THE EFFECT OF ROBOT MEDIATED THERAPY ON UPPER EXTREMITY DYSFUNCTION POST STROKE

Susan Barbara Coote

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School of Physiotherapy

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DECLARATION

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Summary

Stroke is the leading cause of acquired disability with upper extremity (UE) dysfunction being one of the residual deficits associated with stroke. Recovery of the UE is less than that of the lower extremity and contributes largely to decreased well being and quality of life. While physiotherapy is widely accepted as a routine intervention post stroke there is currently little evidence to inform clinical practice. The evidence that does exist suggests that more intervention leads to better outcomes and that repetitive, exercise based intervention produces a positive treatment effect.

Robotic technology is ideally placed to provide high levels of repetitious, exercise based intervention and US studies investigating robot mediated therapy (RMT) have suggested positive treatment effects. The GENTLE/s system advances on US systems by incorporating feedback through virtual representation of the real world and through haptic feedback of the required movement.

The aim of this study was to investigate the effect of the GENTLE/s robot mediated therapy (RMT) system on upper extremity (UE) dysfunction post stroke. This study used a series of 20 single case studies and compared the effect of a period of intervention with the GENTLE/s system to a period with no intervention and to a period of treatment with the same dosage of sling suspension (SS). The length of baseline and order of treatment were randomised with ten subjects following an ABC treatment order and ten following an ACB treatment order. Outcome measures were chosen as they considered the effect at the level of UE motor function, activities and participation and because they were reported to have high levels of sensitivity and test retest reliability, properties which are required by the single case study design.

By comparing the rate of recovery (estimated by the slope of a line through the data generated by a general linear model) during the RMT phase to that of the baseline period the presence or absence of a treatment effect can be seen. If the slope in the RMT phase is greater than that in the baseline RMT can be said to have a positive treatment effect. For the individual results the difference between the phases was considered to be statistically significant ($\alpha=0.05$) if the difference between the rates of recovery (slope) was greater than the 'adjusted minimum detectable change' (aMDC). As a considerable amount of data was generated and to allow comparison to other studies, the average response of the 10 subjects in the ABC and ACB groups for each phase was estimated.

While not statistically significant for individual subjects or on a group basis, there was a trend for greater absolute slope values in the RMT phase than the baseline phase for those variables that considered the shoulder and elbow. This effect was seen at the level of UE motor function and activities but not at the level of participation as measured using the SF-36. This supports the findings of US researchers and studies that suggest that increased dosages of repetitious exercise based interventions have a positive treatment effect.

The rate of recovery during a period of RMT was compared to that during a similar period of SS in order to control for the fact that an increase in intensity of intervention has been shown to have a positive treatment effect. While not statistically significant there was a trend for the slope to be greater during the RMT phase. While both interventions were based on high levels of repetition, RMT had the added features of being motivating and functional, the trends in the results suggest that the addition of these features of the robotic system to the repetitious exercise is beneficial. The comparison of the unit increase per treatment to that of the US studies might suggest a superior effect of the GENTLE/s system, though further studies to investigate this are warranted.

The trend for a rate of recovery greater during the RMT phase than baseline and SS phases in those areas trained by the system was replicated across 6 subjects and was seen on average in both groups for the majority of the variables considering those areas trained by the system. The lack of statistical significance may be attributed to the small dosage of the interventions which, although represents that seen in clinical practice, represents only a tiny proportion of the patients waking hours.

It is possible that the presence of pain and sensory dysfunction contributed to the small responses to RMT, although no conclusive links between the response to RMT and other predictors of UE recovery were found. It is possible that those with scores in the upper 2/3rds of the Fugl Meyer scale and may benefit most from additional intervention delivered by the GENTLE/s system.

In conclusion, the trends in the data suggest a positive treatment effect of RMT delivered by the GENTLE/s system and a superior effect to a similar duration of treatment with sling suspension. Further studies are required to increase the evidence base for this novel treatment.

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A	Baseline phase
AAT	Arm ability training
ADL	Activity of daily living
AElFl	Active elbow flexion
AElX	Active elbow extension
aMDC	Adjusted minimum detectable change
ARAT	Action research arm test
AROM	Active range of motion
AShA	Active shoulder abduction
AShER	Active shoulder external rotation
AShFl	Active shoulder flexion
B	Robot mediated therapy phase
BI	Barthel index
BP	Bodily pain (section of SF-36)
C	Sling suspension phase
CIMT	Constraint induced movement therapy
CofG	Centre of gravity or centre of distribution of MEP
Ct	Control
CVA	Cerebro vascular accident
FAT	Frenchay arm test
FIM	Functional independence measure
FM	Fugl Meyer motor assessment scale
FMA	A (upper arm) section of Fugl Meyer motor assessment
FMB	B (wrist) section of Fugl Meyer motor assessment
FMC	C (hand) section of Fugl Meyer motor assessment
FMD	D (coordination) section of Fugl Meyer motor assessment
fMRI	Functional magnetic resonance imaging
FMT	Total score of Fugl Meyer motor assessment
GH	General health perceptions (section of SF-36)
GHQ	General health questionnaire
GLM	General linear model
HRQOL	Health related quality of life
ICC	Intraclass correlation coefficient
ICF	International Classification of functioning
LE	Lower extremity
MAL	Motor activity log
MAS	Motor Assessment scale
MASA	A (arm) section of Motor Assessment scale
MASB	B (hand activities) section of Motor Assessment scale
MASC	C (advanced hand activities) section of Motor Assessment scale
MAST	Total score of Motor Assessment scale
MDC	Minimum detectable change
MEP	Motor evoked potential
MH	Mental health (subsection of SF-36)
MIME	Mirror Image Motion Enabler
MIT-Manus	Massachusetts Institute of Technology Manus robot
MRI	Magnetic resonance imaging
MRP	Motor relearning programme
MVIC	Maximum voluntary isometric contraction

N	Number (of subjects)
NDT	Neurodevelopmental therapy
NMES	Neuromuscular electrical stimulation
OT	Occupational therapy
PCS	Physical health summary score (of SF-36)
PElFl	Passive elbow flexion
PElX	Passive elbow extension
PET	Positron emission tomography
PF	Physical functioning (section of SF-36)
PH	Physical health (subsection of SF-36)
PPMC	Pearson product moment correlation
PROM	Passive range of motion
PShA	Passive shoulder abduction
PShER	Passive shoulder external rotation
PShFl	Passive shoulder flexion
PT	Physical therapy
RAP	Rehabilitation activities profile
rCBF	Regional cerebral blood flow
RCT	Randomised controlled trial
RE	Role limitations due to emotional problems (section of SF-36)
RMT	Robot mediated therapy
RP	Role limitations due to physical functioning (section of SF-36)
SCC	Spearman (rank) correlation coefficients
SCT	Star cancellation test
SEM	Standard error of the measure
SF	Social functioning (section of SF-36)
SF-36	Short form 36 item health questionnaire
SMES	Sødring motor evaluation
SOMCT	Short orientation memory concentration test
SS	Sling suspension
TENS	Transcutaneous electrical nerve stimulation
TMS	Transcranial magnetic stimulation
Tx	Treatment
UE	Upper extremity
UG	Universal goniometer
UK	United Kingdom
USA	United States of America
VAS	Visual analogue scale
VR	Virtual reality
VT	Vitality (section of SF-36)
WHO	World Health Organisation

1 Chapter 1 - Introduction

1.1 Stroke

The World Health Organisation (WHO) defines stroke as "rapidly developing symptoms and/or signs of focal and at times global, loss of cerebral function with symptoms lasting for more than 24 hours or leading to death with no apparent cause other than that of vascular origin" (WHO 1989). The most frequent expression of the cerebral damage following stroke is in the form of hemiplegia or loss of motor function to one side of the body.

Stroke is the most common cause of acquired physical disability in Ireland. In 1997 there were 8,584 people admitted to hospital with stroke and it is estimated that there are 30,000 people living with residual disability from stroke (Irish Heart Foundation 2000). The American Heart Association (AHA) reports that stroke is the leading cause of long-term disability in the USA with 1.1 million people reporting functional limitations due to stroke in 1999 (AHA 2003).

The consequences of stroke impact both the individual and society. The impact on the individual is perceived as the loss of movement and functional ability and the effect of those on quality of life and participation in their desired lifestyle. At the level of society considerable costs are incurred through the rehabilitation and care of these individuals in addition to losses incurred as they no longer function as part of the productive workforce. The estimated lifetime cost of stroke in the USA in 2004 is $140,048 per individual. (AHA 2003)

The biopsychosocial model of the WHO's 'International Classification of Functioning' framework (WHO 2001) provides a model to describe the sequellae of stroke and the secondary complications arising from it. The impairment of the brain structure (the initial and residual cell death and destruction) contributes to deficits in many body functions including the motor, sensory, visual and speech systems. Arising from these are the limitations in activity, which restrict participation in life situations. Upper extremity dysfunction is one manifestation of stroke that has a significant effect on the individual at all of the above levels. The challenge for rehabilitation is to maximise recovery of cerebral functioning in order to restore movement and hence functional ability to allow maximisation of that individual's participation in society.

1.2 Recovery after stroke

At the level of brain structures recovery is thought to occur through "plasticity" or the ability of the neural cells and networks to adapt to changes in use requirements and to damage. These include the ability of cortical areas to reorganise and of associated pathways to exchange roles in order to take over the function of the damaged area. Studies of animal recovery suggest that repeated practice of tasks has a positive influence on cortical reorganisation (Nudo et al 1996) and that this response is optimised if the task/exercise requires skill and is both challenging and engaging (Plautz et al 2000). In humans the reorganisation of cortical maps of the affected upper extremity is associated with improvements in upper extremity movement following constraint induced movement therapy (Liepert et al 2000) which is a therapy intervention involving high levels of repetition of UE tasks.

As our understanding of the processes underlying the learning of motor tasks are emerging so too is our understanding of the process of motor learning post stroke. Studies investigating the effect of feedback (Winstein et al 1999), task schedule (Hanlon 1996), and object presence (Wu et al 2000) on the learning of upper extremity motor tasks have suggested that, while the areas of brain involved in the task may be different, the process of motor learning for individuals with stroke is similar to that for individuals with intact brains.

The loss of motor function of the upper extremity (UE) contributes directly to the inability to perform activities. For those who present with an initial UE dysfunction the recovery of these abilities is estimated to be between 17% (Broeks et al 1999) and 49% (Wade et al 1983). This is in stark contrast to the rate of recovery of gait ability, which is estimated to be between 76% (Friedman 1990) and 84% (Skilbeck et al 1983). There are many reasons for this difference including the fact that the functioning of the UE is far more complex than that of the lower extremity (LE).

The residual deficits of UE abilities have a significant impact on the sense of well being of the individual post stroke (Wyller et al 1997). Even in the presence of what could be deemed to be adequate UE function, a significant sense of personal loss is evident (Broeks et al 1999) and deficits of UE function contribute to low health related quality of life

(McEwen et al 2000). Thus it is vitally important to optimise the recovery of motor and functional abilities of the UE through physiotherapy intervention as part of the rehabilitation process.

1.3 Physiotherapy Management of individuals with stroke

In the rehabilitation of patients with stroke, physiotherapists function as part of a team of professionals including occupational therapists, speech and language therapists, dieticians, doctors, nurses and social workers. It is widely accepted that a team approach is necessary to address the various complex needs of these patients, with provision of this care in specialised stroke units optimising recovery (Stroke Unit Triallist's Collaboration 1998).

While physiotherapy is considered a routine intervention post stroke, there is little evidence to guide current practice (Pomeroy & Tallis 2000). Physiotherapy intervention is commonly referred to as a "black box", and it is not yet known which components of it are responsible for the improvements seen. In a review of the literature to date, the one message that does arise is that exercise based interventions show positive treatment effects (Pomeroy & Tallis 2000). Another trend that emerges is that an increased amount of intervention leads to better outcomes (Kwakkel et al 1997, Langhorne et al 1996). Despite this, the amount of intervention for the UE that occurs during formal treatment time in a rehabilitation gym (17%, Ballinger et al 1999) is minimal compared to normal activity and as such may not optimise cortical reorganisation post stroke (deWeert & Feys 2002).

1.4 Robotic technology and stroke rehabilitation

Robotic technology is ideally placed to deliver high intensities of exercise based interventions without the need for direct therapist input during treatment. Consistent with the suggestion by Pomeroy & Tallis (2002) that the evaluation of interventions based on our emerging understanding of the processes of recovery is one way forward for physiotherapy research, the principles of robot mediated therapy (RMT) are supported by the neuroscientific principles optimising recovery.

Two research groups in the USA have demonstrated positive treatment effects of RMT systems. Volpe et al (2000) demonstrated significantly greater improvement in motor abilities in the group that received treatment with the MIT-MANUS system than in a control group who received only 1 hour per week of exposure to the robot half of which involved exercising with the impaired UE. Lum et al (2002) demonstrated improvements in the group treated with the MIME system that were significantly greater than those seen in the control group who received the same duration of therapy based on the Bobath concept. While both groups evaluated the effect of these systems on impairments of motor function of the UE they did not evaluate the effect on activity limitations of the affected UE or on participation restrictions.

The GENTLE/s system is similar to the above systems in that it provides passive, assisted or resisted movement for the UE. The system differs in the visual and "haptic" feedback that it provides during treatment. The therapist programmes the robot for the required movement pattern which can be reproduced exactly within and between treatment sessions. The participant receives "haptic" feedback or the feeling from the robot that they are deviating from the required movement pattern and visual feedback in the form of a virtual representation of the real world on screen in real time. In addition the workspace of the system is greater than the other two systems previously evaluated allowing movement patterns to be produced that replicate those required for function of the UE. These three added dimensions further exploit our knowledge of the components required for maximising recovery of the UE post stroke.

1.5 Objectives of this research

The aim of this study was to evaluate the effect of treatment with the GENTLE/s RMT system on the upper extremity function post stroke. This form of intervention incorporates those aspects that have been demonstrated in the neurophysiological and physiotherapeutic research to be effective in optimising UE recovery i.e. highly repetitious, exercise based interventions.

Twenty participants completed the study which consisted of a series of single case studies. The study design compared a period of intervention with the GENTLE/s RMT system to a similar period of no intervention and to a period with another similar intervention of the same duration. This allowed firstly the evaluation of whether this new intervention had a treatment effect and secondly whether this treatment effect was superior to another intervention of similar duration/intensity.

The study outcomes were chosen in order to reflect changes at the level of body functions, activity limitations and participation restrictions (WHO 2001). This was in order to evaluate whether an increase in movement abilities brought about by the treatment had an impact on the ability of the participant to perform activities with the affected UE and to improve their participation in society. In addition the influence of impairments that are thought to be predictors of recovery of the UE are considered.

The first literature review chapter, chapter 2, of this thesis will set the scene and explore the many issues surrounding recovery of the UE post stroke and the consequences of this loss of function. The second, chapter 3, will evaluate the basis and evidence for the many physiotherapeutic interventions currently used. Aspects of the study design, outcome measurement and procedures of this research will be described in chapter 4, with the results presented in chapter 5. A discussion of the results of this study and its limitations follows in chapter 6 with the conclusions and recommendations in chapter 7.

2 Chapter 2 - Recovery of the upper extremity post stroke

The purpose of this chapter is to provide information on the mechanisms and confounding factors of upper extremity (UE) recovery post stroke prior to a critical evaluation of the evidence for current physiotherapeutic interventions in chapter 3. This chapter considers a number of aspects of recovery of the upper extremity (UE) post stroke and the issues surrounding this at the three levels of the 'International Classification of Functioning' framework; impairments of brain structure and motor function, limitations in UE activities and participation restrictions arising from these UE dysfunctions.

This chapter begins with a review of the emerging understanding of the mechanisms of recovery of brain function and motor learning post stroke. This is followed by a consideration of the levels of recovery and aspects that may affect recovery of motor function and functional activities of the UE. Finally the impact of a residual deficit of UE function and its impact on the individual's participation and quality of life are considered as this may be influenced by RMT. The outcome measures used in the research reviewed here and in chapter 3 are summarised in Appendix 1.

2.1 Recovery post stroke of brain structures and functions

2.1.1 Introduction

For many years the brain was considered to be an unchanging "hard wired" organ with no potential for change or recovery. The work of Broca in 1861 and of Brodman in 1909 compartmentalised the brain into strict functional locations leading neuroscientists to believe that the brain was a conceptually rigid entity with significant recovery of function rarely sought or expected (Bach-y-Rita 1992). It is only in the last decade that the concept of the damaged brain as a plastic, ever changing organ has been widely accepted (Hallett 2001). Prior to the development of non-invasive brain imaging techniques for humans, theories of recovery were based on experiments using animal subjects. Transcranial magnetic stimulation (TMS), positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) have more recently enabled significant progress in the understanding of the changes in the damaged and undamaged human brain that lead to changes in movement and function.

2.1.2 Early recovery

Following stroke the cells that are deprived of oxygen for more than a few minutes will inevitably die, with those in the immediate surrounding area receiving less supply than normal. These alive but vulnerable cells are referred to as the ischaemic penumbra. Recovery in the very early stages after stroke are thought to be brought about largely through the resolution of oedema around the lesion, the absorption of necrotic tissue and the opening of collateral circulatory channels to this area (Lee & van Donkelar 1995). In addition to the actual cell death at the lesion, there is disruption of sites distal to the lesion, known as diaschisis. This consists of depression in tissue connected to, but remote from the lesion, which may be due to neural shock, oedema, local blood flow disruption or denervation of postsynaptic neurons. It is now widely believed that the resolution of diaschisis leads in part to spontaneous recovery in the early stages post stroke (Bach-Y-Rita 1992).

2.1.3 Later recovery

Recovery beyond the initial period can most likely be attributed to brain plasticity (Lee & van Donkelar 1995). There are many proposed mechanisms for these changes; unused regions of the brain may take over the functions of the damaged area, or the other areas involved in the specific function will take over the role of the damaged area (redundancy) (Held & Pay 1999). At a cellular level in a relatively short time, the removal of inhibition, strengthening or weakening of synapses (long term potentiation and depression) and changes in neuronal membrane excitability (denervation supersensitivity) may be responsible, while over longer time periods sprouting of new axon terminals and formation of new synapses are likely mechanisms. The processes are not mutually exclusive and our knowledge as to which mechanism is responsible for which phenomenon is as yet only based on model systems (Hallett 2001).

One mechanism of exploring the mechanisms of neuroplasticity responsible for motor recovery is the examination of changes in the functional motor maps of the cortex and research on animal and human brains is described in the following sections.

Results from animal studies

Prior to the advent of non-invasive imaging in humans the results of invasive examination of the brains of animals were used to generate theories of recovery and continue to be used in the absence of information from human studies. Nudo et al (2000) suggest that by examining the representational maps in the motor cortex it may be possible to determine the neurophysiological processes that are responsible for motor recovery and they have conducted work on monkeys to explore this.

Initial studies investigating the changes in the representative area of the digits following injury to the motor cortex showed that the hand area in the motor cortex decreased dramatically without intervention (Nudo & Miliken 1996) but that if the monkeys were trained using repetitive, skilled movement the hand area was spared (Nudo et al 1996). This led the authors to conclude that "motor experience after injury to the motor cortex plays a major role in the subsequent physiological reorganisation in the adjacent intact tissue".

Further studies have suggested that it is not simply use of the impaired hand, but the acquisition of skill that leads to changes in the motor cortex (Nudo et al 2000, Plautz et al 2000). Plautz et al (2000) compared changes in representational maps in monkeys who retrieved pellets out of small (challenging) and large wells. Those practicing the challenging skill that involved learning in addition to repetition showed greater changes. This led the authors to suggest that repetitive activity alone is not sufficient to optimally change motor maps, and that skill acquisition and motor learning are the key prerequisites for these changes.

The role of the environment on this motor recovery has been examined in studies using rat models. Ohlsson and Johansson (1995) demonstrated that rats housed in enriched environments after an induced lesion, had better recovery than those in standard cages. In addition, rats that had the enriched environment before and after showed better outcomes again. The authors suggest that the pre-lesion environment may have had a neuroprotective effect and that enhanced environment after a brain lesion can increase recovery levels. The improvement due to enriched environment has been equated to the environment of a stroke unit (Ploughman 2002), which has been shown to be associated with higher functional outcome compared to general wards (Stroke Unit Trialists' Collaboration 1998).

To consider whether there is a temporal component involved in the positive cortical reorganisation of motor maps, Humm et al (1998) investigated early forced use in rats at differing times post lesion. Their study examined the responses of 33 rats with induced lesions. They found that forced use in the first 7 days produced an exaggeration of injury that was significantly greater than those without forced use, but not significantly different to that produced with forced use during the first 15 days. Those rats that began forced use 7 days after the lesion did not have a significantly larger lesion volume than those with no forced use. The authors suggest that immobilisation and forced use in the first 7 days has severe negative effects on lesion volume, while later forced use may not have an effect on lesion volume. This has not been explicitly replicated in humans.

The above invasive studies on animals suggest that enriched environments and repetitive skill practice have a beneficial effect on functional outcome and cortical representation of upper extremity movement. It is possible that early intensive, forced use may not be beneficial though this has not been investigated in humans. The more recent advent of non-invasive imaging in human brains has allowed consideration of these questions in human subjects and has significantly advanced our understanding of the changes at brain level occurring during recovery post stroke.

Imaging studies of human brains

There are three methods of non-invasive imaging that can be used to examine the human brain transcranial magnetic stimulation (TMS), positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). TMS uses the application of magnetic fields to the cerebral cortex transcranially. The magnetic fields cause the firing of motor neurons, the response of which is measured distally at the muscle using motor evoked potentials (MEP). TMS can therefore be used to map the motor area of a specific muscle, determine the threshold needed to evoke a MEP, and locate the centroid of distribution (CofD) of the MEPs of a specific muscle (Liepert et al 1998).

PET uses radioactively labelled compounds that are injected prior to the scan. It can measure both blood flow and metabolism and hence can be used to map neuronal activity. Most stroke recovery studies have used PET to measure the differences in regional cerebral blood flow (rCBF) with and without activity (Cramer & Bastings 2000).

fMRI measures the small changes in blood flow thought to be accompanied by neuronal activation simultaneously to mapping brain structure. This provides accurate maps as to where the increased blood oxygenation is occurring (Cramer & Bastings 2000), without the need for radioactive materials. The resolution of the images produced is higher than that of PET scans. These three methods of non-invasive imaging allow the investigation of activity levels or areas of brain activation in individuals with peripheral or central damage and the comparison of these to normal responses.

Imaging in intact human brains

Studies have shown that if the peripheral input to the brain is changed, for example with amputation or with increased usage of the hand, the cortical map will change. Cohen et al (1991) used TMS to compare the cortical map representation of muscles of the UE in 7 subjects, who were between one and twelve years post amputation, to their intact UE's. They found that the representation of muscles proximal to the amputation was significantly larger than that of the intact arm and produced greater MEP's suggesting that the residual limb muscles had taken over the area of the amputated one. Brasil-Neto et al (1993) used a blood pressure cuff to induce temporary deafferentation of the forearm and showed that within minutes the amplitude of MEPs from muscles proximal to the deafferentation were significantly increased. This demonstrates how quickly changes occur suggesting that both long and short-term phenomena occur (Hallett 2001).

The effect of practice, skilled practice and mental practice of a task on the map of long finger flexors and extensors was investigated using TMS by Pascual-Leone et al (1995). As with the animal studies they found that use of the hand led to small changes in the motor map of the digits, but skilled practice led to a significantly greater increase in map area. They found that mental practice of the task activated the same areas as the actual movement and also led to an increase in the map area that was similar to the skilled practice group. However the physical practice group had more accuracy in the physical task than the mental practice group. The increasing size of the map was seen following one day of mental and physical practice again suggesting relatively fast processes that may rely on the unmasking of pre-existing neural connections through an increased synaptic efficiency or decreased inhibition (Pascual-Leone et al 1995).

These studies suggest that the cortical map is capable of change in response to changes in activity or to peripheral input and that these changes may occur quickly in response to activity and learning requirements. The responses of subjects with normal brains can be compared with those with lesions post stroke to gain further understanding of the processes involved in recovery.

Imaging in subjects with stroke

TMS Studies

The effect of 12 days of constraint induced movement therapy (CIMT), involving 6 hours per day training and restraint for 90% of waking hours, on the cortical maps of 8 subjects averaging 4.9 years post stroke was investigated by Liepert et al (2000). They used TMS to investigate the area and position of the abductor pollicis brevis (APB) muscle in the cortex before and after the above intervention. They found that before treatment the number of positions that activated APB was 40% smaller in the affected hemisphere than that in the non-affected hemisphere, this changed to being 37.5% greater in the affected hemisphere following treatment. They also noted that the CofD shifted significantly though the direction was not consistent and could be either medial or lateral. This increase in the cortical map representation of the hemiplegic thumb is in parallel to an increase in the motor activity log score (MAL) which considers activities of the affected UE. As the TMS and MAL data at 2 weeks and 1 day before the intervention were not significantly different they suggest that the results seen can be attributed to the intervention and not to the effect of natural recovery.

A second study (Liepert et al 2001) investigated whether one week of just the restraint component of the CIMT protocol had any effect on the brain map in 9 subjects 4-8 weeks post stroke. Following one week of conventional physiotherapy the APB representation was still smaller in the affected hemisphere, but following a subsequent week of restraint in addition to conventional therapy the area in the affected hemisphere was significantly enlarged. They noted also that there was some shift of the CofD after the conventional therapy, which increased further after forced use.

Although the numbers in both studies are small and there were no control groups the results would suggest that following a period of forced use of the affected hand the size of the representational map in the lesioned hemisphere increases. This concurs with the work of Nudo et al (1996) who demonstrated this in monkeys.

PET Studies

Nelles and his associates (1999, 1999a, 2001) have used PET to examine rCBF in subjects early after stroke. They base their hypothesis on the fact that, in healthy subjects, the areas activated by passive movement are the same in location, amount and extent to those during active movement (Weiller et al 1996). This enables them to use this hypothesis to study the brain in subjects who do not have recovery of active movement by comparing rCBF during passive movement to that during rest. The validity of this method could however be questioned as it is based on a property of intact brains and applied to those with large brain lesions resulting in no active movement. The results therefore should be interpreted with caution.

An initial study (Nelles et al 1999) compared the rCBF during passive movement of the UE of non-hemiplegic (n=3) and hemiplegic (n=6) subjects without recovery of movement. They found that subjects following stroke had increases of blood flow in bilateral sensorimotor cortices that were stronger in the ipsilateral motor cortices compared to normal subjects suggesting that these areas are concerned with the generation of active movement in subjects with stroke.

A second study (Nelles et al 1999a) scanned the same subjects after 3 weeks and showed a new area of activation in the premotor cortex of the non-stroke hemisphere that was associated with an average change of 10.8 on the Fugl Meyer scale of motor impairment of the affected UE. The research group used similar methods (Nelles et al 2001) to investigate the difference in changes in rCBF following task oriented training (based on the motor re-learning programme) and non-specific rehabilitation of the same duration in stroke subjects. They found that before treatment both stroke groups had significantly greater difference in rCBF in bilateral inferior parietal cortex compared to normal subjects. Following three weeks of task oriented training (n=5) subjects showed increased rCBF in bilateral parietal and premotor cortex, and contra lateral pre and post central gyrus. In comparison the group that had non-specific training (n=5) retained the activation in the ipsilateral parietal lobe. While both groups demonstrated an improvement in Fugl-Meyer score there was a trend for an average of 9 points greater for the task oriented training group. The authors suggest that task-oriented training incorporates neural networks of bilateral sensory and motor systems to acquire motor skills.

These studies suggest that subjects with stroke have bilateral activation of the motor cortex and associated motor areas which is not seen in the unaffected hand (Chollet et al 1991) or in normal controls (Weiller et al 1993) which may be responsible for producing movement in their affected UE. However, the small numbers in the studies and the validity of the passive movement paradigm necessitate caution in adopting these results.

fMRI studies

Studies using fMRI have been used in a similar way to those using PET but have used active movement to evaluate changes in oxygenation and hence neural activity rather than the passive movement paradigm used for the above PET studies. Cao et al (1998) used fMRI to study finger movement in subjects following stroke and found that six of the eight subjects showed an enlarged activation of the unaffected cortex during movement of the ipsilateral fingers. Three subjects demonstrated activation of bilateral sensorimotor cortices and three demonstrated exclusive activation of the ipsilateral sensorimotor cortex. The authors suggested that pre-existing uncrossed motor pathways may be accessed to compensate for damaged pathways in the affected cortex.

Levy et al (2001) investigated activity during a finger tapping exercise in two subjects before and after CIMT. They found that there was increased activity surrounding the lesion and in the supplementary motor area in both subjects following treatment. These studies suggest that both bilateral activation and activation of the ipsilateral cortex are possible mechanisms of recovery of UE function.

A review of the three methods of brain imaging (PET, TMS and fMRI) in subjects with stroke (Cramer & Bastings 2000) highlights the conflicting evidence of TMS and PET/fMRI studies. PET and fMRI suggest that there is increased activity in the motor areas of the non-stroke hemisphere associated with increased recovery, however TMS studies suggest a decrease in the area of the non-stroke hemisphere that will directly stimulate the muscle. The authors suggest the possibility that the non-stroke hemisphere is actively involved in the suppression of connections or unwanted movements and that this may explain the increased blood flow in the area. Hallett (2001) suggests that competition exists between ipsilateral and contralateral pathways and that in the absence of functional recovery of the contralateral pathway, the ipsilateral one becomes dominant. He suggests that re-organised contralateral control is always superior to ipsilateral control in recovery as presence of contralateral MEPs and preservation of corticospinal tracts is associated with better recovery of function.

In a review of neuroplasticity and its implications for physiotherapy management post stroke, Ploughman (2002) summarises the various neural pathways for motor recovery as:

1) cortical map re-organisation in surrounding tissues,
2) use of associated motor areas in the affected cortex

3) use of associated motor areas in unaffected cortex through redundant callosal connections
4) use of uncrossed pyramidal and reticulospinal pathways in the unaffected cortex.

Under what circumstances each of these modes are used is still as yet unknown. Nudo (2000) suggests, "the neural principles governing recovery …remain puzzling". In a review of neuroplasticity Dobkin (1998) suggests that therapeutic interventions should consider sensory input during the practice of activities that involve repetitive, task-oriented movements.

2.1.4 Motor learning post stroke

The above studies are all concerned with the processes underlying motor recovery. In order to understand how subjects with stroke recover movement and functional abilities it is important to explore the process of learning as well as the processes underlying learning. While our understanding of neuroplasticity has developed considerably over the last decade, there is little work investigating the processes of motor learning post stroke.

Motor learning is the process associated with practice and experience with the acquisition of a skill indicating that learning has taken place (Shumway-Cook & Woolacott 2001). Learning suggests a more permanent change over and above an increase in performance associated with practice, therefore assessment must be completed some time after the practice period to ensure retention (Winstein et al 1999).

Many factors can influence motor learning and studies exploring some of these that relate to relearning after stroke are considered below.

Salmoni et al (1984) in a review of studies suggested that low frequencies of feedback may be better than high frequency for retained learning. Winstein et al (1999) investigated whether this was accurate and whether the process of learning for subjects with stroke was similar to that for healthy individuals. The subjects learned a task with their unimpaired arm to eliminate performance related to a deficit of motor skills. They found that both groups benefited from practice with feedback to acquire a skill, and that there was no difference between continuous and diminishing levels of feedback. They suggest that the motor learning principles derived from healthy participants may be generalised to subjects with stroke (Winstein et al 1999).

Hanlon (1996) investigated the effect of blocks of practice of the same task compared to practice of the task with other tasks interspersed. They found that for subjects at least 6 months post stroke, that the blocked practice was less effective in retaining the task over time.

Wu et al (2000) investigated whether reaching for an object resulted in different outcomes to reaching into space for 14 subjects after stroke and 25 matched normal individuals. They found that when the object was present both groups had significantly better movement kinematics than without it, again suggesting similarities between subjects with stroke and normal individuals.

They did find a correlation between decreased sensation and increased time parameters suggesting that impairments of proprioception may mean that the patient cannot draw from past experience of sensory/motor relationships and therefore have more difficulty reaching the target. They also found that those subjects with a left lesion had less direct movement patterns and suggested that they were less able to translate external information to internal co-ordination of movement.

These studies suggest the processes of motor learning in subjects post stroke are similar to those with intact brains.

While many questions regarding the mechanisms of recovery of brain function post stroke remain unanswered, the above studies suggest that repetitive use of the involved limb may preserve or enhance the areas of cortex responsible for the generation of UE movement. Several mechanisms may be responsible including plastic changes in the area around the lesion and the use of the opposite cortex and the associated motor areas. It is possible that skilled movement involving learning a task may be more useful than purely repetitious activity.

While the areas involved in movement generation post stroke may differ from those in intact brains, the re-learning of motor function post stroke appears similar and until further evidence is available the principles of normal motor learning can be applied to those with stroke.

2.2 Recovery of motor function and activities of the upper extremity

2.2.1 Introduction

Upper extremity dysfunction is one expression of the many detrimental effects of stroke and presents in a significant proportion of those surviving stroke. Studies report varying levels of dysfunction which may be due to the different outcome measures used.

The Scandinavian Stroke study (Nakayama et al 1994) found that 69% of the 636 patients with stroke admitted to hospitals in Copenhagen had some degree of upper extremity paresis on admission as measured by the Scandinavian Stroke Scale, which is a measure of motor impairment.

When considering the activity limitations arising from the deficits in motor function, Wade et al (1983), in their UK sample of 92 patients admitted to a stroke unit, found that 80% of their subjects had sub maximal scores on the Frenchay arm test (FAT) on initial assessment. Williams et al (2001), in their Australian study of 153 patients admitted to a rehabilitation unit, found that 73% of subjects had sub maximal scores on the Motor Assessment Scale (MAS), both of these scales measuring activities performed by the affected UE.

These studies suggest that, depending on whether motor function or activity limitation is measured, between 69% and 80% of subjects who present with stroke will demonstrate some level of UE dysfunction.

Many individuals with UE dysfunction post stroke will learn to perform activities normally involving both UEs using only their unimpaired arm. This recovery of functional abilities through compensation is one of the confounding factors in studies exploring recovery. Global scales of UE functioning such as the Barthel index (BI) (Mahoney & Barthel 1965) and Functional Independence Measure (FIM) (Keith et al 1987) do not require any involvement of the affected UE to score maximally on these tests.

Nakayama et al (1994a) demonstrated that of the 64 subjects who at discharge had an arm with essentially no movement (a Scandinavian Stroke Scale score of less than or equal to 2) 16% had full function as measured by the BI. Broeks et al (1999) demonstrated that while 50% of their 54 subjects at four years post stroke had a non-functional arm as measured by the action research arm test (ARAT), 61% of them had maximal BI scores. Williams et al (2001) found that while 58% of subjects had good recovery as measured by the FIM, only 39% of their subjects had the top score on the MAS.

These studies highlight the fact that an increase in score in the BI or FIM cannot be directly attributed to an increase in motor abilities of the affected UE but are most likely due to the learning of compensatory strategies with the unaffected UE. Therefore "functional recovery" measured by these scales does not necessarily reflect an increase the use of the UE or performance of the task using the affected UE. Only studies that directly measure function of the impaired UE will be considered in this section.

2.2.2 Factors affecting/predicting recovery of UE motor function and activities

Numerous authors have investigated ways of predicting motor recovery post stroke. Kwakkel et al (1996) in their systematic review found 78 studies, however only 11 of these met 8 or more of their 10 methodological criteria for inclusion. The methodological criteria included methods to evaluate internal, statistical and external validity. They concluded that the best negative predictors of functional recovery were severity of paralysis, presence of urinary incontinence, disorientation to time and place and decreased sitting balance on admission. They suggested that while proprioception and spasticity may be important clinical factors, the lack of reliable and validated measures of these properties mean they cannot conclusively be included.

Hendricks et al (2002) reviewed the literature on the prognostic factors for motor recovery. Of the 174 studies found, only 14 met 15 or more of their methodological criteria assessing internal, external and statistical validity. They concluded that "knowledge in this area is more limited than perceived by many" and that motor and sensory evoked potentials may be better predictors of UE recovery than clinical scales reflecting motor and functional recovery.

Degree of dysfunction

Several studies have specifically investigated the confounding factors influencing the recovery of UE motor functions and activities. Shelton et al (2001) used the Fugl-Meyer motor assessment (FM) to assess the correlation between initial impairment and discharge status in 171 patients attending a US rehabilitation hospital. This scale measures the degree of impairment of motor function, with sections for the UE and LE. They found that the initial upper extremity section and total score best correlated with discharge FM UE scores (Spearman rank order correlations, $r=0.91$ for both).

Feys et al (2000) measured several variables at baseline, 2, 6 and 12 months post stroke in 100 patients referred for rehabilitation in four Belgian hospitals. Using a multiple regression analysis to predict final motor score of the UE, they identified the best predictive models as those with the highest r^2 value. In all models the UE FM score accounted for the vast majority of the variance in the model, with it being highest (89%) using the 2 month FM scores to predict motor abilities at one year. Tone, proprioception and BI score also contributed to the models, but to a lesser degree than the FM score.

Other authors have investigated the ability of initial scores to predict the level of activity limitation on discharge. Loewen and Anderson (1990) investigated the ability of initial Motor Assessment Scale (MAS) and BI scores to predict discharge MAS and BI scores. The 50 patients attending for rehabilitation had an average length of stay of 59 days. The MAS has 8 sections, three of which concern UE activities. They found that the highest correlation was for the total of the three UE sections of the MAS at one month and at discharge (Spearman correlation coefficient $r=0.91$) and for the upper arm section of the MAS at one month and at discharge ($r=0.94$). These had better correlations than the values at initial assessment. Using a regression model, the equation with the highest r^2 value was that with the total arm score at 1 month ($r^2=0.95$).

Sunderland et al (1989) investigated the ability of several measures to predict a score of zero on the FAT, which involves 5 activities of the affected UE. Their sample was 38 patients who attended a rehabilitation unit. They found that all subjects who had no grip ability, a Motricity Index score of <18 or a Motor club assessment UE score of <2 on admission had a score of 0 on the FAT at 6 months post stroke.

Other studies have suggested that recovery of motor impairments and activities may be somewhat decreased in subjects with proprioceptive deficits (Rand et al 1999), pain (Wanklyn et al 1996, Roy et al 1995), deficits of sustained attention (Robertson et al 1997) and perceptual problems (Edmans et al 1991). A combination of motor and sensory deficits and hemianopia is associated with poorer recovery than with those deficits in isolation (Shelton et al 2001).

Lesion location and size

Studies investigating the effect of location and size of lesion on motor recovery have had conflicting results and the relationship between these factors remains controversial (Chen et al 2000).

Shelton et al (2001), in their study of 171 patients consecutively admitted to a US rehabilitation hospital, suggested that subjects with both cortical and sub cortical lesions had on average 10 points less on the FM scale at discharge than those with purely cortical and purely sub cortical lesions. A further study (Shelton & Reding 2001) investigated the effect of lesion location on UE recovery in a sample of 41 patients consecutively admitted to a rehabilitation hospital with initial Fugl Meyer UE scores of less than 9 points. The only area that was significantly associated with decreased recovery of isolated UE movement was the posterior limb of the internal capsule. In classifying stroke as they had done in the study above, they found that 75% of subjects with purely cortical strokes achieved isolated movement whereas less than 10% of subjects with subcortical and mixed strokes did. They estimated that those with no recovery had an average initial FM score of 0.6, and those who recovered both synergistic and isolated movement had an average of 3.8 each on admission.

In conclusion several authors have suggested that for patients with stroke presenting for rehabilitation, initial motor impairments may be good predictors of recovery of motor functions and UE activities at discharge. Measurement at 1 or 2 months may be more accurate for prediction than those at baseline. Whether the lesion involved both subcortical and cortical areas should also be noted, in addition to co-existing impairments such as pain and sensory/perceptual deficits that may have a bearing on outcome. The reporting of r values for linear correlations without reporting the quantity of the difference in scores does not allow the differentiation between systematic differences in score and the finding of similar values at both time points.

2.2.3 Proportion of recovery of UE motor functions and activities

An estimation of the proportion of recovery of the UE is confounded by the use of differing outcome measures that measure dysfunction at varying levels. When considering the estimation of the level of impairment of motor functions Broeks et al (1999) used the FM. They assessed 54 subjects at 4 years post stroke and found that only 22% had greater than 51 points on a 54 point FM scale, whereas only 17% had greater than 55 points on the 57 point Action Research Arm test (ARAT) which measures at activities level.

An Australian study by Williams et al (2001) followed 153 subjects from admission to discharge and found that only 39% of them had maximal scores on the UE section of the MAS at discharge (mean 51 days inpatient stay). In the UK Wade et al (1983) found that 49% of the 92 subjects had maximal scores on the Frenchay arm test (FAT) at 2 years post stroke.

Thus we can estimate that only 17% to 49% of subjects score maximally on the scales based on functional activities of the hemiplegic UE at varying times after discharge. This low proportion of functional recovery of the UE is in stark contrast to the recovery of function activity of the lower extremity (LE) (i.e. the ability to walk independently), which in Friedman's (1990) study was achieved by 76% of subjects at 6 months post stroke and in the study by Skilbeck et al (1983) was achieved by 84% of subjects at one year post stroke

Difference between recovery of functional activity of the UE and LE

There are many possible reasons why the recovery of the ability to perform functional abilities with the UE is far less than the recovery of gait ability and these are outlined below.

The ability to compensate with the unaffected UE

In the study by Broeks et al (1999), the addition of an Activities of Daily Living (ADL) questionnaire to their functional outcomes, revealed that while 33 of 54 subjects showed complete functional recovery (BI score of 100), only 4 of them used both UE's to complete all ADLs. Nakayama et al (1994a) in a study of subjects with severe UE paresis revealed that 59% of them recovered full or partial functional recovery (measured by the Barthel Index), again illustrating the ability to function in day-to-day life without any use of the affected UE. This ability to compensate contributes to the phenomenon of learned non-use (Taub 1980) meaning that the patient may not use the affected arm as much as they could do. The same element of learned non use is not possible during LE function, i.e. gait, as it is not possible to replace the function of the affected limb for this task.

Lack of spontaneous stimulation during functional activities

There is an unintentional bias towards the lower extremity as many components of the everyday routine, i.e. transfers, sit to stand, sitting, encourage weight bearing and hence activation of the lower limbs. This leaves the UE with a lack of spontaneous stimulation compared to the LE (Feys et al 1998).

The complex nature of upper extremity function

Duncan et al (1994) studied the recovery of the upper and lower limbs at the level of impairment (as measured by the FM) and found no differences in the rate of recovery. So why don't the UE and LE improve to the same extent at a level of activities/function? While subjects can walk with relatively little recovery of LE motor function, the recovery of activities of the upper extremity is more difficult to achieve as it is involves a complex integration of muscle and sensory activity (Feys et al 1998)

Emphasis on LE training in rehabilitation

Because of the current climate of healthcare and the push for earlier discharge, the initial focus of therapy may be on the attainment of goals related to independent transfers and gait to allow the patient to return safely to their home (Blanton & Wolf 1999). The amount of therapy time spent specifically on UE function is also comparatively less than the time spent on activities that involve the LE. Ballinger et al (1999) evaluated the content of physiotherapy and occupational therapy interventions in Australia and found that only 17% of treatment time was spent specifically addressing the UE.

The time spent in treatment (12.9%) is a tiny proportion of the subjects' day (Tinson 1989) leading treatment dosages to be considered as "homeopathic" in nature (Pomeroy & Tallis 2002a).

Secondary complications

Secondary complications that may occur in the UE following stroke include: inferior subluxation of the glenohumeral joint, shoulder-hand syndrome, soft tissue lesions and painful shoulder. The incidence of shoulder pain varies widely from 38-70% (Griffin 1986) and there is evidence to suggest that shoulder pain is related more to the loss of range of shoulder external rotation than to the presence of subluxation (Zorowitz et al 1996, Bohannon et al 1986).

Studies investigating the effect of shoulder pain on outcome at discharge (Wanklyn et al 1996, Roy et al 1995) suggest that there is a strong association between pain on movement and poor recovery of movement and function. However Broeks et al (1999) found there was no relationship between pain and Fugl-Meyer score in their sample of subjects living at home 4 years post stroke. While shoulder pain may impede and prolong rehabilitation

(Griffin 1986) and the presence of pain is associated with poor outcome on discharge, the relationship between presence of pain and long-term outcome remains uncertain.

Therefore it would seem that because the functions of the UE are more complex than those of the LE, and that it receives less spontaneous stimulation, it would require a greater intensity of treatment to restore that function. In practice the opposite occurs with a small proportion of treatment time devoted to the UE and this may explain the relative lack of recovery of activities using the affected UE.

2.3 Impact of residual dysfunction on participation and quality of life

The loss of function of the upper extremity is perceived by subjects to be a significant problem. Broeks et al (1999) found that 67% of the 54 subjects surveyed reported that their lack of arm function was still a major problem at 4 years post stroke. This was true even for 25% of subjects with near normal function who still considered their UE deficits to be a major problem.

The lack of function of the UE may also be responsible for low mood. A study by Wyller et al (1997) used the General Health Questionnaire (GHQ) to measure subjective well being of 60 subjects one year after stroke and found that low scores on the arm section of the Sødring Motor Evaluation (SMES) and the BI correlated most strongly with low scores on the GHQ. A multiple linear regression model using gender and upper extremity motor score best predicted the GHQ score, the upper extremity motor score attributing to 48% of the variance in GHQ.

McEwen et al (2000) in a similar study used several performance based measures to investigate whether these tests could be used to predict the score on the SF-36 quality of life measure. Their sample of 43 subjects who agreed to participate in the study completed quality of life questionnaires by phone. They found that the physical health summary score (PCS) was best predicted in women by the Chedoke McMaster scale, which explained 39% of the variance in scores. The PCS for men was best predicted by the box and block test for the affected UE which explained 39% of the variance. The authors hypothesise that the gender difference may be present as some scales reflect traditional female roles that do not have the same consequences in men when they are no longer possible.

The above studies would all suggest that the residual deficits in UE function remain a significant problem for subjects, even those with relatively mild impairments and that these deficits are strongly associated with a decreased quality of life.

2.4 Conclusion

There are still many unanswered questions as to how recovery of motor function post stroke occurs, however some themes emerge from the research. Plasticity is use dependent and use of the affected limb may preserve and enlarge areas of cortex responsible for movement generation. The area around the lesion, the opposite cortex, and the associated motor areas may all have a role to play in brain plasticity that leads to motor recovery above and beyond that which occurs spontaneously.

Environment and experience appear to be important, both before and after stroke, and enhanced environments are associated with increased recovery. Repetition of movement that is skilled as opposed to purely increased usage of a limb is more likely to bring about neuroplastic reorganisation.

Though the areas and systems in the brain used to generate movement post stroke differ from that in non-damaged brains, the re-learning of motor function post stroke appears similar in nature to the learning of skills in intact brains. Therefore, until further evidence is available, the principles of motor learning post stroke can be based on learning in non-damaged brains.

UE dysfunction is present in a large proportion of subjects with stroke and many of these individuals will recover the ability to function independently by using only their unimpaired UE to complete activities. When considering the recovery of motor dysfunction and activities of the affected UE, the degree of motor dysfunction at 1 or 2 months may be the best tool available to physiotherapists to predict discharge status.

The recovery of UE function is far less than that of the LE with a considerably higher proportion regaining the ability to walk than to use their affected UE for activities. The reasons for this include the ability to compensate with the unaffected UE and the complex integration of movements involved in UE activities. Despite this the UE receives considerably less direct therapy intervention than the LE.

Even relatively minor levels of residual dysfunction of the UE are considered a significant problem by people with stroke and UE dysfunction appears to be a major contributing factor to decreased well being and quality of life.

Thus physiotherapy interventions should aim to optimise the recovery of motor functions and UE activities and hence positively impact on the quality of life of the individual post stroke. Chapter 3 will consider the many forms of physiotherapeutic interventions for the UE and the levels of evidence for their effectiveness.

