores for each test for Assessment Week 20

M.A.S. - Modified Ashworth Scale

N.H.P.T. - Nine Hole Peg Test

A.R.A.T. - Action Research Arm Test

Subject Number	Assessment Week 32			
	M.A.S.	Grip Strength	N.H.P.T.	A.R.A.T.
1	2	0	0.000	0
2	1	6	0.008	32
3	0	7	0.129	44
4	0	18	0.360	57
5	1	0	0.000	0
6	3	5	0.000	1
7	3	0	0.000	0
8	4	0	0.000	0
9	3	8	0.000	7
10	2	0	0.000	2
11	4	0	0.000	0
12	2	0	0.000	0
13	2	0	0.000	0
14	0	28	0.257	57
15	3	9	0.000	1
16	2	6	0.082	40
17	0	28	0.321	57
18	4	0	0.000	1
19	3	4	0.000	0
20	0	31	0.200	57
21	1	14	0.300	57
22	0	27	0.429	57

Individual Scores for each test for Assessment Week 32

M.A.S. - Modified Ashworth Scale

N.H.P.T. - Nine Hole Peg Test

A.R.A.T. - Action Research Arm Test