3 Chapter 3 – Physiotherapy treatments for upper extremity dysfunction post stroke – a review of the literature

3.1 Introduction

This chapter reviews the literature on physiotherapy treatments for the upper extremity (UE) post stroke. There are many different treatment approaches available to the therapist to address the deficits in the UE, e.g. Bobath, also termed Neurodevelopment al Therapy (NDT) in the USA, (Bobath 1978), Brunnstrom (Brunnstrom 1970), Conductive Education (Cotton & Kinsman 1983), Johnstone (Johnstone 1983), Motor Re-learning programme (Carr & Shepherd 1982), Proprioceptive Neuromuscular Facilitation (Knott & Voss 1968), and Rood (Rood 1954). In addition to these general approaches there are other specific interventions, such as the use of exercise based treatments, electrotherapy (transcutaneous electrical nerve stimulation (TENS), neuromuscular electrical stimulation (NMES), biofeedback), acupuncture and more recently, the use of robotic technology, virtual reality and mental practice to assist the therapist in the rehabilitation of the patient following stroke.

While the Bobath concept is the most widely used treatment approach in the UK (Davidson & Waters 2000) and Ireland (Coote & Stokes 2003) the great majority of therapists in both countries use an eclectic approach to treatment incorporating elements from 2 or more treatments. This has led physiotherapy post stroke to be named a "black box" of interventions that as a package is widely accepted as a routine intervention post stroke. However the question regarding the optimal content and duration of therapy in this "black box" continues to remain unanswered (Ernst 1990, Ashburn 1993, Pomeroy & Tallis 2000).

Because ethically treatment cannot be withheld, research strategies have aimed to establish the content and duration of interventions that produce the most positive treatment effects. This is further confounded by the fact that patients with stroke frequently exhibit a wide range of coexisting impairments alongside their motor and functional deficits. Impairments in sensation, perception, speech and cognition are a few of the factors a physiotherapist must take into account when treating patients with stroke in addition to the time after stroke, age, coexisting diseases and differing social backgrounds. An intervention that is extremely effective for one patient may not have any effect for another with differing background characteristics. Therefore it is important that these confounding factors are considered when reporting the results of trials in this area.

This chapter reviews clinical trials evaluating the many different treatment interventions available. References were sourced by performing searches on the Medline, AMED and CINAHL databases with the key words: stroke or cerebrovascular accident (CVA), upper extremity or arm, and physiotherapy or physical therapy. The search was limited to the years 1990-2004 and to papers in English. Studies were excluded if they did not report outcome measures that recorded motor function or activities of the UE, or if they included drug treatment. This search revealed 45 papers reporting the results of clinical trials on physiotherapy interventions for the UE. Additional articles cited in articles in the original list and thought to be of relevance were also included in this review. In order to include all studies concerning robot mediated therapy for the UE the principle investigators of projects were contacted and forwarded any papers from the medical and engineering literature that reported on clinical trials.

Appendix 1 contains a summary of the outcome measures used in the trials and outlines the level at which they measure the UE (motor function, activities or participation), the scoring for the measure (where available) and a brief outline of the construct of the measure.

In order to assess the validity of the studies the guidelines for Cochrane reviewers (Alderson et al 2004) were used. This method rates the validity (or extent to which the study design is likely to produce systematic errors (Moher 1995)) of the studies by assessing the presence of selection, performance, attrition and detection bias. If all of the criteria are met the study is said to have a low risk of bias and hence a low risk of "false negative" or "false positive" results. Alderson et al (2004) suggest that simple approaches like the above are preferable to quality scales and checklists as those methods are less likely to measure validity. They also provide guidance for the evaluation of non randomised controlled trials, which make up a large proportion in stroke rehabilitation research.

Selection bias refers to the methods of assignment to control or treatment groups. The randomisation of subjects is ideally completed by someone outside of the recruitment process and should be concealed from recruiters and participants until after a decision about eligibility. Allocation concealment should be considered integral to the method of randomisation (Alderson 2004), and the four possible ratings for this section are adequate, unclear, inadequate or no allocation concealment. If allocation to groups was not randomised (i.e. consecutively allocated) this was rated as inadequate.

Performance bias refers to systematic differences in the care provided to the participants in the study apart from the intervention under investigation. This includes contamination of control group with part of the treatment intervention or cointervention by giving care to either group that may affect results. The blinding of participants to their intervention is suggested by Alderson et al (2004) as a criterion for performance bias though this is not explicitly possible in rehabilitation research. This section is rated as met, unmet or unclear. If no control, in the form of a control group or in the form of pre-test or baseline phase measurements was present, the study was considered not to have met this criteria.

Attrition bias refers to differences in groups due to loss of participants during the study, which may also be known as exclusion bias. This section is rated as met, unmet or unclear.

Detection bias is less likely to occur in studies where the outcome assessor is blind to the intervention allocation. It refers to systematic differences between the comparison groups in outcome assessment. This section is rated as met, unmet or unclear. A difference in the baseline characteristics in terms of time post stroke or in terms of motor impairment is a confounding factor to intervention, therefore studies were rated unmet if they did not compare groups to those criteria or if outcome assessment was not blinded.

If all of the above criteria are met the study is said to have a low risk of bias. If one or more is partly met it has a moderate risk and if one or more are not met it has a high risk of bias.

3.2 Comparison of treatment concepts

Two studies that compared the effect of two treatment concepts on the UE were found. Langhammer & Stanghelle (2000) completed a randomised controlled trial to examine the difference in outcome between therapy delivered according to the Bobath concept (BB) and Motor Re-learning programme (MRP). Their sample consisted of 61 of the 185 patients admitted to a Norwegian hospital over a ten month period. Patients were randomised to treatment with the Bobath concept (n=28) or the MRP (n=33) and received the intervention for the duration of their hospital stay. They found a statistically significant difference in the UE section of the Sødring motor evaluation scale (SMES) (which is a measure of motor function) between the two groups in favour of the MRP after two weeks that was not present at initial assessment. Their other main finding was that there was a significant difference in the length of stay of the two groups with those in the MRP group having on average 13 days shorter inpatient stays. While the initial scores of the groups on the SMES were not statistically different, the mean score for the MRP group was 8 points higher than that of the BB group, which may have contributed to their greater increase in motor function. This superior outcome for the MRP group was not maintained at follow up at 1 and 4 years post stroke (Langhammer & Stanghelle 2003).

Nelles et al (2001) compared a treatment of the UE with the MRP for 45 minutes four times per day for 3 weeks (n=6) to non specific intervention involving stretching, and soft tissue mobilising of the same duration (n=3). Both groups demonstrated an improvement in Fugl-Meyer score but there was a trend for an average of 9 points greater for the task oriented training group. They also investigated brain activation using PET to measure regional cerebral blood flow. They found that before treatment both stroke groups had significantly greater difference in regional cerebral blood flow (rCBF) in bilateral inferior parietal cortex compared to normal subjects. Following three weeks of task oriented training patients showed increased rCBF in bilateral parietal and premotor cortex, and contra lateral pre and post central gyrus. In comparison the group that had non-specific training retained the activation in the ipsilateral parietal lobe. The authors suggest that task-oriented training incorporates neural networks of bilateral sensory and motor systems to acquire motor skills and have demonstrated a change in brain activation in parallel to a change in motor functioning.

In terms of methodological criteria both studies would be considered to have a high risk of bias as the allocation/randomisation process was unclear, and performance bias would have been unmet as the same therapist carried out both treatments, which may have led to contamination of groups. While the results suggest that the MRP may have a superior treatment effect over treatment with the BB concept, and that it may positively affect neuroplasticity and brain mapping, further studies are required to draw definite conclusions due to the bias of these trials. In addition studies that evaluate the effect of the BB concept and compare this widely used intervention to other concepts and treatments are required.

3.3 Effect of greater intensity of intervention

Four studies investigating the effect of higher intensities of physiotherapy for the UE were found and are summarised in Table 3-1. The study by Parry et al (1999) presents a post hoc analysis of the study by Lincoln et al (1999). Three of these studies showed a significantly greater outcome with greater intensities of therapy, whereas two found no difference in outcome between regular and additional intervention. The two studies that showed no significant effect either had small differences in duration of the additional therapy between the control and intervention groups or did not consider the difference between mild and severe patients. In the study by Lincoln et al (1999) only half the participants in each group completed the additional 2 hours treatment per week, while the total content of the interventions by Rodgers et al (2003) (comprising OT and PT individually and jointly, OT and PT assistants and care worker intervention) differed by only a median of 11 minutes per day greater in the intervention group. Thus the quantities of additional treatment time are small in comparison to the difference of 76 minutes per week seen by Sunderland et al (1992) who did find a positive outcome.

The particular benefit of the increased intensity of intervention for those patients in the acute stage with less severe impairments is replicated by Parry et al (1999) and Sunderland et al (1992) but not by Rodgers et al (2003) and was not reported by Kwakkel et al (1999). Again the lack of differences in the duration and the differing content of the interventions in the Rodgers et al (2003) study may be responsible for the lack of detectable difference between mild and severe patients. It is interesting to note that while Sunderland et al (1992) found significantly greater improvements in the UE group at the level of UE impairment, they did not find a translation to function (as measured by the Frenchay arm test which evaluates the ability to complete 5 UE tasks on a pass/fail basis). This may have occurred as there had not been sufficient improvement at the level of impairment to translate into functional abilities, or the FAT may have had a floor effect which did not capture smaller improvements in functional ability. The validity of these trials is summarised in Table 3-2.

A follow up of the study by Sunderland et al (1992) after 1 year (Sunderland et al 1994) revealed no significant difference between enhanced and conventional therapy groups for either the severe or mild subgroups indicating that the while the performance was maintained, the differences between groups was no longer significant. They did not however account for any attrition between the study end and the follow up leading to a high risk of bias.

Kwakkel et al (2002) followed up 86 of the original 101 patients of their original study (Kwakkel et al 1999) at 1 year post intervention and found that the increase in Barthel index (BI) scores in the two additional intervention groups was maintained at 1 year but the difference between the groups was no longer statistically significant. These studies (Sunderland et al 1994, Kwakkel et al 2002) conclude that while increasing intensity early after stroke may accelerate recovery at that point it does not result in significantly different outcomes at 1 year.

Kwakkel et al (1997) conducted a meta-analysis of 9 studies 1966 to 1995 that considered both UE and LE treatments and found "small but statistically significant improvements in activities of daily living, neuromuscular and functional outcome variables as a result of higher intensities of rehabilitation". This concurred with the results of a previous meta-analysis by Langhorne et al (1996) who stated that "intensive physiotherapy may reduce impairment and disability" but that there is inadequate information to make decisions as to exactly how much treatment is necessary. A systematic review of "exercise therapy" by van der Lee (2001) also concluded that those studies providing more intense intervention led to better study outcomes.

The above studies suggest that a significant increase in intensity of treatment early in rehabilitation can result in better outcomes earlier but that this may not result in significantly different outcome at one year. There is insufficient evidence to suggest how much of an increase is needed, and the dosage required may depend on the level of severity. It would appear that patients with milder initial deficits resulting in some active movement of their UE benefit most from the additional treatment.

	Trial type	Patients	Outcome measures	Intervention	Results
Sunderland et al 1992	Single centre stratified RCT n=132	Patients <21 days post stroke	FAT, NHPT, MI, MCA	Ct: conventional physiotherapy based on Bobath concept, median 53 mins per week Tx: eclectic approach plus conventional median 129 mins per week	Recovery pattern of Tx group significantly better than control for MI. At 6 months mild group had better arm function in all but FAT.
Lincoln et al 1999	Single centre RCT, n=282	Patients median 12 days post stroke	RMA, ARAT,	1) Routine physiotherapy, 2) additional with physio, 3) additional with assistant Only 56% (2) and 46% (3) completed >9 hours additional therapy over 5 weeks	No significant difference between groups at 4 or 6 months
Parry et al 1999	Trial as for Lincoln et al 1999			Sub groups of less severe (>1 on ARAT) from above study	Patients who had completed >9 hours additional treatment had significantly better scores on RMA and ARAT at 5 weeks and 6 months. Group 3 > group 2
Kwakkel et al 1999	7 centre RCT n=101	Patients <14 days post stroke	ARAT, BI, NHP	Regular care for both groups plus 1) immobilisation in inflatable splint (30 mins, 5days per week) 2) arm training same duration 3) leg training same duration	Groups 2 and 3 had significantly better outcome at 6, 12 & 20 weeks on ARAT, BI. Group 2 had higher ARAT scores than group 1 at 12, 20 & 26 weeks.
Rodgers et al 2003	Single centre RCT N=123	Patients <10 days post stroke	ARAT, MI, FAT, BI, N E-ADL	Tx: stroke unit tx, median 38 mins per day inpatient, 56 min per day OP Ct: additional intervention to above total tx time 52 mins per day inpatient, 25 mins per day OP	No significant differences in outcome at 3 months

Table 3-1. Trials of increased intensity of intervention

	Rodgers et al 1992	Kwakkel et al 1999	Lincoln et al 1999	Sunderland et al 1992
Randomisation	Yes, stratified to UE impairment level	Yes. Concealed allocation.	Yes, random numbers in sealed envelopes	Yes, but stratification unclear
Selection bias	Unclear	Adequate	Unclear	Unclear
Performance bias	Unmet, duration and content of treatments different between and within groups	Met	Unmet. Not all patients completed additional treatment	Met
Detection bias	Met	Met	Met	Met
Attrition bias	Unmet, patient with second CVA left into follow up results	Met	Met	Unclear
Risk of bias	High	Low	High	Moderate

Table 3-2. Validity of intensity trials

3.4 Exercise based interventions

Four studies investigating the effect of repetitious exercise based interventions were found and are outlined in Table 3-3. Three of the studies reported significant treatment effects from their trials. The 'arm ability training' investigated by Platz et al (2001) consisted of the practice of one minute blocks of 8 functional tasks with the difficulty increasing as patients progressed. The activity evaluated by Feys et al (1998) was also functional as it involved pushing with the UE to rock a rocking chair while Bütefisch et al (1995) used strengthening exercises of the wrist and hand in their study. The intervention evaluated by Woldag et al (2003) that did not show a positive treatment effect was similar to these other trials in that it involved repetitive tasks with a similar intensity of intervention. It is possible that the difference in outcome is due to the content of the intervention, which was not functionally based and involved simulated sawing and a triangular reaching exercise. As the baseline status of the patients in this trial is not comprehensively outlined it is not possible to evaluate whether a difference in patient characteristics was responsible for this difference in outcome.

	Trial type	Patients	Outcome measures	Intervention	Results
Platz et al 2001	Single centre RCT N=60	Patients with stroke (n=45) and head injury (n=15) 3 to 24 weeks post event with mild impairment	TEMPA, reach kinematics	1) Additional daily AAT for 3 weeks 30 mins per day 2) Additional AAT and knowledge of results 3) No AAT	Groups 1 and 2 improved significantly in TEMPA over the treatment period and maintained improvement at 1 year. No significant differences between groups 1 and 2
Bütefisch et al 1995	Multiple baseline AB/ACB single case studies. n=27	Patients 3-19 weeks post CVA	Grip strength, isometric & isotonic wrist extension, RMA	A=baseline with regular therapy only, B=additional strength training twice daily for 15 minutes (total 30 mins per day), Ct=additional TENS	No statistically significant changes during baseline and TENS phases. Statistically significant increase in motor performance and UE function during treatment phase
Feys et al 1998	Multicentre RCT n=100	Patients 2-5 weeks post CVA	FM, ARAT, BI	Tx: 30 mins 5 days per week for 6 weeks, pushing with affected UE in inflatable splint to move rocking chair Ct: Fake short wave whilst sitting in rocking chair	Significantly better recovery pattern in tx group at midway, post 6 and post 12 months on FM only. Sub group with greater motor impairment, hemianopia and hemi-inattention did significantly better than rest of patients
Woldag et al 2003	Multiple baseline AB single case studies n=21	Patients mean 7 weeks post CVA	Grip strength, isotonic wrist extension, 3D motion analysis, RMA	A=baseline with regular therapy only B=Reach/transport and sawing exercise 10 mins each, twice daily (total 40 mins per day) for four weeks	No significant differences in outcome measures in baseline and treatment phases. Trend towards improvement in precision in reaching towards target in treatment phase

Table 3-3. Trials of Exercise based interventions

Bütefisch et al (1995) and Platz et al (2001) demonstrated an improvement in motor function in addition to an improvement in functional activity of the affected UE that was not demonstrated by Feys et al (1998). The intervention evaluated by Feys et al (1998) was more effective in patients with severe motor deficit and hemi-inattention or hemianopia, the authors suggesting that this was due to repeated sensory stimulation of the UE in a weight bearing position. A follow up study of 62 of the original patients at 5 years post study (Feys et al 2004) revealed that the significant difference seen in FM score at 6 months and one year was maintained at 5 years and that the non significant difference in ARA at 1 year had become significant at 5 years. Their initial hypothesis (Feys et al 1998) that the acquired activity did not immediately carryover to function but formed the basis for training which carried on during the follow up period is supported by their follow up results.

All of these studies have investigated whether there is a treatment effect, rather than comparing it to another intervention of a similar duration. It is therefore possible that the positive results are due to the effect of increasing the intensity of intervention rather than to the superior quality of any of these interventions. Further studies comparing these treatments to other interventions of similar duration are warranted.

The positive results of these three studies suggest that exercise based interventions involving the repeated practice of meaningful movements may be beneficial in improving both motor function and functional activities of the affected UE. When this is provided to more severe patients in the form of a repetitive, functional, weight bearing activity it may be especially beneficial. This form of intervention is supported by a review of neuroplasticity (Dobkin 1998), which suggests that physical therapies should pay attention to sensory inputs during repetitive practice of task oriented movements. The levels of bias in all four studies (Table 3-4) is high, of particular concern is the differences between control and treatment groups in the study by Feys et al (1998) and the lack of stable baseline to which the treatment was compared in the study by Woldag et al (2003) both factors may have influenced the outcome significantly.

	Platz et al 2001	Bütefisch et al 1995	Feys et al 1998	Woldag et al 2003
Randomisation	Yes, stratified to CVA/TBI. Concealed allocation	Unclear	Yes, stratified to stroke type and severity	Length of baseline by throw of dice
Selection bias	Adequate	Unclear	No allocation concealment	Inadequate
Performance bias	Met	Unclear	Unmet, same therapist performed both treatments, contamination may have been present	Unmet, insufficient baseline length to control for learning effect of outcomes or to investigate underlying recovery pattern
Detection bias	Met	Unmet, outcome assessment not blinded	Unmet, significant difference between groups in time post stroke. Controls were all haemorrhagic CVA	Unmet, outcome assessment not blinded
Attrition bias	Unmet, 14 lost patients unaccounted for, only 37 at follow up	N/A	Unmet, 14 patients lost and unaccounted for	N/A
Risk of bias	High	High	High	High

Table 3-4. Validity of exercise based interventions

3.5 Constraint-Induced Movement Therapy (CIMT)

The idea of "learned non-use" for patients with UE dysfunction following stroke was introduced by Taub (1980). He hypothesised that patients learn, through failure, not to use their affected upper limb in the initial stages after stroke. The continuous use of compensatory strategies masks the spontaneous recovery of the limb and patients will preferentially use the unimpaired limb for functional tasks. Taub et al (1999) describe CIMT as a "family of techniques" that include constraint of the unimpaired and training, through shaping, of the impaired arm. Shaping is an operant conditioning method for training in which the behaviour (in this case motor activity) is gradually made more difficult, the participant receiving positive reinforcement for success and no punishment for failure (Page et al 2001). Taub & Uswatte (2000) stress the importance of the 1:1 patient therapist ratio to truly get the benefits of shaping training. Thirteen studies investigating CIMT were found. These can be broadly categorised as 1. standard protocol in chronic patients, 2. application of standard protocol in other settings and 3. application of a modified protocol.

3.5.1 Standard CIMT protocol in chronic patients

The standard CIMT protocol typically involves restraint of the unaffected UE for 90% of waking hours, and training of the affected for 6 hours a day for 2 weeks (Taub et al 1993). The studies have strict inclusion criteria with patients having at least 20 degrees of active wrist extension and 10 of finger extension in addition to being able to walk independently without an assistive device and having no cognitive or comprehension deficits. The four studies evaluating this standard protocol are outlined in Table 3-5

Van der Lee et al (1999) compared similar intensities of CIMT and NDT based treatment. They found significantly greater increases in the Action research arm test (ARAT) and Motor activity log (MAL) for the CIMT group with only the effect on the ARAT maintained at 1 year follow up. Notably they found significantly greater benefit from CIMT in MAL amount of use scores for patients with hemineglect and in ARAT for those sensory disorders. However due to the high levels of bias in this study the results should be interpreted with caution and further studies investigating this are required.

While Taub et al (1993), Miltner et al (1999) and Kunkel et al (1999) have all demonstrated significant increases in outcomes after treatment with CIMT care must be taken in the interpretation of these results as the level of bias in the studies is high (see Table 3-6). The lack of controls, the small numbers and the selection process warrant particular concern. These studies have also only investigated the effect in patients representing a small proportion of patients with stroke with relatively good motor return on entering the studies. It is also difficult to assess whether the improvement in function was due to intense treatment (6 hours a day for 12-14 days), due to constraint, or due to a combination of both. The small differences in outcome seen at the level of UE activities between the same intensity of NDT and CIMT suggest that the addition of the restraint component has only a small effect and that the other improvements can be attributed to the high intensity of treatment received.

	Trial type	Patients	Outcome measures	Intervention	Results
Taub et al 1993	Single centre RCT. Tx n=4, Ct: n=5	Ranged 1.2 to 18 years post CVA	AMAT, MAL, PROM, WMFT	**Tx**: standard CIMT protocol **Ct**: self ROM, instruction to focus attention on UE, "physical therapy" twice with no AROM or stretching	Significantly faster performance time quality of movement and functional abilities in Tx group for AMAT and WMFT. Marked increase in usage of affected UE post intervention and at 2 year f/u for Tx and not controls
Miltner et al 1999	Treatment trial n=15	Ranged ½ to 17 years post stroke, mean 5.1 yrs	WMFT, AMAT, MAL	**Tx**: restraint 90% waking hours plus shaping training 7hrs per day for 8 days over 2 week period	Significant increase in MAL and WMFT over treatment phase and not between pre intervention measures.
Kunkel et al 1999	Treatment trial n=5	Ranged 3 to 15 years, median 3	AUT, MAL, WMFT, AMAT	**Tx**: restraint 90% waking hours plus shaping training for 6hrs per day for 10 days over 2 weeks	AUT increased 98%, MAL increased 166%, significantly reduced time to complete AMAT tasks, maintained at 3 months
Van der Lee et al 1999	RCT Tx n=31, Ct n=31	Ranged 1 to 20 years post CVA, median 3 yrs	ARAT, RAP, FM, MAL, Problem score	**Tx**: 6 hours a day, 5 days a week for 2 weeks plus restraint. **Ct**: same duration tx with NDT method	Significantly greater increase in ARAT, MAL amount of use score after intervention in Tx group. No significant change in RAP, FM or MAL quality of movement for either group.

Table 3-5. Trials of standard CIMT protocol

	Taub et al 1993	Van der Lee et al 1999	Miltner et al 1999	Kunkel et al 1999
Randomisation	Yes	Yes but 11 deviations from schedule	No	No
Selection bias	Inadequate, select sample	Unclear	Inadequate, select sample	Inadequate, select sample
Performance bias	Met	Met	Unmet, no control group	Unmet, no control group
Detection bias	Unclear	Unmet, statistically significant differences in groups at intake	Unclear	Unclear
Attrition bias	N/A	Met	Unclear	N/A
Risk of bias	High	High	High	High

Table 3-6. Validity of standard CIMT trials

3.5.2 Standard CIMT protocol applied to other settings

The studies in the previous section have all investigated the effect of CIMT in patients with some residual antigravity movement in their wrist and fingers. Five studies applying CIMT in other populations were found and are summarised in Table 3-7. The results would suggest that CIMT may not produce positive treatment effects in patients who do not meet the minimum criteria of the standard protocol (Tremblay & Tremblay 2002, Bonifer & Anderson 2003) but may be effective when applied in the patients home (Tremblay & Tremblay 2002). However, as these results are in the form of case reports caution should be exercised and further studies investigating this question are required.

There is however more evidence to suggest that CIMT has a positive treatment effect in acute patients (Dromerick et al 2000, Blanton & Wolf 1999). When comparing similar durations of CIMT and traditional OT intervention in the acute setting only significant differences in ARAT total and pinch scores were found. This is a similar finding of that of van der Lee et al (1999) who also demonstrated significant increases in ARAT score in chronic subjects.

	Trial type	Patients	Outcome measures	Intervention	Results
Blanton & Wolf 1999	Case report	61 year old lady 4 months post CVA. Met minimum criteria	WMFT, MAL,	Restraint for 90% waking hours (mitt) treatment 6 hours per day for 10 days over 2 weeks	Improvement in WMFT timed tasks and MAL scores over treatment period and from treatment to follow up
Dromerick et al 2000	Treatment trial n=15	Patients <14 days post CVA. Met minimum criteria	ARAT, BI, FIM	**Tx:** restraint 6 hours per day plus shaping training 2hrs per day for 10 days over 2 week period in addition to routine treatment **Ct:** same duration of "traditional" OT	Significantly greater increase in ARAT total score, pinch subsection and FIM UE dressing score for CIMT group.
Sabari et al 2001	Case report	79 year old lady with concurrent CVA and fracture of unaffected head of humerus	AMAT, MAL	Retrospective analysis of chart indicated regular intervention and restraint of unaffected UE in sling due to fracture	Motor recovery greater than that expected for her baseline scores and stroke sub type
Tremblay & Tremblay 2002	2 case reports	53 year old man 2 months post CVA who met minimum criteria, 61 year old man 3 months post CVA with limited hand function	WMFT, NHPT, TMS	Training at home for 4 hours a day, 5 days a week for 2 weeks plus restraint for 90% waking hours.	Improvement in patient meeting minimum criteria but not in patient with limited hand function
Bonifer & Anderson 2003	Case report	53 year old woman 15 years post stroke with minimal volitional movement	Modified WMFT, MAL, FM	Restraint for 90% waking hours, training for 5 days per week over 3 weeks	Increased motor activity on FM, MAL scale not maintained at 6 month follow up. MWMFT improved at 6 month follow up

Table 3-7. Trials of CIMT in other populations

	Blanton & Wolf 1999	**Dromerick et al 2000**	**Sabari et al 2001**	**Tremblay & Tremblay 2002**	**Bonifer & Anderson 2003**
Randomisation	No	Yes	No	No	No
Selection bias	Inadequate	Adequate	Inadequate	Inadequate, select sample	Inadequate, select sample
Performance bias	Unmet, no control	Met	Unmet	Unmet, no control	Unmet, no control
Detection bias	Unmet,	Met	Unclear	Unclear	Unmet
Attrition bias	N/A	Met	N/A	N/A	N/A
Risk of bias	High	Low	High	High	High

Table 3-8. Validity of CIMT trials in other populations

Only one of the trials in this area has a low risk of bias, the lack of control intervention contributing to performance bias in the other studies. This decreases the internal validity of the studies, as it is not possible to discriminate between the effect of concurring events or natural recovery and that of the treatment. The study by Dromerick et al (2000), which has a low level of bias, suggests that CIMT is superior to regular OT at the level of UE activities for acute subjects. Further replication of this result is desirable, as are additional studies of the effect of CIMT for more impaired subjects and in settings other than the clinic.

3.5.3 Modified CIMT protocol

Four studies investigating the effect of a modified CIMT protocol of lesser intensity were found and are summarised in Table 3-9. The results would suggest that while a modified protocol with less intensive treatment does produce positive treatment effects, it may not be as effective as the standard protocol. This concurs with the findings of the literature outlined earlier that reports increased outcomes with increased intensity of treatment. As with the earlier sections all trials have a high risk of bias and results should be considered with caution (see Table 3-10). The case reports provide little internal validity and the increase in outcome cannot be directly attributed to the intervention. The lack of similarity of control and treatment groups by Sterr et al (2002) may bias the outcome towards the group receiving higher intensities and further studies are required before definite conclusions of this result can be made.

	Trial type	Patients	Outcome measures	Intervention	Results
Page et al 2001	RCT n=6	Patients 2 to 5.5 months post CVA meeting minimum requirements	FM, ARAT, WMFT, MAL	1) (n=2) Training based on PNF for 60 mins three times weekly for 10 weeks. Restraint 5 hrs per day 5 days per week. 2) n=2 Training as above, no restraint 3) n=2 No treatment	Modified protocol feasible. Group 1 improved more on FM, WMFT and ARAT than group 2 and 3
Page et al 2002	Case report	68 year old woman 5 months post CVA meeting minimum criteria	FM, ARAT, WMFT, MAL	Training based on PNF for 60 minutes three times weekly for 10 weeks. Restraint 5 hours per day for 5 days per week	Improvements in ARAT, MAL and FM after tx that were not present across pre-test phase.
Page et al 2002a	Case report	67 year old man 28 months post CVA meeting minimum criteria	FM, MAL, ARAT	Training based on PNF for 60 minutes three times weekly for 10 weeks. Restraint 5 hours per day for 5 days per week	Improvements in ARAT, MAL and FM after tx that were not present across pre-test phase.
Sterr et al 2002	RCT n=15	Patients aged 23-77 yrs at 1-17 yrs post post stroke	MAL, WMFT	Constraint for 90% waking hours for 14 days with training for 1) 6 hours per day (n=7) or 2) 3hours a day (n=8) for 10 of those days	Improvement in both groups after treatment in MAL and WMFT that was not present across pre-test phase. Significantly greater in 6 hr group for both sections of MAL but not for WMFT

Table 3-9. Trials investigating modified CIMT protocol

	Page et al 2001	Page et al 2002	Page et al 2002a	Sterr et al 2002
Randomisation	Yes	No	No	Yes
Selection bias	Inadequate, select sample	N/A	N/A	Unclear
Performance bias	Met	Unmet, no control	Unmet, no control	Met
Detection bias	Met,	Met	Unclear	Unmet, group 2 mean 19 years younger
Attrition bias	N/A	N/A	N/A	N/A
Risk of bias	High	High	High	High

Table 3-10. Validity of modified CIMT trials

In conclusion, while there have been many case reports and quasi experimental studies showing positive treatment effects of CIMT only 2 RCTs (van der Lee et al 1999, Dromerick et al 2000) have been published, of which only one has a low level of bias, showing advantages of CIMT over the same dosage of other interventions at the level of UE activities. While a less time intensive protocol may have a positive treatment effect this may not be as effective as the standard protocol. Whether it is the element of restraint or the content and delivery of the training component (which in the standard protocol is based on "shaping") that is responsible for the very positive treatment effects suggested by the results of the earlier studies cannot be distinguished from these papers. The high risk of bias inherent in the majority of studies in this area suggest that while the results seem extremely positive additional studies are required to draw conclusions as to the effectiveness of this form of intervention and the optimal content of the protocol.

3.6 Electrical stimulation

The search revealed 9 studies looking at the effect of electrical stimulation on the hemiparetic upper extremity. Two of the papers report the results of the same clinical trial and therefore are considered together (Faghri et al 1994, Faghri & Rodgers 1997). Difficulties arise in the definition and description of the type of stimulation used. For the purpose of this review the studies are divided into electromyographic (EMG) biofeedback, neuromuscular electrical stimulation (NMES) and sensory stimulation.

3.6.1 Electromyographic (EMG) biofeedback

EMG biofeedback is used to give visual and auditory feedback to the patient regarding the activity of muscles. There are two components to EMG biofeedback training: to teach the patient to relax spastic muscles and then to facilitate activation of weak or paretic muscles (Kelly et al 1979). While there is much published literature regarding the use of EMG biofeedback following stroke (Moreland and Thompson found 88 articles in a search for their meta-analysis in 1994) many of the studies have unsatisfactory research designs, small samples and failed to use random allocation to treatment groups. Two meta-analyses found different conclusions as to the effect of EMG biofeedback. Moreland and Thompson (1994) assessed 6 studies that met their criteria and stated that they "cannot conclude that EMG is superior to conventional therapy" while Schleenbaker and Mainous (1993) concluded that this approach is an effective tool for neuromuscular re-education for patients following stroke. The meta-analyses used similar methodology but differed in that Schleenbaker and Mainous (1993) included studies that didn't compare EMG to another intervention and included studies involving the LE.

3.6.2 Neuromuscular electrical Stimulation (NMES)

Neuromuscular electrical stimulation can be divided into two broad categories, functional (FES) and therapeutic (TES) electrical stimulation.

FES involves the provision of the electrical stimulus to provoke the appropriate muscle activity in time with a functional activity, this differs in principle from TES, which purely involves a repetitious and cyclic passive activation of the muscle (Chae & Yu 1999). NMES is a technique that applies a current either to the paretic muscles directly or the associated peripheral nerve (Glanz et al 1996). It is used to activate, strengthen and maintain length in paretic muscles following stroke and may also result in increased circulation, decreased pain and increased sensory awareness (Kralj et al 1993). Another branch of therapeutic electrical stimulation is EMG triggered NMES, this requires a cognitive effort on behalf of the patient to generate electrical activity in the muscle that, at a certain threshold, triggers the delivery of stimulation to the muscle.

3.6.3 Sensory stimulation

TENS is more widely known for its application in pain relief. Sonde et al (1998) hypothesised that an increased sensory input, stimulated by TENS application, could enhance brain plasticity and hence motor output.

The studies that investigated treatments with electrotherapy are summarised in Table 3-11 with the validity of the trials summarised in Table 3-12. The results of the trials would suggest that NMES may have a positive effect at the level of body functions but a transfer of this effect to UE activities level has only been evaluated in one trial. In contrast EMG triggered NMES has been shown to have a positive treatment effect at the level of UE motor functions and activities. The high risk of bias in all trials suggests the need for further research before drawing definite conclusions. In addition full descriptions of the currents applied and the method of application is required to be able to compare the many different modes of application of electrical stimulation.

	Trial type	Stimulation type	Patients	Outcome measures	Intervention	Results
Faghri et al 1994, Faghri & Rodgers 1997	RCT n=26	TES	Patients average 16 days post CVA average age 67 with flaccid UE	EMG, ROM lateral rotation of shoulder, Bobath arm function scale	Tx: Conventional therapy plus NMES to supraspinatus and post deltoid 1.5 to 6 hours per day Ct: conventional therapy only	Increase in motor function, tone and EMG activity post treatment in tx group that was significantly greater than controls maintained up to 6 weeks post intervention
Pandyan et al 1996	2 case studies	TES	1) 57 year old man in "subacute phase" 2) 41 year old man 7 years post CVA	1) AROM wrist extension 2) resting wrist angle	Patient 1: ABAB design where A=baseline, B=30 mins ES four times per day. Each phase 4 weeks Patient 2: BAB design each phase 2 weeks.	Increase in wrist extension against gravity for patient 1, increase in resting wrist angle for case 2
Sonde et al 1998	N=44	TENS	Patients 6-12 months post CVA	FM, modified Ashworth, BI	Tx: TENS over wrist and elbow extensors 60 mins, 5 days per week plus regular physiotherapy twice weekly Ct: regular intervention only	Significantly greater increase in scores in tx group. Greater mean change in FM maintained at 3 months in subgroup with higher FM scores at initial ax. No change in BI scores. No adverse effect on tone
Mackenzie-Knapp 1999	Case report	TES	25 year old man four weeks post CVA	Subluxation amount, MAS, Painful ROM	Stimulation over supraspinatus 20 mins per day over 4 ½ week period	Reduction of subluxation by 1cm, maintenance of pain free shoulder, MAS increased by 8 points

Table 3.11 Trials of electrotherapy, continued on next page..

Cauraugh et al 2000	Crossover trial n=11	EMG triggered NMES	Patients average 3.5 years post CVA	Box & Block, MAS, FM, EMG - reaction time and sustained muscle contraction	Tx: stim 60 mins 3 days per week for 2 weeks to wrist/finger extensors Ct: PROM, voluntary contraction of wrist/finger extensors	Significantly greater increase in Box & Block test in tx group. No significant differences in MAS or FM scores. Significant increase in sustained muscle contraction time tx group
Cauraugh & Kim 2003	RCT n=34	EMG triggered NMES s	With minimum 10 degrees wrist extension	Box & Block, EMG - reaction time and sustained muscle contraction	2 days of 90 minute training for 2 weeks in 1) blocked schedules (n=14), 2) random schedules (n=14) 3) similar duration of PROM and voluntary contraction (n=6)	Significantly greater increase in Box & Block for both tx groups with no difference between practice schedules. Blocked practice group had faster reaction times post treatment

Table 3-11. Trials of electrotherapy

	Faghri et al 1994	**Pandyan et al 1996**	**Sonde et al 1998**	**Mackenzie-Knapp 1999**	**Caurraugh et al 2000**	**Caurraugh et al 2004**
Randomisation	Yes	No	Yes	No	Yes, modified crossover	Yes
Selection bias	No allocation concealment	Inadequate	No allocation concealment	Inadequate	Inadequate	Inadequate
Performance bias	Unclear	Unclear	Met	Unmet, no control	Unclear	Met
Detection bias	Unclear	Unmet	Unclear	Unclear	Unclear	Unclear
Attrition bias	N/A	N/A	N/A	N/A	N/A	N/A
Risk of bias	High	High	High	High	High	High

Table 3-12. Validity of electrotherapy trials

3.7 Acupuncture

Acupuncture has been used successfully in China for thousands of years and the World Health Organisation has recognised post stroke paresis as an impairment potentially treatable with acupuncture since 1979 (Hopwood & Lewith 1997). Two studies that investigated acupuncture for the UE were identified. Hopwood and Lewith (1997) looked at a series of 6 single case studies in an ABCBC or ACBCB design where A was baseline measurement B was acupuncture treatment 30 mins daily for 2 weeks and C was placebo TENS to the acupuncture points for 30 minutes. While they did find a trend in the Rivermead motor assessment (RMA) and motricity index (MI) indicating improvement with acupuncture, there was no statistical significance when applied in group form. The study has a high level of bias as participants were not randomly allocated and outcome assessments were not blinded.

Sze et al (2004) conducted a RCT of 106 consecutively admitted patients with CVA stratified to BI score 3-11 or 11-15. Both groups received standard intervention in a Chinese hospital with the treatment group receiving additional acupuncture 30 minutes per day on treatment days. The study met all methodological criteria except detection bias as the higher BI score groups differed in terms of initial FM score. They failed to show any statistical differences in increase in FM scores between treatment and control groups in either the low or high BI score stratifications. It is possible that the BI did not accurately reflect function of the affected UE and therefore their stratification process may not have reflected the difference between subjects with higher motor function in the UE. The results of the above studies would suggest that additional acupuncture does not significantly increase the outcome of the UE post CVA.

3.8 Mental practice

Mental practice involves the cognitive rehearsal of physical skills. It is based on the psychoneuromuscular theory which suggests that the motor schemas involved in the actual activity are reinforced during imagery (Page et al 2001a). Studies have shown that the same muscles and areas of the brain that are active during the actual physical task are activated during imagery (Livesay and Samaras 1998, Decety 1996) and that this is also true for patients with hemiplegia (Weiss et al 1994).

Three studies investigating the effect of imagery on the hemiplegic UE were found and are outlined in Table 3-13. None of the three studies are RCT's and only one has a control group though this was not randomised. The level of bias in all three studies can be considered high as selection bias is unmet and detection bias is unclear in all studies, as it was not specified that outcome assessment was blinded.

In the studies by Page et al (2001a) and Crosbie et al (2004) the only additional feature between the interventions is the mental practice component and the increase in scores compared to baseline measurements and to the control group would suggest that this intervention has a positive treatment effect. The lack of screening by Crosbie et al (2004) of the ability of the patients to image may have resulted in the lack of detectible effect in 2 patients.

While this treatment modality is founded on scientific principles that are effective in normal populations, and the results of these preliminary studies would suggest a positive treatment effect, further studies would be needed to make any evidence based conclusions as to its effectiveness.

	Trial type	Patients	Outcome measures	Intervention	Results
Page et al 2001a	Feasibility study n=16	Patients 1 to 12 months post CVA with ability to image and with only mild increases intone	FM, ARAT,	Therapy three times per week for 30 mins for UE for 6 weeks. **Tx:** additional imagery – 10 minutes listening to tape daily. **Ct:** tape of stroke info at similar duration	Modified protocol feasible. Substantial increase in FM and ARA scores for tx group not present in controls or between pre-test measures
Page et al 2001b	Case report	56 year old man 5 months post CVA with ability to image	FM, ARAT, STREAM	2 baseline measures without intervention, NDT therapy three times per week for 30 mins for UE for 6 weeks. Additional imagery 10 minutes listening to tape daily	FM score not stable over baseline but post intervention was higher than both baseline scores. ARA and STREAM stable over baseline, and increased post treatment
Crosbie et al 2004	Series single case studies n=10	Inpatients in stroke unit, 10 to 176 days post CVA	MI	Additional mental practice protocol 5 days per week for 14 days: physical practice with less affected UE then mental practice with less affected and affected UE	8 out of 10 patients demonstrated statistically significant increase in score in tx period not present in baseline.

Table 3-13. Trials of mental practice

3.9 Virtual reality (VR)

VR uses visual feedback on a computer screen of the movement competed by the subject. Feedback as to the position in this virtual environment may be given as force feedback by the device or visual feedback of the position in a 3-D environment. Two studies investigating whether VR training shows positive treatment effects have been published. The first study (Merians et al 2002) used a "CyberGlove" to deliver sensory feedback and a "Rutgers Master force feedback glove" to deliver force feedback. The three single cases described showed improvement in both motor function and UE activities, using the 2 week practice schedule and inclusion criteria of the CIMT studies. However their treatment consisted of 1/3 VR training and 2/3 of dexterity tasks on real objects, it is therefore not possible to determine which element of the training was responsible for the improvement, and to attribute the treatment effects to anything more than a dosage effect.

The results of a single case study (Deutsch et al 2002) was a modification of this second study in which the training consisted solely of the VR component. A 73 year old man, 2 years post stroke showed improvements in grip strength over the 13 day treatment period. The initial work in this area would suggest that VR augmented training may have a role to play in the rehabilitation of motor impairments, however this effect has only been demonstrated in 1 case and its effect in other patients and in comparison to other interventions would need to be established.

3.10 Bilateral practice

The treatment techniques above have all involved the stimulation and or movement of the affected arm in isolation. The studies presented in this section draw from another branch of studies on neurophysiology and plasticity that suggest that bilateral movement of the limbs may also lead to changes at brain level and hence functional recovery.

Mudie and Matyas (2000) propose that when the two arms are moved simultaneously but independent of each other (i.e. not hands linked), the groups of corticomotor neurones responsible for that task in the unaffected hemisphere are made available to the injured hemisphere of the brain through known intercortical connections. When a limb is moved unilaterally the ipsilateral cortex is inhibited, but when moved bilaterally this inhibition is not present. They suggest that repeated bilateral practice initially unmasks latent pathways in the undamaged hemisphere leading to long term potentiation and establishing the firing patterns needed to perform the task unilaterally. Three studies using this basis for the intervention were found and are summarised in Table 3-14. While all three suggest a positive treatment effect for this intervention that is based on neurophysiological principles, all studies have a high level of bias as selection was based on convenience and outcome assessment was not blinded. In addition numbers in the studies are low and the intervention is not compared with other interventions of similar duration so results may be due to an intensity effect rather than due to the superior nature of the intervention.

One mode of the MIME robot therapy system is also based on the bilateral model of recovery and is discussed in the robot mediated therapy section below.

	Trial type	Patients	Outcome measures	Intervention	Results
Mudie & Matyas 1996	8 Multiple baseline single case studies	Patients aged 57 to 83, six to 78 weeks post CVA	Kinematics of movements	**Baseline**: Three movements (block placement, simulated drinking, peg placement group 1 unilateral, group 2 bilateral assisted. **Tx**: bilateral training of above movements	A meta-analysis of all 24 data series showed a positive treatment effect on movement pattern for the bilateral training
Whitall et al 2000	Single group pilot study n=14	Patients median 30 months post stroke	FM, WMFT, AROM, isometric strength	6 weeks of Bilateral Arm Training with Rhythmic auditory cueing	Significant increase in FM, WMFT, isometric elbow and wrist flexion power, and ROM variables. Maintained at 2 month follow up
Sathian et al 2000	Case study	57 year old man 6 months post CVA	Grip strength, time for functional tasks, distance of functional reach	Practice of movements of affected UE while viewing response of unaffected UE in mirror progressing to forced use training	Increase in grip strength, distance of functional reach and decrease in time taken to perform functional tasks. Maintained at 3 month follow up

Table 3-14. Trials of bilateral therapies

3.11 Robot Mediated Therapy (RMT)

The term “Robot” refers to “a programmable machine that physically manipulates objects” (Mahoney 1996). The use of robots as aides or as assistants for disabled individuals has existed for some years and has progressed to the development of robots as “therapy aides” (Reinkensmeyer et al 1996). There are 4 projects that have reported results of patient trials. The MIT MANUS (Aisen et al 1997), the MIME (Burgar et al 2000), and an initial study on the arm trainer (Hesse et al 2003) have published results in the clinical literature. The results of the ARM guide (Kahn et al 2001) have been published in engineering literature. The four main trials are summarised in Table 3-15 their validity is summarised in Table 3-16. Details of pilot trials for these main trials are also discussed in the respective sections.

	Trial type	Patients	Outcome measures	Intervention	Results
Volpe et al 2000 MIT-Manus	RCT n=56	Patients mean 22 days post stroke N=20 robot, n=36 controls	FM, MP, MSS, FIM	Additional 1hr per day 5 days per week. Control group used unaffected UE 50% of time and robot never assisted affected UE if couldn't generate movement. Tx group used MIT-Manus robot	Mean change in pre-post scores was significantly higher in robot group for motor power scale and shoulder elbow component of MSS and motor component of FIM.
Lum et al 2002 MIME	RCT n=27	Patients >6 months post CVA n=13 robot, n=14 control	FM, BI, FIM, max voluntary isometric contraction	24 sessions of 60 minutes over 2 months 1) stretching plus MIME consisting of reaching movements in bimanual, passive, active assisted and active constrained modes 2) NDT	Robot group had significantly greater improvements in FM total and subsections than controls after two months treatment. Maintained at 6 month follow up but no longer significant. Statistically greater increase in elbow extension and shoulder adduction and flexion strength in robot group post tx.
Hesse et al 2003	Single group pilot study n=12	Patients minimum 6 months post CVA with severe impairments	M Ashworth, RMA	15 sessions of 15 minutes training for 3 weeks with ARM trainer facilitating movements of wrists, forearm and elbow in unilateral and bilateral modes	Improvements in tone post treatment, improvement in RMA in those with initial score greater than or equal to 2
Fasoli et al 2003	Pre-post test design	20 patients 1-5 years post stroke with minimum grade 2 movement in UE	M Ashworth, FM, MRC test of motor power, MSS	Baseline measures for 2 weeks pre treatment followed by 1 hr per day, 3 days per week for 6 weeks intervention with MIT – Manus robot. Performed goal directed planar reaching tasks.	Trend for increase across three baseline measures though not statistically significant. Statistically significant increase from last baseline to end treatment for FM, and MSS. Significantly larger effect for wrist/hand section of MSS for progressive resisted treatment group

Table 3-15. Trials of robot mediated therapy

	Volpe et al 2000	Lum et al 2002	Hesse et al 2003	Fasoli et al 2003
Randomisation	Yes	Yes	No	No
Selection bias	No allocation concealment	No allocation concealment	Inadequate	Inadequate
Performance bias	Met	Met	Unmet, no control	Unmet, unstable baseline
Detection bias	Met	Unclear	Unclear	Met
Attrition bias	N/A	N/A	N/A	N/A
Risk of bias	Moderate	High	High	High

Table 3-16. Validity of robot mediated therapy trials

3.11.1 MIT - Manus

The MIT-Manus device (Figure 3-1, MIT Manus robot) involves the patient sitting in a chair with the patients' hand in a resting splint that is attached to the end of the robotic arm.

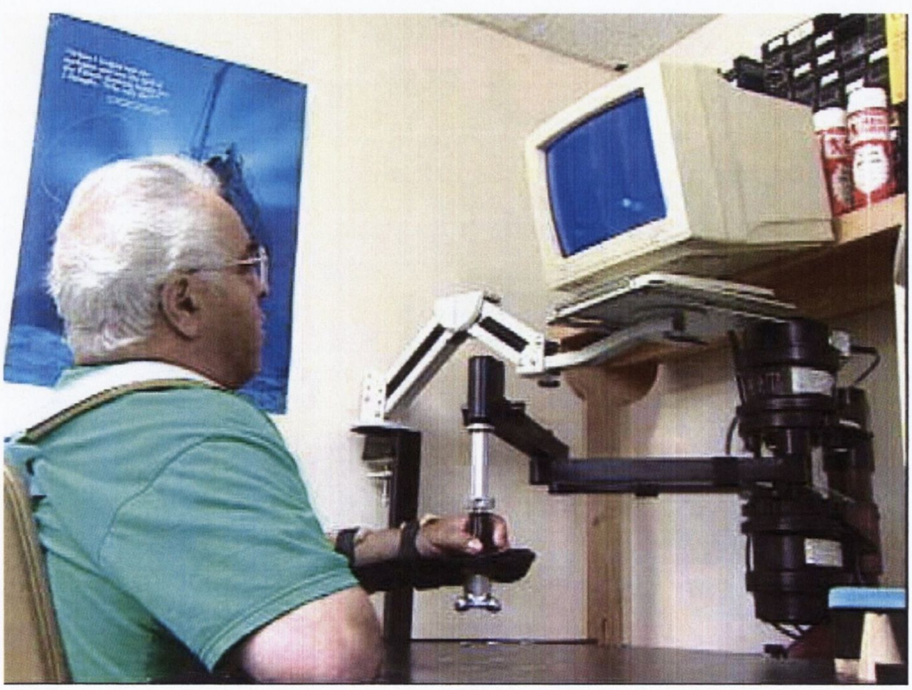

Figure 3-1, MIT Manus robot

The robot has two degrees of freedom that allows the patient to reach in any direction parallel to the table surface (Figure 3-2). Targets are placed on the table, and are also shown on the screen in the form of computer games. The intervention consists of repetitive reaching for targets. The robot provided assistance if the patient did not move towards the target.

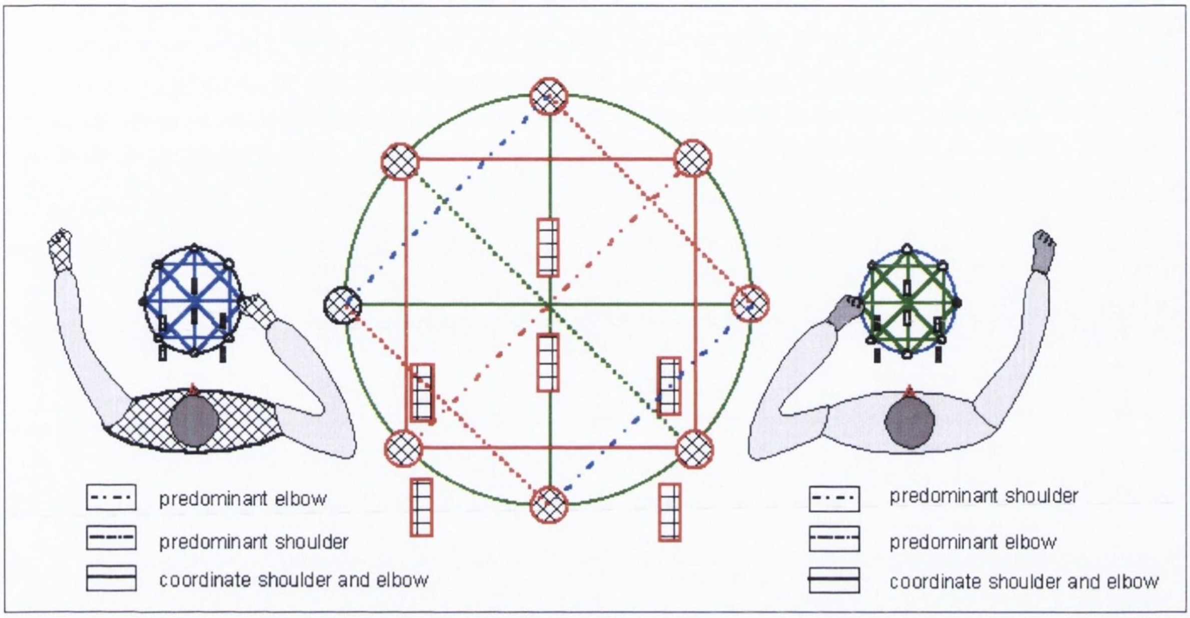

Figure 3-2, Patterns of movement of MIT Manus robot

A pilot trial of the MIT-Manus device (Aisen et al 1997, Krebs et al 1998) was conducted with patients two to four weeks post stroke. The treatment group received an additional 4-5 hours per week of therapy delivered by the robotic device and a control group had 1 hour per week of robotic exposure, ½ of which involved exercising with the uninvolved arm, the other half of exercising the impaired arm but without assistance from the robot. Over the seven week intervention period both groups improved with the only statistically significant difference between the groups being in the shoulder and elbow section of the motor status scale (MSS). The MSS was developed by the authors and is based on the movement criteria of the FM scale (Volpe et al 2000). There was also a trend for the treatment group to have greater change (1.5 units) than the control group on the motor power (MP) scale (a five point scale devised by the authors and similar to the Oxford scale).

Thus the authors (Aisen et al 1997) concluded that the device had a positive effect on the trained areas (the shoulder and elbow). However the treatment group only improved by four points more than the control group on the FM scale, despite an additional 24.5 hours of treatment. This does not represent a clinically important difference considering the intensity of additional treatment received. In addition there is no literature available to establish validity and reliability of the MSS and MP scales used by the authors.

A three year follow up (Volpe et al 1999) of twelve of the original 20 patients showed that the change in score from admission to follow up was essentially the same for the treatment and control groups for FM- shoulder elbow and coordination (FM-SEC), FM-wrist and hand (FM-WH), and MSS-wrist and hand. The change in the MSS-SE score remained significantly higher for the treatment than the control group.

The results of 56 patients in a study (Volpe et al 2000) involving the same methodology employed above are also published in the clinical literature. The control and treatment groups were similar at baseline, the only difference was that the control group had a larger lesion volume ($76cm^3$ compared to $52\ cm^3$), which might suggest less potential for improvement. The robot treated group demonstrated significantly greater changes in MSS-SE and MP scores than the control group. While the results suggest that the MIT-Manus robot system has a positive effect on the aspects that it trained (shoulder and elbow movement) there is no evidence to suggest that it is more than a dosage effect, or that there is any carry over into activities and participation.

The researchers reported that the change in FIM score was greater for the robot than the control group; the FIM measures self care, mobility, locomotion, communication and social cognition, therefore it can not be deduced that a change in this measure can be directly attributed to an improvement in the motor status of the UE as many other confounding variables exist.

When the results of the above studies were combined (Krebs et al 2000) to give a sample size of 76 (treatment n=40, control n=36) again only the MP and MSS-SE were statistically greater in the robot trained group The change in FM score only had a 2.1 mean difference between the two groups.

The above studies would suggest that in the acute patient additional therapy with MIT-Manus robot has a positive treatment effect at the level of body functions, which, on one scale devised by the authors, is maintained at three years. The superiority of this to another treatment of a similar duration has not been investigated to date. Fasoli et al (2003) established a positive treatment effect on chronic patients but without comparison to a control intervention. Further studies are required to expand on this initial work.

3.11.2 MIME

The Mirror Image Motion Enabler (MIME) system (Figure 3-3) involves the patient being seated at an adjustable height table with their shoulders strapped to prevent compensatory trunk movement.

Figure 3-3, MIME Robot

The robot has six degrees of freedom, thus allowing the arm to move anywhere in space. The patients' arm is attached to the robot via a splint, similar to that used in the MIT-Manus system that maintains the wrist in neutral. In bimanual mode the unaffected arm is attached in a similar fashion to a digitiser, which detects movement of the unaffected arm and reproduces the mirror movement of the affected arm by the robot.

The preliminary results from the MIME trial (Burgar et al 2000) which includes data from 11 robot group subjects and 10 controls, compared 24 one hour sessions delivered over 2 months of NDT based intervention with the same duration of therapy from the MIME system. They showed statistically greater increases in the shoulder and elbow component of the FM scores of the patients in the robot trained group. In addition to this they showed statistically greater increases in adduction and shoulder flexion strength in the robot trained group, with a trend towards greater strength improvements in elbow extension, internal/external rotation and abduction.

Lum et al (2002) presented results from a randomised controlled trial of twenty seven patients. They compared 24 one hour sessions delivered over 2 months of NDT based intervention with the same duration of therapy from the MIME system. The MIME intervention consisted of 4 modes, passive (5 minutes), active assisted, active constrained (20 minutes) and bimanual (12 minutes). The groups were equally matched for severity and time post stroke at baseline. The change in scores across the treatment phase for the robot group was statistically significantly greater than those of the controls for the shoulder and elbow scores of the FM, a proximal strength score, and the strength of elbow extension and shoulder flexion, abduction and abduction.

The FM and FIM were measured at 6 months, the difference in change in FM score which had been significant after treatment was no longer so, and there was a significant difference in FIM score in favour of the robot group. The authors hypothesise that the lack of difference at 6 months follow up may be because of an emphasis in the NDT group in teaching the patient independent exercises that were then carried out at home once the treatment phase had ended.

In contrast to the MIT group, the MIME group have shown that this therapy may be more beneficial than conventional therapy in patients greater than six months post stroke. Although the difference is still greater at 6 month follow up, it is not statistically so. Whether this effect is transferred to activity and participation as a direct result of the increase in UE abilities has not been investigated.

This research group are currently using a similar methodology for acute and sub acute patients. They are also comparing the unilateral and bimanual modes and investigating a dosage effect of one versus two hours of intervention per day (Lum et al 2002).

3.11.3 ARM guide

The Assisted Rehabilitation and Measurement (ARM) guide was initially developed as an assessment tool for the reaching component of UE movement and progressed to use as a treatment tool. An initial study (Kahn et al 2001) compared free reaching to robot assisted reaching with the ARM guide. Both groups improved their movement ability as measured by the Chedoke-McMaster test, but to a similar degree. This led the authors to suggest that it may be the repetitive reaching movement and not the assistance given by the robot that is responsible for the improvement, however these were only preliminary trials with very small numbers (n=12).

3.11.4 Arm trainer

The arm trainer described by Hesse et al (2003) delivered wrist flexion/extension and forearm pronation/supination as repetitive exercises. Patients were all greater than 6 months post stroke and had severe arm impairments with only two of the 12 able to achieve 20 degrees of elbow flexion/extension. They received an additional 15 minutes of intervention for 15 sessions. Of the 12 patients five improved on the Rivermead Motor Assessment though not significantly so. They all had baseline values of 2 or more on the scale indicating minimal motor function. The authors suggest that this may be a viable treatment for more severely impaired patients, but further clinical trials including control groups are needed.

In conclusion researchers have proposed that the repetitive intervention that has been shown to be clinically effective may be delivered more efficiently (in both cost and time) through the use of robotic technology. Lum et al (2002a) suggest that it may be factors such as duration, intensity and frequency of the interventions that are the critical components of the intervention as opposed to the unique qualities of the different robotic systems that can deliver these key components. Studies comparing the different devices or using the same methodology to allow comparison are warranted at this point to establish the elements of each system that might produce improved outcomes.

3.12 Conclusion

In terms of levels of evidence for intervention; if high levels are achieved through replication of positive results in one or more well designed trials, then the evidence can be considered to be small for any of the treatments outlined in this chapter. This concurs with the results of a systematic review of the same topic by Pomeroy and Tallis (2000). The lack of evidence for those interventions that have been researched coupled with the lack of research into the most commonly used treatment concept (Bobath) leaves a very limited evidence base to guide current practice in physiotherapy for the UE post stroke.

The heterogeneity of the stroke population leading to unequal control and treatment groups, and hence detection bias, is one factor that may weaken the validity of randomised controlled trials (RCT). One of the major assumptions for a RCT is that the control and treatment groups are the same; while most researchers have matched patients by age or by stroke side, very few have matched patients by sensory loss, location of CVA, presence of proprioceptive or attention deficits, all of which may effect the recovery potential and hence bias the results of the trial.

While many studies have demonstrated a positive effect at the level of motor functioning of the UE there are few who have measured and/or demonstrated an improvement at the level of activity limitations in the UE. Only one study summarised in this chapter considered the measurement of the impact of the intervention on quality of life of the subjects.

The strongest trend that emerges is that an increased dosage of intervention produces an improvement in recovery rate. This can be delivered by any method from sensory stimulus or high doses of CIMT or robot guided treatment. This improvement can be seen in patients up to 5 years post stroke and patients with relatively minor impairments may benefit most from additional intervention.

Another trend that emerges is that therapy that involves repetition of movement appears to be effective in increasing abilities at both the impairment of body functions and at the activities level. This form of therapeutic intervention is supported by animal and human studies of brain activity post stroke (see chapter 2) and the connectionist models of recovery (Robertson & Murre 1999). Dobkin (1998) in a review of neuroplasticity suggested that therapeutic interventions should pay attention to activities that involve repetitive task-oriented movements. This repetitive intervention forms a key component of CIMT, exercise based interventions and intervention delivered by robotic systems.

Robot mediated therapy can deliver high intensities of repetitious, exercise based therapy that is functional challenging and engaging hence adopting the evidence to date. The GENTLE/s RMT system considered in this thesis is the first European system to reach clinical trials and builds on those developed in the US that have demonstrated positive treatment effects by providing real time visual feedback on screen and haptic feedback through the robotic attachment to the forearm. The methodology of the first study evaluating the GENTLE/s system is described in the following chapter.

4 Chapter 4 - Methodology

The aim of this study was to investigate the effect of the GENTLE/s robot mediated therapy (RMT) system on upper extremity (UE) dysfunction post stroke. This section outlines the methodology used in the clinical trial which used a series of single case studies and measured the outcome at the level of impairment (of body functions), activities and participation (WHO 2001). The proposed methodology (study design, outcome measure, participants, procedures) was prepared by the investigator and presented to members of the GENTLE/s consortium. Agreement by the consortium on all of its components was reached prior to commencement of the study.

4.1 Study Design

The study consisted of a series of 20 single case studies with non-concurrent multiple baselines using a randomised ABC, ACB design. The A phase represented a period of baseline measures. Measurement continued during the B phase, where RMT was introduced, and during the C phase where sling suspension was introduced. Subjects attended three times a week for 9 weeks, with the treatment phases having 9 data points in each phase. The subjects were randomised to either the ABC or ACB order and to a baseline of 8, 9 or 10 data points. These components of the trial are described in the following sections.

4.1.1 Rationale behind choice of study design

The GENTLE/s system was the first European RMT system to reach the stage of clinical trials. The prototype was evaluated (Coote & Stokes 2003a) to assess its feasibility and the attitudes of subjects to the concept, however no clinical trials had been completed prior to this study therefore no information as to the effect of intervention with this system was available. Consistent with the recommendation of Sunderland (1990) the single case study design was used for this study to identify whether the intervention was useful prior to a group study to demonstrate its general application.

RMT using the GENTLE/s system is tailored to the individuals' needs and involves three different levels of assistance, three visual environments and any movement pattern. The ability of the system to be adapted to the individual needs of the subjects was considered a key feature of the system's design and mirrored current physiotherapeutic interventions in this way. It was therefore not appropriate to apply an identical treatment protocol to all subjects, a feature that is necessary for a strong RCT (Domholt 2000). The use of RCTs is most suited when the research question asks if "all subjects with a particular problem should be given a particular treatment" (Evans 1994). Authors have suggested that the information produced by single case studies may be more valuable to therapists who seek to find information in the literature as to which treatment is suitable for an individual patient with individual characteristics (Sunderland 1990, Riddoch & Lennon 1994, Ottenbacher & Hinderer 2001). The single case study design is not uncommon in stroke rehabilitation research with approximately ¼ of the studies reviewed in the previous chapter being of this type.

The fact that patients with stroke are an inherently heterogeneous group has been commented on by many researchers and the lack of similarity of control and treatment groups in terms of levels of motor function, coexisting impairments and time post stroke has led to the presence of performance bias in the literature reviewed in the previous chapter and hence the possibility of false positive or negative results. By using the single case study design the suitability of a particular treatment regime for a particular subject, with specific background characteristics, at a particular time can be assessed. This allows the investigation of the effect of RMT on subjects with wide ranging abilities and co-existing impairments and the assessment of which sub groups of subjects might gain most benefit from this therapy. It also acknowledges the fact that current physiotherapy practice does not apply similar interventions to all patients but tailors it to differing needs.

The RMT system was based in a single centre in Dublin and patients were required to attend the centre three times per week over a nine week period. This restricted the population of patients that could be considered for availability for inclusion into the trial and hence the possibility of recruiting sufficient numbers to produce the similar treatment and control groups required for a RCT.

The lack of any previous clinical trials, the practical constraints of the system's location and the heterogeneous nature of subjects with stroke and the treatment delivered by the GENTLE/s system, all suggested that a RCT was not suitable. This first clinical trial on the GENTLE/s system sought to investigate its effect on a variety of subjects with differing characteristics in order to potentially inform the design of a subsequent RCT.

This study aimed to assess whether treatment with the system produced a positive treatment effect and to begin to explore which subgroups of patients would benefit most from this form of intervention. A positive treatment effect would be seen if the rate of recovery during the RMT phase was greater than that in the baseline phase. The study aimed to recruit 20 subjects to reflect a broad range of characteristics within the recruitment restrictions, to allow for any attrition during the investigation period and to have sufficient numbers to allow replication of the effect across subjects.

Internal/External validity of clinical studies

The aim of any therapeutic trial is to investigate the effect of a treatment on one or more individuals in such a way that the results can be generalised to other subjects with similar impairments and to other settings. To do this the study must have strong internal and external validity.

Internal validity is a property of scientific studies that suggests that the response to treatment is due to the intervention itself and not to external confounding variables such as history (concurrently occurring changes in environment) and maturation (for example natural recovery). The external validity of a study is the property that allows the treatment effect seen to be generalised to other subjects, populations or environments.

Within the context of the single case study design a number of factors that influence the internal and external validity of the study necessitate consideration. The type of design, length of the baseline and treatment phases, use of a control variable, and the replication of the results across several individuals are considered in the following sections.

Types of single case study designs

Single case studies involve the repeated measurement of a characteristic over time. There are 4 types of single case study design: AB, withdrawal, multiple baseline and alternating treatment (Domholt 2000).

AB design

The AB design traditionally involves the A phase representing a baseline measurement phase and the B phase the treatment phase. The trend or level of the data in the A phase is compared to that in the B phase to assess the effect of introducing a treatment. This is illustrated Figure 4-1.

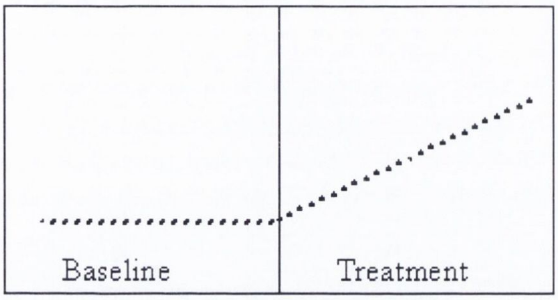

Figure 4-1. AB study design

The simple AB design is the weakest of all the study designs and controls poorly for factors such as history and maturation (Sunderland 1990, Riddoch & Lennon 1991). There is no evidence to suggest that the change in rate seen above did not coincide with an event such as change in medication, addition of more treatment hours etc.

Hesse et al (1994) used the AB design in a slightly different way, and compared the effect of one method of restoring gait (treadmill - A) with standard (Bobath - B) treatment. As there was already sufficient evidence to support treadmill training the researchers could ethically withhold normal treatment while using treadmill training. In the case of RMT with the GENTLE/s system this was not possible as there were no studies evaluating whether or not it had a positive treatment effect.

Withdrawal design

The withdrawal design involves an ABA sequence of phases. Following the baseline and treatment phases, the treatment is then withdrawn and the effect of this noted. This is illustrated in Figure 4-2.

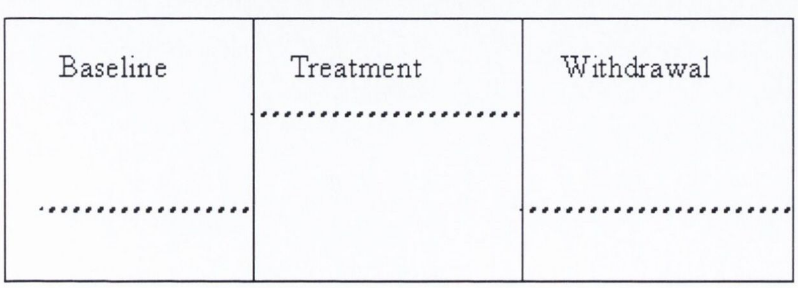

Figure 4-2. ABA study design

Several authors suggest that a withdrawal (ABA) design should only be used when it is expected that the dependent variable will return to baseline. (Zahn & Ottenbacher 2001, Kazdin 1982, Barlow & Hersen 1984). The treatment interventions used in this study aim to effect muscle activation/strength and functional abilities, variables that do not change instantly on withdrawal of treatment. The results of other RMT studies would suggest that this effect of RMT is maintained over time and does not withdraw on cessation of treatment (Volpe et al 1999, Lum et al 2002). The ABA design would be better suited to evaluating the effect of an appliance, such as an ankle foot orthosis, which when removed, returns the movement parameters to their previous state.

Alternating treatment design

Alternating treatment designs can be used to compare the effects of two or more treatments concurrently and is suited to measuring the effect of orthotics or assistive technology on function (Backman & Harris 1999). This is illustrated in Figure 4-3.

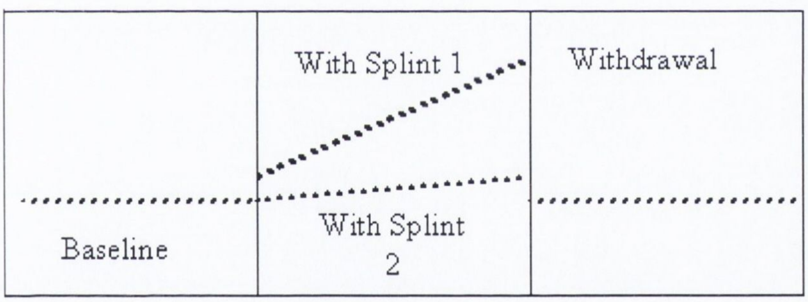

Figure 4-3. Alternating treatment study design

Typically the two treatments are administered on the same day during the B phase, the outcome with the application of each intervention being compared to both the baseline and the other treatment (Domholt 2000). This design was not considered appropriate for this study as the effect of RMT was shown in previous studies (Volpe et al 1999, Lum et al 2002) to be more longstanding and not comparable to the temporary effect of wearing different orthoses, the suggested application of this design.

Multiple baseline design

Multiple baseline studies involve the random allocation of the length of the baseline measurement phase. If the dependent variable only changes when the treatment is introduced, which is at different time for different subjects, it can be deduced that the change was due to the introduction of the treatment and not to a confounding variable such as a change in environment or other time factor. This design has stronger internal validity for this reason. This is illustrated in Figure 4-4.

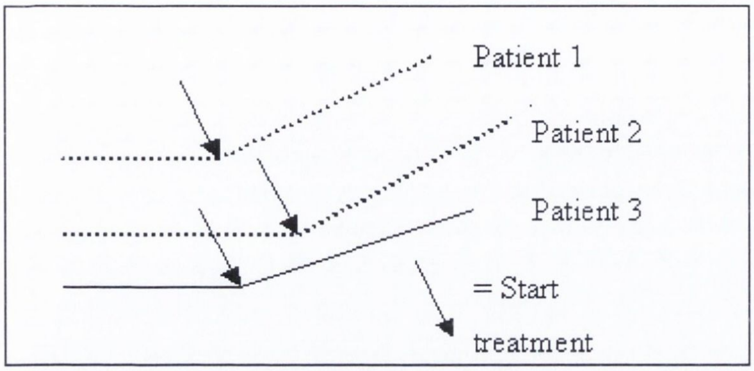

Figure 4-4. Multiple baseline study design

The term "non concurrent baselines" means that each subject starts their baseline at a different time. This further strengthens the internal validity in the same way as the differing lengths of baseline. "Non concurrent" refers to the fact that the subjects in this study presented at varying time intervals post stroke.

Sunderland (1990) suggests that the multiple baseline design should be the "method of first choice wherever possible" due to their superior internal validity to the other single case designs. This type of design has been used by Bütefisch et al (1996) who also evaluated a therapeutic intervention that aimed to increase strength in the upper extremities of subjects with hemiplegia.

The study design chosen was a non-concurrent multiple baseline design with A as the baseline measurement phase, B as the robot mediated therapy phase and C as the sling suspension phase. The subjects were randomly allocated a baseline length of 8, 9 or 10 data points. There were 4 study periods, with 5 subjects at varying times post stroke taking part in each period.

Length of phases

One element of the single case study design which strengthens its internal validity is the number of measurements in each phase. Each phase needs to have sufficient data points to identify a trend in the data so that the trends in phases can be compared. Should the outcome measures have poor test-retest reliability and produce a variable output, the phases would need more data points to compensate for this. Backman & Harris (1999) and Sunderland (1990) suggest that 10 data points per phase is optimal to allow statistical analysis. To coincide with attendance three times a week 9 data points per phase were chosen for this study.

Strengthening of internal validity

The multiple baseline study design has higher internal validity than the AB design (Zahn & Ottenbacher 2001) as it effectively controls for history (concurrently occurring changes in environment) and maturation (for example natural recovery), which are the biggest threats to internal validity.

The use of multiple baselines across several individuals controls for history – if the motor performance in every person only changes when the intervention is introduced the effect can be attributed to the intervention rather than to extraneous events (Bütefisch 1996). The use of non-concurrent baselines (i.e. occurring at different times during the year) further controls for events such as staff changes, seasonal changes to the rehabilitation environment, discharge home etc., and further strengthens the internal validity of the study. As mentioned previously, the baseline measurement phase was randomly allocated as 8, 9 or 10 data points and the order of treatment to ABC or ACB, the randomisation process further strengthening internal validity.

Using a baseline period and establishing a recovery trend before treatment begins allows the subject to be used as his or her own control. This allows the rate of recovery due to the addition of the intervention to be compared to that of the underlying recovery rate and control for the effect of spontaneous recovery (maturation). The use of a long baseline phase aims to control for the contribution of a learning effect of the outcome measures. When performing repeated measures an increase in score may be due to practice in completion of the measure as opposed to an increase due to actual clinical change. By assigning a baseline length of 8, 9 or 10 measures, a clear trend in the data after an initial learning effect could be established.

The addition of a control variable (in this case grip strength) further strengthens the internal validity. As RMT guides movement from the wrist it is expected that only the movement parameters of the shoulder and elbow will be affected. If the trend of recovery of grip strength does not change from the rate of recovery during the baseline phase and the trend of recovery of shoulder and elbow parameters does, it adds weight to the hypothesis that the addition of the independent variable (RMT) improves the dependent variable (elbow and shoulder movement parameters) and that other extraneous factors such as history and maturation are not responsible.

Strengthening of external validity

The strength of external validity of single case studies is evident when a positive treatment effect demonstrated for one individual case is replicated across other subjects. That is, while a positive treatment effect demonstrated for one individual with certain characteristics may hold information of limited value for the population in question, once this is replicated across several individuals the external validity of the study is strengthened.

The use of a series of single case studies allows the establishment of not only the individuals' response to the treatment, but also to investigate whether this can be replicated hence further validating the results.

The duration and frequency of treatment (30 minutes, 3 days a week) may not be replicable to the outpatient setting (where treatment may occur as little as once a week) but should be replicable to inpatient settings.

Control for intensity of intervention

There is a body of literature that suggests that an increase in the amount of therapy produces better outcomes post stroke (see chapter 3 section 3). It would seem from the review of the literature in chapter 3 that the essential factor is not the type of intervention, but the dosage. The comparison of the effect of additional RMT to another intervention of similar duration sought to control for this factor.

The ideal situation would be to compare additional RMT and additional conventional therapy. Studies suggest that treatment based on the Bobath concept is the most widely used treatment concept in Ireland (Coote & Stokes 2003) however, the lack of description of this method of treatment coupled with the predominance of an eclectic approach by the majority of therapists (Coote & Stokes 2003, Davidson & Waters 2000) makes definition of conventional therapy for research purposes extremely difficult.

One of the themes of physiotherapy research post stroke is to begin to "unpack the black box" of physiotherapy treatment to begin to explore what the key components of an effective intervention are. One way of doing this is through comparison of interventions that differ by only a few key elements. For this reason sling suspension (SS) was chosen as the control treatment. RMT and SS share the common elements of repetition of identical movement patterns and a de-weighted environment. By comparing the rate of recovery during the RMT and SS phases the effect of the addition of the robotic assistance, visual feedback and motivational component offered by the GENTLE/s system to these common elements can be evaluated. Thus the effect of additional intervention (comparison of baseline and RMT or baseline and SS) and the effect of the addition of the robotic components (comparison of RMT and SS) may be evaluated through this study design.

In order to control for the possibility that the greatest response to treatment may occur in the first treatment phase, patients were randomised to the order of treatment they received, i.e. ABC or ACB order.

4.2 Outcome Measures

The measures used in this study can be divided into three categories: subject information, background characteristics and study outcomes. They were chosen to reflect recovery at the level of impairment (of body structures and functions), activity and participation.

The single case study design places special demands on the test-retest reliability of measures (Sunderland 1990, Bithell 1994), and the measures must be sensitive enough to show changes in trends of recovery over short periods of time (Riddoch & Lennon 1991). The measures used in the study were chosen to reflect recovery at the level of impairment (of body structures and functions), activity and participation and because they satisfactorily demonstrated the above characteristics.

Finch et al (2002) define a reliable measure as one that can firstly "provide consistent values with small errors of measurement" and secondly "be capable of differentiating among the clients on whom the measurement is applied". Test-retest reliability reliability refers to the ability of the measure to produce consistent results both over time when the subjects status is not expected to have changed (Anastasi & Urbina 1997, Finch et al 2002). Reliability can be expressed as either the relative reliability or the absolute reliability. The correlation coefficient expresses relative reliability and the standard error of the measure expresses absolute reliability (Finch et al 2002). Previously linear correlations in the form of the Pearson correlation coefficient were used to express reliability of measures. However this method of determining reliability may be inherently biased as it considers the linear relationship between two measurements and can produce high r values when one rater consistently reports higher values than another hence falsely reporting high reliability of measurements. Rankin and Stokes (1998) suggest that ideally both the intraclass correlation coefficients (ICC) and the Bland and Altman method of assessing reliability should be reported and should include the ICC equation used as different equations may elevate or minimise the significance of the result. Providing the easily interpretable ICC with the magnitude and direction of the differences seen allows full interpretation of the results seen (Rankin & Stokes 1998).

The terms sensitivity to change and responsiveness of a measure have been used interchangeably. Liang (2000) defines sensitivity as "the ability of an instrument to measure change regardless of whether it is relevant or meaningful to the decision maker" and Finch et al (2002) suggest that the term responsiveness should therefore be used to indicate the ability to detect relevant clinical change. Some authors consider that responsiveness of a measure as an integral part of the validity of a study (Finch et al 2002). The ability of a measure to detect non-important change is also referred to as longitudinal validity and can be measured by the effect size (mean change in score/standard deviation of baseline measure) or the standardised response mean (mean change in score/standard deviation of change scores). The term sensitivity will be used in this chapter to reflect the ability of a measure to detect small amounts of change that are not necessarily clinically relevant.

"Validity is the property of the measure that considers its content, the populations for which it may be used and the interpretation that can be applied to its output" (McDowell & Newell 1996). In simple terms it assesses the extent to which the measure evaluates what it is meant to. Validity can be expressed as face, content, criterion or construct validity. Face validity refers to the clinical credibility of the measure simply by examining the elements of the measure and their relationship to the desired attribute being measured; for example does a test of UE motor function examine movement at UE joints. Content validity refers to whether the measure has examined all aspects of the attribute for example does the test of UE motor function consider movement at all joints in isolation and simultaneously. Criterion validity refers to the consistency of the measure to produce results that are consistent with those of a "gold standard" test of the same attribute and can be considered as concurrent or predictive in nature. Construct validity can be further broken down as convergent, known group and discriminant validity (Finch et al 2002) and in broad terms considers whether the scores obtained are consistent with what was predicted by the theoretical model.

4.2.1 Subject information

The "subject information sheet" is presented in Appendix 2. It contains demographic information such as age, time post stroke, current treatment, stroke type, and CT results. When available the cerebral infarct is classified according to the Bamford classification (Bamford et al 1991). It also served as a log in which to document any concurrent events that may have had a bearing on the study outcome such as cessation of current treatment or discharge from a service.

4.2.2 Background measures

The background measures were collected on four occasions, on the first measurement day (at the start of the baseline), at the end of the baseline, at the end of the first treatment and at the end of the second treatment (which coincided with the end of the study). Sensation, visuospatial neglect, tone, pain, memory/cognition, hemianopia, and motor ability were measured, as these were all factors that have been shown to influence the level of recovery and hence may influence the response to treatment (Table 4-1).

In addition to investigating the influence of pain and tone at baseline on the outcome of motor recovery, the effect of the intervention on these two variables was also investigated and reported.

Domain	Relationship to recovery	Measurement tool
Sensation	Associated with decreased functional loss at 3 months (Parker et al 1986). Predictor of motor recovery at 6 months (Feys et al 2000). Decreased kinaesthesia associated with poor outcome (Rand et al 1999)	Nottingham sensory assessment, light touch, pressure, kinaesthesia sections (Lincoln et al 1998)
Visuospatial neglect	Negative predictor for functional outcome (Edmans et al 1991, Katz et al 1999). Strong association with poor functional outcome (Friedman 1992, Cherney et al 2001)	Star cancellation test (SCT) (Wilson et al 1987)
Tone	Emphasis on normalisation of tone before facilitation of movement (Lennon et al 2001). Link to outcome uncertain.	Modified Ashworth scale (Bohannon & Smith 1987)
Pain	Associated with poor outcome (Roy et al 1995). Negatively influences motor recovery (deWeerdt et al 1987)	Visual analogue scale if SCT normal, verbal if abnormal (Price et al 1999)
Hemianopia	Part of screening for perception and neglect (Wade 2000) which are negative predictors of functional outcome (Edmans et al 1991, Katz et al 1999)	Standard method described by Fuller 1993

Table 4-1 - Background measures

Sensation

The level of sensory disturbance is strongly associated ($p<0.001$ on Chi squared test) with functional loss at three months post stroke (Parker et al 1986). Deep sensation was also found to be a predictor of motor recovery at six months post stroke (Feys et al 2000) and deficits in kinaesthesia were associated with poorer motor outcome (Rand et al 1999). Thus it was important to measure the presence or absence of this deficit as it may have a bearing on the outcome of the intervention. In addition the literature review revealed that some interventions produced more positive results in subjects with less or more sensory disturbance and the inclusion of this measure sought to evaluate whether this was the case for RMT.

The level of sensory dysfunction was measured using sections of the Nottingham Sensory Assessment (Appendix 3) (Lincoln et al 1998). It is a detailed assessment of tactile sensation, temperature and kinaesthetic sensation. It was developed (Lincoln et al 1991) in response to what the authors perceived to be a lack of standardised testing of a routinely assessed domain. The scale originally had its reliability evaluated (Lincoln et al 1991), however results for test-retest reliability were poor for some sections, possibly due to the time between test occasions (up to two weeks). It was revised by omitting unnecessary sections and clarifying scoring systems and retested for interrater reliability (Lincoln et al 1998). Using Fleiss categories for classification of the Cohen Kappa coefficients (Fleiss 1981) the light touch, pressure and kinaesthetic sub-scales were found to be the most reliable, although the agreements for kinaesthesia of the hand were only 0.32 indicating a poor level of agreement. Test retest reliability was not reported in the study. The sub-sections for light touch, pressure, and kinaesthesia were used in this study as they were the most reliable (Lincoln et al 1998) and clinically relevant subsections while bilateral simultaneous touch was evaluated as this forms part of a test battery for inattention (see below).

Visuospatial neglect

This domain was measured as the presence of visuospatial neglect has a negative effect on the outcome of functional rehabilitation post stroke (Edmans et al 1991). It is a negative predictor for outcome (Katz et al 1999) and is significantly associated with poorer functional outcome (Friedman 1992, Cherney et al 2001). For this reason it was considered important to measure the presence of this deficit.

The presence of visuospatial neglect was measured using the star cancellation test (SCT) (Appendix 4). This widely used test forms one part of the behavioural inattention test (BIT) (Wilson et al 1987) and was found to be the most sensitive of the 6 measures of neglect of the BIT, all subjects whose overall score on the BIT was below 130/146 scored abnormally (less than 54) on the SCT (Halligan et al 1989). The convergent validity of this measure is reinforced by its correlation to the other components of the BIT (Halligan et al 1989). Bailey et al (2000) found it to be the most sensitive of a battery of 6 items that measured visuospatial neglect.

Tone

It was felt that it was important to quantify tone, as it is perceived to be an entity that has a negative effect on the restoration of normal movement. For this study tone was defined as resistance to passive movement. Therapists using the Bobath concept (who make up the vast majority of physiotherapists in the UK and Ireland), place a particular emphasis on the normalisation of tone before facilitating the restoration of movement (Lennon et al 2001). There is a belief amongst therapists that interventions that increase tone have a negative effect on functional outcomes.

The quantification of tone remains a controversial and unsolved puzzle for those involved in rehabilitation. It is acknowledged that the currently available measures of tone (Ashworth, Modified Ashworth Scale) have uncertain reliability and validity (Pomeroy et al 2000, Gregson et al 2000). The Modified Ashworth Scale (Bohannon & Smith 1987) (Appendix 5) was chosen in the absence of a validated, reliable alternative. In a review of the Ashworth scales Pandyan et al (1999) found the modified Ashworth scale to be moderately reliable when classifying the resistance to passive movement of the elbow and wrist flexors, the two muscle groups assessed in this study.

Pain

Shoulder pain has been found by some authors to be associated with poor outcome (Roy et al 1995) and to negatively influence motor recovery (deWeert et al 1987). Pain was measured firstly to investigate whether RMT (or SS) had any effect on the pain levels in the affected UE and secondly to assess the contribution that the presence of pain made to motor and functional recovery.

Pain was measured using a standard visual analogue scale (VAS) (Finch et al 2002) with a 10cm horizontal line (Appendix 6). The convergent validity of this test is suggested by its correlation to other measures of pain intensity (Finch et al 2002). As subjects who scored abnormally on the SCT had a high probability of incorrectly using a horizontal VAS (Price et al 1999) those subjects who scored abnormally on the star cancellation test (<54/54) used a verbal analogue scale. No studies evaluating the test-retest reliability of this measure for patients with stroke were found. This measure was chosen as it represented a simple, continuous scale for rating pain.

Hemianopia

The robot mediated therapy system relies on visual feedback, therefore the presence of hemianopia may influence the effectiveness of the treatment. The presence of hemianopia and visual neglect was assessed using the method described by Fuller (1993). This involves placing the examiners hands at 30cm above eye level and 50cm apart. The subject is asked to indicate which fingers are being moved. If one side is not seen when the fingers are moved simultaneously, but is seen in isolation, this is termed visual inattention.

The assessment of hemianopia forms part of the three part screening test for perception/neglect (Wade 2000) along with the star cancellation test and tactile inattention (bilateral simultaneous touch) which have also been measured.

Memory/Cognition

This information established the subjects' ability to give informed consent and also qualified their ability to complete the testing and outcome measures used in the study.

The Short Orientation Memory Cognition test (SOMCT) (Katzman et al 1983) was used to measure this domain (Appendix 7). The maximum score possible is 28 with a score greater than 20 being "normal" (Wade 2000). This test was tested for criterion and construct validity by comparing it with the presence of plaque counts on autopsy and investigating the differences between known groups, the results suggest high levels of validity (Katzman et al 1983). The 6 items included in the SOMCT were weighted according to their ability to predict total score in a multiple regression model. The face validity of this test is apparent in the components included in it and it is a simple and quick method of establishing the presence or absence of cognitive deficits.

4.2.3 Study outcomes

These four measures were taken at the start of every day of attendance at the clinical trial. The 1st measurement in the treatment phases represents the measurement 2 days after the 1st treatment. The time and order of testing were kept constant in addition to using the same rater throughout the study in order to minimise the effect of these confounding factors.

The outcome measures were chosen by examining their constructs and psychometric properties, particular attention was paid to test-retest reliability and sensitivity, as single case studies require high levels of both these properties.

Impairment level

Fugl-Meyer Assessment (FM)

The FM was developed by Fugl-Meyer et al (1975) to assess physical recovery after stroke (Appendix 8). It evaluates volitional movement using the Brunnstrom phases of recovery (Brunnstrom 1966) and can be considered a measure of impairment of body (motor) function. The upper extremity segment is divided into 5 sections: reflexes, arm, wrist, hand and co-ordination. Each of the items is allocated a score on a three point ordinal scale of 0, 1 or 2. The maximum score is 66 for the upper extremity and indicates high level of motor function.

Validity

The content validity of the scale was established initially by Fugl-Meyer et al (1975) when the progressive motor recovery of 28 subjects with CVA was recorded using the FM. The construct validity of the instrument was established by comparing the scores to the Brunnstrom phases of recovery, the authors finding that an increase in scores coincided with a transition in the phases of recovery. The criterion validity of the UE section was investigated by Berglund and Fugl-Meyer (1986) who compared it to the de Souza arm test (deSouza et al 1980). They found significant correlations between the UE measures of 0.95 using a linear regression model and 0.90 using Spearman rank correlation coefficients (SCC). Malouin et al (1994) also investigated the concurrent criterion validity by comparing it with the MAS. They found SCC of 0.89-0.93 for the correlation of UE FM and MAS scores. The scale has been used as the "gold standard" by many authors (e.g. Poole & Whitney 1988) validating new outcome measures and is widely used in UE rehabilitation research.

Test-retest reliability

Sanford et al (1993) investigated the test-retest reliability of the FM and found an intraclass correlation coefficient (ICC) of 0.97 for the UE subsection for a group of 11 subjects less than 6 months post stroke, rated by therapists with greater than 10 years experience. Duncan et al (1983) found Pearson Product-Moment Correlation Coefficients (PPMC) of 0.995 for the UE section for a group of subjects greater than 1-year post stroke and no significant differences in the values at the three measurement occasions using ANOVA. While the statistical methods may not be optimal with no consideration of the possibilities of systematic differences in the results, the results would suggest that the scale may be reliable. While both authors found strong linear correlations between measurements, neither indicated the magnitude of the average difference in score found which is the recommended reporting of reliability data (Rankin & Stokes 1998).

Sensitivity

Malouin et al (1994) compared the FM with the Motor Assessment scale (MAS) and found that a greater proportion of MAS scores than FM fell into the lower bands suggesting a floor effect for the MAS. They found significantly different levels of recovery in subjects with lesser motor abilities suggesting that for subjects with less return the FM was more responsive than the MAS. The fact that the MAS is a measure of UE activities whereas the FM is a measure of motor function may explain that discrepancy. The results reported by Sanford et al (1993) suggest that the standard error of measurement for the UE section is 3.6 meaning that on 68% of occasions the true score (or that without any error) would fall within 3.6 points of the observed score.

Range of motion (Goniometry)

Universal goniometry (UG) is a widely used assessment tool both in the clinical and research arenas for measuring joint range of motion (ROM) or describing a particular position of a joint. Goniometry involves positioning the arms of the measuring instrument along the bones immediately proximal and distal to the joint being measured (Norkin & White 1995) with the axis over a fixed reference point. This measurement provides an impairment level measurement which has the potential to pick up small changes in recovery.

The active (AROM) and passive (PROM) ranges of motion for shoulder flexion, external rotation and abduction and elbow flexion and extension were measured in this study. AROM identifies the degrees of movement available through the contraction of the patients' muscles while PROM indicates that no action on behalf of the patient is complete. As the GENTLE/s RMT system moves the patient to the extremes of some ROM it may have an effect on PROM. The completion of repetitive exercise based interventions may have an effect on AROM of the relevant joints.

Validity

The purpose of goniometry is to measure the range of motion at the joint. There is little literature on the validity of this measurement as it is assumed that the angle created between the arms of the UG represents the angle between the bones on either side of the joint (Norkin & White 1995).

Test re-test reliability

Studies of goniometric reliability are varied in their design, methods and outcome. Few studies report the magnitude of the difference seen between measurement occasions and many use the PPMC despite its potential bias. Rothstein et al (1983) report the test re-test reliability of AROM elbow flexion and extension measurements on patients with elbow pathology using a UG. The reported ICC of 0.86 for extension and 0.97 for flexion but don't report the ICC equation used or give the magnitude of the differences seen. Mayerson and Milano (1984) combine the results for test retest reliability for 22 joints and report an average PPMC. This does not provide useful information as to the reliability at the various joints which is acknowledged to differ depending on joint type and structure. They do however report an average difference between measures as $+1.6^{o}$ or -0.9^{o} depending on the rater. As the confidence intervals for this range from –0.9 to 4.6 and –2.3

to 4.11 they suggest that changes of greater than 5 degrees should be seen before the change can be attributed to actual change rather than measurement error. When considering patients with pathology (Duchenne muscular dystrophy) Pandya et al (1985) reported ICC of 0.84 for AROM shoulder abduction and 0.94 for elbow extension. Like the study by Rothstein et al (1983) they fail to indicate the equation used or the magnitude of the difference seen. Sabari et al (1998) reported ICC values for measuring shoulder flexion and abduction in sitting and supine for one rater. Their values are similar to those of the other studies and range from 0.93 to 0.99 using the (2,1) equation. They did not find a significant difference between either testing positions or between AROM and PROM and did not report the magnitude of the difference. More recently Hayes et al (2001) assessed the test retest reliability of shoulder goniometry in comparison to 4 other measures of AROM. When considering the test retest reliability of measurement by an orthopaedic surgeon of symptomatic shoulders they reported ICC values of only 0.53 to 0.65, (with shoulder flexion being reported as less reliable than shoulder abduction) considerably lower than the other studies reported. Should their SEM values be used a change of 46^0 would need to be observed before the difference could be attributed to anything other than measurement error.

These studies suggest that test retest reliability might be high when measured by a physiotherapist but little information is provided as to the magnitude of the differences seen with two studies that do report it providing very different results.

Sensitivity

As goniometry measures in degrees of motion it is potentially sensitive to small changes in this domain. However care should be taken when differentiating between actual change and measurement error. Boone et al (1978) recommend that a change of at least 5 degrees should be present before a true change in joint motion is deduced. The SEM values reported by Hayes et al (2001) would suggest that a change of 46^0 would be required before a change in abilities can be differentiated from measurement variability though these values far exceed other estimations.

Goniometry was chosen as a measure of impairment as it is widely used in clinical practice and is capable of detecting small change in both mildly and severely impaired subjects.

Dynamometry (Maximal Voluntary isometric contraction - MVIC)

Hand held dynamometry involves the measurement of the force exerted by the limb on a force gauge using a hand-held device. The Power Track 2 hand held dynamometer (J-Tech corporation) was used for this study (Figure 4-5). Isometric shoulder flexion and extension and elbow flexion and extension were measured. For both tests the subject was positioned in supine. For the shoulder measurements the arm was supported in 90^o shoulder flexion with neutral rotation and for the elbow the shoulder in neutral flexion and rotation with the elbow flexed to 90^o (Bohannon 1986). An average of 3 readings in the one session was used.

Figure 4-5. Power track dynamometer

Validity

The measurement of muscle strength (or force generated in known conditions) in subjects with upper motor neuron lesions is a much-debated topic. There is a known relationship between cortical and pyramidal tract activity and muscle force production in primates. Hence it can be concluded that a lesion to one of these systems will lead to a decrease in strength. The other facet to decreased force generation in muscle is resistance by the antagonist group. While hand held dynamometry does not distinguish between these two components, it is nonetheless a valid measure.

Bohannon (1989) argues that while the underlying mechanism for the production of the force is unknown, this is not a valid reason for not measuring it. He compares it to the measurement of body temperature blood pressure etc, which also fail to indicate underlying mechanisms, but are nonetheless widely used and reported. He advocates its use as a measure of progression of recovery, comparison to the intact side or normative values. Strength testing is, in the case of this study, being used to indicate the subjects' capacity to activate a muscle group under known circumstances.

Information regarding the strength deficits in subjects with stroke is useful to clinicians as it has a strong relationship to performance of many functional activities (Bohannon & Smith 1987a). The hand held dynamometer measures the force applied by the subject to the force plate and therefore can be presumed to be measuring the force that the subject can generate in that muscle group in that position.

Muscle strength has been found to correlate to fine and gross motor skills and co-ordination (Smedley et al 1986) and to skilled movement (Dohrmann & Nowak 1974) suggesting concurrent convergent validity. It can also be used to predict functional outcome (Fullerton et al 1988) suggesting longitudinal convergent validity.

Test re-test reliability

Bohannon (1986) investigated the test-retest reliability of hand held dynamometry for patients with neurological deficits using well described UE positioning and testing procedures. Using PPMC to calculate correlation coefficients he reported values for the UE muscle groups of between 0.96 and 0.99 with no significant differences in test occasion as expressed by ANOVA on repeated measures. This study was replicated by Riddle et al (1989) who reported both PPMC and ICC values (using the 1,1 equation). They reported similar ICC and PPMC values (suggesting that non systematic error was responsible for the differences in score) of between 0.97 and 0.98 for the paretic limb when tested on the same day and of between 0.94 and 0.98 when tested two days apart. When comparing the correlations between the first measurement on each occasion and an average of 3 measurements they reported slightly higher ICC values for the elbow when the average of 3 was considered. Kilmer et al (1997) completed a similar study on patients with neuropathic weakness, though they didn't report which ICC equation was used they reported values of 0.94 for shoulder flexion and 0.92 for shoulder extension. The mean percentage difference in score was –0.3 for shoulder flexion and 5.5 for shoulder extension.

The consistency of the above results all of which report high levels of agreement for shoulder and elbow measurements suggest a high level of test retest reliability for hand held dynamometry for patients with neurological impairments when measured using defined positions and techniques.

Sensitivity

The instrument used (J-Tech hand held dynamometer, Figure 4-5) measures in increments of 0.5kgs. This small increment means that small deviations in the force produced can be detected. A search of the literature revealed no studies directly investigating this property.

Grip strength

Grip strength was measured using the Jamar™ hand-held dynamometer (**Error! Reference source not found.**). The subject was seated with their forearm resting on a table. The time of day and testing position were consistent on each occasion.

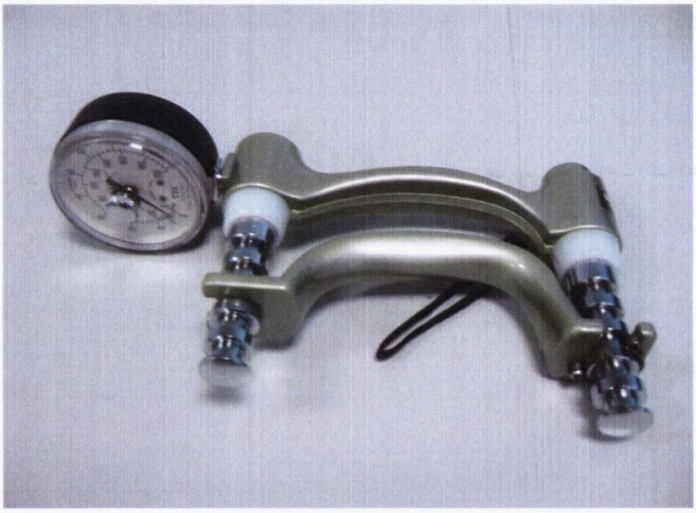

Figure 4-6. Jamar hand-held dynamometer

Grip strength was measured as a control variable. As the hand was not directly treated an increase in the rate of recovery of this variable over and above natural recovery was not expected.

Validity

The Jamar dynamometer directly measures the force generated by the grip of the hand. As with hand held dynamometry, the elements contributing to the generation of grip force are not fully understood and may combine elements of strength, muscle extensibility and antagonist properties. However when this is recognised its face and content validity are acknowledged to be good.

The accuracy of its measurement was established by Mathiowetz et al (1984) by hanging known weights from the dynamometer and the dynamometer used in this study had recently been calibrated.

The absence of measurable grip one month after stroke has been found to be a predictor of poor functional outcome (Heller et al 1987) suggesting longitudinal convergent validity. Other authors have shown it to be a valid measure of arm function in stroke subjects (Turton & Fraser 1986, Sunderland et al 1989, Bohannon 1987) by correlating grip strength to measures of UE activities suggesting cross sectional convergent validity. It has been shown to correlate highly with the Motricity Index (r=0.87) the Frenchay Arm Test (r=0.86) and the Motor Club Assessment (r=0.81) (Sunderland et al 1989).

Test re-test reliability

Bohannon (1995) investigated the test retest reliability of grip strength in patients early after stroke and found a SCC of 0.95 he did not report the magnitude of the difference however. Boissy et al (1999) found an ICC of 0.91 when combining the results of 3 test occasions on the same day. The standard error of measurement for the affected hand of 15 stroke subjects was 25 N (2.5kg).

Sensitivity

The Jamar dynamometer measures in increments of 1 kilogram and is therefore capable of detecting small changes in grip strength. A search of the literature revealed no studies directly investigating this property.

Activities level

Motor Assessment Scale

The Motor Assessment Scale (MAS) was developed by Carr and Shepherd (Carr et al 1985) as a tool to evaluate motor function in subjects post stroke. It is a measurement of activity based on functional tasks.

The full MAS consists of 8 sections, 3 of which concern the function of the upper limb. The three sections, upper arm, hand and advanced hand, comprise 6 activities each. It is a non-hierarchical scale and each item scores one point if it is completed successfully the maximal score for the UE being 12. The original scale had a section that evaluated tone this has since been omitted. The scale with the tone section removed is sometimes referred to as the modified MAS (MMAS).

Validity

The MAS was designed specifically to measure motor function post stroke. Poole and Whitney (1988) compared scores on the MAS to those of the FM and found Spearman correlation coefficients for the upper arm section of both scales was 0.89, with the two MAS sections for the hand, and the wrist and hand (B and C sections) of the FM having a correlation of 0.92. The total scores for both measures were correlated at 0.91. Malouin et al (1994) found a SCC of 0.96 for the total scores of both measures, and 0.92 and 0.89 for the upper extremity sections suggesting greater correlation than found by Poole and Whitney (1988) the results of both studies suggest criterion validity for the MAS

Although the FM and MAS scores have been shown to be correlated, the MAS provides additional information regarding the completion of functional activities that are not specifically addressed by the FM. The FM can be considered a measure of impairment (of body structures and functions) whereas the MAS is a measure of activities.

Test re-test reliability

Carr et al (1985) investigated the test re-test reliability on a group of chronic stroke subjects at four-week intervals. They found an average PMCC of 0.98 and suggested high reliability. They did not report an ICC or an estimate of the magnitude of the difference. As there was a significant time period between the two measurements this may not have accurately measured test re-test reliability, which assumes no change in status between the two measurements (Finch et al 2002). Loewen and Anderson (1988) also investigated the test retest reliability of the MAS. They reported SCC from 0.81 for one therapist to 1.00 for 3 therapists with the majority of subsections having excellent reliability (Kappa coefficient >.75). They did not report ICC or Bland and Altman limits of agreement and the mean difference in score was not reported.

Sensitivity

The distribution of scores on the MAS was compared to those of the FM by Malouin et al (1994). They found that for subjects with less return the FM was more sensitive to change than the MAS. Low functioning subjects tended to accumulate at the bottom end of the MAS, whereas scores were more evenly distributed on the FM.

Although there is little psychometric analysis on the MAS, it was chosen over other measures of UE activity as it only considered activities of the affected UE and its construct suggested less floor and ceiling effects than other measures of UE activity. Thus the scale has the potential to detect change at the level of activities in both low and high functioning subjects. Other studies have not explicitly investigated the effect of a treatment intervention on the three levels of functioning (WHO 2001), which was one of the aims of the present study. In addition the MAS is widely used in clinical practice in Ireland and the UK allowing results to be meaningful to the clinical setting.

Participation level

SF-36

Health related quality of life (HRQOL) was measured using the SF-36 on four occasions – at the start of the study and then at the end of each phase.

The 36 item short form (SF36) was derived from the Medical Outcomes Study questionnaire. It was initially designed as a generic indicator of health status (McDowell & Newell 1996). It includes eight scales measuring physical functioning (PF), role limitations due to physical health problems (RP), bodily pain (BP), general health perceptions (GH), vitality (VT), social functioning (SF), role limitations owing to emotional problems (RE), and mental health (MH). From these items physical health (PCS) and mental health (MCS) subscales can be derived.

This survey was chosen primarily because in searching the literature, it was the only outcome measure found that had an acute version that refers to perceptions of quality of life over the past week (others refer to longer time periods). This was important as the impact of a relatively short duration of intervention (three weeks) was to be assessed.

The SF36 can be self administered or used in interview format. The survey was self administered when possible and used in interview format as a second choice. The mode of administration was constant for each subject during the study.

The survey was scored using the online scoring demonstration at www.sf-36.com
This method uses norm-based scoring algorithms which transforms weighted scores to a scale of 0 – 100, with 100 representing better HRQOL.

The survey has undergone extensive psychometric analysis, the results of which are published in manual and paper format (Ware et al 1993, McHorney et al 1994) a brief summary of stroke related research is presented below.

Validity

The SF36 includes eight of the most frequently measured health concepts ensuring content validity (Finch et al 2002). Its construct validity for patients with stroke has been examined by Anderson et al (1996). They found clear differences in the 8 subsections suggesting discriminant validity and correlation of mental and physical health scores with the GHQ 28 and the BI respectively (Mann-Whitney test for comparison of ranked scores) suggesting known group validity. It detected appropriate differences from norms in a New Zealand population of subjects with stroke (Hackett et al 2000) suggesting discriminant validity.

Test re-test reliability

Dorman et al (1998) investigated the test-retest reliability of the SF36 in subjects with stroke. They found that the SF-36 had small mean differences in score between tests (0.2-3.1) and ICCs ranging from 0.28 for mental health, to 0.81 for general health when completed by the patient. Questionnaires completed by the subjects had better test-retest reliability than those administered by proxy. The discrepancy between the small mean differences and low ICC values may be explained by the large standard deviation in difference in scores which was between 15 and 22 points. It had similar reliability estimates to the EuroQol, the authors therefore concluded that it is an effective measure for discriminating health related quality of life.

Sensitivity

In their comprehensive review of the psychometric properties of the SF36 McDowell and Newell (1996) found that the SF-36 was generally sensitive to change in subjects' status. No studies directly investigating this property in patients post stroke were found.

4.3 Procedure

4.3.1 Subject selection

A sample of convenience was utilised and subjects were sourced from three primary locations: The Department of Age Related Healthcare at the Adelaide and Meath Hospital Tallaght (AMNCH), the Stroke Unit at Baggot Street Community Hospital (BS) and the Department of Medicine for the Elderly in St James' Hospital (SJH). The senior physiotherapists at these 3 locations were contacted and the inclusion/exclusion criteria presented. They then forwarded the names of suitable current subjects to the author. In addition to this a search of the stroke database at AMNCH and BS was completed to identify other suitable participants not currently receiving treatment.

Subjects were contacted by the senior physiotherapists and, if expressed an interest, were sent an information leaflet outlining details of the study. During the course of the study the author was contacted by several subjects, who had learned of the study through word of mouth, two of whom were suitable to participate.

Those subjects who expressed an interest in taking part in the trial were assessed for suitability by the author (presence of a deficit in UE function and SOMCT >20) to establish ability to give informed consent and complete all assessments. Their treating physician was then contacted and medical suitability was established. For one subject with expressive aphasia their speech and language therapist (SLT) was consulted to establish sufficient levels of communication and comprehension to complete the SF36 and other outcome measures.

4.3.2 Inclusion/Exclusion criteria

As the study consisted of a series of single case studies comparing each subject to their own baseline it was possible to recruit subjects with varying levels of impairment and at varying times post stroke using broad inclusion and exclusion criteria.

Inclusion criteria:

To be considered for inclusion into the study subjects had to meet the following criteria: Subjects with a first stroke with residual UE dysfunction where stroke was defined by the WHO definition: "rapidly developing symptoms and/or signs of focal and at times global, loss of cerebral function with symptoms lasting for more than 24 hours or leading to death with no apparent cause other than that of vascular origin" (WHO 1989).

In addition subjects must have been medically stable (as assessed by their treating physician) and able to give informed verbal or written consent (SOMCT score greater than 20).

Exclusion criteria:

Subjects were excluded from the study if they met any one of the criteria below: A documented history of previous stroke. Communication deficits that meant they could not follow the testing or RMT procedures (consultation with speech and language therapist where appropriate). Hemiplegia due to subarachnoid haemorrhage. Pacemaker (due to electromagnetic fields omitted by the safety mechanisms of the RMT system).

4.3.3 Subject consent

The joint ethics committee of SJH and AMNCH approved the study (Appendix 9).

Each subject completed a written consent form prior to commencing the study (Appendix 10) and was provided with a subject information leaflet (Appendix 11).

4.3.4 Randomisation

The twenty subjects were randomised in two ways: to the order that treatments were received (i.e. ABC and ACB where A was baseline measurement, B RMT and C SS) and to the length of the baseline phase (i.e. 8, 9, or 10 data points).

Twenty brown envelopes containing the 20 options (10 ABC, 10 ACB) for treatment order and twenty one white envelopes containing the 21 options for baseline length (7 for 8 data points, 7 for 9 data points and 7 for 10 data points) were prepared before the start of the trial. The subjects on their second visit chose one white and one brown envelope. The options contained in the envelope were assigned to that subject and marked on the subject data sheet.

4.3.5 Description of treatments

Robot Mediated Therapy

Robot mediated therapy (RMT) used the first prototype of the GENTLE/s system which was developed by the members of the GENTLE/s consortium (www.gentle.rdg.ac.uk) (Figure 4-7, Figure 4-8, Figure 4-9). The investigator was involved in the development of the prototypes of the system and spent time at the Cybernetics department in the University of Reading giving input as to the needs of both the physiotherapy and patient users as to the computer interface and programme requirements (for example navigation by the physiotherapist through menus and programming aspects and ease of use for the patient of the system, cues on screen, operation buttons). Several meetings at various locations were attended, where the physical attributes, practical requirements and safety elements of the physical system were evaluated, discussed and modified accordingly. A short pilot study to investigate the clinical applicability of both the physical and computer aspects of the first prototype of the system was carried out (Coote & Stokes 2003a) after which alterations to the programming and physical components (attachment of UE to system) were made.

The system (Figure 4-7) includes the robot control system and computer and the robot arm. As these components cannot be moved once the system is installed two adjustable chairs are provided so that both the right and left arm of the patient can be attached to the robot arm. The rotating monitor can be placed in front of either chair. The overhead support system can be moved into position over either chair and the free moving supports allow nearly frictionless movement of the arm in space. The supporting platform under the chairs slides left and right so that the patient can be transferred into the chair safely and then the entire chair and platform slid under the table to position the patient appropriately at the work station.

Figure 4-7. The GENTLE/s system

The subject is connected to the system via a wrist and an elbow orthosis (Figure 4-8). The elbow orthosis had a free moving hinge and two support wires attached to an overhead frame. The function of the elbow orthosis system is to de-weight the arm and in so doing to minimise the presence of subluxation. It also permits movement that cannot normally be accomplished by the patient due to the effects of gravity. The function of the wrist orthosis was to support the wrist in a functional position (15 degrees extension) and to attach the subject to the robot arm. The attachment to the robot was via a magnetic breakaway connection which served to disconnect the subject's arm from the robot should an excessive traction force be applied.

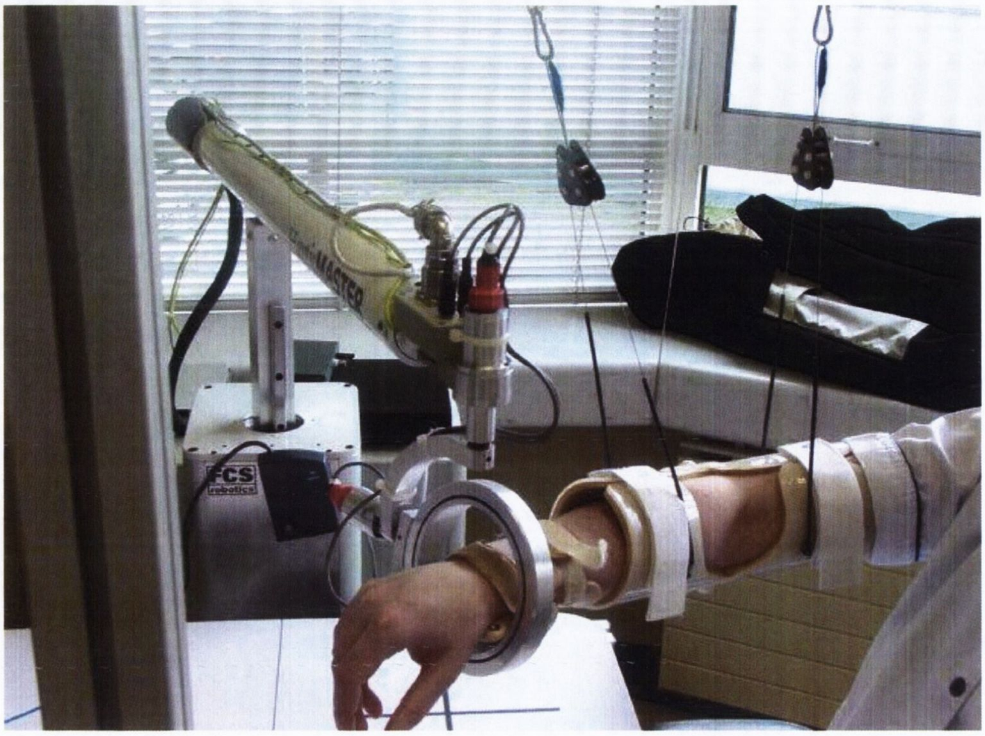

Figure 4-8. Arm attachment to the GENTLE/s system

Exercising with the GENTLE/s system involved the subject being seated in the adjustable height chair with a body harness in place to limit compensatory movements with the trunk and shoulder girdle and to provide a physical prompt when the subject initiated these compensations.

The movement of the robot arm was represented on the screen by a pink ball with a blue ball representing the target at the end of the required movement trajectory (Figure 4-9).

Figure 4-9. Visual representation of robot location

The subjects exercised in two visual environments (Figure 4-10), a 3-D virtual representation of the real world (B) or a virtual room (C).

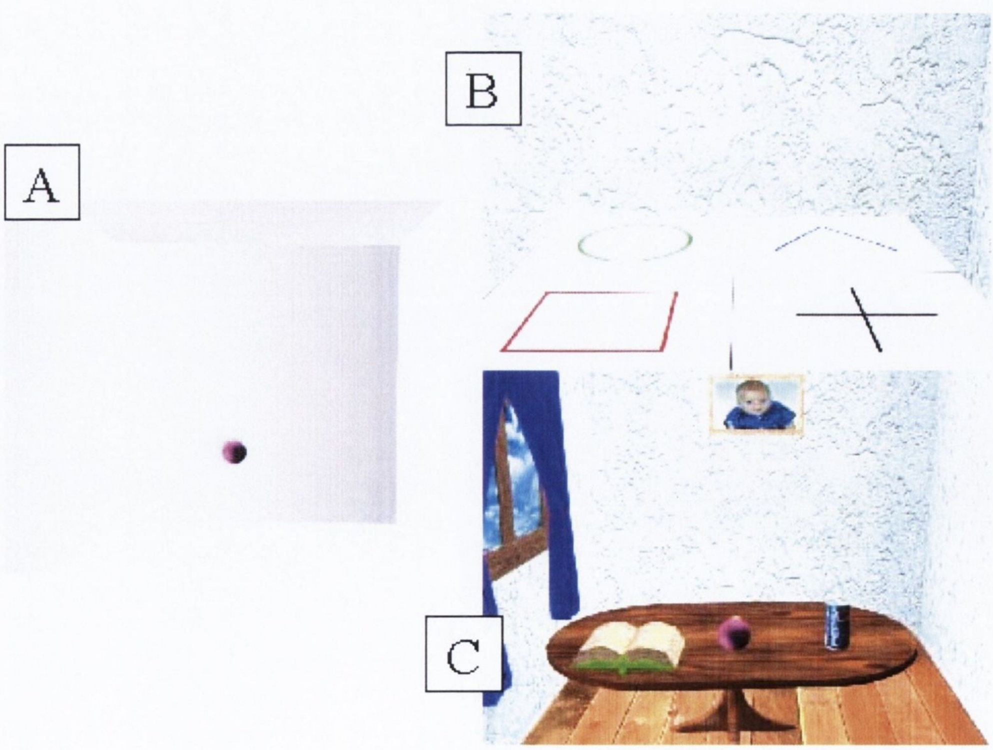

Figure 4-10. Virtual representation on screen

The subject completed three exercises that were repeated daily over the 9 treatments in the RMT phase. These exercises were tailored to the individuals' movement abilities and available range of motion. The exercises were constructed in the set up mode of the robot and involved the subjects' arm being guided through the required movement pattern and points being inserted at the end of the movement trajectories. These movement patterns were then saved to the computer memory to allow exact reproduction from session to session. Generally each patient completed a reaching exercise, a hand to mouth exercise and a transport exercise from one side of the workspace to the other.

Three activity levels are available in the GENTLE/s system: passive, active assisted and active. In passive mode the subjects' arm is moved along the pre-programmed path by the robot. Subjects who were unable to generate sufficient force in the desired direction, usually those with no muscle activity or a flicker without AROM, used this mode. In this mode subjects were given verbal cues to try and move with the robot while watching the movement on screen.

In active assisted mode, the robot completed the movement along the path only once the subject generated sufficient force towards the target at the end of the path. This mode was used for subjects who could generate some muscle activity but not enough to use active mode. In this mode subjects were given verbal instructions to try to move the pink ball to the target blue ball.

In active mode the movement generated was of an isokinetic nature. The subjects were instructed to move along the path and perceived that the harder they pushed the harder the robot pushed against them. Those subjects with only little muscle activity could achieve movement of their arm while attached to the system that they could not achieve otherwise due to the de-weighting component of the system and the method of delivery of this mode.

Sling suspension

The sessions of treatment using sling suspension followed the standard procedure for this treatment (Hollis & Fletcher-Cook 1999).

The subject was positioned in side lying with their affected arm uppermost. (Figure 4-11). Axial suspension was used, with the "s hook" and point of fixation directly over the joint being moved and one sling under the humerus and one under the hand. The subject completed 3 exercises, which consisted of movement of the joint in one plane, elbow flexion/extension, shoulder flexion with elbow flexion and shoulder flexion with elbow extension.

The subjects who could move through the full range of motion exercised independently. Those who could achieve partial range had assistance from the therapist in the completion of the movement (active assisted). For those who could not generate any movement the therapist completed the movement for them and gave cues for them to assist as able (as for the passive mode of RMT).

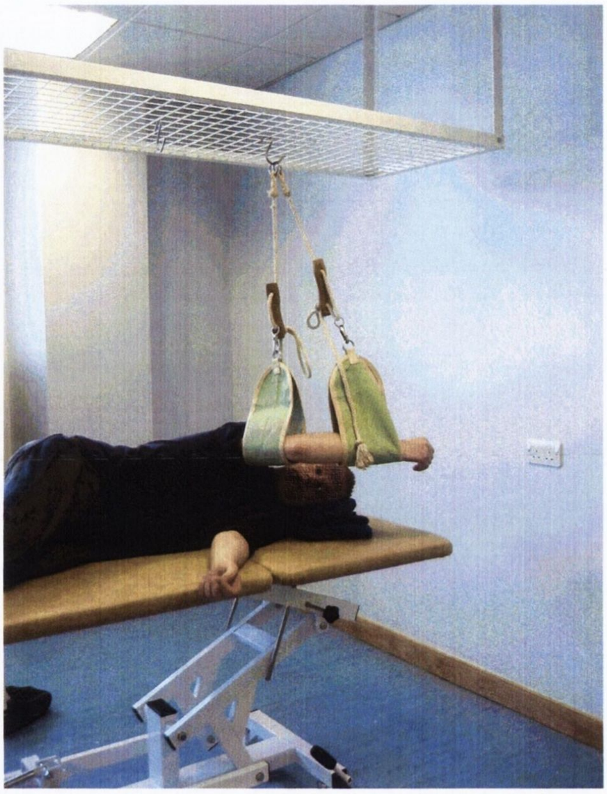

Figure 4-11. Sling suspension, shoulder

As with the RMT phase of the trial each of the 3 exercises was done for 10 minutes each per treatment with a total treatment time of 30 minutes.

4.4 Study Course

Twenty subjects were enrolled in the study, which took place between September 2001 and 2002. The study was divided into four phases each of 9 weeks duration. Only 5 subjects could participate at a time due to appointment schedules and equipment availability thus ensuring non concurrent baselines. The reasons for missed appointments and any concurring events are documented in the results for each individual subject.

Early in the baseline phase of one of the first 5 subjects, one patient reported having practiced doing the components of the outcome measure at home. All patients were subsequently informed that they should not change their routine at home in terms of content and duration of home exercise programmes (HEP) or activity where possible for the duration of the study. They were asked to report any changes in duration of therapy or of content or duration of HEP to the investigator. These are documented in the results for the individual subjects.

Some patients were receiving therapy at the time of the study and some had been discharged. The baseline phase captures their rate of recovery under the relevant circumstances and comparison of this to the treatment phases allows the investigation of either the treatment effect of the GENTLE/s system or of the effect of additional treatment with the GENTLE/s system.

4.5 Data analysis

4.5.1 Introduction

The aim of the study was to investigate whether RMT had a positive treatment effect on the hemiplegic UE at the level of body functions, activities and participation. The background measures and the SF-36 were measured at the start of each phase and at the end of the study. The study outcomes measured the level of recovery of the UE during a baseline period and continued measuring during a period of treatment with RMT and with SS. The effect of RMT was assessed by comparing the rate of recovery during the treatment phase with that of the baseline and SS phases. The output of the study design provided a series of 26, 27 or 28 data points (depending on randomised baseline length) for each of the 20 patients. The data for each outcome measure and sub-section for each subject was entered into an Excel spreadsheet. Initial analysis consisted of plotting the data on line graphs so that the trend and changes in trend between phases could be examined visually.

4.5.2 Visual analysis

Traditionally single case experiments have been analysed using visual analysis of graphed data, it is only in more recent years that statistical and semi-statistical methods of analysis have been employed.

Visual analysis of the data identifies the presence or absence of a change in level, variability, trend or slope (Kazdin 1982, Zhan & Ottenbacher 2001). When changes in performance are large and easily interpreted statistical methods are not needed (Sunderland 1990, Zhan & Ottenbacher 2001). However, other properties of data such as non-stable baselines, poor evidence of a trend in data and variability between data points may be better dealt with through the use of statistical tests (Kazdin 1982).

There is much debate as to the reliability of visual analysis as it is based on the subjective interpretation of the plotted data (Broboviz & Ottenbacher 1998). Several authors have suggested a low inter-rater agreement in visually analysed data (Backman et al 1997, Zhan & Ottenbacher 2001).

While visual analysis may reveal a difference between data in two phases of the study it does little to quantify this difference. It is a useful tool in first assessing the data (Brobovitz & Ottenbacher 1998), but does not allow the numerical comparison of the results between individuals.

This study was replicated across individuals with different background characteristics and sought to investigate which individuals or sub-groups of subjects would benefit most from this treatment. It was necessary to employ a method of analysis that would allow the comparison of the rates of recovery between individuals or groups of individuals in addition to visually analysing those graphs with a clear trend in them. For this reason, after the data was plotted in line drawings for visual analysis, the data was analysed using a general linear model (GLM) in SPSS.

4.5.3 General linear model

The research question asked whether the amount of recovery during the RMT phase was significantly different to that in the baseline and SS phases. A line through the data points seemed to best represent the rate of recovery in the phase. Authors have suggested drawing lines through the graphed data to assist in visual analysis (Kazdin 1982, Ottenbacher 1986) in this case a GLM was used to mathematically define least squares lines through the phases of the data. This described the lines through the phases in terms of the values for the intercept with the y axis and the slope of the line. Riddoch and Lennon (1991) and Sunderland (1990) suggest using linear regression to statistically evaluate single case studies by quantifying best fit lines through the data. The analysis of repeated measures data in this way using similar measurement scales is also suggested in the statistical literature by Dobson (2001) and by Everitt (1995) in a review of repeated measures analysis. While this method has not been reported previously in rehabilitation research it has been suggested by both physiotherapy researchers and statisticians as an appropriate means of analysing data such as that reported in this study.

The data for each group (ABC or ACB order of treatments) for each outcome measure was combined in an SPSS data sheet with indicator variables for each patient and each phase (Appendix 12). Missing data points were left as blank cells and not replaced and the GLM considered only the data points available when fitting the predicted lines to the data. The model used (Table 4-2) allowed for an interaction effect between each patient and each time variable and accounted for the fact that each patient started at a different first value and had a different rate of recovery during each phase.

Statistical Model Used, Univariate GLM in SPSS	
Fixed factor	Patient
Covariates	Time A, Time B, Time C
Model	Patient, Time A Time B Time C Patient*Time A Patient*Time B Patient*Time C

Table 4-2, Statistical model used

An example of a set of data for one variable for patient 1 is shown in Figure 4-12. The navy line represents the line through the values obtained for the FMA score at each visit. The pink line is the least squares line drawn through the data by the GLM. The value for the slope (or unit increase in FMA score) for each phase is indicated in the figure. Thus the GLM provides a numerical quantification of the straight line representing the rate of recovery of each subject for each phase for each variable and allows the comparison of the rates of recovery between phases and between patients.

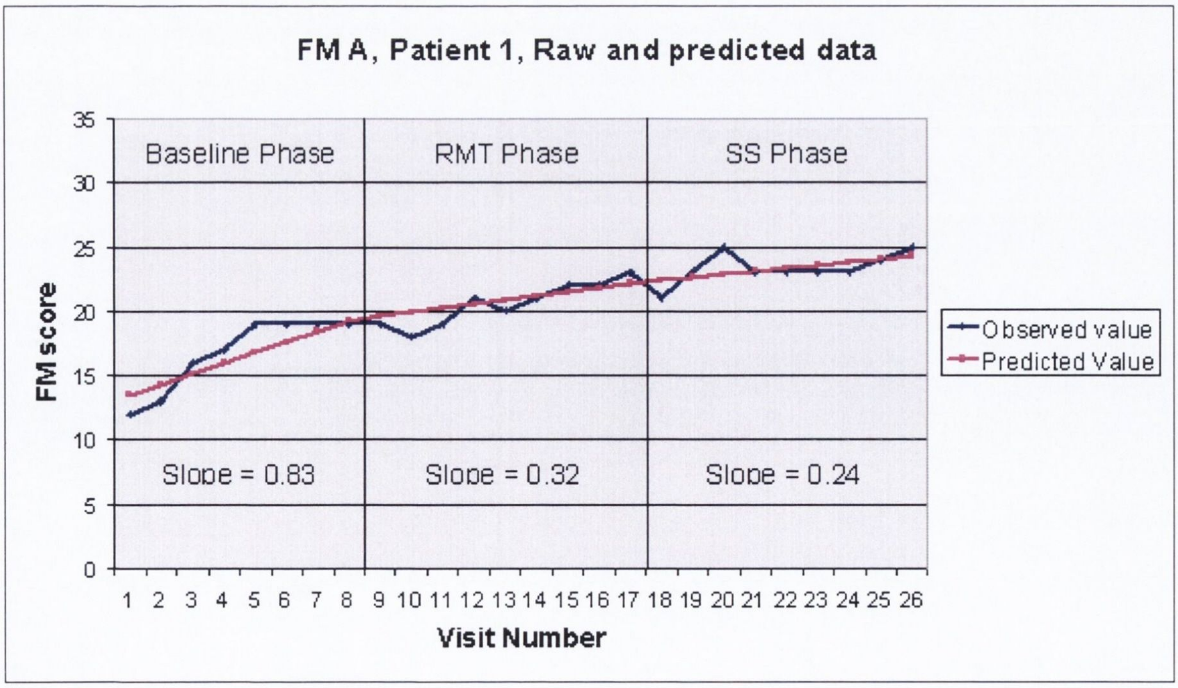

Figure 4-12. Observed values and values predicted by GLM

To check whether the model used adequately fits the data it is important to compare the fitted model to the actual data (Myers et al 2002) this was done by examining plots of the observed and the predicted values for each variable. Figure 4-13 is a plot of the raw data for this variable for the ten patients in group 1 and Figure 4-14 is a plot of the line drawn in the data by the GLM. The continuity of the lines in these figures and the similarity of the plotted raw data to the predicted data for each variable demonstrated that the model used is a good representation of the raw data and suggests that the slope values obtained accurately represent the rates of recovery during the phases.

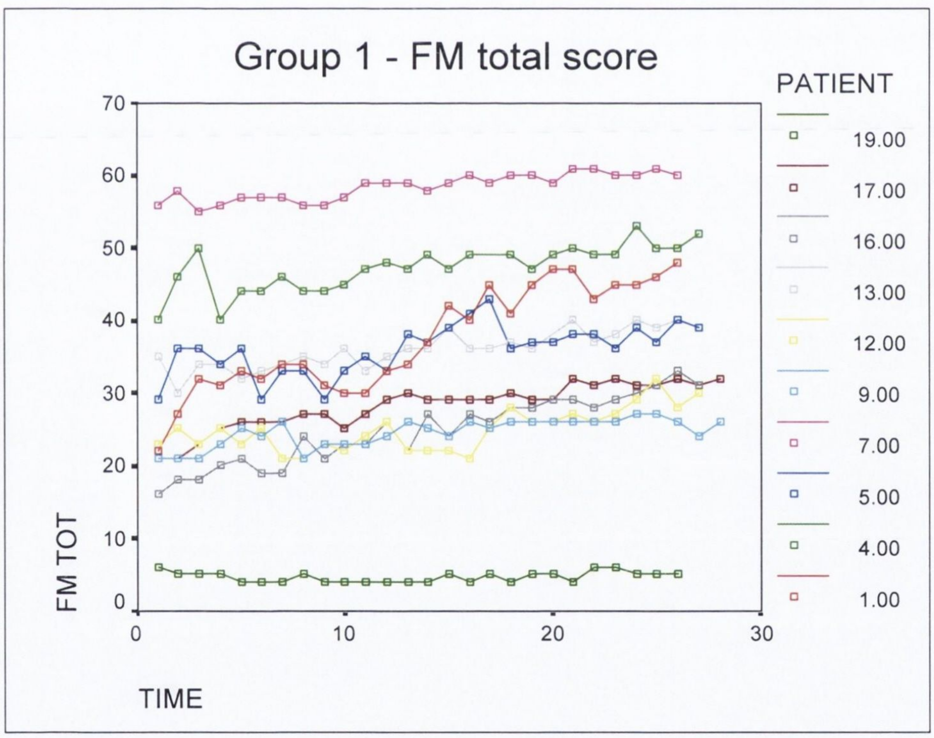

Figure 4-13. Plotted raw data, FM total

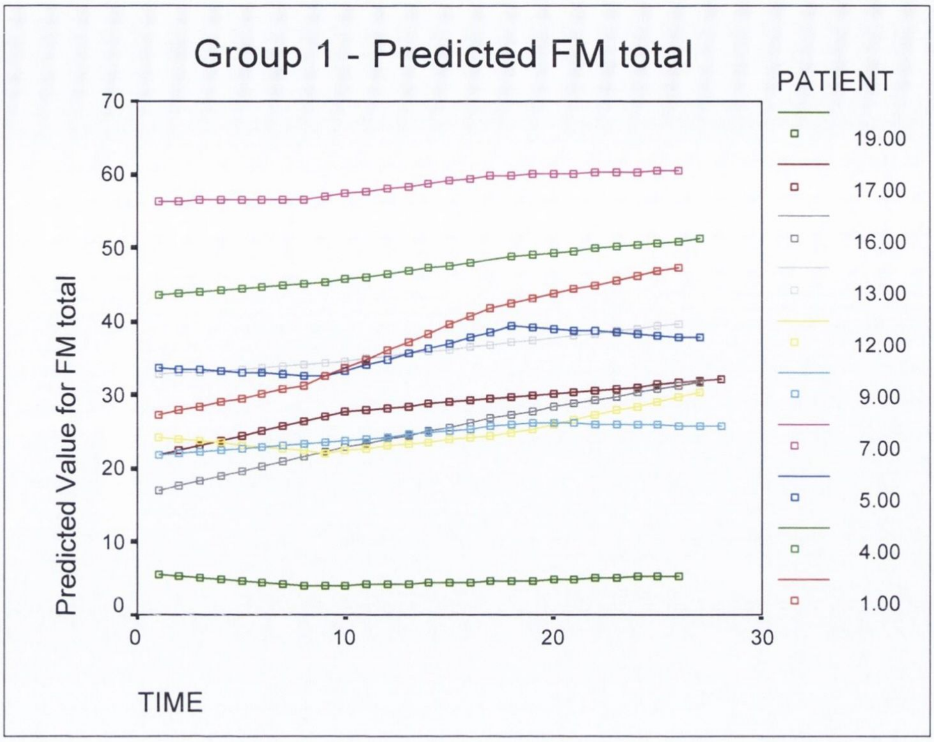

Figure 4-14. Plotted predicted lines through data from GLM

To verify that none of the least squares regression assumptions are violated, the residuals from the least squares fit should be examined (Myers et al 2002). Plots of the data should be used to check the validity of the regression assumptions and if they show variations from normal distribution, independence or constant variance, the model should be considered invalid (Woolfson & Clarke 2002). Examination of the standardised residuals versus the dependent variable, normal probability plots of the residuals, and the observed and predicted values of the dependent variable showed all but the MAS C variable to be satisfactory. For this variable there was an excess of residuals with a value of 0, which suggested that most of the data points fitted exactly on the line. This can be explained by the fact that many of the subjects had a score of 0 on the MAS C section hence the predicted line was drawn through the value of 0 and many residuals were located there.

This was disregarded as to transform this one variable, which is a subsection of a measure, in isolation would deem its comparison to others void. Following examination of all of the above plots the model was considered appropriate for this data set as none of the assumptions were violated.

In the first instance the difference between the absolute values for the slope, or rate of recovery, was compared by subtracting the baseline slope from the slope during the RMT phase. Secondly the rate of recovery in the treatment phases was compared by subtracting the slope during the SS phase from the RMT phase.

4.5.4 Criteria for true change

In recent years a debate has developed over a difference between measurements that is statistically significant, versus a difference that is clinically significant. Differences between sets of measurements can become statistically significant either by increasing the number of cases in which the difference is seen, by decreasing the variability between cases or by increasing the actual difference. It is therefore possible that a relatively small difference on two measurement occasions can become statistically significant while only representing a 3 or 4 point difference on a clinical scale out of 100. This change may be statistically significant, but fails to represent a clinically meaningful change in the patients' status.

For this reason authors have suggested the use of a criterion for change based on the measurement error between occasions rather than on traditional statistical methods (Guyatt et al 1987, Ottenbacher et al 1988, Dixon & Keating 2000, Stevenson 2001, Stratford et al 1996, Kwakkel et al 2002). This criteria based on the standard error of the measurement (SEM) was used in this study.

An example of the application of this SEM based criterion for chang is the statistically significant difference in FM score found in the study by Krebs et al (2000). The difference in improvement between the treatment and control groups was only 2.1 points on the 66 point FM scale, yet it was statistically significant ($p<0.05$). A difference of 2.1 points does not represent a large difference clinically and if we apply the SEM based criterion for the FM scale found by Sanford et al (1993) which suggests that on 68% of occasions the true score will fall within 3.6 points of the obtained score, a change of greater than 9.97 FM units would have to be seen before the difference can be attributed to anything other than measurement error.

SEM based criterion for change

For every measurement taken the value obtained contains the true measurement and an element of error. In order to assess whether the difference in slope values could be attributed to true change or to change due to measurement error a criteria for change based on the standard error of the measure was used. The standard error of the measure or absolute reliability of a variable (Finch et al 2002) represents the magnitude of error associated with an outcome measure. The SEM combines rater, occasion and error variance, is expressed in the units of the measure, and is calculated as follows

$SEM=\sigma\sqrt{1-R}$ (σ=standard deviation, r=Intraclass Correlation Coefficient).

This is mathematically equivalent to the square root of the mean square error term for within subjects from the ANOVA table (Stratford et al 1996). The value of 1 SEM indicates that on 68% of occasions the "true" measurement will fall within 1 SEM of the measure obtained or on 95% of occasions the "true" value will fall within 1.96xSEM (Finch et al 2002).

In order to calculate whether the difference in two scores is greater than that due to error the SEM is multiplied by $\sqrt{2}$ to account for the error of the two measurement occasions (SEM_{diff}). To establish how great a difference would be seen by chance at α=0.05 the SEM_{diff} is multiplied by 1.96. This is described as the minimum detectable change (MDC) (Stratford et al 1996), reliability change index (Ottenbacher et al 1988), minimum difference to be exceeded (Eliasziw et al 1994) or smallest real difference (Beckerman et al 2001). If a change in score is greater than the MDC the change can be attributed to true change and not measurement error. Thus the MDC is calculated as follows

$MDC=1.96 \times \sqrt{2} \times SEM$

The use of the MDC to evaluate "true" change, as opposed to that brought about by the error of the measurement in physiotherapy studies has been advocated by many authors (Guyatt et al 1987, Ottenbacher et al 1988, Dixon & Keating 2000, Stevenson 2001, Stratford et al 1996, Kwakkel et al 2002). The advantages of this criterion for change lies in the fact that it is independent of the variation in scores between individuals and that it is expressed in terms of the units of the measure. It can therefore be used in this study for each individual and to compare the effect of RMT on one subject to another and to assess whether the difference in rate of recovery between phases can be attributed to the error between measurements or true, clinically meaningful, change in the rate of recovery.

The value for the SEM, or absolute reliability of the measure, was calculated from the last 2 values of each measure in the baseline phase (i.e. data point 8 and 9 for those with baseline length of 9). These values were chosen to rate the reliability of the measure as it was expected that the learning effect of the subject and the rater would have been minimal at this point in the study. The use of the within subjects mean squared error for the GLM could also have been used, but as it considered all data points for all subjects it would have contained within subject variability due to the effect of treatment also. There was no treatment occurring during the last two data points of the baseline phase therefore the within subjects variability at this point in time would have been less than that found in that of the GLM.

As this study is concerned with the change in rate of recovery across phases and the slope value represents the unit increase per treatment an adjusted MDC had to be calculated. In order to compare differences in slope value (or unit increase per treatment) the MDC for the measure is divided by the number of treatments per phase (i.e. 9 per phase). This adjusted MDC value (aMDC) is the criteria for change used in the results section. The SEM, MDC and aMDC for each variable are reported in the results chapter.

4.5.5 Analysis of different variables

The MVIC and ROM data are continuous in nature whereas the FM and MAS are numerical scales scored by rating movement in categories. The SF-36, while based on categories is treated as continuous data as the scoring algorithm represents a percentage of normal values which constitutes a continuous scale. The FM and MAS, as with the majority of other measures of UE motor function and activities, are subjective measures where a rater matches the observed movement to a numerical category best describing the patient's abilities. For the purposes of the analysis of the data from this study the FM and MAS were treated as interval scales.

It could be argued that mathematically the FM and MAS measures are not categorical but interval in nature as the authors have constructed them in such a way that they involve the summing of scores. Once numerical values have been allocated to sub scores and these summed to give a total score, the assumption is made that the numbers allocated to the underlying categories have a meaning and can therefore mathematically be treated as interval data. The numbers allocated to the scales indicate a level of function, with an increase in number representing an increase in ability. The GLM is being used purely to quantify that increase in score by drawing a line through the data that best fits the data (least squares line) and calculating a slope value, which represents the unit increase per treatment. As reported in the previous section the criteria for GLM/least squares analysis have been rated as met as the analysis of residual plots suggested that the model suited the data.

The analysis of the FM using parametric tests has been widely reported in the clinical literature (see Table 4-3) and considerable consultation with statisticians suggested that there was no equivalent non-parametric test that would generate the desired output. The MAS has not been used extensively in clinical trials and similar data was unavailable. Of the two studies where it was used to evaluate the outcome of a clinical trial one (Langhammer & Stanghell 2000) used t-tests, and the other (Poole & Whitney 2001) treated it as an ordinal scale.

Authors	Study	Analysis used
Duncan et al 1983	Reliability of FM	ANOVA, ICC
Duncan et al 1992	Recovery of UE and LE	t-tests, Chi squared tests,
Sanford et al 1993	Reliability of FM	ANOVA, ICC
Feys et al 1998	Study of treatment effect of rocking chair with affected UE	ANOVA
Krebs et al 1998	RCT of treatment effect of RMT system	t-tests
Sonde et al 1998	RCT of treatment effect of TENS	Mann-Whitney U, SCC
Van der Lee et al 1999	RCT on effect of forced use on affected UE use and function	GLM
Volpe et al 1999	RCT on RMT system	t-tests
Krebs et al 2000	RCT of treatment effect of RMT system	t-tests
Cauraugh et al 2000	RCT of EMG triggered electrical stimulation	ANOVA
Volpe et al 2000	RCT of RMT system	Kruskal Wallis, Mann Whitney U
Whitall et al 2000	Single group pilot study of bilateral training	ANOVA (Tukeys test)
Lum et al 2002	RCT of treatment effect of RMT system	ANOVA following test for normality and homogeneity of variance
Fasoli et al 2003	RCT of treatment effect of RMT system	ANOVA, t-tests

Table 4-3. How authors treated the FM scale

Therefore the analysis of the FM and MAS data in this study is consistent with current practice and uses methods that allow the comparison of these results to those of other studies in this area for discussion purposes. The question as to whether the evaluation of human movement using subjective, category based measures is appropriate and the subsequent analysis of the data obtained is a topic outside of the scope of this thesis. The analysis used in this study has used methods based on the normal distribution of the data, which is deemed suitable by the majority of other researchers in this area and which has not violated the assumptions of the model used.

4.5.6 Analysis of change in background measures

The pain and tone measures and the SF-36 were taken at the start of each phase and at the end of the study. The scores for each subject are reported individually but as it was not possible to calculate SEM values and hence MDC values, and none were found in the literature, it was not possible to indicate the significance of the change in these variables. To do this the mean change in score across each phase of the 10 individuals in the ABC and ACB groups was calculated and assessed for significance using paired t-tests for pain and SF-36 and Wilcoxon Signed-rank test for tone (modified Ashworth scale). To evaluate whether the change in score across one phase was significantly different to the change in another phase the "change in score variable" for the phases were compared as above. This involved creating new variables that were calculated by subtracting the score of one phase from the other. The similarity of the groups in terms of background characteristics is assessed using t-tests or Chi-squared tests.

4.5.7 Average response to treatment

The responses of the 20 subjects for the 24 variables is reported and their individual results are compared to MDC values to assess the significance of the difference in rate of recovery between phases for each subject. This generated a large amount of data which did not allow trends to be seen and did not allow the investigation of the effect of the order of the treatment received. Therefore for ease of interpretation and discussion and to assess the effect of the order of treatment received on the rate of recovery during the RMT phase, the average response of the 10 individuals in the ABC and ACB groups are presented in table format.

The average slope value for each treatment phase is calculated by estimating the mean of the 10 slope values for each phase, the significance of the difference between phases is estimated using paired t-tests.

Thus the results chapter reports the response of the 20 subjects to RMT by comparing the rate of recovery (slope value or unit increase per treatment) in the RMT phase to that in the baseline and SS phases. The significance of this change is estimated by comparing the difference in slope values to the value of the MDC.

For the baseline measures the change across each phase and the difference between the "change over phase" variables are reported for each group. The difference of the background characteristics of each group is compared using 2-sample t-tests or Chi-squared tests. For ease of interpretation and discussion the average response of the 10 subjects in each group is reported.

5 Chapter 5 – Results

The study aimed to investigate the effect of the GENTLE/s robot mediated therapy (RMT) system on upper extremity (UE) dysfunction post stroke. The study design allowed the comparison of the rate of recovery during the robot mediated therapy (RMT - B) phase to a baseline recovery (A) phase and to another treatment, sling suspension (SS - C).

The rate of recovery is estimated by calculating the slope of a least squares line through the data. The slope value obtained estimates the unit increase per treatment for that phase.

Section 5.1 presents the values for the standard error of the measure (SEM), minimum detectable change (MDC) and adjusted MDC (aMDC) for the study variables. The aMDC is the criteria for change used to distinguish true change from measurement error for those measures taken every day of attendance (see Chapter 4.5.4).

Section 5.2 presents the results for each individual subject. Line plots for visual analysis, the numerical slope values for the rate of recovery in each phase and the difference in slope value between each phase for each study variable are presented.

Section 5.3 presents the results for the background measures of pain and tone and the SF-36 results. The average response of the 10 subjects in group 1 and the 10 in group 2 are presented. Whether there was a significant change over the phase and the comparison of "change over phase" variables to each other is presented.

Section 5.4 presents the comparison of groups 1 and 2 according to baseline motor ability, tone, pain, sensory deficit, time post stroke and age.

Section 5.5 presents a summary of the results. The individual results are summarised in table format. In addition the average responses of the groups is presented.

Table 5-1 presents the outcome measures used, the range of scores and the abbreviations used in this chapter. Table 5-2 presents the background measures used and their range of scores. For all measures a high score indicates higher/more normal functioning unless otherwise indicated.

Abbreviation	Full name	Range of scores
FMA	A section (shoulder and elbow) of Fugl Meyer motor assessment	0-36
FMB	B section (wrist) of Fugl Meyer motor assessment	0-10
FMC	C section (hand) of Fugl Meyer motor assessment	0-14
FMD	D section (coordination of Fugl Meyer motor assessment	0-6
FMT	Total score on Fugl Meyer motor assessment (sum A to D)	0-66
MASA	A section (upper arm) of Motor Assessment Scale	0-6
MASB	B section (hand activities) of Motor Assessment Scale	0-6
MASC	C section (advanced hand activities) of Motor Assessment Scale	0-6
MAST	Total score of Motor Assessment Scale (sum A to C)	0-6
ElbFlex	Maximum voluntary isometric contraction of elbow flexors	Pounds
ElbExt	Maximum voluntary isometric contraction of elbow extensors	Pounds
ShoFlex	Maximum voluntary isometric contraction of shoulder flexors	Pounds
ShoExt	Maximum voluntary isometric contraction of shoulder extensors	Pounds
AShFl	Active range of motion of shoulder flexion	Degrees
PShFl	Passive range of motion of shoulder flexion	Degrees
AShA	Active range of motion of shoulder abduction	Degrees
PShA	Passive range of motion of shoulder abduction	Degrees
AElX	Active range of motion of elbow extension	Degrees
PElX	Passive range of motion of elbow extension	Degrees
AShER	Active range of motion of shoulder external rotation	Degrees
PShER	Passive range of motion of shoulder external rotation	Degrees
AElFl	Active range of motion of elbow flexion	Degrees
PElFl	Passive range of motion of elbow flexion	Degrees
Grip	Grip strength	Kilograms

Table 5-1. Outcome measures and abbreviations

BACKGROUND MEASURES	Range of scores
Short Orientation Memory Concentration Test	0-28
Star Cancellation L	0-27
Star Cancellation R	0-27
Star Cancellation Total	0-54
Pain	0-10 (0 = no pain)
Hemianopia	Absent = 0 Visual inattention = 1 Present = 2
Tone Wrist	0-5 (0 = no increase in muscle tone)
Tone Elbow	0-5 (0 = no increase in muscle tone)
Sensation Light Touch	0-8
Sensation Pressure	0-8
Sensation Bilateral Simultaneous	0-8
Sensation Kinaesthesia	0-12
Sensation Total	0-36

Table 5-2. Background measures used

5.1 MDC values

The MDC value is obtained by the following formula MDC = 1.96*√2*SEM. In this study the SEM was calculated using the square root of the mean squared error term from the ANOVA table from the reliability calculation using the last two measurements of the baseline phase. As the MDC indicates the change that must occur over a phase, and the slope value represents the unit change per treatment, the MDC is divided by the number of visits per phase (9) to get the aMDC value. Values for the SEM, MDC and aMDC for all variables is presented in Table 5-3. If the difference between the slope values is greater than the aMDC it can be considered statistically significant at α=0.05.

Measure	SEM	MDC	aMDC
FMA	1.32	3.66	0.41
FMB	0.59	1.64	0.18
FMC	0.63	1.75	0.19
FMD	0.39	1.08	0.12
FMT	1.47	4.07	0.45
MASA	0.32	0.89	0.10
MASB	0.22	0.61	0.07
MASC	0.22	0.61	0.07
MAST	0.32	0.89	0.10
ElbFlex	1.31	3.63	0.40
ElbExt	1.45	4.02	0.45
ShoFlex	1.56	4.32	0.48
ShoExt	2.5	6.93	0.77
AShFl	6.58	18.24	2.03
PShFl	4.52	12.53	1.39
AShA	5.5	15.25	1.69
PShA	6.46	17.91	1.99
AElX	5.74	15.91	1.77
PElX	2.64	7.32	0.81
AShER	2.35	6.51	0.72
PShER	3.92	10.87	1.21
AelFl	3.66	10.15	1.13
PelFl	3.42	9.48	1.05
Grip	0.83	2.30	0.26

Table 5-3. Criteria for change for study outcomes.

5.2 Results for 20 subjects

The individual results for each of the 20 subjects are presented in this section.

The subject's background characteristics, their randomization and their study course are described. The results for each variable are presented as a line plot for visual analysis and as the numerical slope value and the difference in the slope value between phases. The difference in the slope values for the phases is compared to the adjusted minimum detectable change value (aMDC) for each variable in order to establish statistical significance.

For ease of interpretation results are highlighted in different colours: when the absolute value for the RMT slope is greater than both the baseline and SS phases the variable name is highlighted in red. When the RMT slope is greater than baseline only the variable name is highlighted in blue and when it is greater than SS only it is highlighted in green.

When the difference in slope value is greater than the aMDC value they are considered statistically significant and are highlighted in yellow.

5.2.1 Subject 1

Mr SG was a 71-year-old man who had a right CVA, five months prior to the start of the study. His CT scan showed a lacunar (LACI) infarct. At the start of the study he was living at home with his wife and attending the Day Hospital at St James's Hospital once a week where he received 45 minutes of physiotherapy.

He was previously a very active man, involved in the local athletics club. He had a past medical history of bilateral total hip replacements. His medications included Tizanidine for reduction of tone. He was randomised to 8 baseline measurements and to the ABC group. He spent 26.8% of the time exercising in active assisted mode and 71.1% in active mode.

Events during course of study

Visit 2 - physiotherapy increased to twice a week.

Visit 6 - reported increased stiffness following treatment at the Day Hospital on the previous day

Visit 18 - reported feeling very tired

Background data

His background data is presented in Table 5-5. His SOMCT improved from start to end of baseline to the maximum score and remained at maximum for the rest of the study.

His star cancellation test decreased over the baseline by 2 points and increased by 1 point per phase back to the maximum score.

His pain levels decreased over each phase, the greatest decrease taking place over the SS phase. While the tone in his elbow remained unchanged as measured by the modified Ashworth scale, his wrist tone decreased from 3 to 1 over the RMT phase. His sensation remained within one point of maximal for the duration of the study.

Subject 1, Summary	
Age	71
Time post stroke	5 months
Side affected	Left
CT result	Lacunar infarct
Current physiotherapy treatment	45 minutes once a week
Randomisation	ABC, 8
Exercise mode	AA 26.8%, A 71.1%

Table 5-4. Subject 1, summary

BACKGROUND MEASURES	Start A	Start B	Start C	End C
Short Orientation Memory Concentration	24	28	28	28
Star Cancellation L	27	25	26	27
Star Cancellation R	27	27	27	27
Star Cancellation Total	54	52	53	54
Pain	2	1	0.9	0.45
Hemianopia	1	1	1	1
Tone Wrist	3	3	1	1
Tone Elbow	2	2	2	2
Sensation Light Touch	8	8	8	8
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	8	8	8	8
Sensation Kinaesthesia	11	12	12	11
Sensation Total	35	36	36	35

Table 5-5. Subject 1, Background data

Fugl-Meyer

For all subsections of the FM the rate of recovery during the RMT phase was higher than that in the SS phase. For all except the FMA section the slope value was higher in the RMT phase than the baseline. The plotted raw data shows that the slope for FMA in the baseline phase increased sharply initially but stabilised at the end of the baseline before the introduction of the treatment phases.

The rate of recovery for FM total score in the RMT phase was 0.61 units per treatment more than that in the baseline phase. This represents 5.49 units difference over the 9 visits of the phase. All of the differences between the baseline and RMT rates of recovery are above the aMDC for that section.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
FMA	12.66	0.83	0.32	0.24	-0.51	-0.08
FMB	5.63	-0.21	0.46	0.14	0.67	-0.33
FMC	7.29	0.00	0.20	0.11	0.20	-0.09
FMD	1.19	-0.05	0.20	0.12	0.25	-0.08
FMT	26.76	0.57	1.18	0.61	0.61	-0.57

Table 5-6. Subject 1, Fugl-Meyer

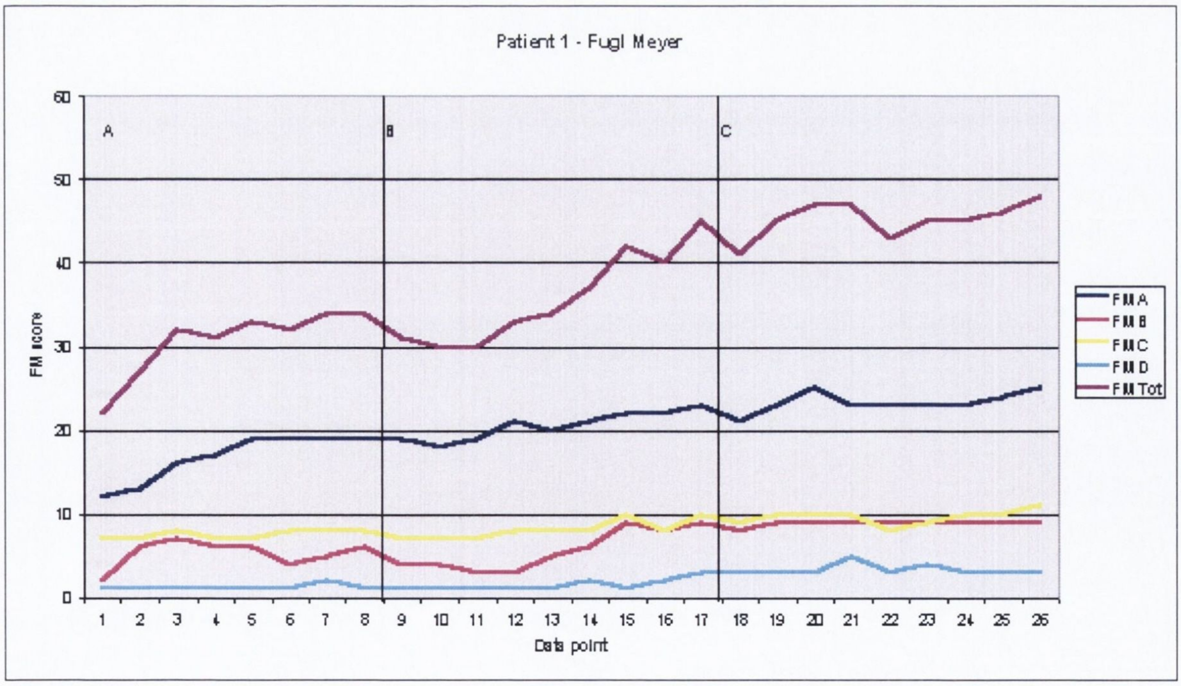

Figure 5-1. Subject 1, Fugl-Meyer

Motor Assessment Scale

The rate of recovery during the RMT phase was higher than both the baseline and SS phases for the MASB, MASC and MAS Total scores. These values were statistically significant for the MAST section only. For the MASA the slope value of the RMT phase was higher than the baseline but not the SS phase.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
MASA	3.09	-0.03	0.07	0.18	0.10	0.11
MASB	0.30	0.08	0.12	0.05	0.05	-0.07
MASC	1.94	0.14	0.17	-0.04	0.04	-0.21
MAST	5.33	-0.09	0.30	0.20	0.39	-0.11

Table 5-7. Subject 1, MAS

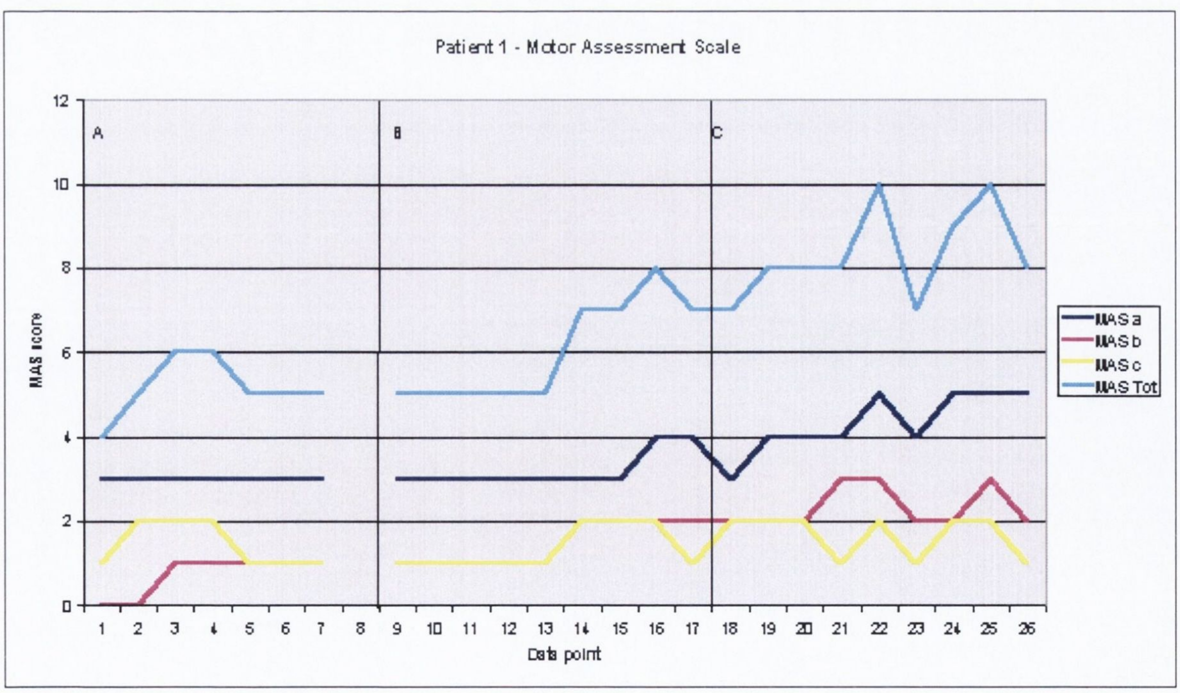

Figure 5-2. Subject 1, MAS

Maximal voluntary isometric contraction

The rate of recovery during the RMT phase was higher than both the baseline and SS phases for all variables. The power generated by elbow and shoulder flexors was less than that of their antagonist extensors throughout the study. For all variables the difference in the rate of recovery between the baseline and RMT phases was higher than the aMDC value. For shoulder extension the RMT slope was also significantly higher than the SS slope.

The plotted data shows variability between sequential measures, however the underlying trend of little recovery during the baseline, with an increase during the RMT phase, which continues during the SS phase, (though at a lesser rate) is apparent from the raw data.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
Elbow Flexion	8.41	0.01	0.52	0.36	0.51	-0.16
Elbow Extension	10.66	-0.12	0.48	0.27	0.60	-0.21
Shoulder Flexion	5.01	-0.07	0.43	0.26	0.50	-0.17
Shoulder Extension	8.90	-0.25	0.71	0.09	0.96	-0.62

Table 5-8. Subject 1, MVIC

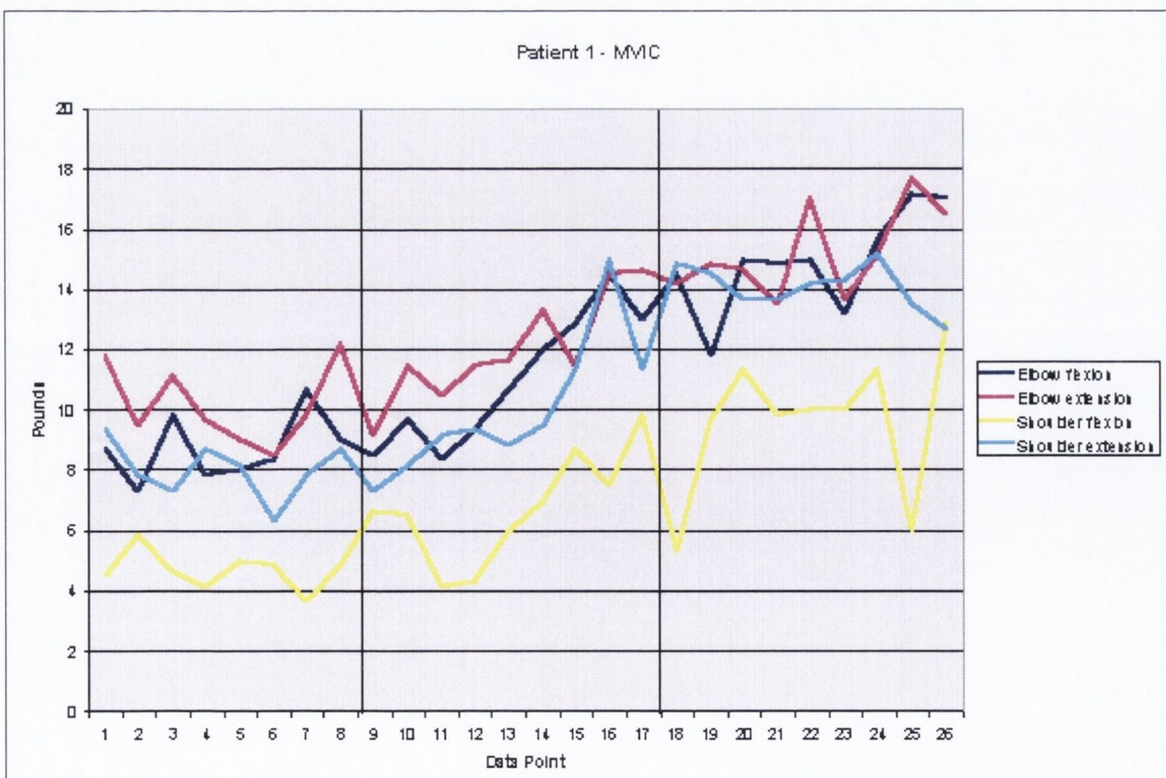

Figure 5-3. Subject 1 MVIC

Range of Motion

The rates of recovery for active elbow extension, active shoulder and elbow flexion are significantly greater during the RMT phase than the baseline phase. The rate of recovery for active shoulder flexion is also significantly greater during the RMT phase than the SS phase.

The sharp increase in passive shoulder external rotation during the baseline phase seen in the plotted data is significantly higher than both RMT and SS.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
AShFl	56.70	0.43	2.59	0.38	2.16	-2.21
PShFL	102.22	-0.35	0.34	0.22	0.69	-0.11
AShA	48.02	-0.08	1.02	1.19	1.10	0.17
PShA	75.84	0.15	-0.17	0.11	-0.32	0.29
AElX	-21.07	-1.30	1.54	0.48	2.84	-1.06
PELX	0.45	-0.33	0.34	0.00	0.67	-0.34
AShER	0.10	-0.03	0.33	0.02	0.37	-0.32
PShER	16.00	1.99	-0.58	0.45	-2.57	1.03
AELFl	116.37	-0.30	0.97	1.13	1.27	0.16
PELFl	144.20	0.10	-0.02	-0.05	-0.12	-0.03

Table 5-9. Subject 1, ROM

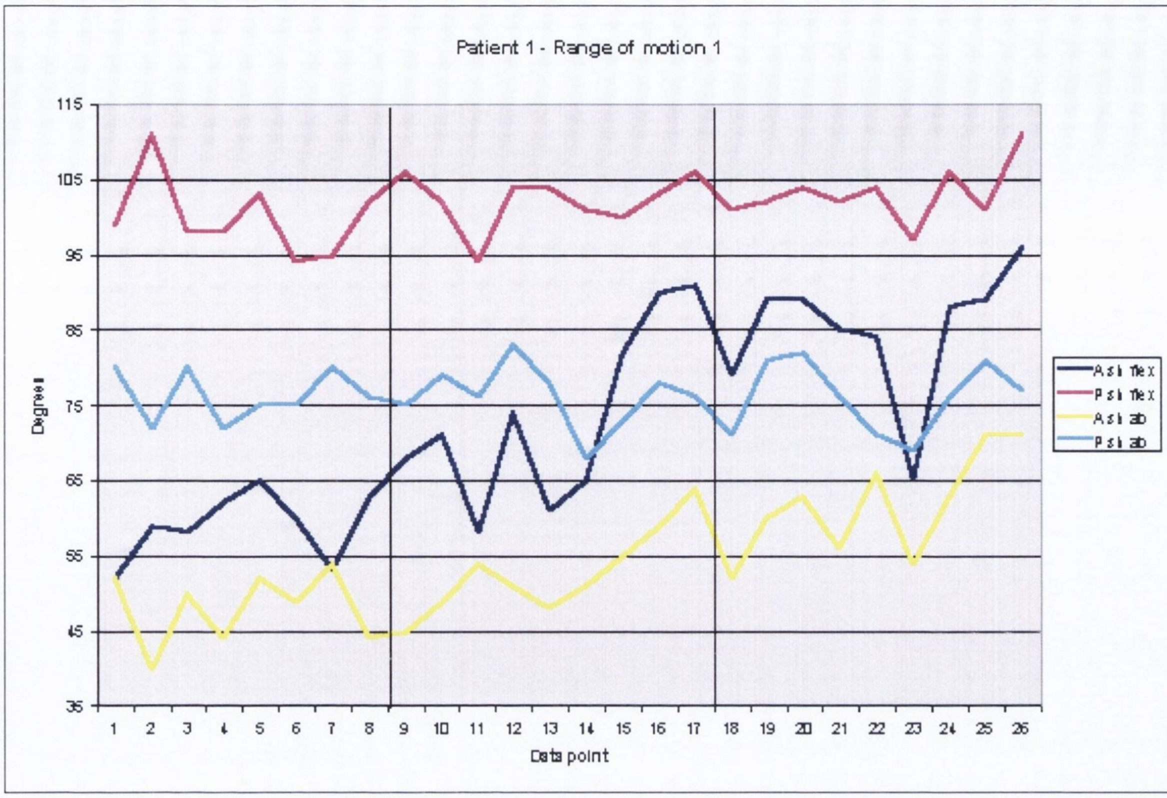

Figure 5-4. Subject 1, ROM 1

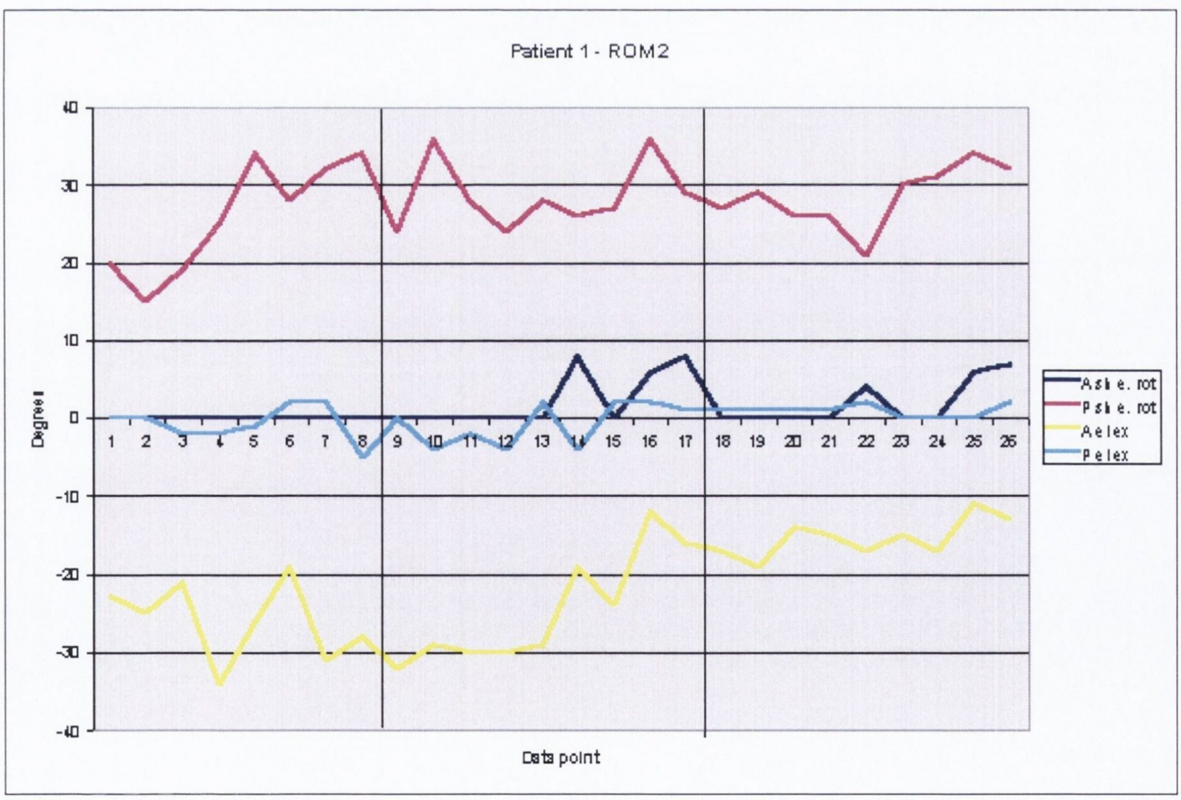

Figure 5-5. Subject 1, ROM 2

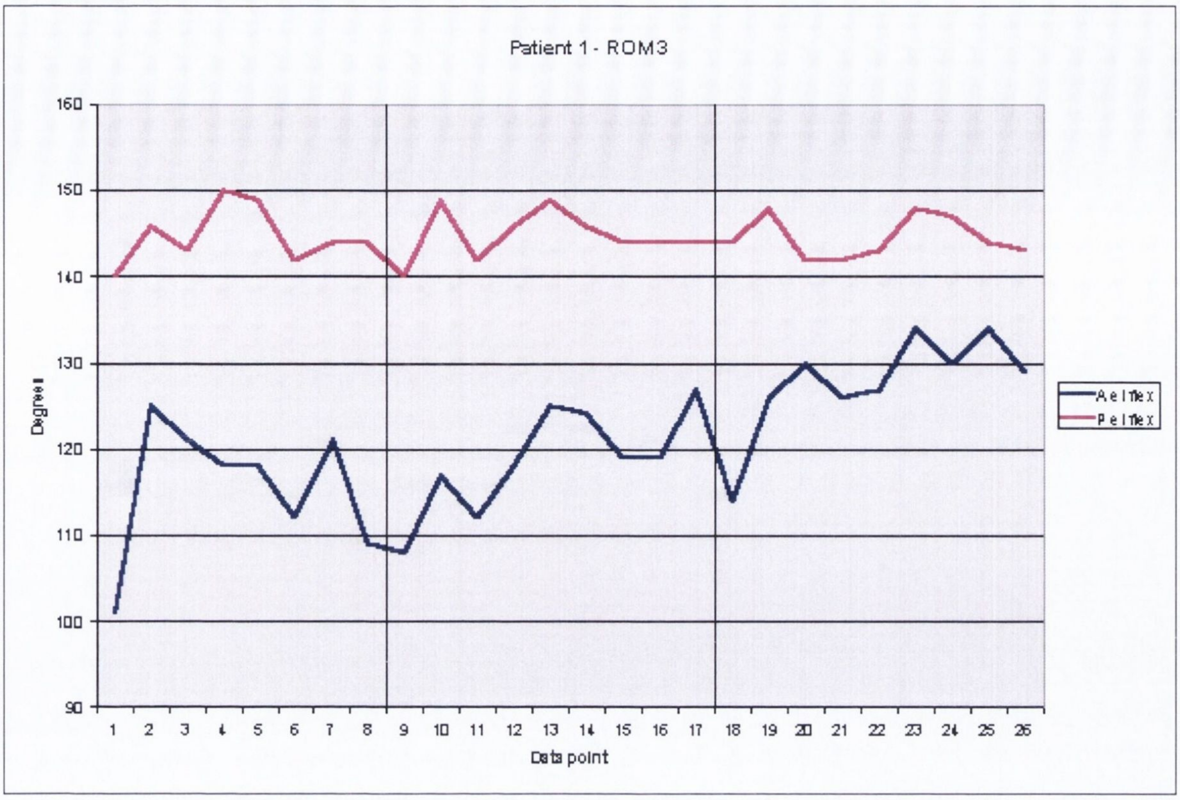

Figure 5-6. Subject 1, ROM 3

Grip Strength

The rate of recovery of grip strength was higher in the RMT phase than both the baseline and SS phase though this was not greater than the aMDC value.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
Grip	3.46	0.08	0.27	0.17	0.19	-0.11

Table 5-10. Subject 1, Grip

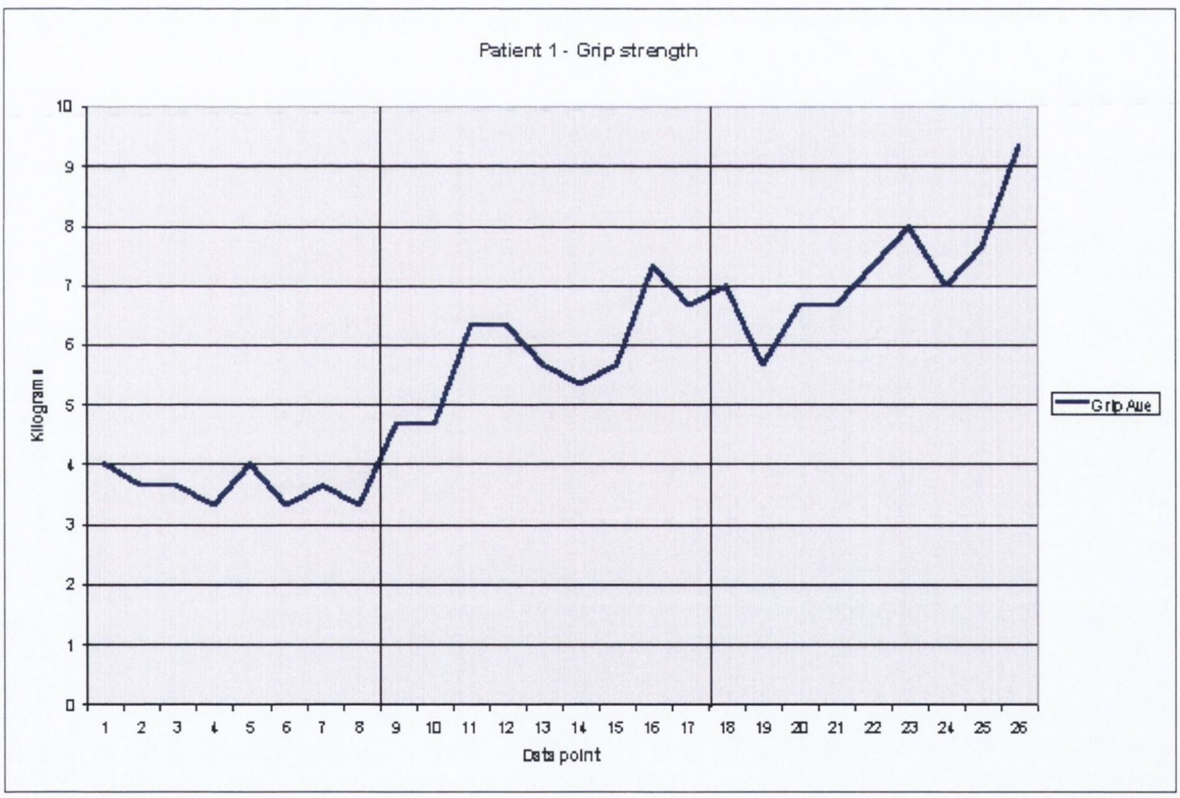

Figure 5-7. Subject 1, Grip

Quality of Life

The plotted data shows a trend for a decrease over the baseline phase and an increase over the SS phase. The physical health score fluctuates up over the baseline, down over the RMT and up over the SS phase ending 1 point higher than baseline, which is a negligible difference. The mental health subscore ends 2 points lower than baseline.

SF 36 Domain	Start	End A	End B	End C
Physical Functioning	29.7	31.8	31.8	31.8
Roles - Physical	32.4	37.3	32.4	39.7
Bodily Pain	55.4	51.1	53.7	55.4
General Health	62.5	60.1	55.3	55.3
Vitality	70.8	64.6	64.6	67.7
Social Functioning	56.8	45.9	40.5	51.4
Roles - Emotional	44.2	40.3	48.1	48.1
Mental Health	64.1	64.1	64.1	64.1
Physical Health Score	38.5	39.9	36.3	39.4
Mental Health Score	67.2	60.5	62.8	65.4

Table 5-11. Subject 1, SF-36

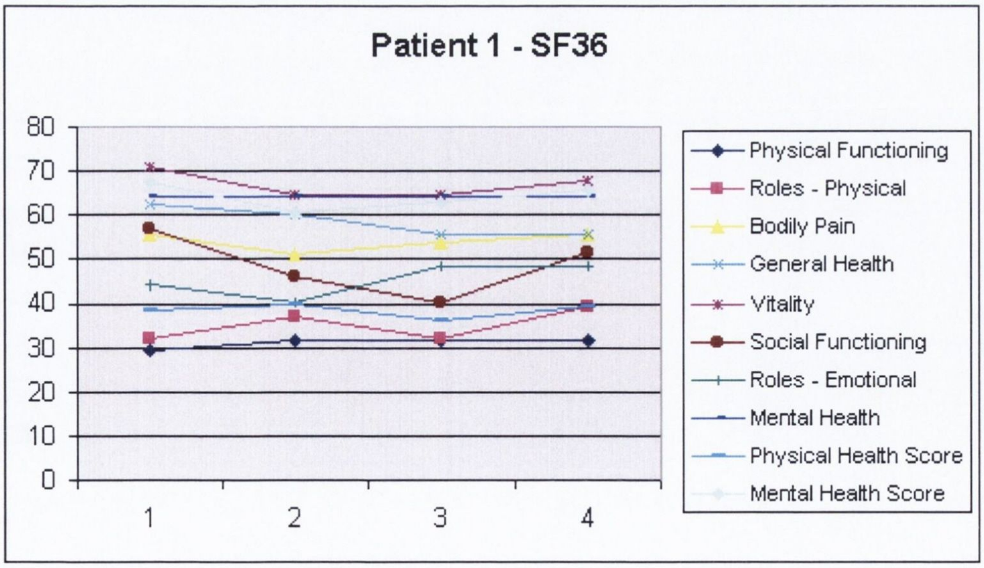

Figure 5-8. Subject 1, SF-36

5.2.2 Subject 2

Mr. JO was a 79 year old man who had a left CVA three months prior to the start of the study. His CT scan showed a left parietal infarct, classified as PACI.

At the time of the study he was living at home with his wife and attending the Day Hospital in Adelaide and Meath incorporating National Children's Hospital (AMNCH) once a week when he received 45 minutes of physiotherapy.

His past medical history included chronic obstructive airways disease (COAD) and atrial fibrillation (A-fib), he was on Warfarin and medications for his co-existing conditions.

He was randomised to 10 baseline measurements and to the ACB group. He spent 98.4% of his time exercising in active mode and 1.6% in active assisted mode.

Events during course of study

Visits 13, 14, 15 were missed due to a family bereavement.

There were no other events of note.

Background data

His SOMCT fluctuated between 26 and 28 for the duration of the study. His star cancellation test score decreased from the maximal score of 54 to 52 at the end of the baseline and increased by 1 point over each phase. His pain score increased over the baseline, decreased significantly over the SS phase and increased over the RMT phase. He had no hemianopia, and no significant tone abnormalities. His sensation decreased during the SS phase (by 2 points in the kinaesthesia domain).

Subject 2, Summary	
Age	79
Time post stroke	3 months
Side affected	Right
CT result	Left parietal infarct
Current physiotherapy treatment	45 minutes once a week
Randomisation	ACB, 10
Exercise mode	AA 1.6%, A 98.4%

Table 5-12. Subject 2, Summary

BACKGROUND MEASURES	Start A	Start C	Start B	End B
Short Orientation Memory Concentration	26	26	28	26
Star Cancellation L	27	26	27	27
Star Cancellation R	27	26	26	27
Star Cancellation Total	54	52	53	54
Pain	2.3	3.2	0.3	2.9
Hemianopia	0	0	0	0
Tone Wrist	0	0	0	0
Tone Elbow	1	0	0	0
Sensation Light Touch	8	8	8	8
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	8	8	8	8
Sensation Kinaesthesia	11	11	9	10
Sensation Total	35	35	33	34

Table 5-13. Subject 2, Background data

Fugl-Meyer

The rate of recovery during the RMT phase was higher than both baseline and SS for the FMA, FMB and FMT sections. For the FMC and FMD sections the rate of recovery during the baseline phase was higher than both the RMT and SS phases.

The potted raw data shows little fluctuation in any of the sections, represented by the very small slope values. The maximal score for FM is 66, the subject started at an estimated 56.5 giving only little room for change.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
FMA	34.00	-0.05	0.06	0.06	0.11	0.00	0.11
FMB	8.97	0.00	0.00	0.03	0.00	0.03	0.03
FMC	10.58	0.16	0.13	0.06	-0.03	-0.07	-0.09
FMD	3.01	0.16	0.07	0.13	-0.09	0.07	-0.02
FMT	56.55	0.26	0.13	0.29	-0.14	0.16	0.02

Table 5-14. Subject 2, Fugl-Meyer

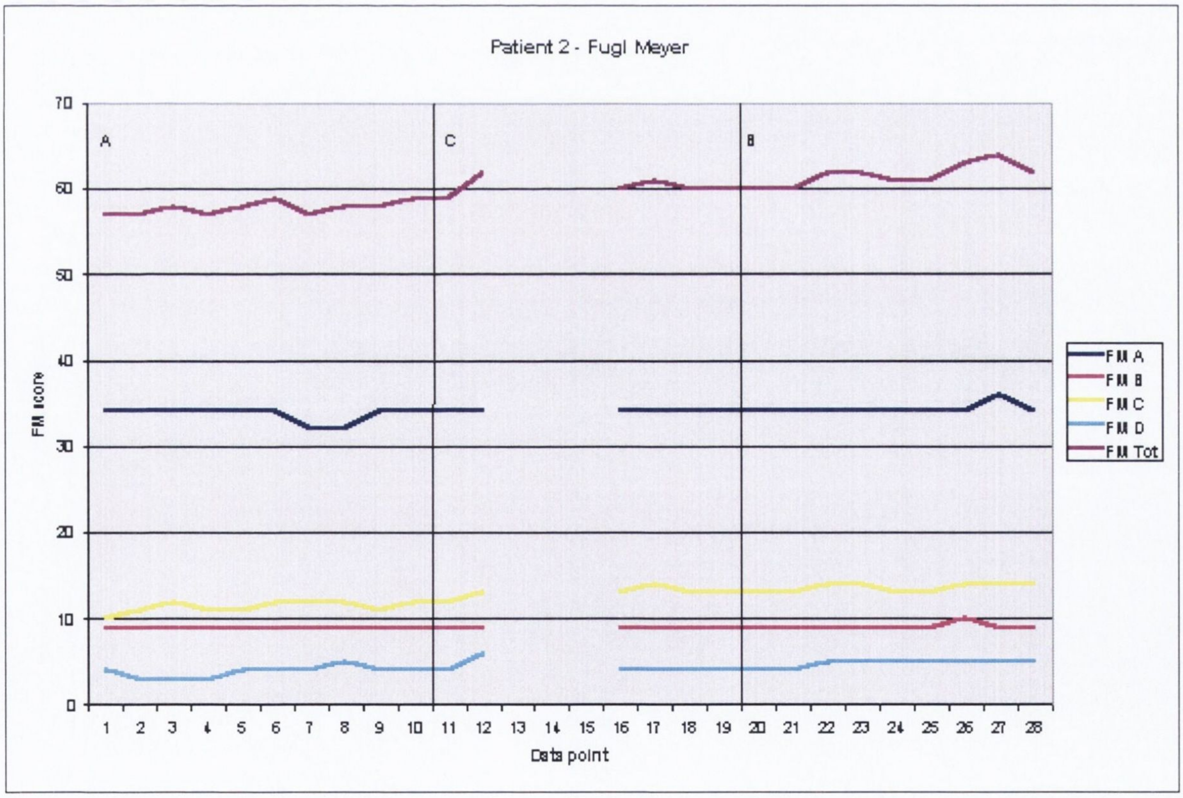

Figure 5-9. Subject 2, Fugl-Meyer

Motor Assessment Scale

The maximal score for the MASA section is 6, therefore no change was possible in this section. The slope for the MASB was highest in the RMT phase though only the difference between the RMT and baseline slopes was significant. For the MASC the slope was highest in the baseline phase, this was significantly different to the baseline and RMT phases, and it is this which contributed most to the slopes in the total score.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
MASA	6.00	0.00	0.00	0.00	0.00	0.00	0.00
MASB	4.05	0.05	0.08	0.11	0.02	0.03	0.06
MASC	2.17	0.24	-0.02	0.09	-0.26	0.11	-0.15
MAST	12.21	0.29	0.06	0.20	-0.24	0.14	-0.09

Table 5-15. Subject 2, MAS

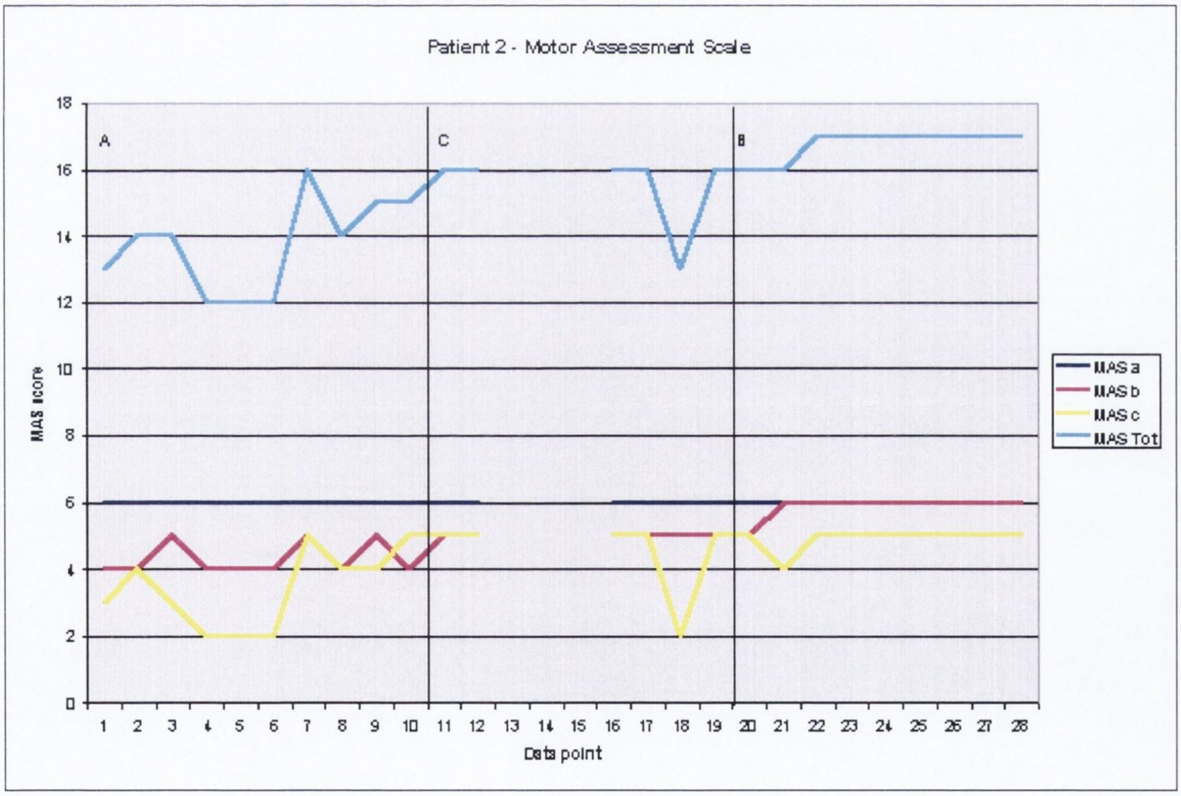

Figure 5-10. Subject 2, MAS

Maximal voluntary isometric contraction

The rate of recovery during the RMT phase was higher than both the SS and baseline phases for all four muscle groups. The difference between the RMT and baseline slopes was significant for all but elbow flexion and shoulder extension. The difference between the RMT and SS slopes was significant for elbow flexion and shoulder extension, though as the SS slope is negative for elbow flexion this should be interpreted with caution.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
ElbFlex	27.19	0.47	-0.11	0.58	-0.58	0.69	0.11
ElbExt	28.55	-0.13	0.45	0.63	0.58	0.18	0.76
ShoFlex	25.33	-0.58	0.47	0.73	1.05	0.26	1.31
ShoExt	23.01	0.12	0.13	0.81	0.01	0.68	0.68

Table 5-16. Subject 2, MVIC

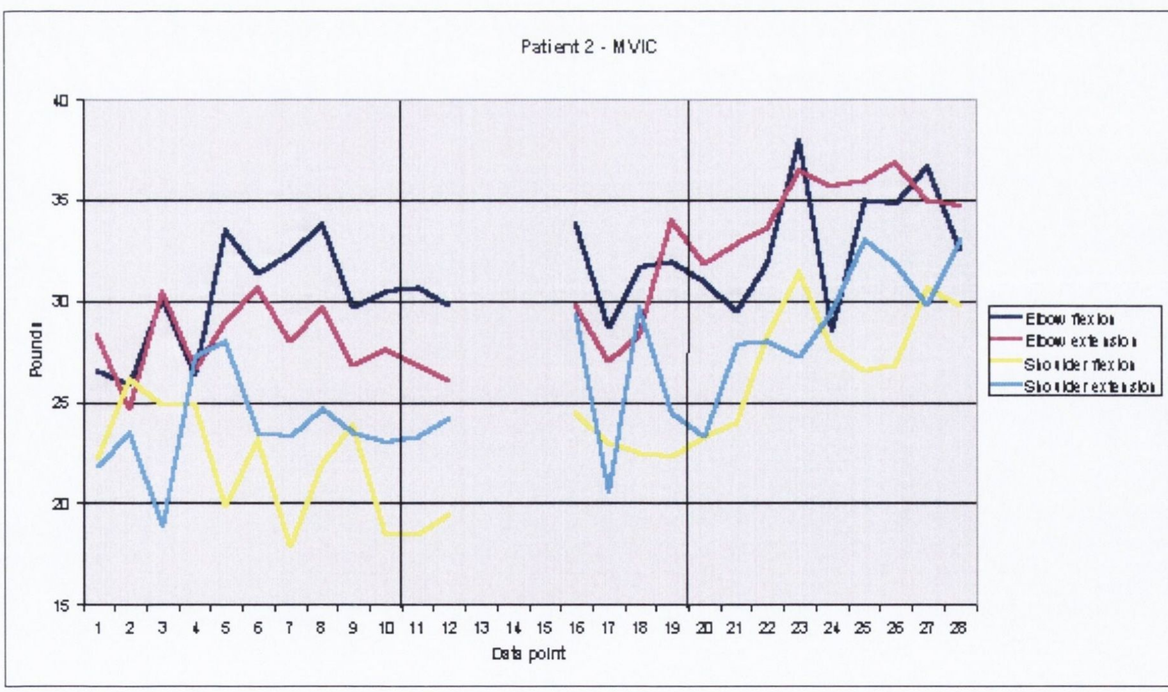

Figure 5-11. Subject 2, MVIC

Range of Motion

The rate of recovery for all shoulder measures was higher during the baseline phase than both the RMT and SS phases.

The rate of recovery during the RMT phase was higher than both baseline and SS phase for active and passive elbow extension, however only the difference between the treatment and baseline phase slopes can be considered significant.

For active and passive elbow flexion the SS phase had a higher rate than both baseline and RMT.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
AShFl	147.40	1.69	-0.10	0.58	-1.80	0.69	-1.11
PShFL	154.95	1.18	0.05	0.31	-1.14	0.26	-0.87
AShA	149.40	2.09	-0.01	-0.23	-2.11	-0.21	-2.32
PShA	160.32	1.15	0.10	-0.25	-1.06	-0.35	-1.40
AElX	-8.07	-0.47	0.12	0.79	0.60	0.66	1.26
PELX	-1.71	-0.01	0.11	0.38	0.12	0.26	0.38
AShER	64.07	1.02	-0.41	0.13	-1.43	0.54	-0.89
PShER	73.37	0.84	-0.67	0.29	-1.51	0.96	-0.55
AELFl	147.61	0.00	0.56	-0.11	0.56	-0.67	-0.11
PELFl	153.26	-0.27	0.55	-0.24	0.81	-0.78	0.03

Table 5-17. Subject 2, ROM

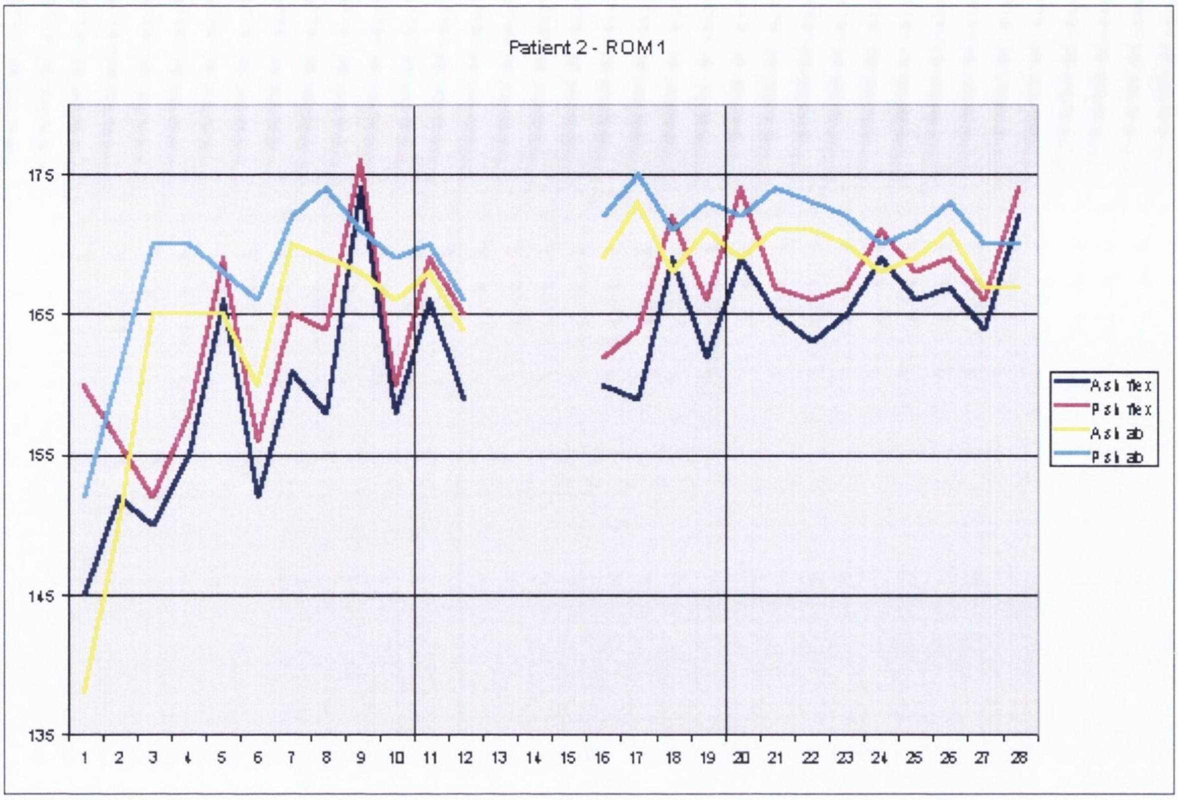

Figure 5-12. Patient 2 ROM 1

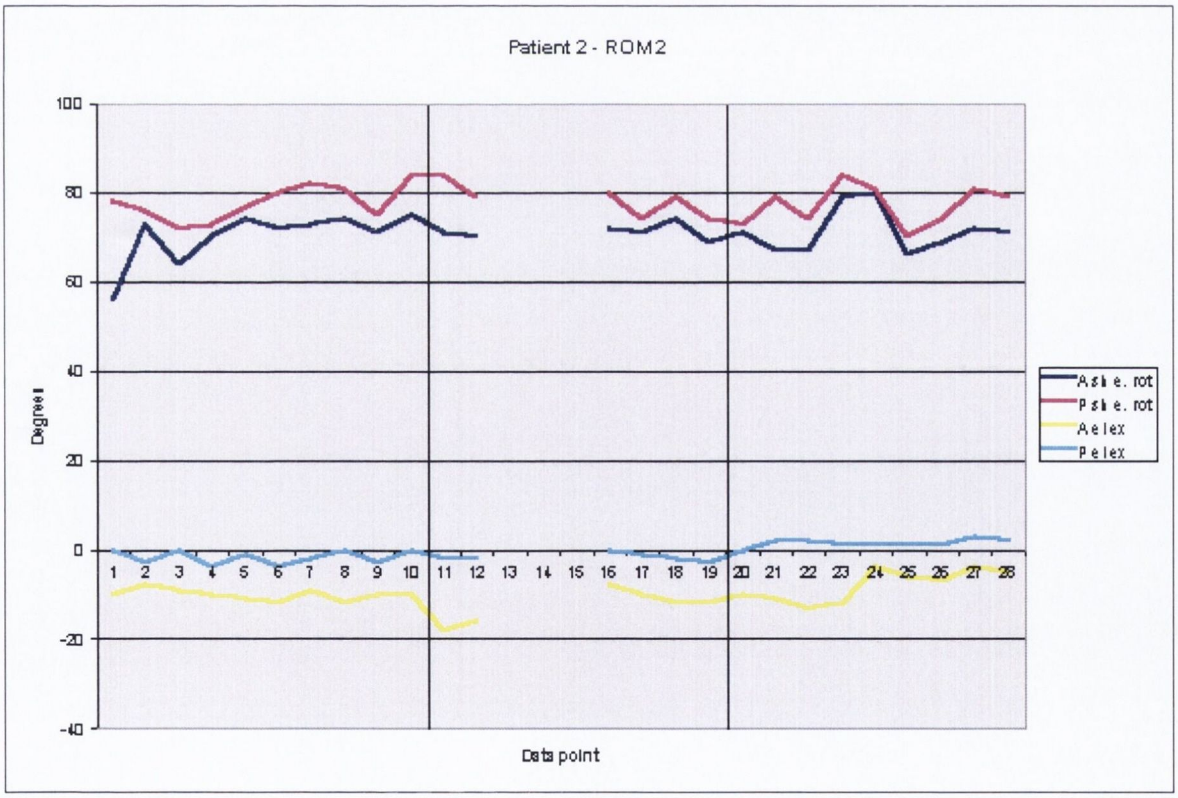

Figure 5-13. Subject 2, ROM 2

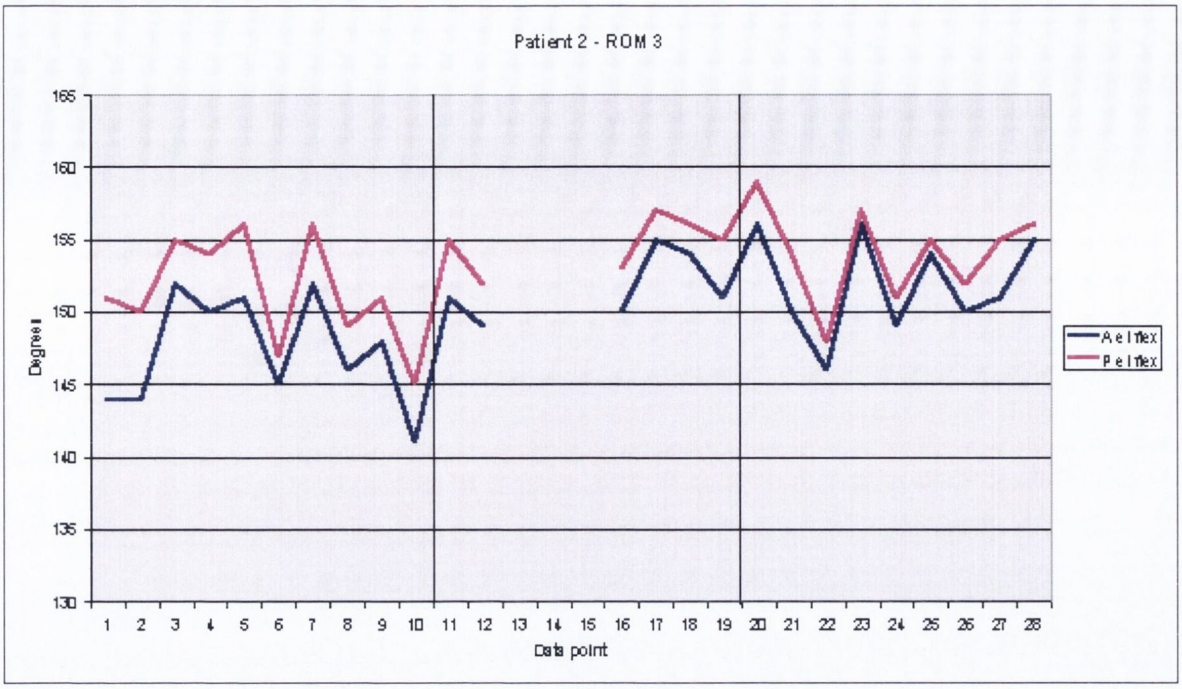

Figure 5-14. Subject 2, ROM 3

Grip Strength

The rate of recovery was significantly higher in the RMT than both the baseline and SS phases. However the difference is small, 0.27 kg per visit represents 2.43 kg difference over the length of the phase.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
Grip	9.32	0.23	0.43	0.70	0.19	0.27	0.47

Table 5-18. Subject 2, Grip

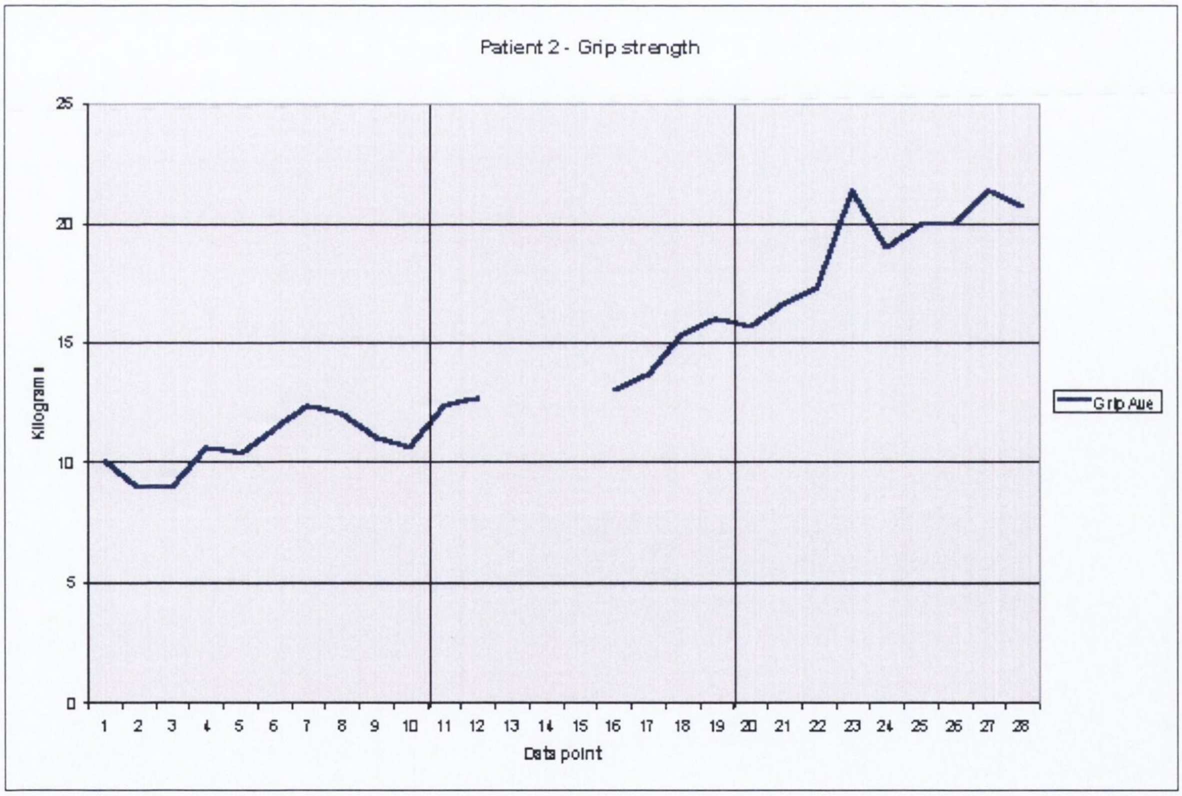

Figure 5-15. Subject 2, Grip

Quality of Life

Mental health, the mental health summary score and vitality drop significantly over the 2nd phase. This can most likely be attributed to the family bereavement that occurred during this phase of the study. Despite this his physical health score rose over the same phase and fell slightly over the RMT phase, though ended at a higher score than baseline.

SF-36 Domain	Start	End A	End C	End B
Physical Functioning	40.2	29.7	31.8	42.3
Roles - Physical	22.6	20.1	17.7	20.1
Bodily Pain	24.9	50.3	51.1	62.1
General Health	55.3	52.9	57.7	52.9
Vitality	45.8	36.5	30.2	58.3
Social Functioning	18.7	29.6	35	18.7
Roles - Emotional	24.8	32.6	17	28.7
Mental Health	58.5	64.1	13.4	61.3
Physical Health Score	32.7	31.7	47.2	42.9
Mental Health Score	41.8	48.9	17.2	44

Table 5-19. Subject 2, SF-36

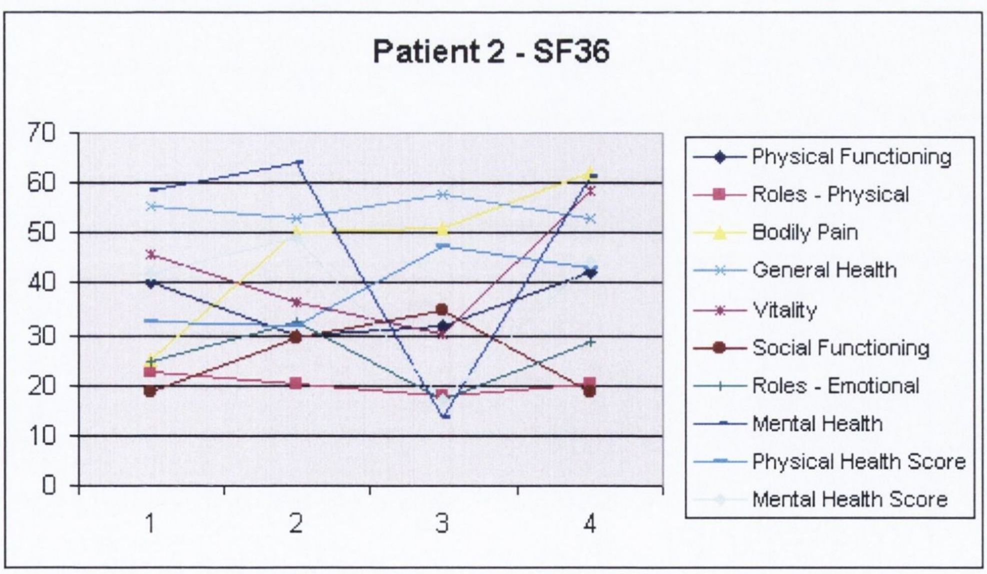

Figure 5-16. Subject 2, SF-36

5.2.3 Subject 3

Mrs. BH was an 80 year old lady who had a left CVA 19 months prior to the start of the study. Her CT scan showed an infarct in the left internal capsule and was classified a lacunar infarct (LI).

She was living at home with her daughter and was not receiving any treatment at the time of the study. She had a past medical history of right total hip replacement and a ligamentous injury to her right shoulder 21 months before the start of the study. Se was on non-steroidal anti-inflammatories for pain relief.

She was randomised to 10 baseline data points and to the ACB group. She exercised in active assisted mode for 89.1% of the time and active mode for 10.9%.

Events during course of study

Visit 22 - complaining of increased arm pain over weekend.

No other events of note during the study

BH reported increased pain in her shoulder 3 weeks after finishing the study, the management of which is ongoing and includes referral to pain management service.

Background data

Her SOMCT increased to 24 after the baseline phase and remained at that level for the duration of the study. Her star cancellation test decreased by 1 point after the baseline and increased to the maximum at the end of the SS phase.

Her pain score decreased significantly over the baseline phase, increased over the SS phase and slightly over the RMT phase, however was half her baseline score at the end of the study. Her elbow tone remained unchanged, with her wrist tone fluctuating during the course of the study. Her sensation score was within 1 point of maximal for the duration of the study.

Subject 3, Summary	
Age	80
Time post stroke	19 months
Side affected	Right
CT result	Lacunar infarct
Current physiotherapy treatment	None
Randomisation	ACB, 10
Exercise mode	AA 89.1%, A 10.9%

Table 5-20. Subject 3, Summary

BASELINE MEASURES	Start A	Start C	Start B	End B
Short Orientation Memory Concentration	22	24	24	24
Star Cancellation L	27	26	27	27
Star Cancellation R	26	26	27	27
Star Cancellation Total	53	52	54	54
Pain	8.9	3.1	4.4	4.6
Hemianopia	0	0	0	0
Tone Wrist	1	2	0	1
Tone Elbow	2	2	2	2
Sensation Light Touch	8	8	8	8
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	8	8	8	8
Sensation Kinaesthesia	12	11	11	11
Sensation Total	36	35	35	35

Table 5-21. Subject 3, Background data

Fugl-Meyer

The rate of recovery during the SS phase was greater than the RMT phase for all sections of the FM. The RMT phase was higher than the baseline for all sections apart from the FMA, which had the highest value in the baseline phase. The significant differences are highlighted below. The plotted data shows an initial rise in the baseline phase slope which flattened out after the 4th measurement.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
FMA	21.56	0.31	0.13	0.02	-0.18	-0.12	-0.30
FMB	9.22	-0.13	0.13	-0.02	0.26	-0.16	0.11
FMC	12.78	-0.28	0.32	0.00	0.60	-0.31	0.28
FMD	3.85	-0.12	0.18	0.09	0.29	-0.09	0.21
FMT	47.41	-0.21	0.76	0.27	0.97	-0.49	0.48

Table 5-22. Subject 3, Fugl-Meyer

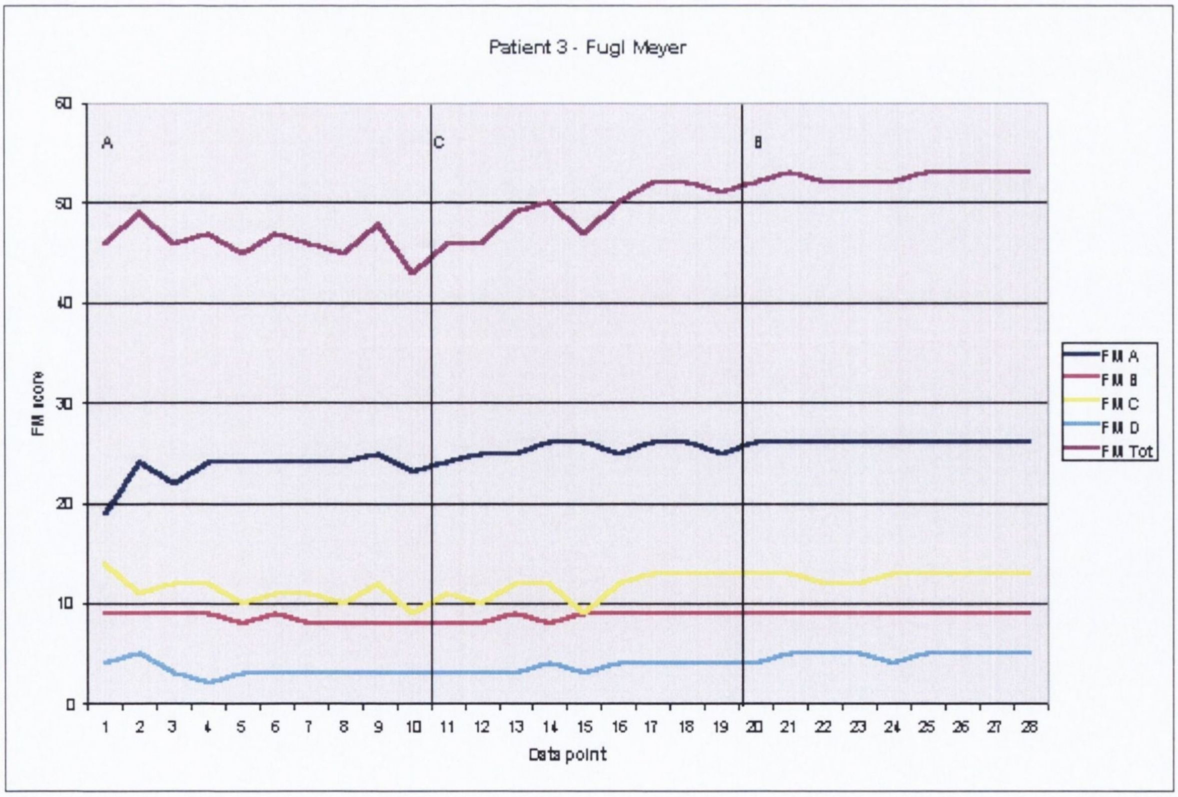

Figure 5-17. Subject 3, Fugl-Meyer

Motor Assessment Scale

The rate of recovery during the SS phase was higher than the RMT phase for the MASA and MASB sections though this was not significant. The rate of recovery during the RMT phase was higher than the baseline phase for MASB, MASC and MAST, and higher than SS for the MASC and MAST scores. The significant difference in the rate of recovery for MASC between the RMT and baseline and SS phases contributed mostly to the significant differences for the MAS total score.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
MASA	2.79	0.06	0.06	0.01	0.01	-0.05	-0.05
MASB	3.04	-0.02	0.14	0.04	0.15	-0.10	0.05
MASC	1.40	0.09	-0.11	0.18	-0.20	0.28	0.09
MAST	7.23	0.13	0.09	0.23	-0.04	0.13	0.10

Table 5-23. Subject 3, MAS

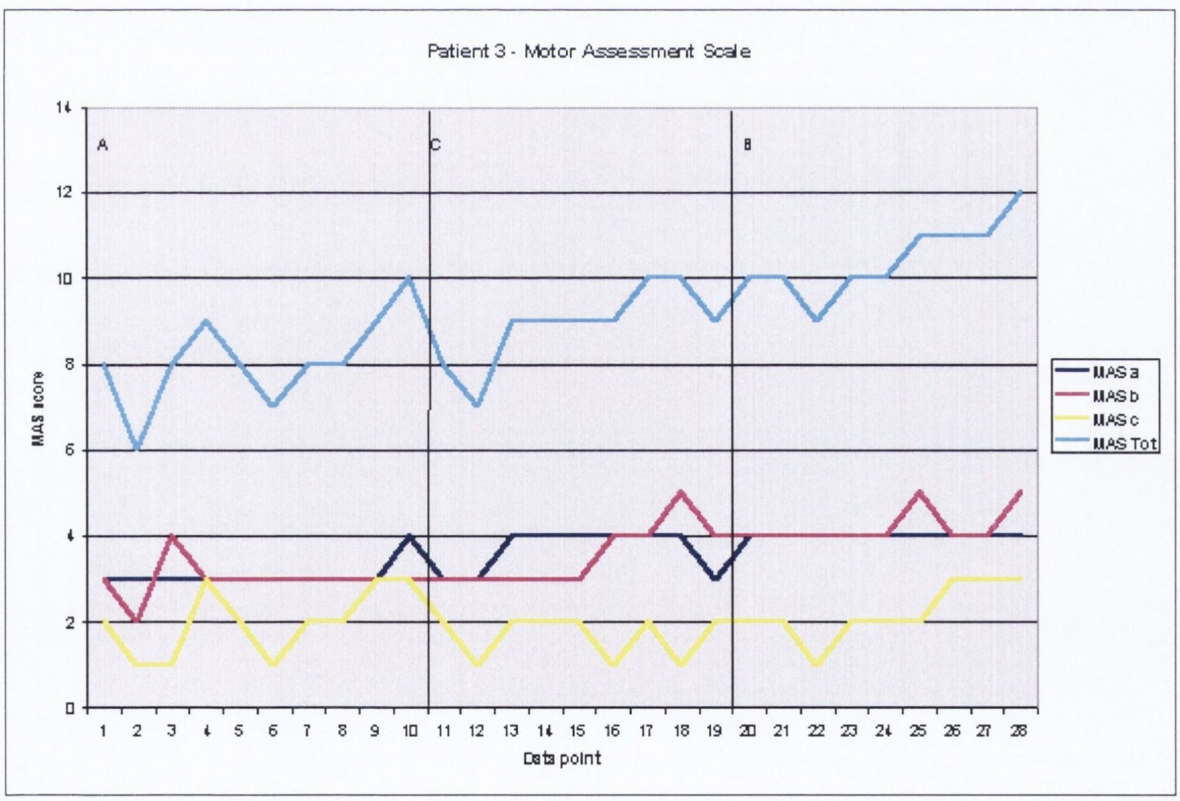

Figure 5-18. Subject 3, MAS

Maximal voluntary isometric contraction

For elbow flexion and extension and shoulder extension the rate of recovery during the SS phase was higher than both baseline and RMT. The rate of recovery for shoulder flexion was equal for RMT and SS, both being higher than the baseline. None of these differences in slopes were significant.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
ElbFlex	12.96	-0.00	0.20	-0.08	0.20	-0.28	-0.08
ElbExt	13.08	0.09	0.16	-0.07	0.07	-0.23	-0.15
ShoFlex	4.84	0.02	0.11	0.11	0.11	0.00	0.11
ShoExt	12.75	0.08	0.12	0.01	0.04	-0.11	-0.07

Table 5-24. Subject 3, MVIC

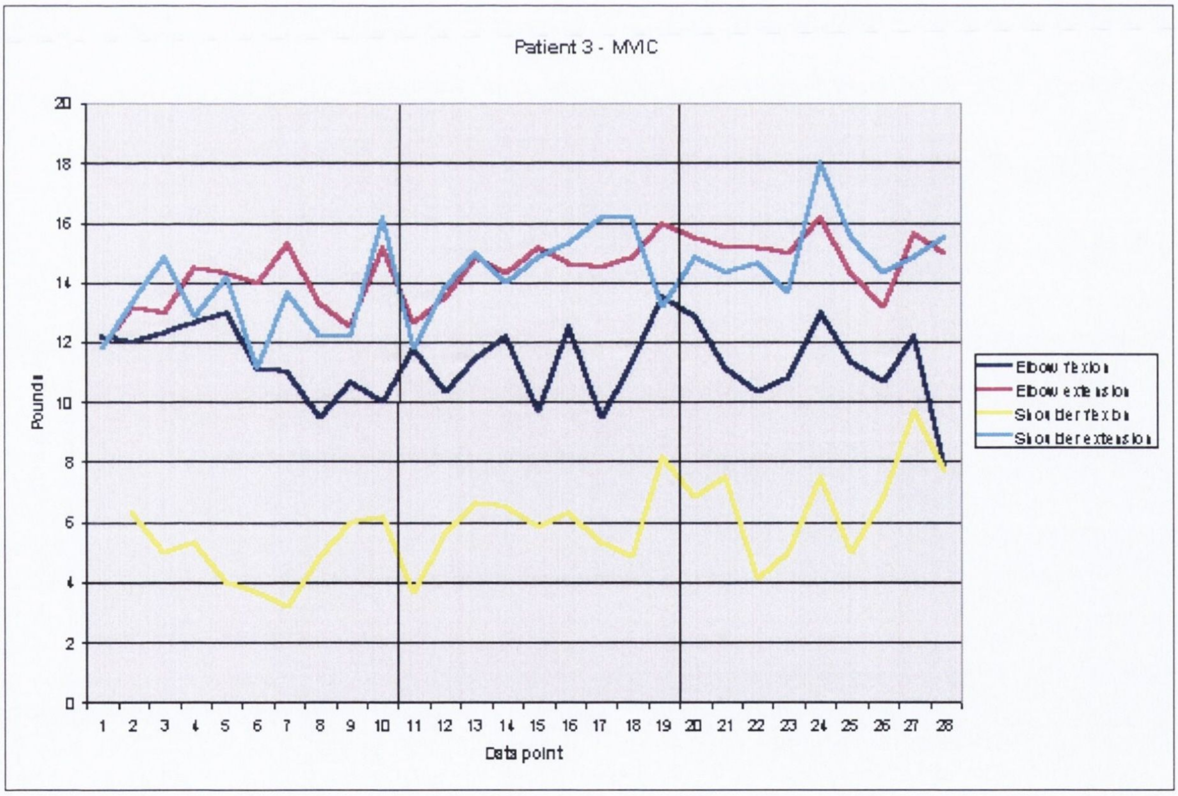

Figure 5-19. Subject 3, MVIC

Range of Motion

The rate of recovery for passive elbow flexion and extension, active and passive shoulder abduction and active shoulder external rotation were higher in the RMT than the baseline and SS phases. However this was only significant for active shoulder external rotation.

The rate of recovery for the RMT phase was significantly higher than baseline for active shoulder external rotation. The rate of recovery of passive shoulder external rotation decreased significantly over the SS phase and increased over the RMT phase.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
AShFl	28.57	1.61	2.48	1.31	0.87	-1.17	-0.30
PShFL	103.75	-0.02	0.94	-0.21	0.96	-1.15	-0.18
AShA	53.41	0.09	-0.13	0.15	-0.22	0.28	0.06
PShA	77.76	0.58	-0.20	0.61	-0.78	0.82	0.03
AElX	-17.77	-0.86	0.84	0.17	1.70	-0.67	1.03
PELX	-3.28	-0.23	0.24	0.43	0.47	0.19	0.66
AShER	10.68	-0.83	0.22	0.41	1.06	0.19	1.25
PShER	26.72	0.67	-0.69	0.64	-1.36	1.34	-0.02
AELFl	135.74	0.31	0.07	0.28	-0.24	0.22	-0.02
PELFl	141.86	0.29	-0.08	0.36	-0.37	0.44	0.07

Table 5-25. Subject 3, ROM

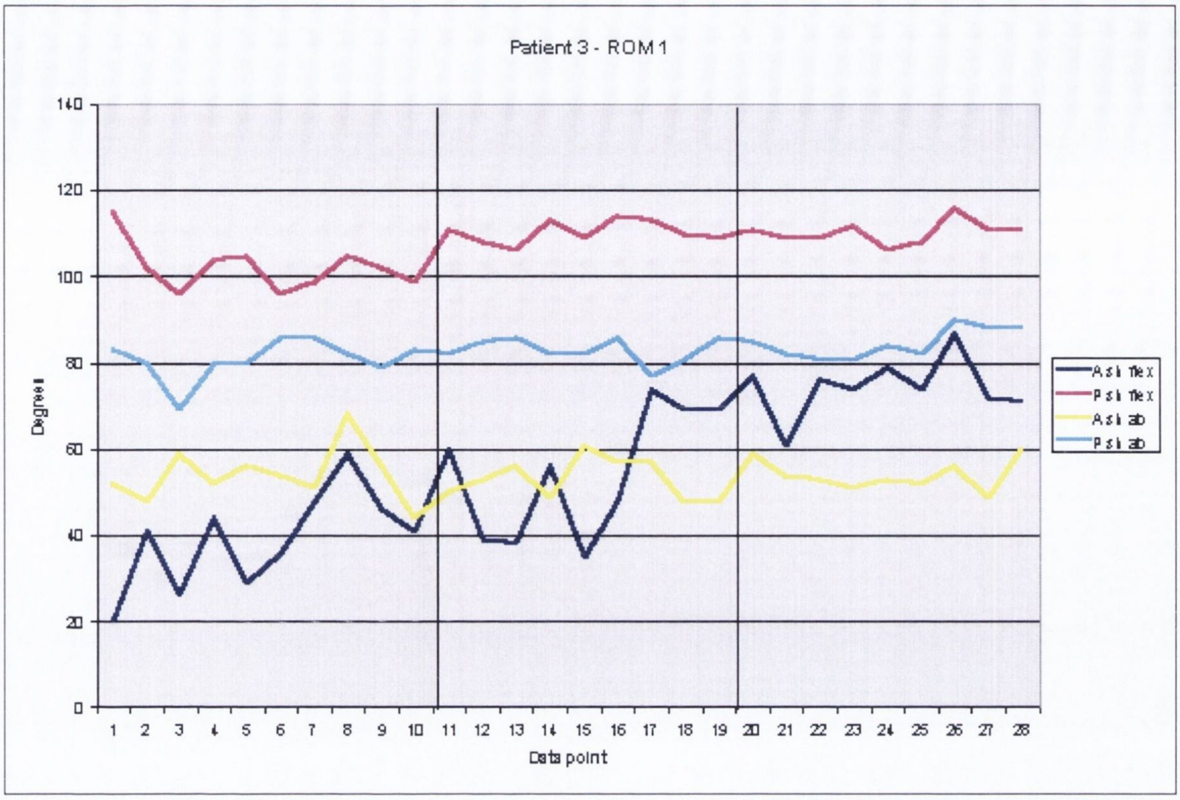

Figure 5-20. Subject 3, ROM 1

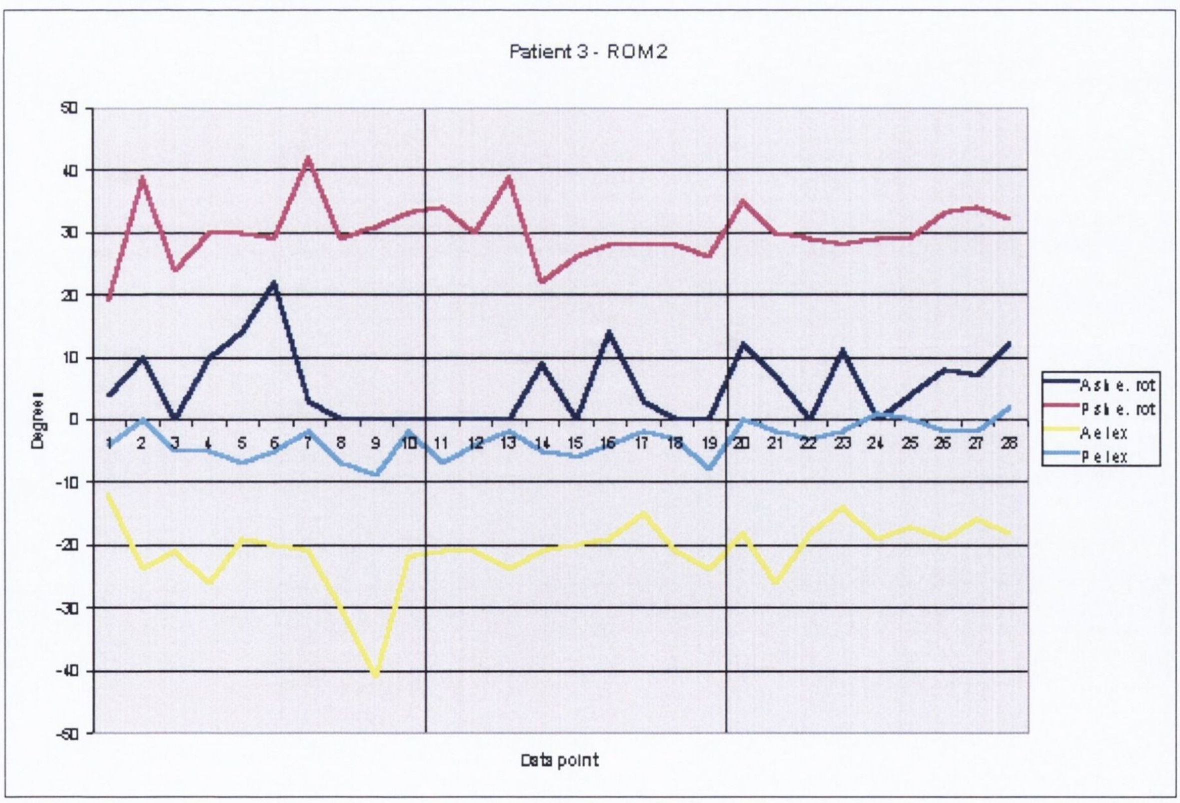

Figure 5-21. Subject 3, ROM 2

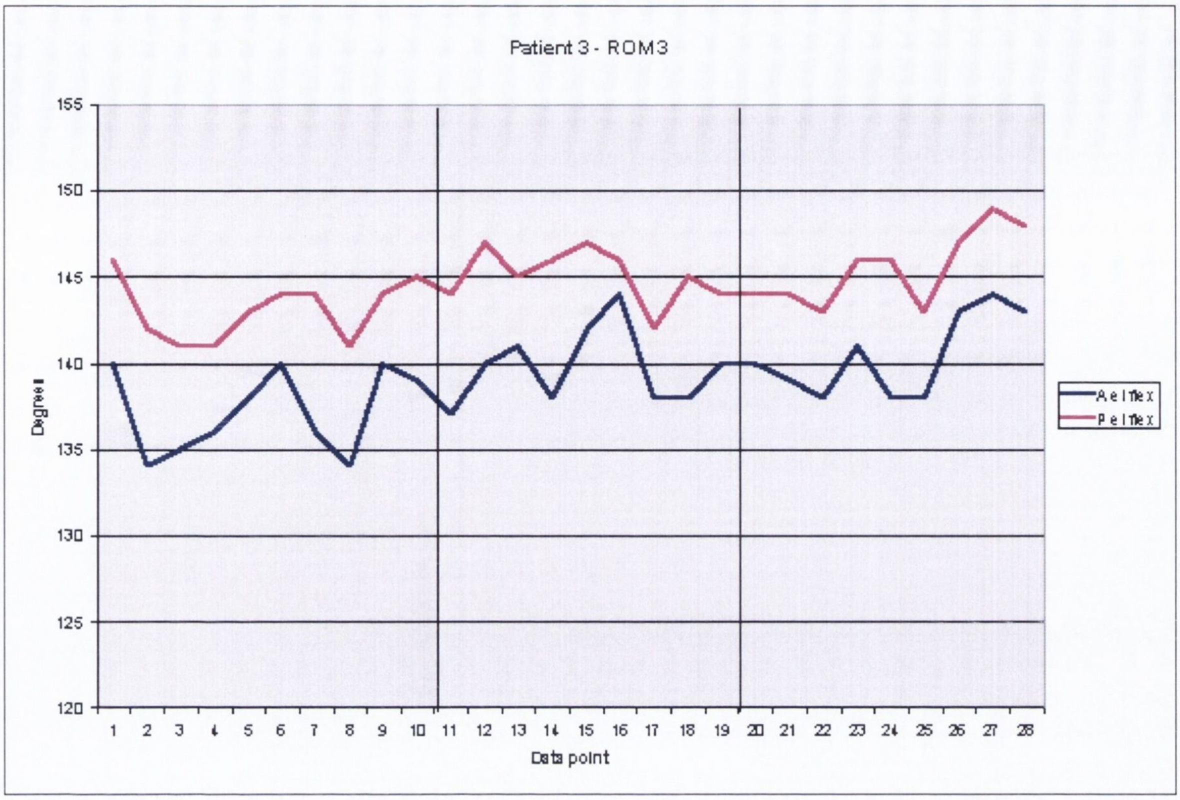

Figure 5-22. Subject 3, ROM 3

Grip Strength

The values for the slopes across each phase are very low, indicating minimal change in this measure. The plotted data shows large variability with a fluctuation around 11kg.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
Grip	10.69	0.02	0.07	-0.06	0.05	-0.13	-0.08

Table 5-26. Subject 3, Grip

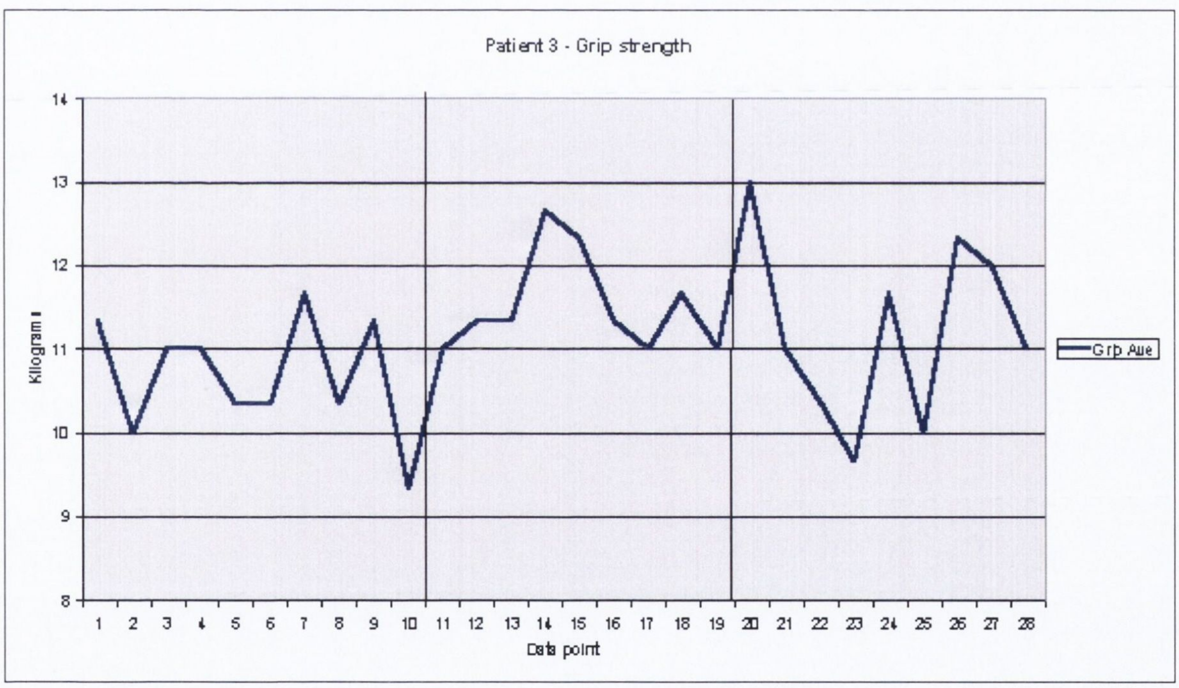

Figure 5-23. Subject 3, Grip

Quality of Life

There is little change in most variables, however the bodily pain score increases over the course of the study by 17.8% indicating a reduction in subjective perception of pain. Her physical health score also increases from 28.1% of normal to 41.4% from start to end of the study.

SF-36 Domain	Start	End A	End C	End B
Physical Functioning	29.7	29.7	31.8	31.8
Roles - Physical	29.9	56.9	44.6	47.1
Bodily Pain	37.6	45.6	51.1	55.4
General Health	57.7	57.7	62.5	60.1
Vitality	58.3	52.1	58.3	58.3
Social Functioning	56.8	56.8	56.8	56.8
Roles - Emotional	55.9	55.9	55.9	55.9
Mental Health	64.1	64.1	64.1	64.1
Physical Health Score	28.3	40.1	39.8	41.4
Mental Health Score	71.4	65.9	67.7	67.1

Table 5-27. Subject 3, SF-36

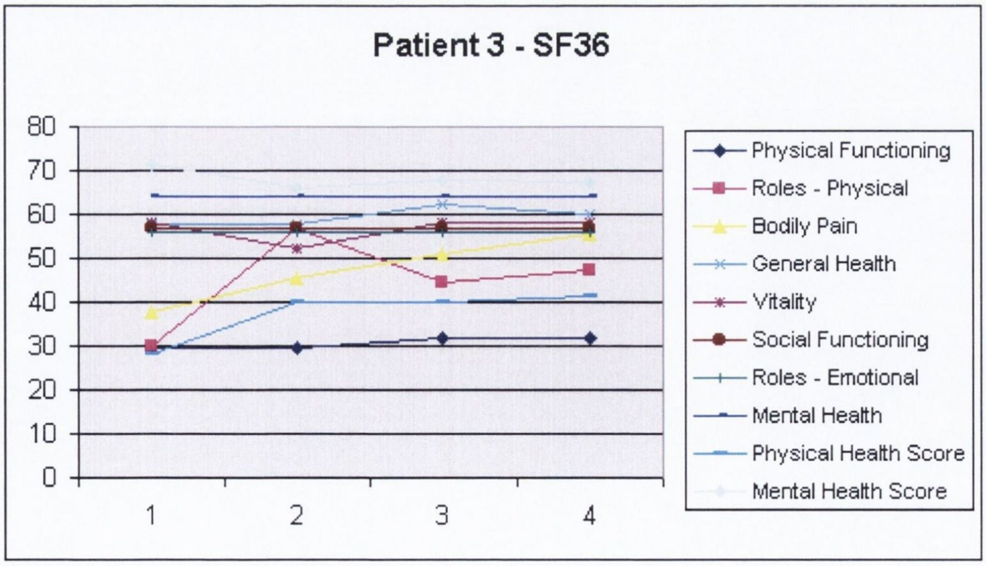

Figure 5-24. Subject 3, SF-36

5.2.4 Subject 4

Mrs. PN was a 69 year old lady who had a right CVA 22 months prior to the start of the study. Her CT scan revealed a right middle cerebral artery infarct.

At the time of the study she was living with her husband and was very active in local clubs and societies. She was not receiving treatment at the time, but was on review at Baggot Street Community Hospital stroke unit.

She had a past medical history of hypertension and high cholesterol. She was on aspirin and Neurontin for arm pain.

She was randomised to 10 baseline data points and to the ABC group. She spent 47.7% of the time exercising in active assisted mode and 52.3% in active mode.

Events during course of study

Visit 16 - reported increased pain

Visit 20 - reported picking up her grandchild for the first time

Background data

Her SOMCT fluctuated over the course of the study and reached its maximum after the RMT phase. Her star cancellation test reached its highest at the end of the baseline and reverted to baseline by the end of the study.

Her pain score did not change over the baseline phase but decreased over the B and SS phases. Wrist and elbow tone decreased over the course of the study. Her sensation scores fluctuated between 21 and 27 out of 36, the maximum being reached at the end of the RMT (B) phase.

Subject 4, Summary	
Age	69
Time post stroke	22 months
Side affected	Left
CT result	Right middle cerebral artery infarct
Current physiotherapy treatment	None
Randomisation	ABC, 10
Exercise mode	AA 47.7%, A 52.3%

Table 5-28. Subject 4, Summary

BACKGROUND MEASURES	Start A	Start B	Start C	End C
Short Orientation Memory Concentration	26	24	28	26
Star Cancellation L	24	26	25	25
Star Cancellation R	26	27	27	25
Star Cancellation Total	50	53	52	50
Pain	3.8	3.8	2.9	1.2
Hemianopia	0	0	0	0
Tone Wrist	0	1	0	0
Tone Elbow	1	2	2	1
Sensation Light Touch	4	6	6	6
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	1	6	2	3
Sensation Kinaesthesia	8	6	9	8
Sensation Total	21	26	27	25

Table 5-29. Subject 4, Background data

Fugl-Meyer

The rate of recovery during the RMT phase was higher than both SS and baseline for the FMA and FMT sections and was significantly greater than SS for the FMA section. The slope values for the other sections are extremely low indicating little change however the differences for the FMC section are significant.

The plotted raw data shows initial variability in the FMA and FMC sections, which contribute to the variability of the total score.

	Intercept	Slope A	Slope B	Slope C	Slop B-A	Slope C-B
FMA	24.52	0.04	0.35	-0.09	0.31	-0.43
FMB	8.60	0.05	0.01	0.00	-0.04	-0.01
FMC	7.61	0.15	-0.01	0.19	-0.16	0.19
FMD	2.57	-0.01	0.05	0.17	0.07	0.11
FMT	43.30	0.23	0.38	0.27	0.16	-0.11

Table 5-30. Subject 4, Fugl-Meyer

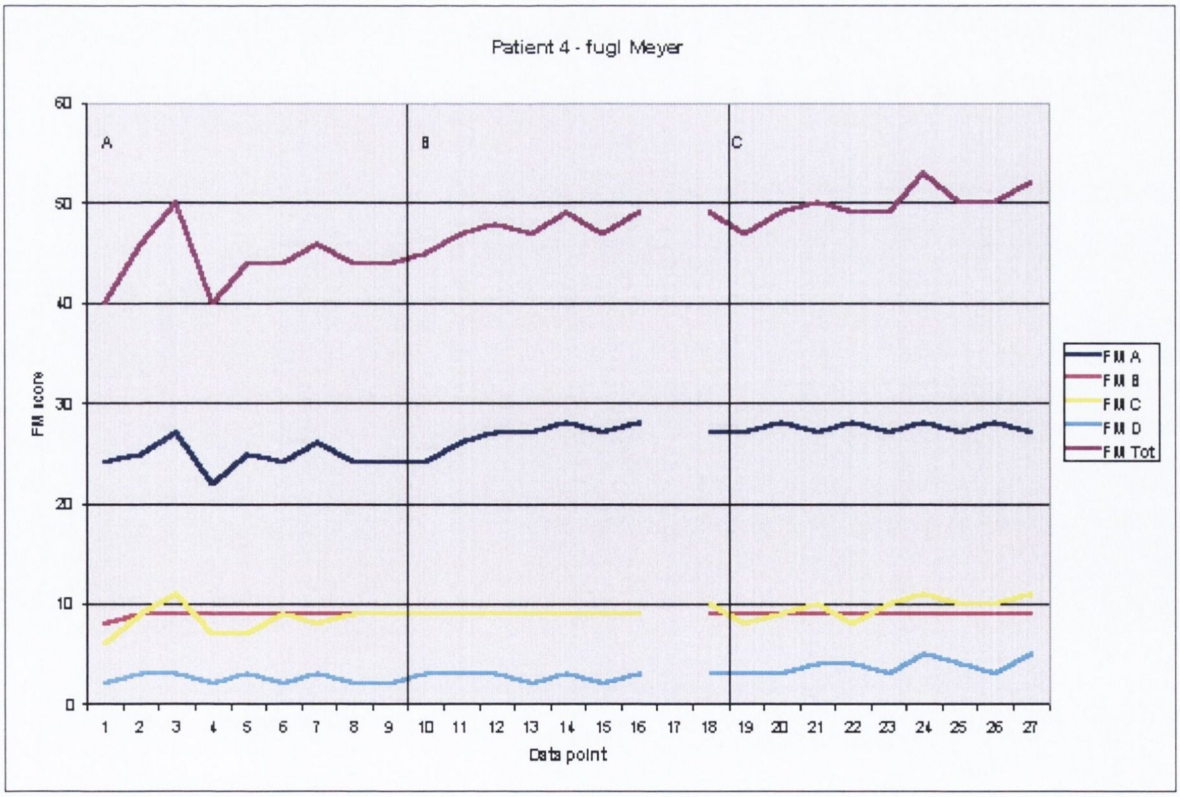

Figure 5-25. Subject 4, Fugl-Meyer

Motor Assessment Scale

The rate of recovery during the RMT phase was higher than both baseline and SS for all sections of the MAS, this difference was significantly greater for all except the difference between the B and SS slopes for the MASA and MASB sections.

The plotted raw data shows initial variability which contributes to the negative value of the baseline phase slopes.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
MASA	3.90	-0.12	0.14	0.13	0.26	-0.02
MASB	2.70	-0.02	0.16	0.03	0.18	-0.13
MASC	1.38	-0.06	0.07	0.05	0.13	-0.02
MAST	7.89	-0.20	0.38	0.21	0.57	-0.17

Table 5-31. Subject 4, MAS

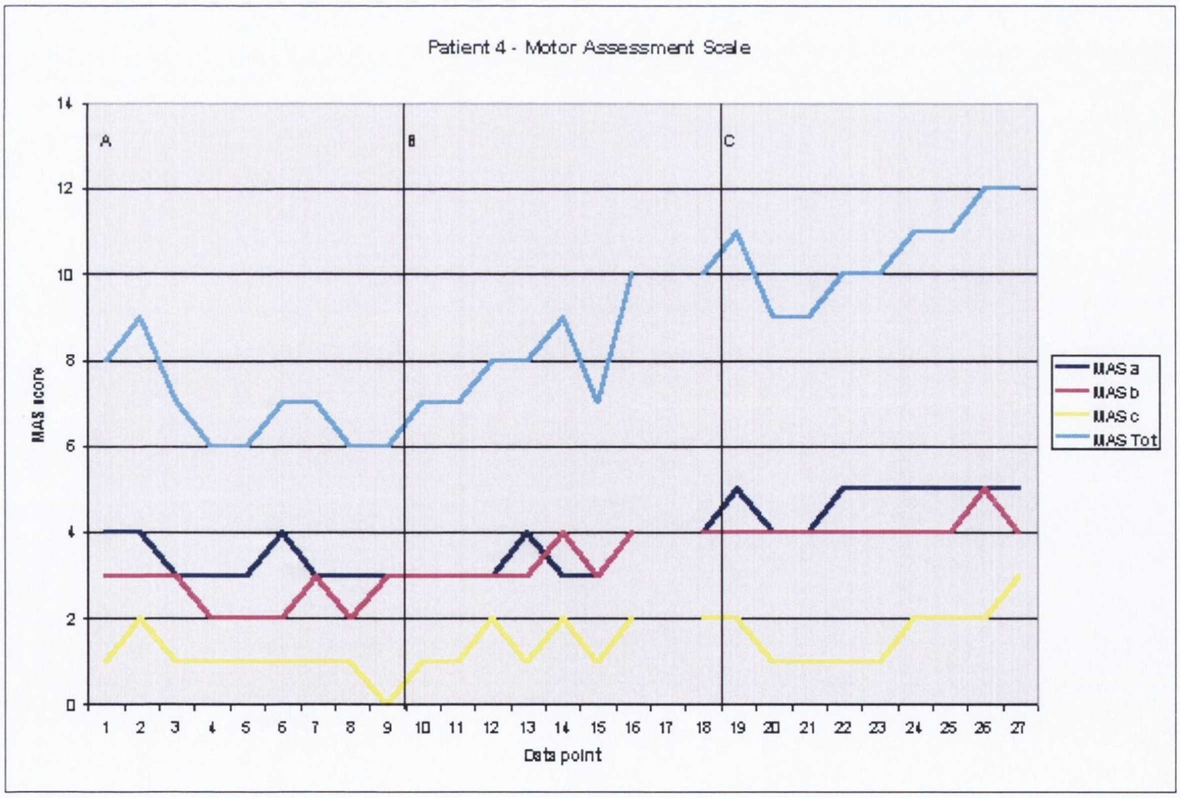

Figure 5-26. Subject 4, MAS

Maximal voluntary isometric contraction

The rate of recovery during the RMT phase is higher than both the baseline and SS phases for all four variables. The difference compared to baseline is greatest for elbow flexion. The rate of recovery during the RMT phase was significantly higher than that of the baseline for 3 of the variables.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
ElbFlex	11.80	-0.42	0.63	0.34	1.04	-0.29
ElbExt	13.00	-0.35	0.41	-0.02	0.76	-0.43
ShoFlex	4.76	-0.05	0.16	0.11	0.20	-0.04
ShoExt	16.06	-0.31	0.53	0.12	0.84	-0.41

Table 5-32. Subject 4, MVIC

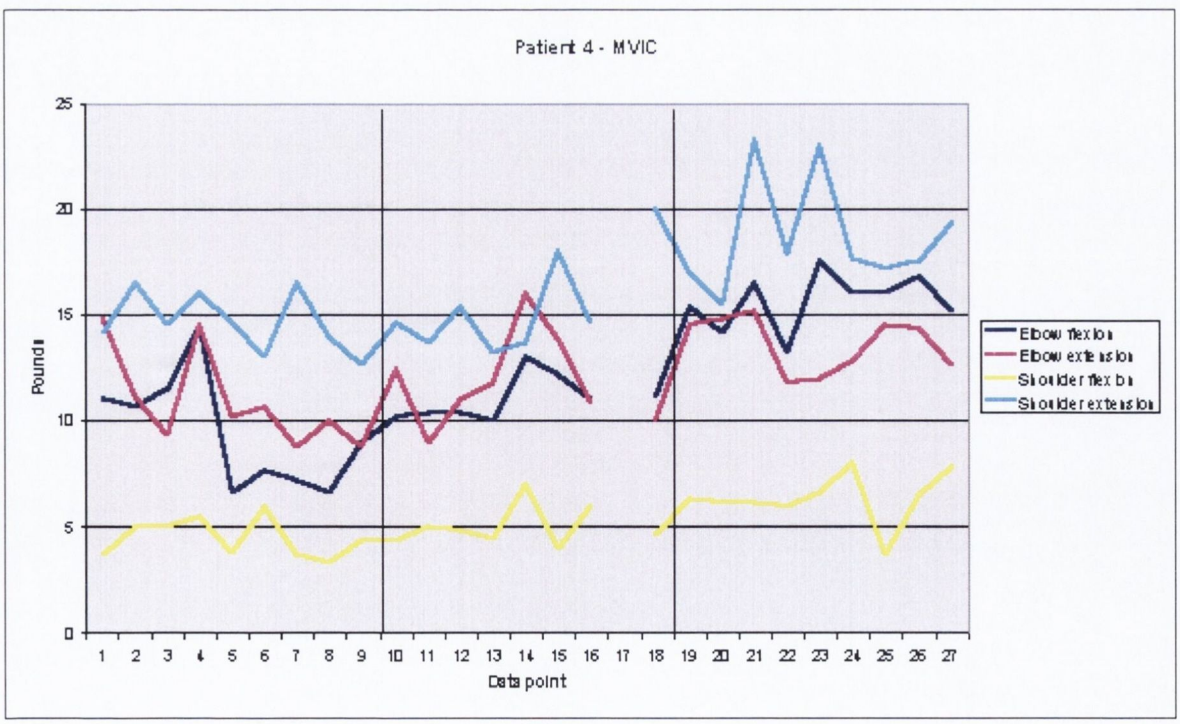

Figure 5-27. Subject 4, MAS

Range of Motion

The rate of recovery during the RMT phase is significantly higher than both baseline and SS for active and passive shoulder flexion. It is significantly higher than baseline for active shoulder abduction and active elbow extension. For many of the variables the slope was greatest during the baseline.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
AShFl	78.66	-1.29	2.35	-0.20	3.64	-2.55
PShFL	94.08	0.24	1.63	-0.56	1.39	-2.18
AShA	52.78	-0.59	0.72	-0.08	1.31	-0.80
PShA	69.11	0.43	-0.09	-0.40	-0.53	-0.30
AElX	-26.86	-0.77	1.82	0.37	2.59	-1.45
PELX	-0.53	0.24	-0.07	0.19	-0.32	0.26
AShER	19.89	0.09	0.24	-0.29	0.15	-0.53
PShER	34.94	0.48	-0.46	-0.32	-0.94	0.14
AELFl	115.25	1.01	0.67	0.01	-0.34	-0.65
PELFl	134.44	0.47	0.18	-0.09	-0.28	-0.27

Table 5-33. Subject 4, ROM

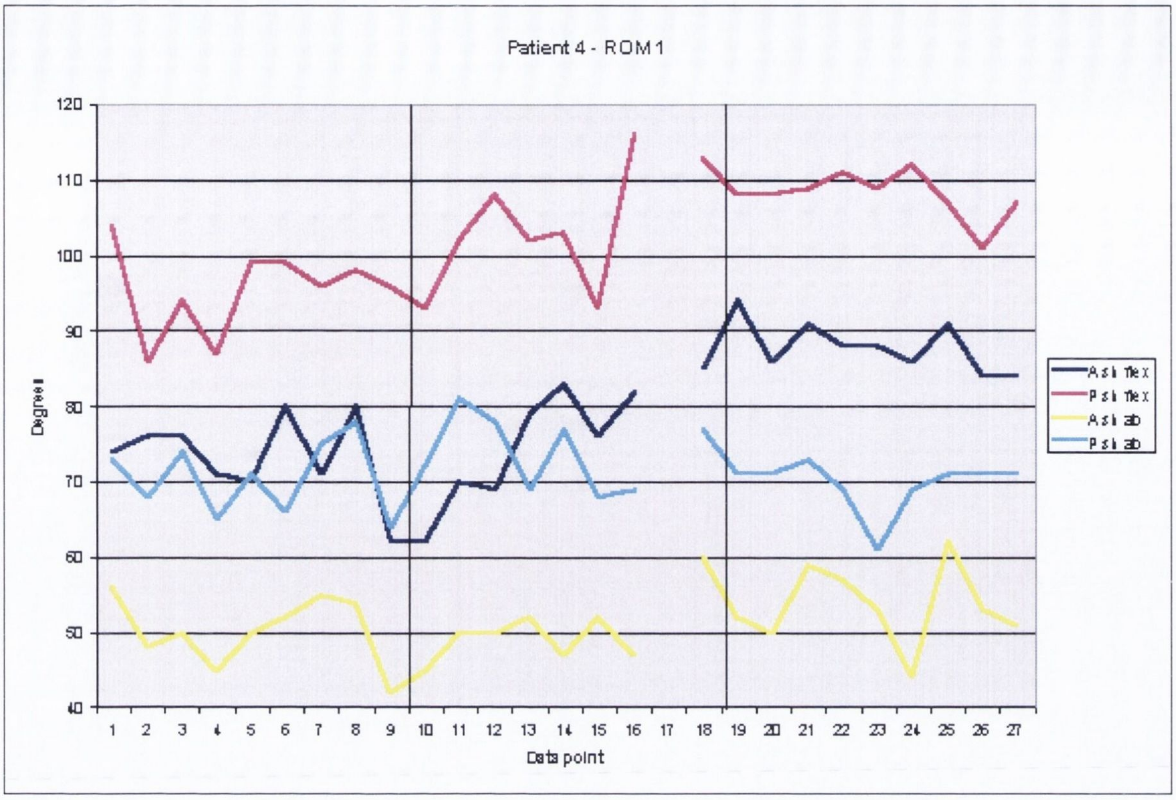

Figure 5-28. Subject 4, ROM 1

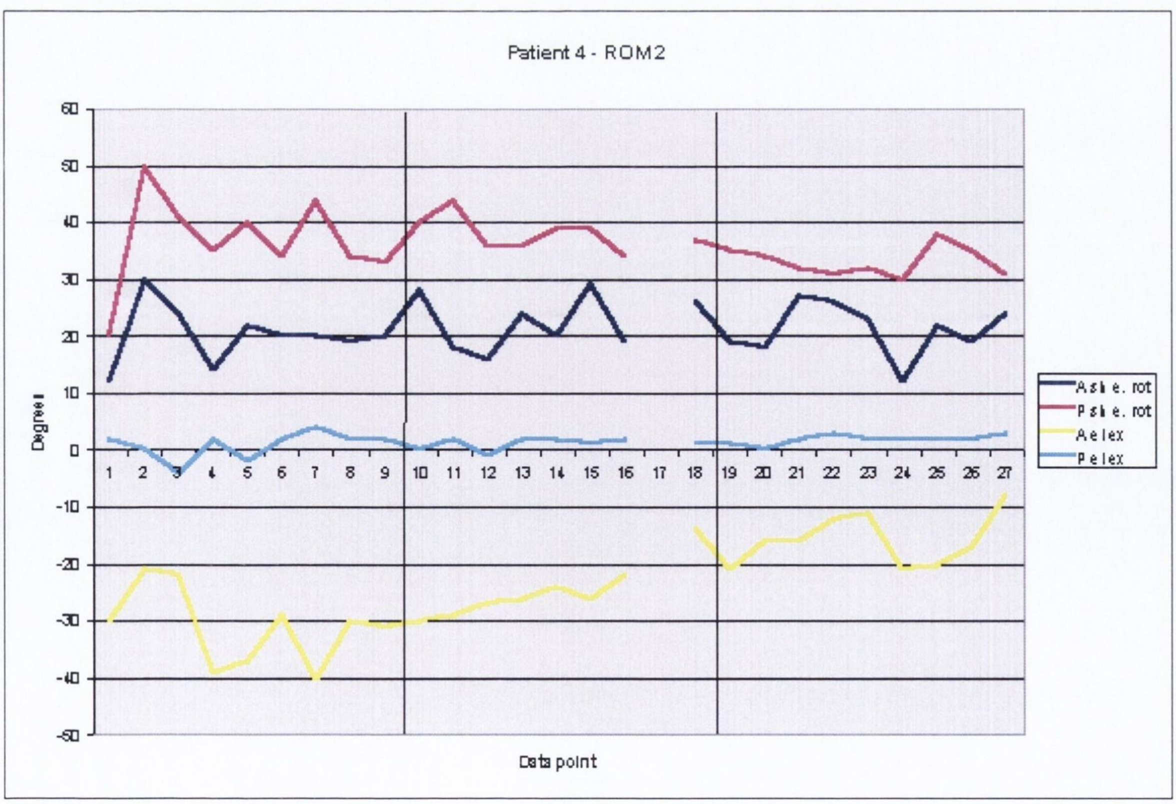

Figure 5-29. Subject 4, ROM 2

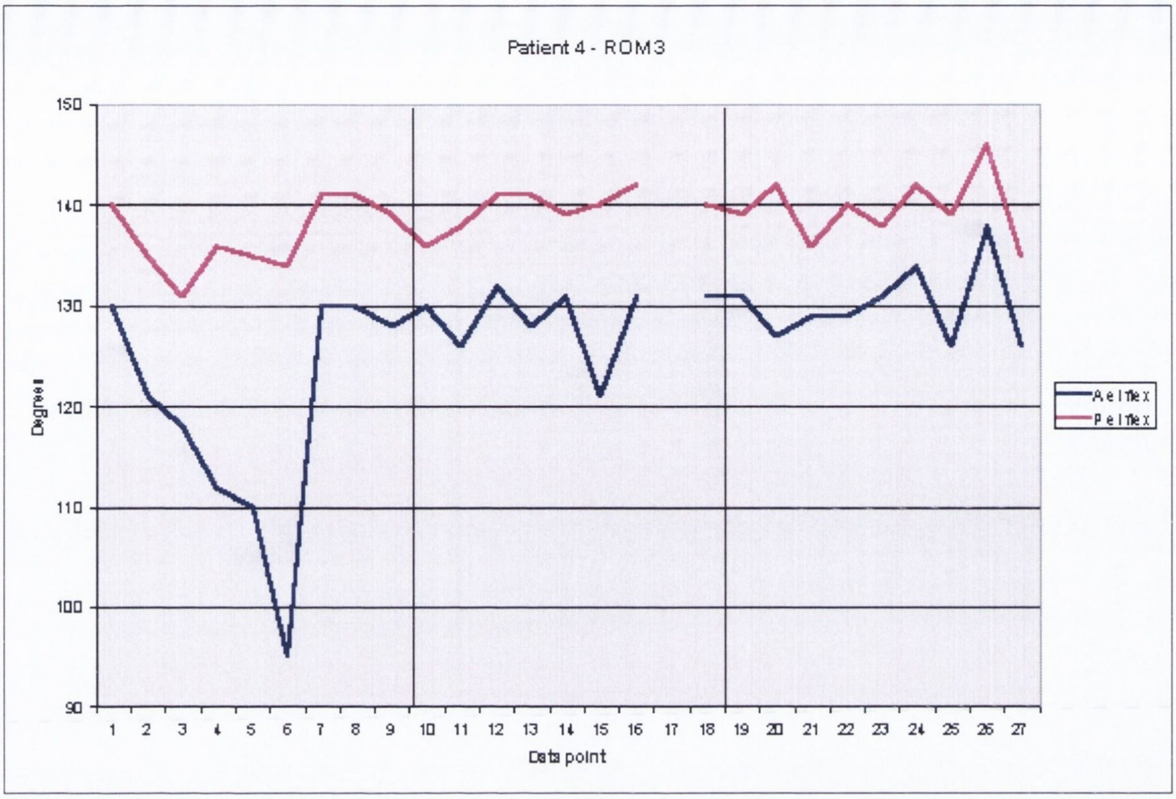

Figure 5-30. Subject 4, ROM 3

Grip Strength

The slopes for the RMT and SS treatment phases are negligible in size, the baseline phase slope being higher than both of these phases.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
Grip	4.48	0.26	-0.02	0.01	-0.29	0.03

Table 5-34. Subject 4, Grip

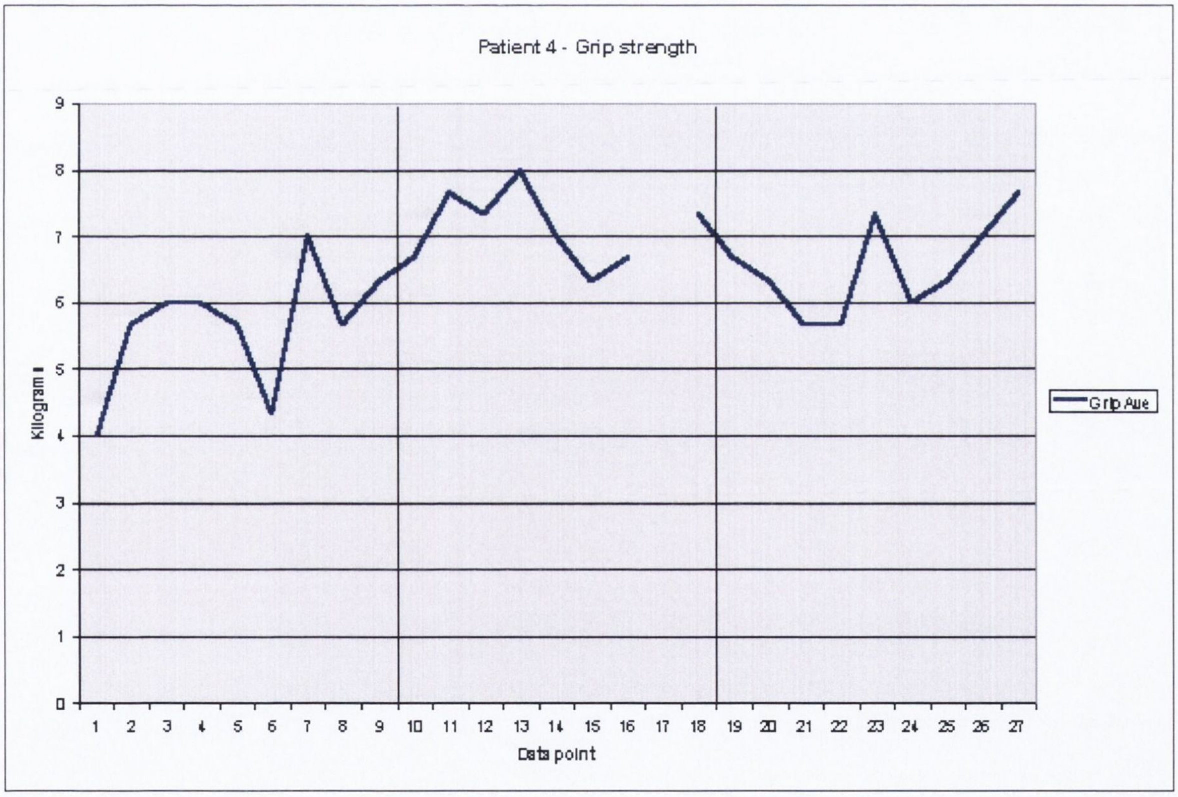

Figure 5-31. Subject 4, Grip

Quality of Life

The plotted data shows a trend for a decrease over the baseline and RMT phases and an increase over the SS phase. The physical health summative score ends 10.1% higher than baseline, while the mental health score ends lower than baseline.

SF-36 Domain	Start	End A	End B	End C
Physical Functioning	27.6	33.9	29.7	42.3
Roles - Physical	34.8	39.7	37.3	52
Bodily Pain	46.1	45.6	46.1	41.4
General Health	37.7	37.7	28.1	35.3
Vitality	45.8	42.7	42.7	45.8
Social Functioning	56.8	56.8	56.8	56.8
Roles - Emotional	55.9	48.1	40.3	55.9
Mental Health	52.8	47.2	52.8	44.4
Physical Health Score	28.9	35.8	31.2	41
Mental Health Score	62.4	53.5	54.3	53.3

Table 5-35. Subject 4, SF-36

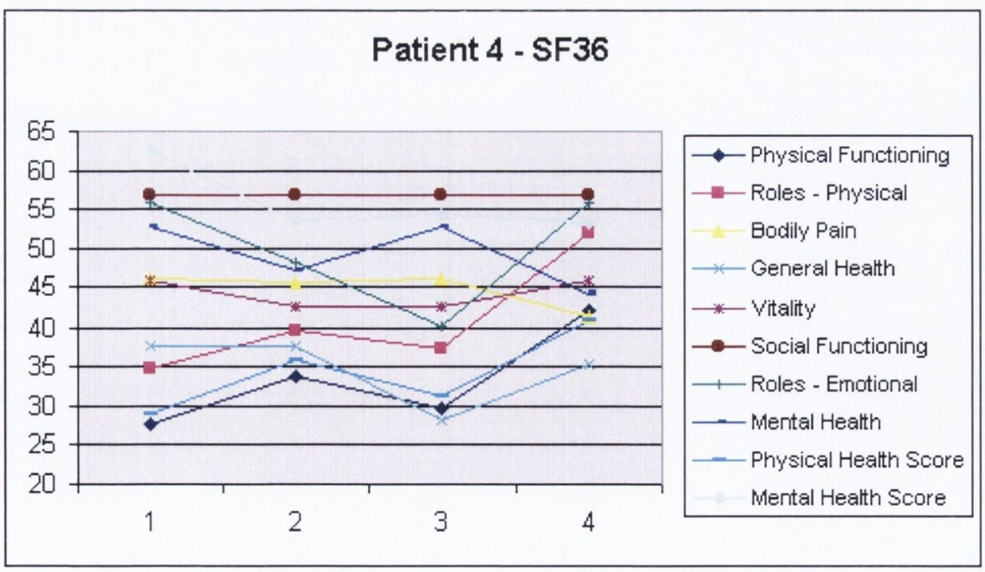

Figure 5-32. Subject 4, SF-36

5.2.5 Subject 5

Mrs. EO'R was a 79 year old lady who had a right CVA 22 months prior to the start of the study. Her CT scan showed a right external capsule infarct and was classified a PACI.

At the time of the study she was living alone and was not receiving any treatment, she was on review at Baggot Street Community Hospital stroke unit. Her past medical history included depression and A-fib. Her medications included Warfarin and antidepressants.

She was randomized to 9 baseline measures and the ABC group. She spent 4.7% of time exercising in passive mode, 90.4% in active assisted and 4.9% in active mode.

Events during course of study

There were no events of note

Background data

Her star cancellation test decreased over the baseline and increased over the course of the study back to baseline. She had no pain in her UE. Her wrist tone decreased significantly over the RMT phase, with her elbow tone decreasing over the SS phase. Her sensation score was initially extremely low, 5/36, which increased over the duration of the study, the greatest increase over the baseline and RMT phases.

Subject 1, Summary	
Age	79
Time post stroke	22 months
Side affected	Left
CT result	Right external capsule infarc
Current physiotherapy treatment	None
Randomisation	ABC, 9
Exercise mode	P 4.7%, AA 90.4%, A 4.9%

Table 5-36. Subject 5, Summary

BASELINE MEASUREMENTS	Start A	Start B	Start C	End C
Short Orientation Memory Concentration	24	22	26	28
Star Cancellation L	27	27	27	27
Star Cancellation R	27	24	26	27
Star Cancellation Total	54	51	53	54
Pain	0	0	0	0
Hemianopia	0	0	0	0
Tone Wrist	4	4	2	3
Tone Elbow	3	3	3	2
Sensation Light Touch	0	0	0	0
Sensation Pressure	2	6	8	8
Sensation Bilateral Simultaneous	0	0	0	0
Sensation Kinaesthesia	3	5	6	7
Sensation Total	5	11	14	15

Table 5-37. Subject 5, Background data

Fugl-Meyer

The rate of recovery during the RMT phase was significantly greater than baseline and SS for the FMA, FMD and FMT sections. The values of the FMB and FMC slopes are negligible.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
FMA	21.50	-0.12	0.55	-0.22	0.67	-0.77
FMB	1.87	0.04	0.00	-0.04	-0.04	-0.04
FMC	8.02	0.02	0.03	0.08	0.01	0.05
FMD	2.43	-0.08	0.17	-0.01	0.25	-0.18
FMT	33.82	-0.15	0.76	-0.18	0.91	-0.94

Table 5-38. Subject 5, Fugl-Meyer

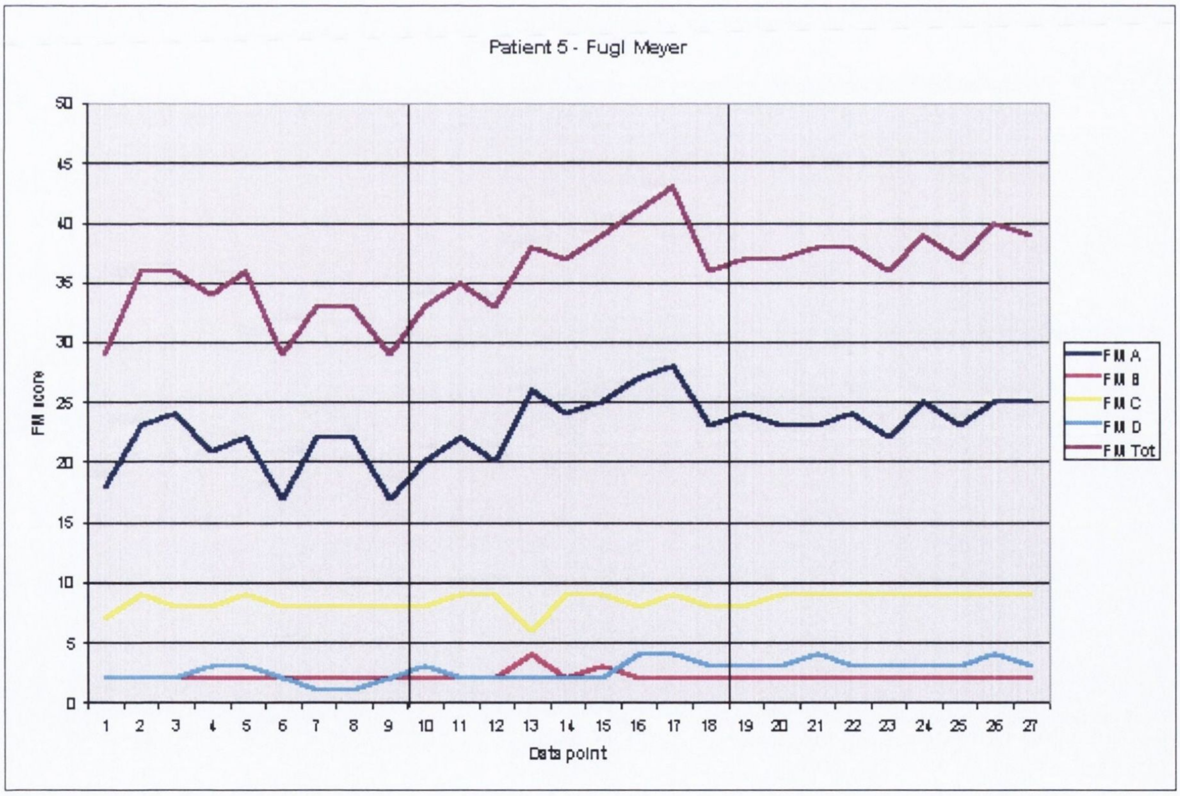

Figure 5-33. Subject 5, Fugl-Meyer

Motor Assessment Scale

The rate of recovery during the MASA, MASB and MAST sections was significantly higher during the RMT phase than both baseline and SS.

The plotted raw data clearly demonstrates this. The MASC section remained unchanged for the RMT and SS phases.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
MASA	3.41	-0.08	0.28	-0.07	0.36	-0.35
MASB	1.06	-0.02	0.13	-0.03	0.15	-0.17
MASC	0.12	0.11	-0.01	0.00	-0.12	0.01
MAST	4.58	0.01	0.41	-0.10	0.40	-0.51

Table 5-39. Subject 5, MAS

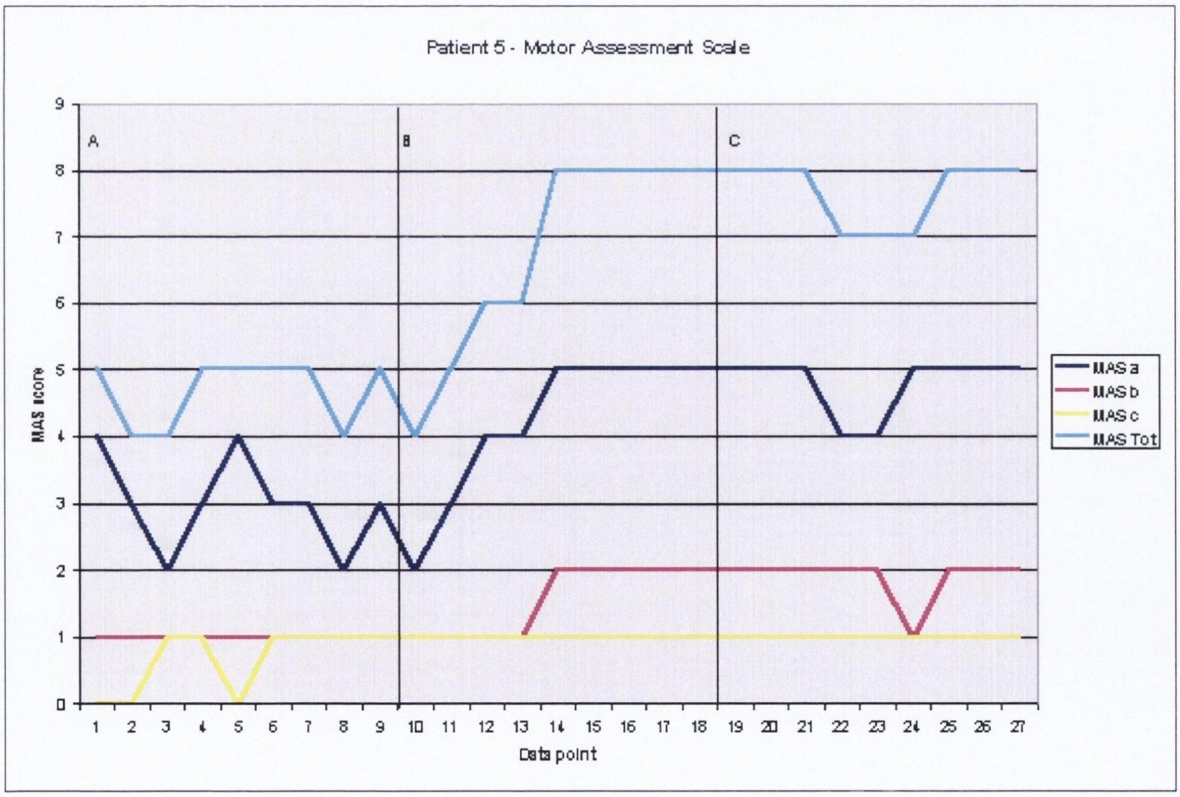

Figure 5-34. Subject 5, MAS

Maximal voluntary isometric contraction

The rate of recovery was higher during the RMT phase than both SS and baseline for all but elbow flexion where the RMT slope was significantly lower than both baseline and SS.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
ElbFlex	12.62	0.83	-0.37	0.39	-1.19	0.76
ElbExt	10.85	0.14	0.17	-0.08	0.04	-0.25
ShoFlex	5.83	-0.24	0.13	-0.03	0.37	-0.16
ShoExt	12.98	-0.04	0.11	0.10	0.15	-0.02

Table 5-40. Subject 5, MVIC

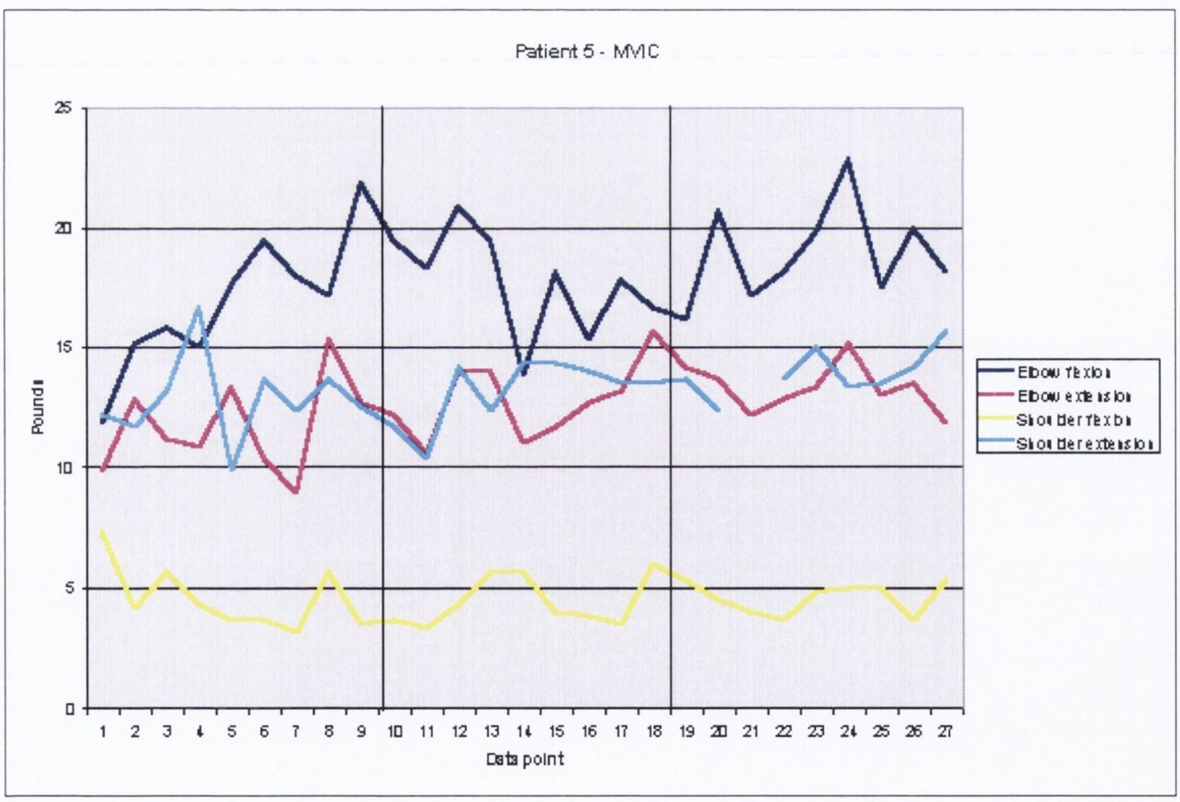

Figure 5-35. Subject 5, MVIC

Range of Motion

The rate of recovery during the RMT phase was higher than both SS and baseline for 6 variables, though none of them were significant. The rate of recovery during RMT was significantly lower than baseline for passive shoulder abduction.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
AShFl	92.01	-0.57	1.27	-0.33	1.84	-1.61
PShFL	99.10	1.24	0.28	0.13	-0.95	-0.16
AShA	60.40	0.06	0.67	0.09	0.61	-0.58
PShA	69.86	1.48	-0.85	0.88	-2.33	1.73
AElX	-26.12	0.32	0.80	-0.19	0.48	-0.99
PELX	-3.98	0.18	-0.20	-0.14	-0.38	0.06
AShER	31.33	0.56	0.57	0.02	0.01	-0.55
PShER	47.70	0.11	0.44	0.23	0.33	-0.21
AELFl	135.80	0.05	0.58	-0.12	0.53	-0.70
PELFl	144.78	0.31	-0.08	0.11	-0.39	0.20

Table 5-41. Subject 5, ROM

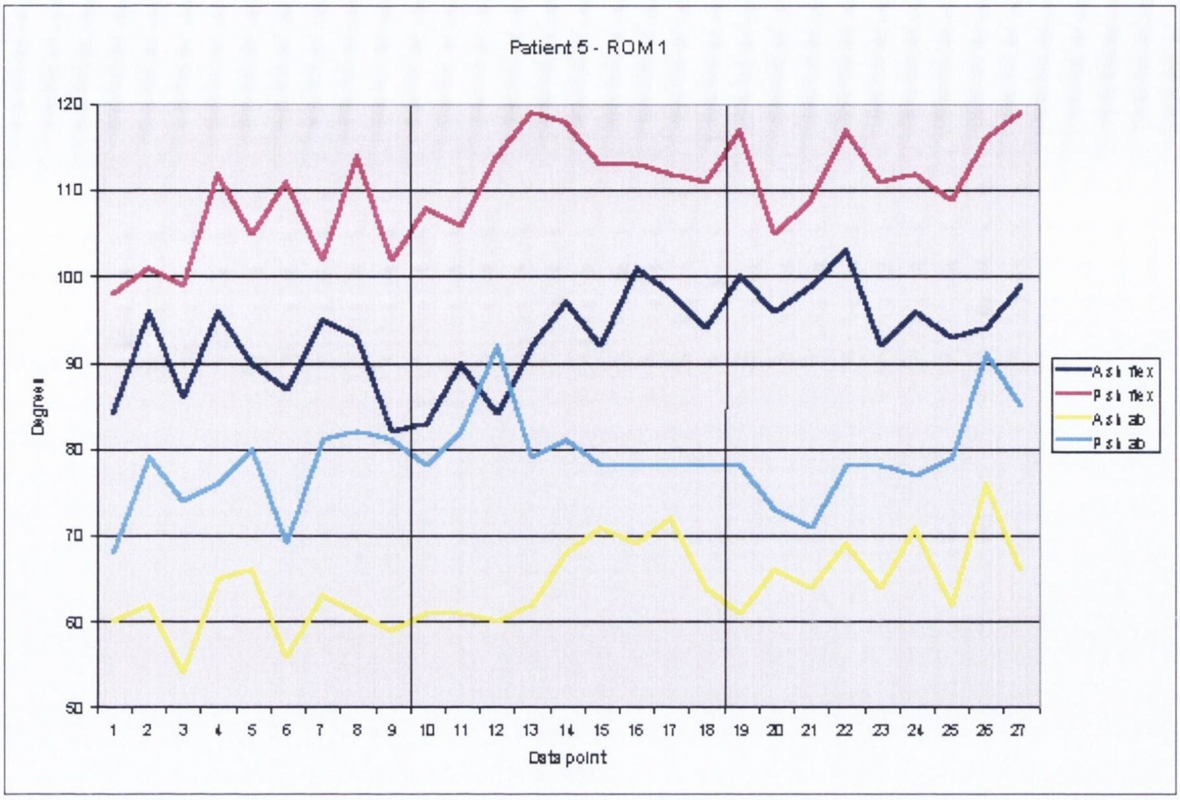

Figure 5-36. Subject 5, ROM 1

Figure 5-37. Subject 5, ROM 2

Figure 5-38. Subject 5, ROM 3

Grip Strength

All slope values and differences in these are negligible indicating little recovery in this domain. The slope is marginally higher in the SS phase. The plotted data shows variability fluctuating around 2kg.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
Grip	3.21	-0.09	-0.04	0.02	0.05	0.06

Table 5-42. Subject 5, Grip

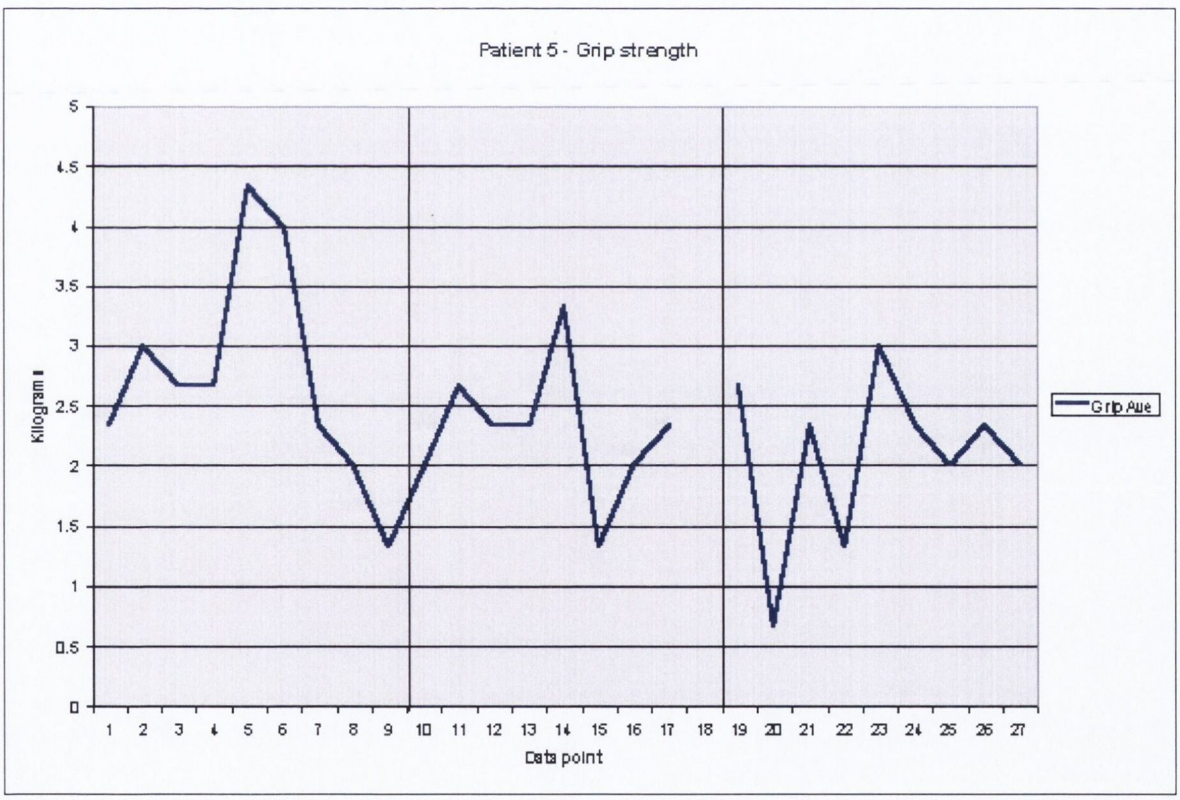

Figure 5-39. Subject 5, Grip

Quality of Life

Two of the mental health domains and the mental health score decrease in the SS phase, while the physical health score increases. All subscales fluctuate, the physical score finishing 12.5% higher than the baseline with he mental health score dropping 11.2% from baseline.

SF-36 Domain	Start	End A	End B	End C
Physical Functioning	31.8	38.1	31.8	29.7
Roles - Physical	17.7	17.7	20.1	34.8
Bodily Pain	62.1	62.1	62.1	62.1
General Health	52.9	60.1	48.2	55.3
Vitality	30.2	39.6	42.7	45.8
Social Functioning	51.4	40.5	45.9	29.6
Roles - Emotional	48.1	55.9	44.2	28.7
Mental Health	38.7	38.7	38.7	27.5
Physical Health Score	37.8	41.1	38.6	50.3
Mental Health Score	46.4	47.5	45.9	28.6

Table 5-43. Subject 5, SF-36

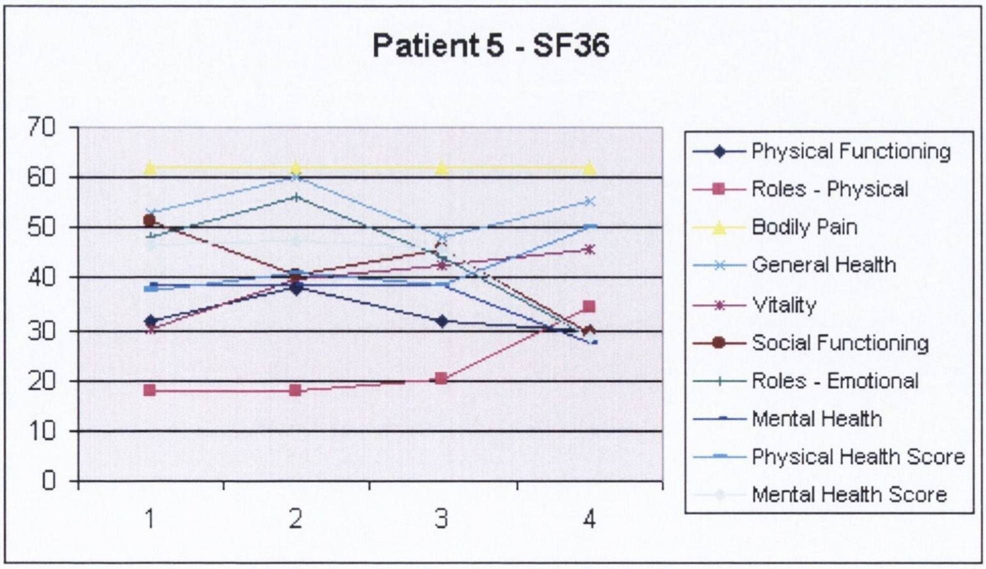

Figure 5-40. Subject 5, SF-36

5.2.6 Subject 6

Mrs. PB was a 79 year old lady who had a right CVA 32 months prior to the start of the study. Her CT scan results were unavailable. She lived alone and was extremely active in local clubs.

She was not receiving any treatment at the time of the study. Her past medical history included a viral infection leading to aortic valve replacement around the time of her CVA. Her only medication was Warfarin.

She was randomized to 9 baseline data points and ACB group. She exercised in active assisted mode for 1.3% of the time and active mode for 98.7% of the time.

Events during course of study

There were no events of note.

Background data

Her star cancellation test fluctuated within 2 points of maximum over the course of the study. She had no pain in her arm at any stage. Her elbow tone increased slightly over the SS phase and decreased again over the RMT phase. Her sensation score increased by 1 point over the RMT phase.

Subject 6, Summary	
Age	79
Time post stroke	32 months
Side affected	Left
CT result	Unavailable
Current physiotherapy treatment	None
Randomisation	ACB, 9
Exercise mode	AA 1.3%, A 98.7%

Table 5-44. Subject 6, Summary

BACKGROUND MEASURES	Start A	Start C	Start B	End B
Short Orientation Memory Concentration	26	28	28	26
Star Cancellation L	25	26	27	26
Star Cancellation R	27	27	27	26
Star Cancellation Total	52	53	54	52
Pain	0	0	0	0
Hemianopia	0	0	1	0
Tone Wrist	0	0	0	0
Tone Elbow	3	2	3	2
Sensation Light Touch	8	8	8	8
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	8	8	8	8
Sensation Kinaesthesia	9	9	9	10
Sensation Total	33	33	33	34

Table 5-45. Subject 6, Background data

Fugl-Meyer

The rate of recovery during the RMT phase was greater than that during the SS phase for all sections. The rate of recovery during the RMT phase was greater than the baseline and SS for the FMA, FMB and FM total score. It was only significantly so for the total score.

The plotted raw data shows that the only variable that changed significantly during the study was the FMA section.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
FMA	27.59	-0.20	0.21	0.48	0.41	0.26	0.67
FMB	6.51	0.07	-0.03	0.08	-0.10	0.11	0.01
FMC	12.38	0.20	-0.03	0.01	-0.23	0.04	-0.19
FMD	2.62	0.08	0.01	0.04	-0.07	0.03	-0.04
FMT	49.11	0.16	0.13	0.61	-0.04	0.48	0.45

Table 5-46. Subject 6, Fugl-Meyer

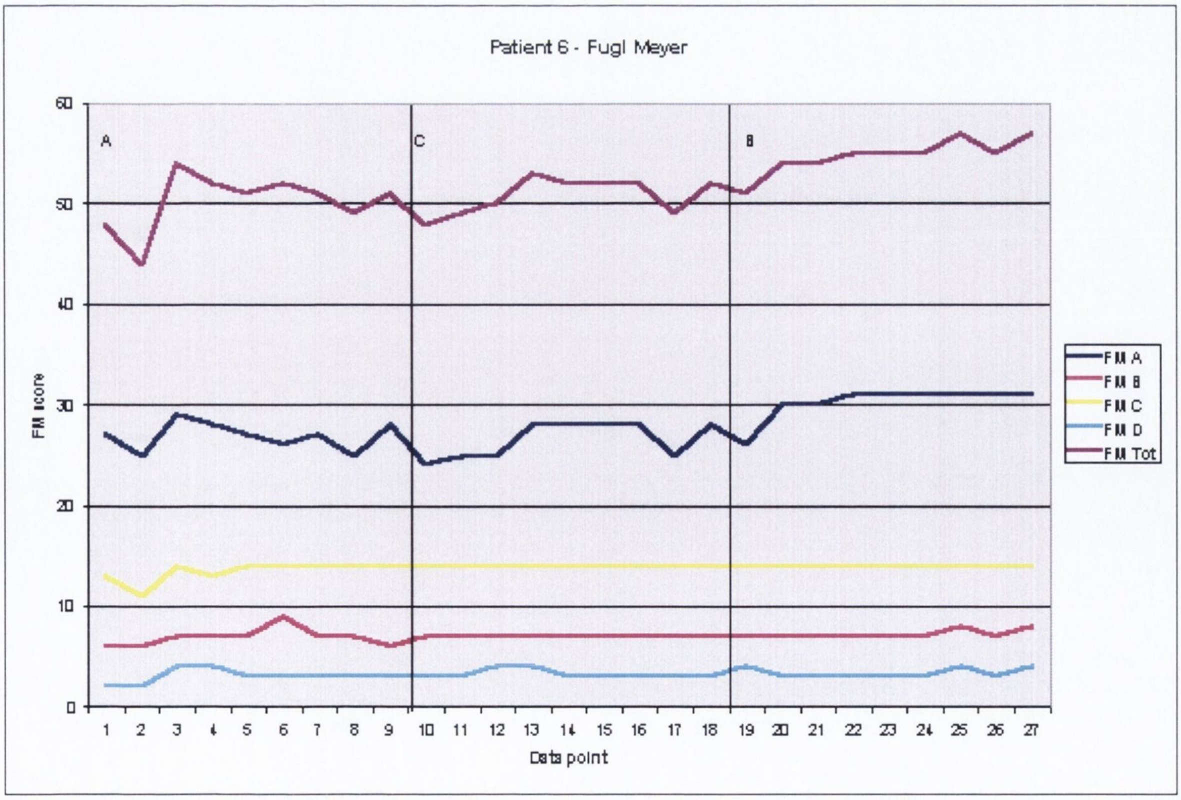

Figure 5-41. Subject 6, Fugl-Meyer

Motor Assessment Scale

The rate of recovery during the RMT phase was greater than that of the baseline and SS phases for all sections. The SS phase slope was less than baseline for all sections. The slope of the RMT phase was significantly higher than the SS phase for 3 of the sections. It was not significantly higher than the baseline for any.

The plotted data shows high variability in the scores.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
MASA	3.69	0.13	0.00	0.16	-0.14	0.16	0.03
MASB	4.10	0.07	0.02	0.09	-0.05	0.07	0.02
MASC	3.72	0.02	0.00	0.02	-0.02	0.02	0.00
MAST	11.52	0.22	0.02	0.27	-0.20	0.25	0.05

Table 5-47. Subject 6, MAS

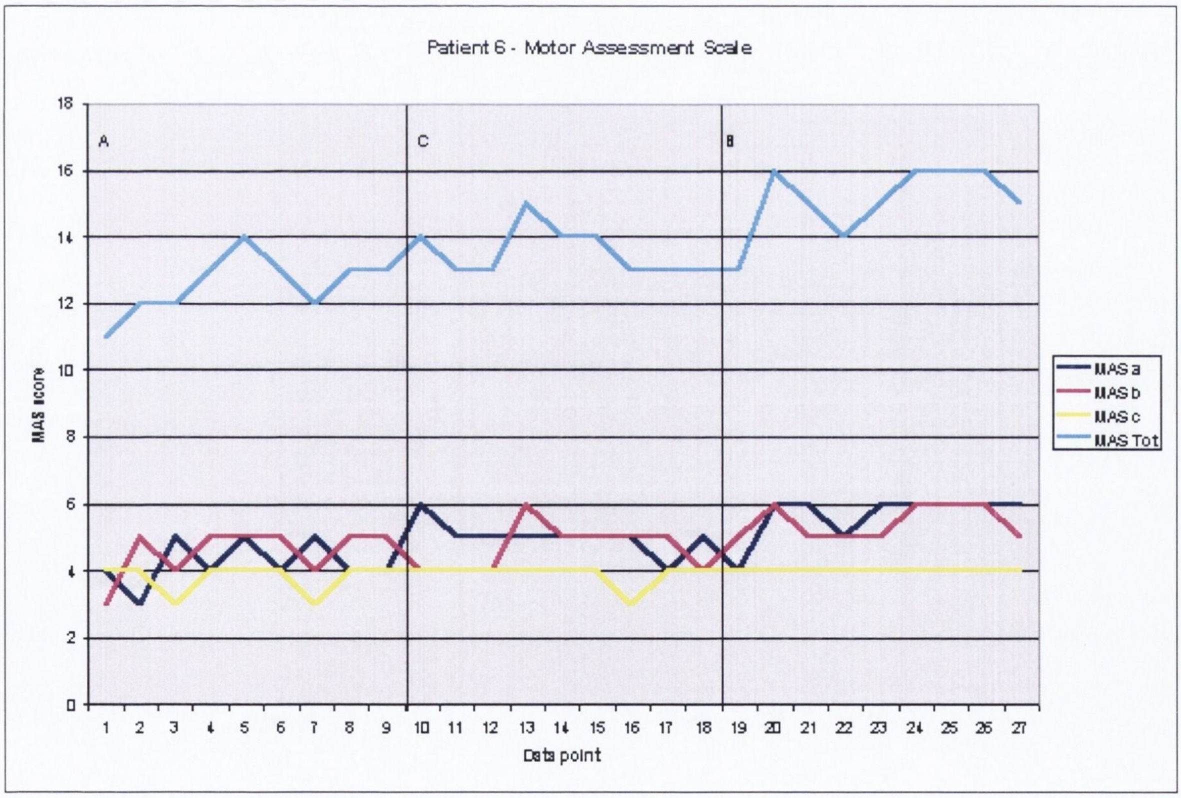

Figure 5-42. Subject 6, MAS

Maximal voluntary isometric contraction

The rate of recovery during the RMT phase was greater than both the baseline and SS phase for 3 muscle groups. It was higher than baseline for all but elbow extension.

The plotted raw data demonstrates high variability in this measure.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
ElbFlex	20.97	-0.01	0.19	0.45	0.21	0.26	0.47
ElbExt	12.14	0.65	0.00	0.31	-0.64	0.31	-0.33
ShoFlex	13.85	0.32	0.08	0.39	-0.24	0.31	0.07
ShoExt	18.48	0.26	-0.08	0.49	-0.35	0.57	0.22

Table 5-48. Subject 6, MVIC

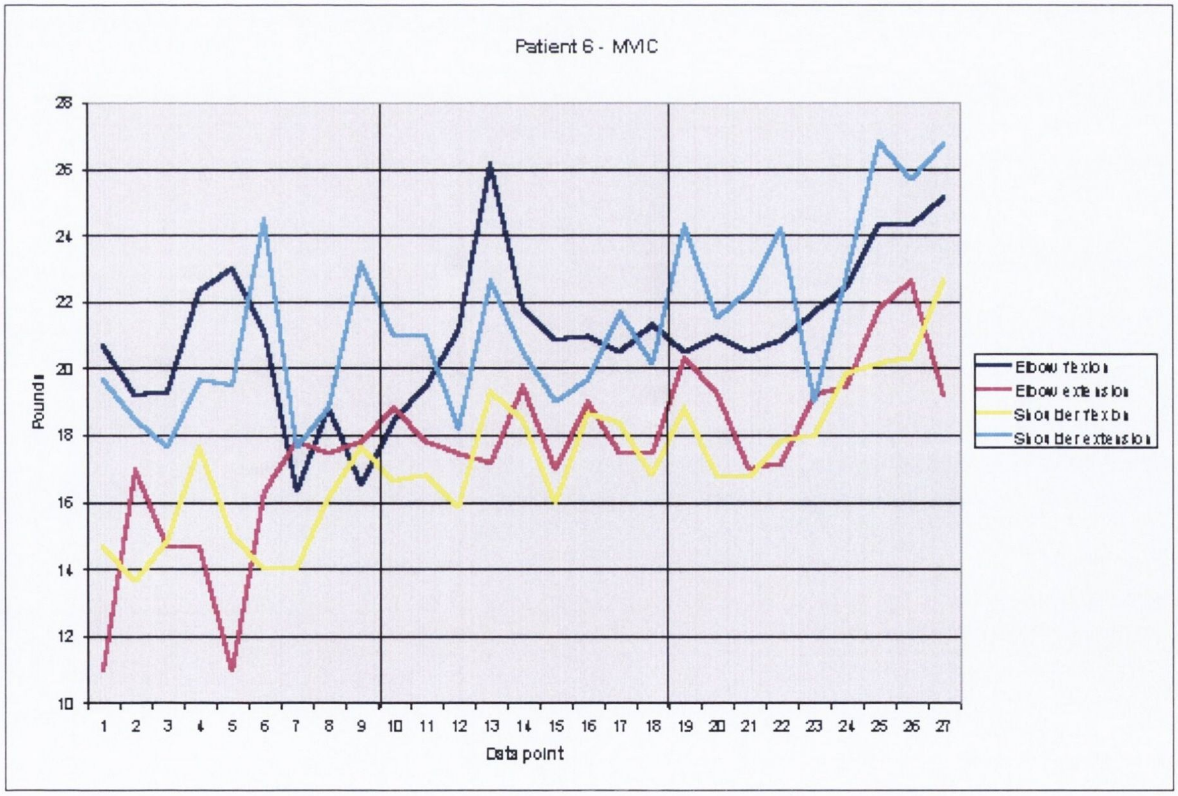

Figure 5-43. Subject 6, MVIC

Range of Motion

The rate of recovery was higher in the RMT than the SS and baseline for 5 variables. It was significantly higher than both for active and passive abduction. It was significantly less than SS for active shoulder external rotation.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
AShFl	99.55	0.73	0.73	1.41	-0.01	0.69	0.68
PShFL	125.38	-0.12	0.13	1.02	0.25	0.89	1.14
AShA	86.72	-1.26	0.11	4.06	1.37	3.95	5.32
PShA	90.87	0.10	0.12	3.52	0.02	3.40	3.42
AElX	-30.42	1.69	-0.50	0.64	-2.19	1.14	-1.05
PELX	-6.80	0.75	-0.14	0.37	-0.89	0.51	-0.38
AShER	11.02	0.58	1.02	0.03	0.44	-1.00	-0.55
PShER	30.91	-0.06	0.62	0.33	0.67	-0.29	0.39
AELFl	143.77	-0.49	0.77	0.19	1.26	-0.58	0.68
PELFl	150.85	0.02	-0.01	0.33	-0.03	0.34	0.31

Table 5-49. Subject 6, ROM

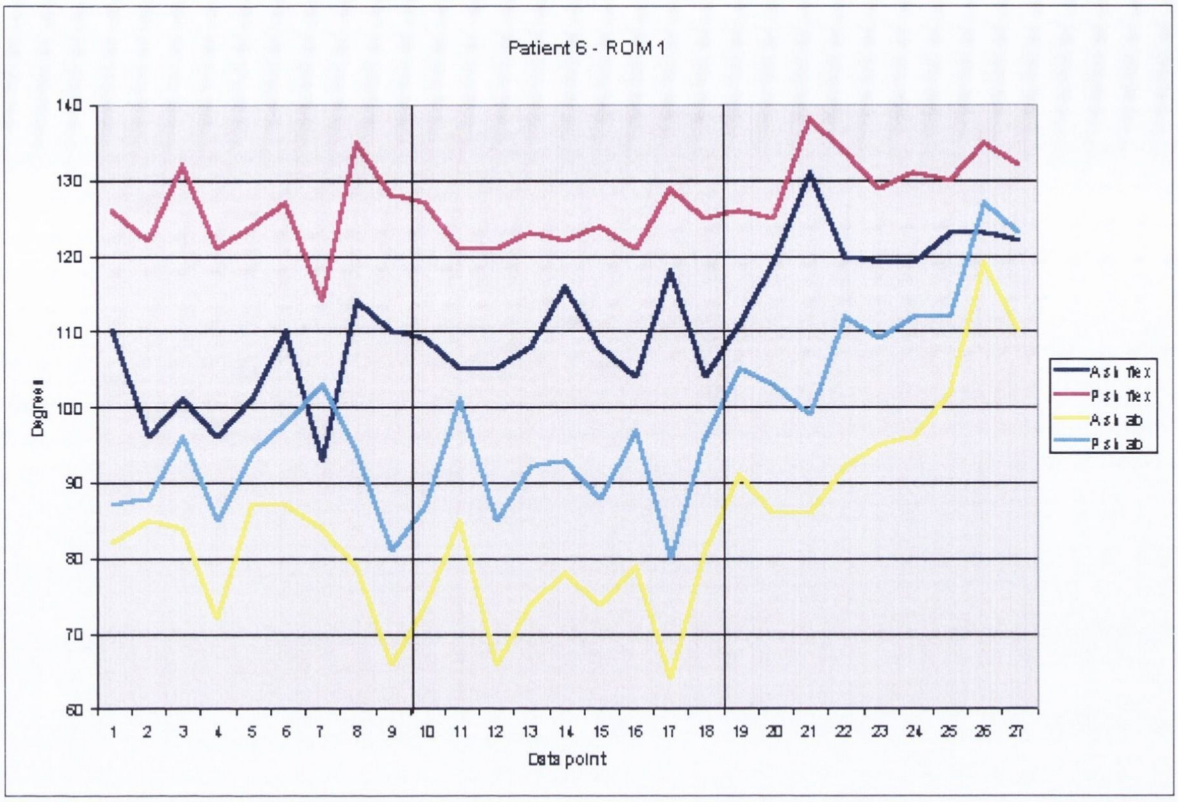

Figure 5-44. Subject 6, ROM 1

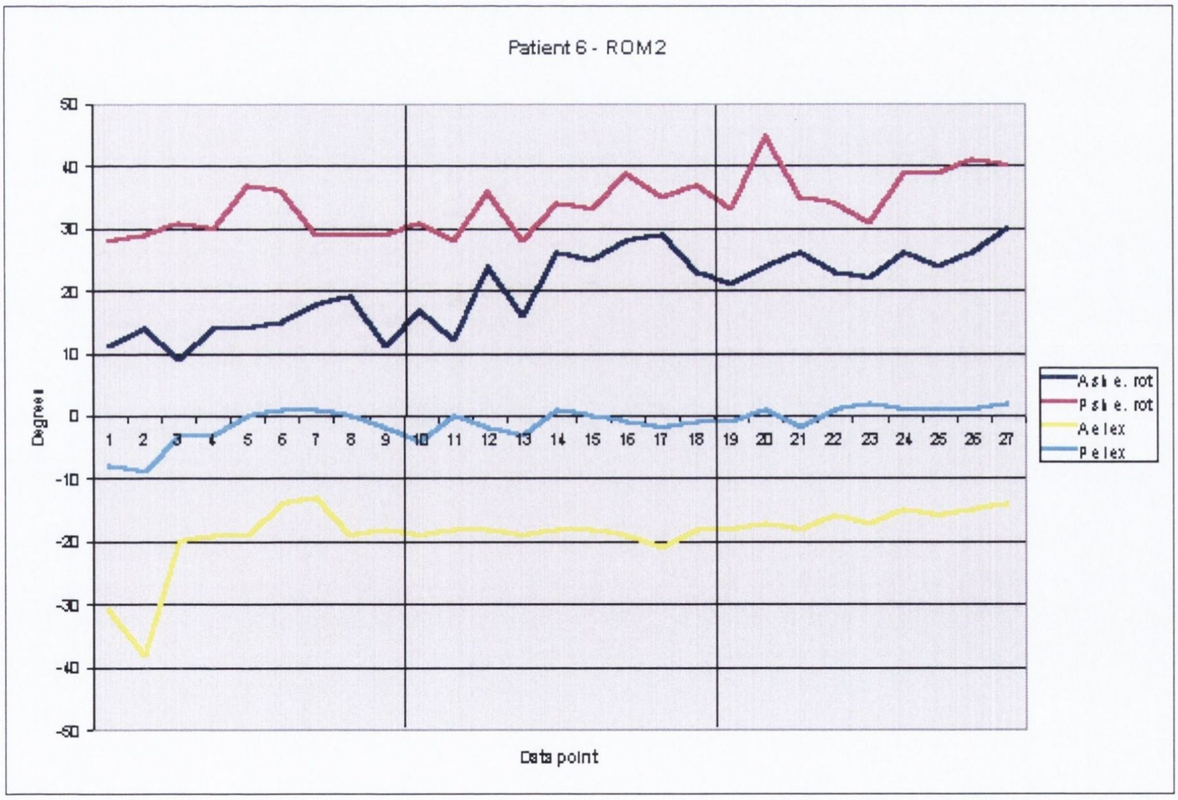

Figure 5-45. Subject 6, ROM 2

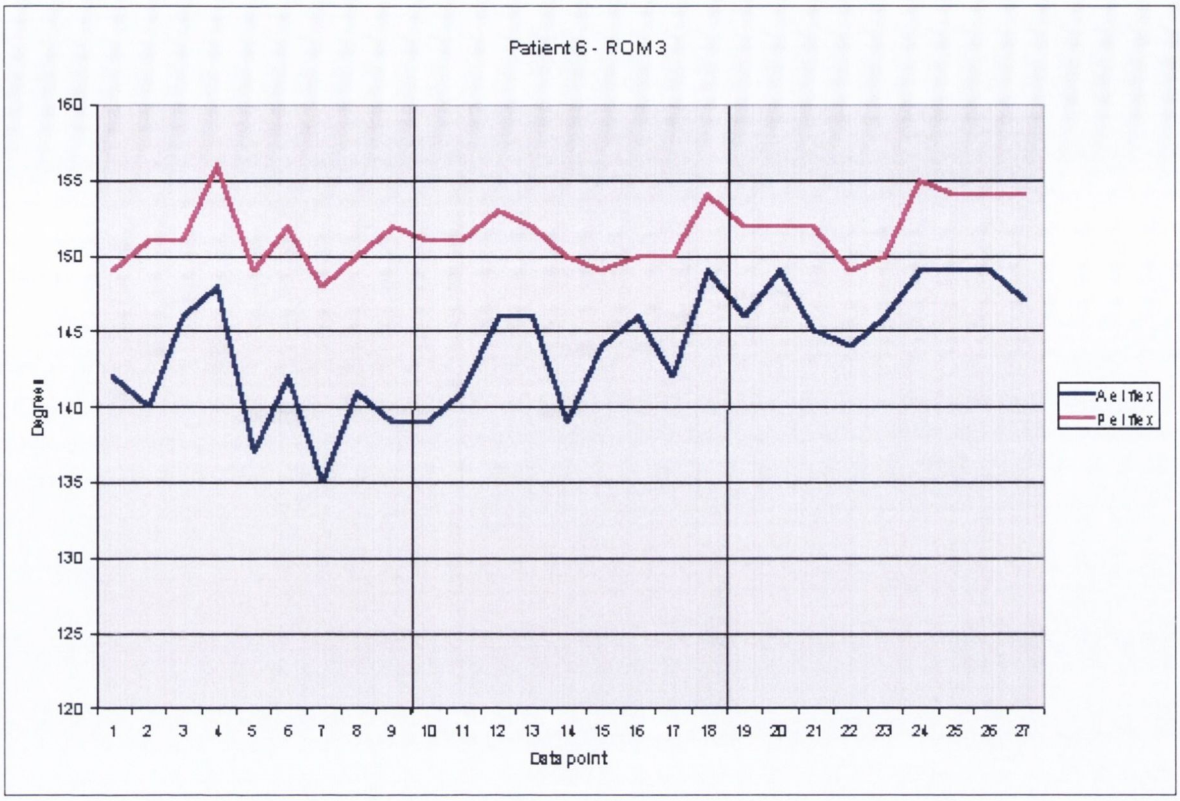

Figure 5-46. Subject 6, ROM 3

Grip Strength

The rate of recovery during the RMT phase was highest. The values for the slopes of baseline and SS phases are relatively low.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
Grip	11.25	0.10	-0.10	0.26	-0.20	0.36	0.16

Table 5-50. Subject 6, Grip

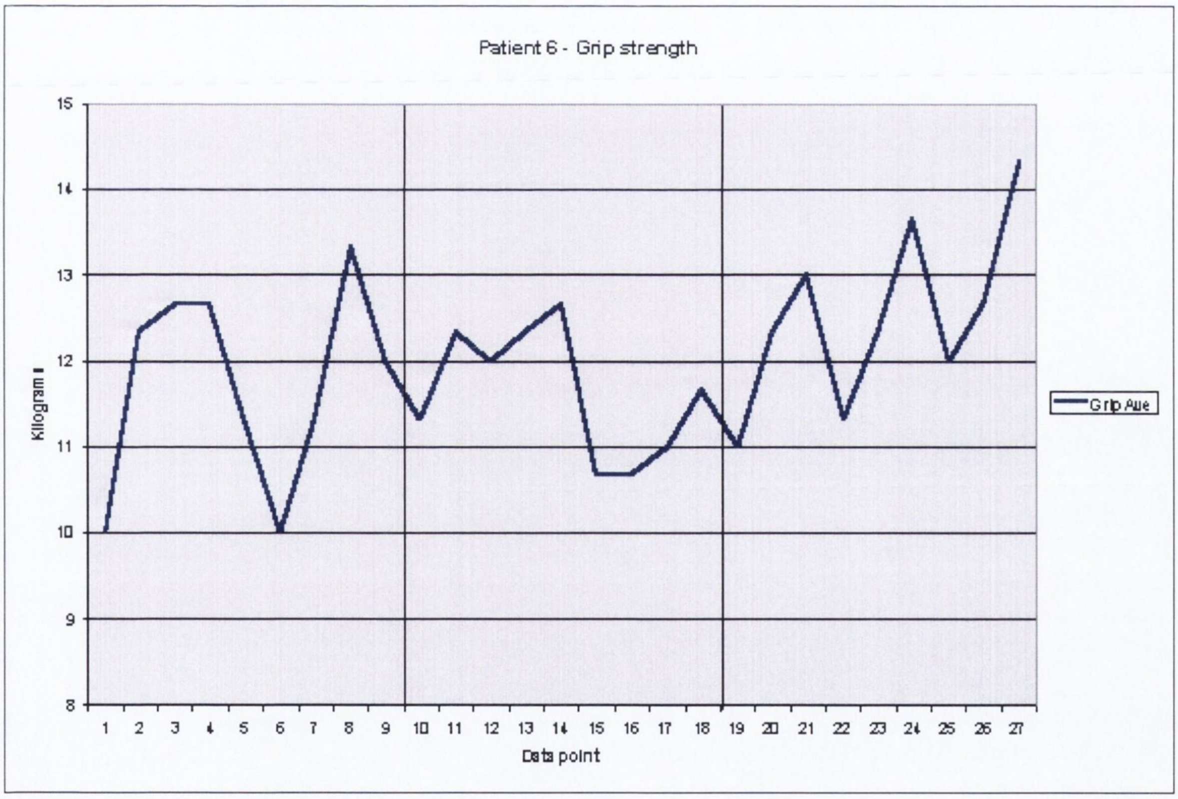

Figure 5-47. Subject 6, Grip

Quality of Life

There is missing data for a number of domains at the second measurement as the questionnaire was noticed to be incomplete at the time of data entry. No clear trends emerge from the data.

SF-36 Domain	Start	End A	End C	End B
Physical Functioning	44.4	46.5	52.8	46.5
Roles - Physical	25	32.4	34.8	37.3
Bodily Pain	62.1	62.1	62.1	62.1
General Health	45.8		57.7	43.4
Vitality	30.2		52.1	49
Social Functioning	40.5	56.8	56.8	56.8
Roles - Emotional	40.3	48.1	17	28.7
Mental Health	27.5		41.6	35.9
Physical Health Score	48		59.8	53.4
Mental Health Score	30.9		33.8	36.8

Table 5-51. Subject 6, SF-36

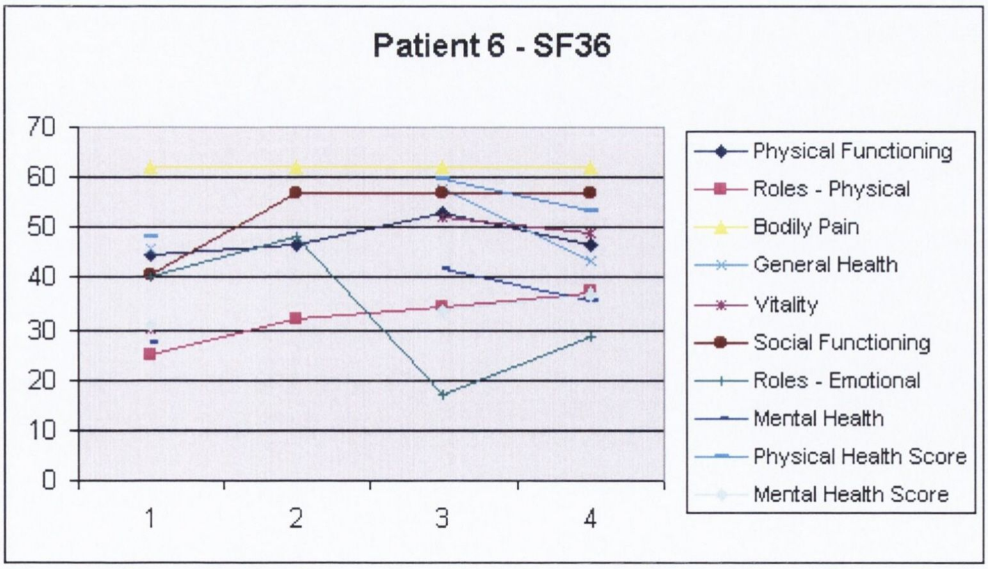

Figure 5-48. Subject 6, SF-36

5.2.7 Subject 7

Mr. PD was a 65 year old man who had a left CVA 24 months prior to the start of the study. His CT scan showed a left internal capsule infarct and was classified LI.

He lived with his wife and family. He was discharged from Baggot Street Community Hospital stroke unit 1 year prior to the start of the study.

He was randomised to a baseline of 8 data points and the ABC group. He exercised in active mode for 100% of the time.

Events during course of study

There were no notable events during the course of the study.

Background data

His star cancellation and SOMCT scores remained at maximum for the duration of the study. His wrist tone remained unchanged, his elbow tone decreased during the RMT phase and increased again during the SS phase. His sensation score remained at 1 point from maximum for the duration of the study.

Subject 7, Summary	
Age	65
Time post stroke	24 months
Side affected	Right
CT result	Left internal capsule infarct
Current physiotherapy treatment	None
Randomisation	ABC, 8
Exercise mode	A 100%

Table 5-52. Subject 7, Summary

BACKGROUND MEASURES	Start A	Start B	Start C	End C
Short Orientation Memory Concentration	28	28	28	28
Star Cancellation L	27	27	27	27
Star Cancellation R	27	27	27	27
Star Cancellation Total	54	54	54	54
Pain	1.3	0.1	0	0
Hemianopia	0	0	0	0
Tone Wrist	1	1	1	1
Tone Elbow	2	2	1	2
Sensation Light Touch	8	8	8	8
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	8	8	8	8
Sensation Kinaesthesia	11	11	11	11
Sensation Total	35	35	35	35

Table 5-53. Subject 7, Background data

Fugl-Meyer

The rate of recovery during the RMT phase was greater than both baseline and SS for the FMA, FMD and FMT sections. The FMB and FMC sections were at maximum for the duration of the study. The slope values are small for all phases. His FMA and FMD scores were nearing maximum at baseline, indicating little room for improvement.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope B-C
FMA	29.90	-0.06	0.21	0.05	0.27	-0.16
FMB	10.00	0.00	0.00	0.00	0.00	0.00
FMC	14.00	0.00	0.00	0.00	0.00	0.00
FMD	2.44	0.10	0.14	0.02	0.04	-0.12
FMT	56.35	0.04	0.35	0.07	0.31	-0.28

Table 5-54. Subject 7, Fugl-Meyer

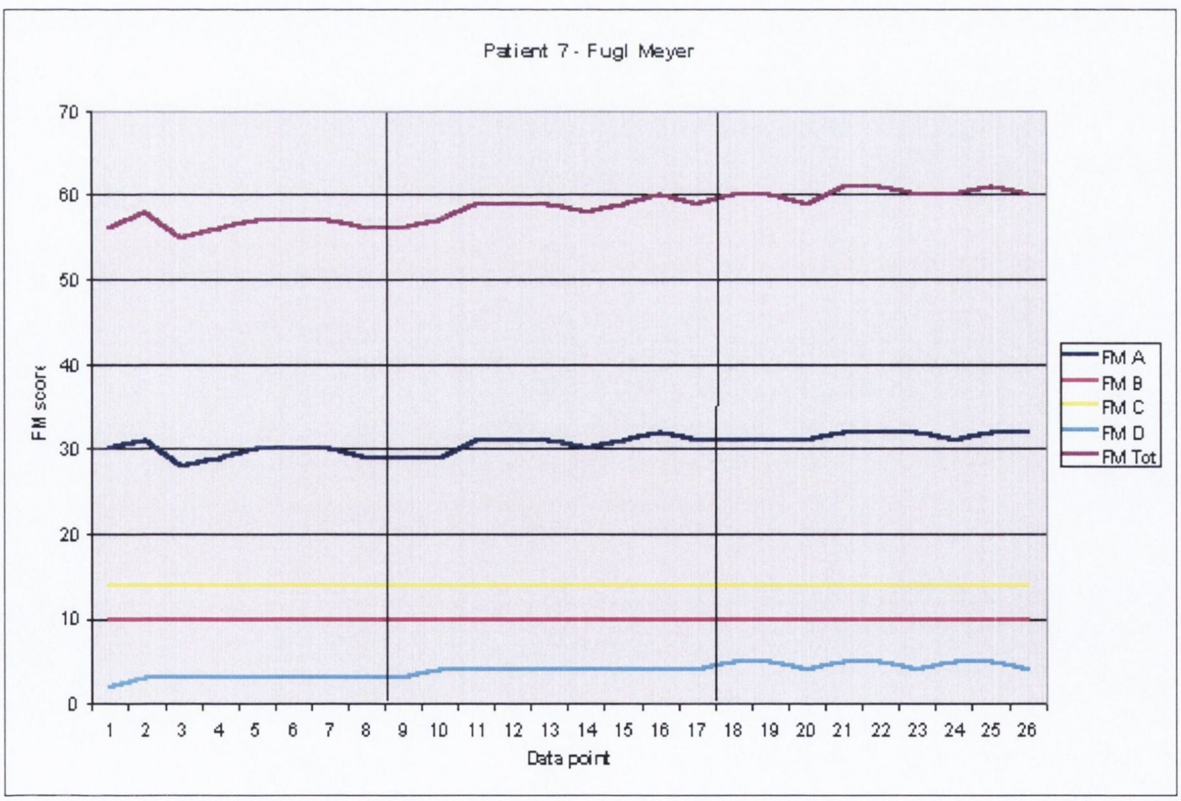

Figure 5-49. Subject 7, Fugl-Meyer

Motor Assessment Scale

The maximum score for each section is 6, with the total score 18. The MASA section total was reached in the middle of the RMT phase, as was the total score. The low slope values for each value in each section indicate only minimal change in this domain.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
MASA	4.67	0.04	0.10	0.00	0.06	-0.10
MASB	4.97	0.11	0.02	0.00	-0.08	-0.03
MASC	5.15	0.01	0.03	0.05	0.02	0.02
MAST	14.79	0.15	0.15	0.04	0.00	-0.11

Table 5-55. Subject 7, MAS

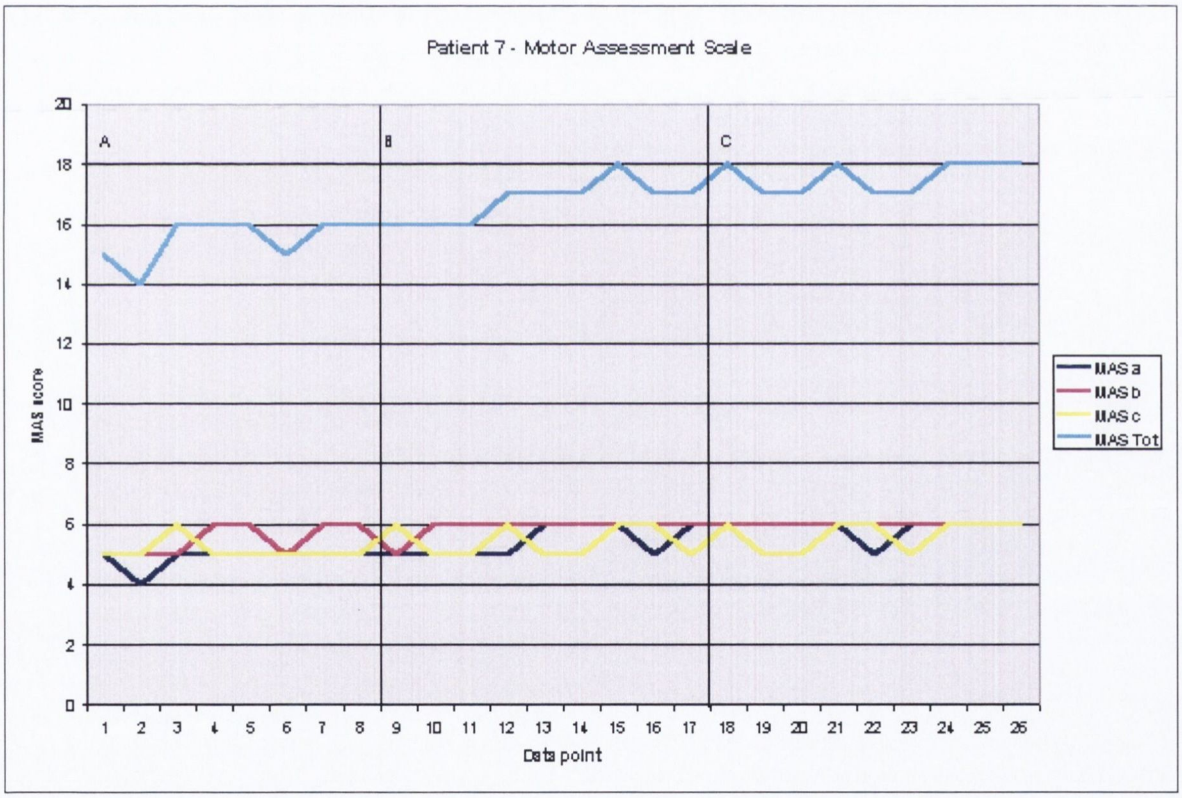

Figure 5-50. Subject 7, MAS

Maximal voluntary isometric contraction

The rate of recovery of this variable was greater or equal to the baseline and SS phases for the RMT phase in all but shoulder extension, which was greatest in the baseline. The difference between the rate of recovery in the phases was significantly so for elbow extension and shoulder flexion.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
ElbFlex	38.98	0.22	0.22	-0.29	0.00	-0.51
ElbExt	33.94	-0.10	0.83	0.08	0.94	-0.75
ShoFlex	24.39	0.18	0.77	-0.10	0.59	-0.87
ShoExt	22.44	0.63	0.52	0.48	-0.11	-0.04

Table 5-56. Subject 7, MVIC

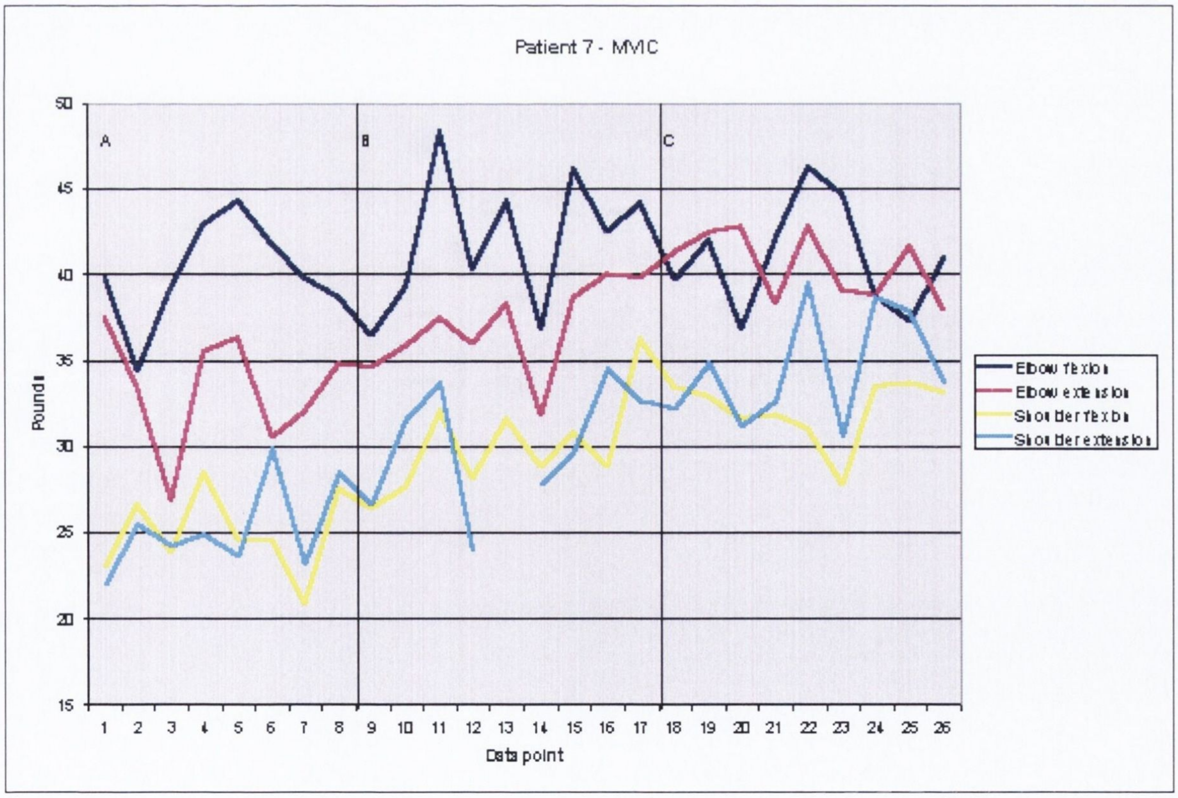

Figure 5-51. Subject 7, MVIC

Range of Motion

The rate of recovery was greater in the RMT phase than both SS and baseline for 7 of the ROM variables, but was only significantly greater than the baseline for active and passive shoulder flexion. For active shoulder external rotation the rate was significantly higher than baseline in the SS phase.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
AShFl	102.33	-0.62	2.36	1.16	2.98	-1.20
PShFL	119.31	-0.58	1.22	0.91	1.80	-0.31
AShA	81.69	0.44	1.31	0.55	0.87	-0.76
PShA	92.95	0.53	0.92	0.22	0.39	-0.70
AElX	-27.82	0.57	0.76	-0.19	0.19	-0.95
PELX	-6.92	-0.05	0.41	-0.13	0.46	-0.54
AShER	47.71	-2.07	0.55	0.97	2.62	0.42
PShER	52.78	-0.83	-0.21	0.73	0.62	0.94
AELFl	139.26	0.15	-0.01	-0.16	-0.16	-0.15
PELFl	149.82	-0.26	-0.23	-0.30	0.03	-0.07

Table 5-57. Subject 7, ROM

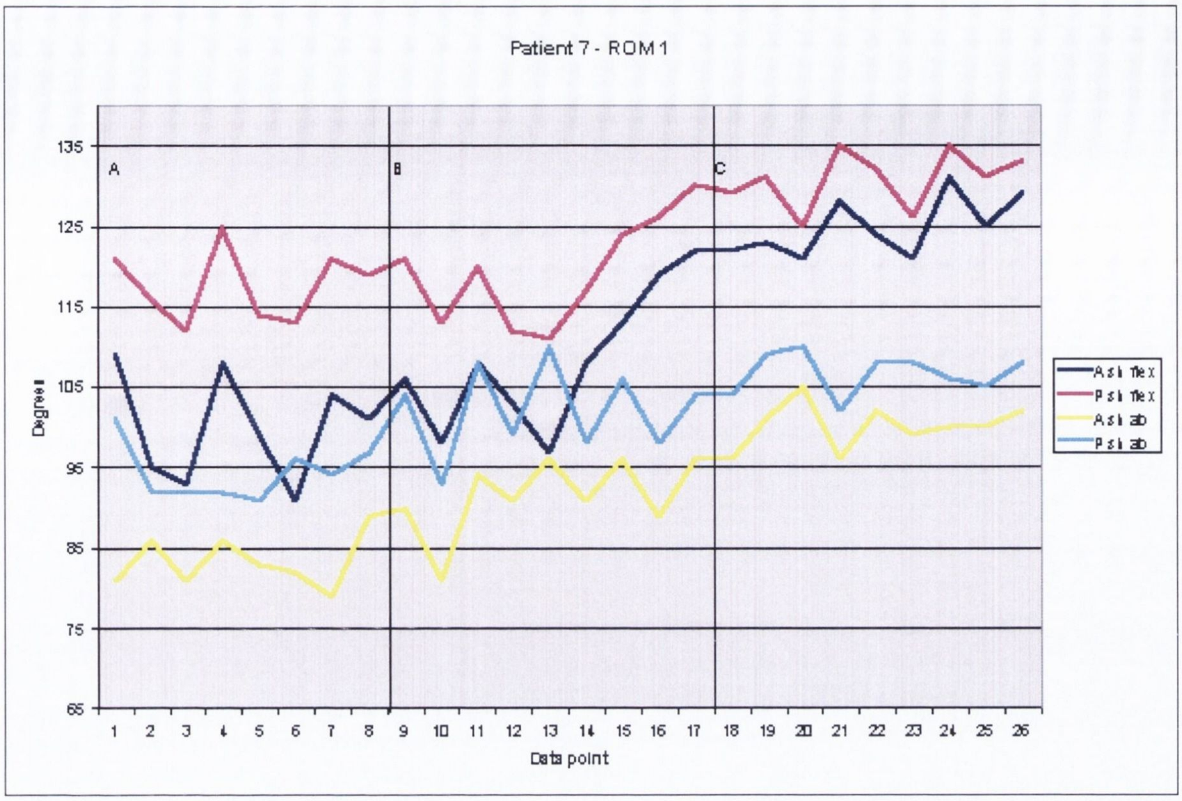

Figure 5-52. Subject 7, ROM 1

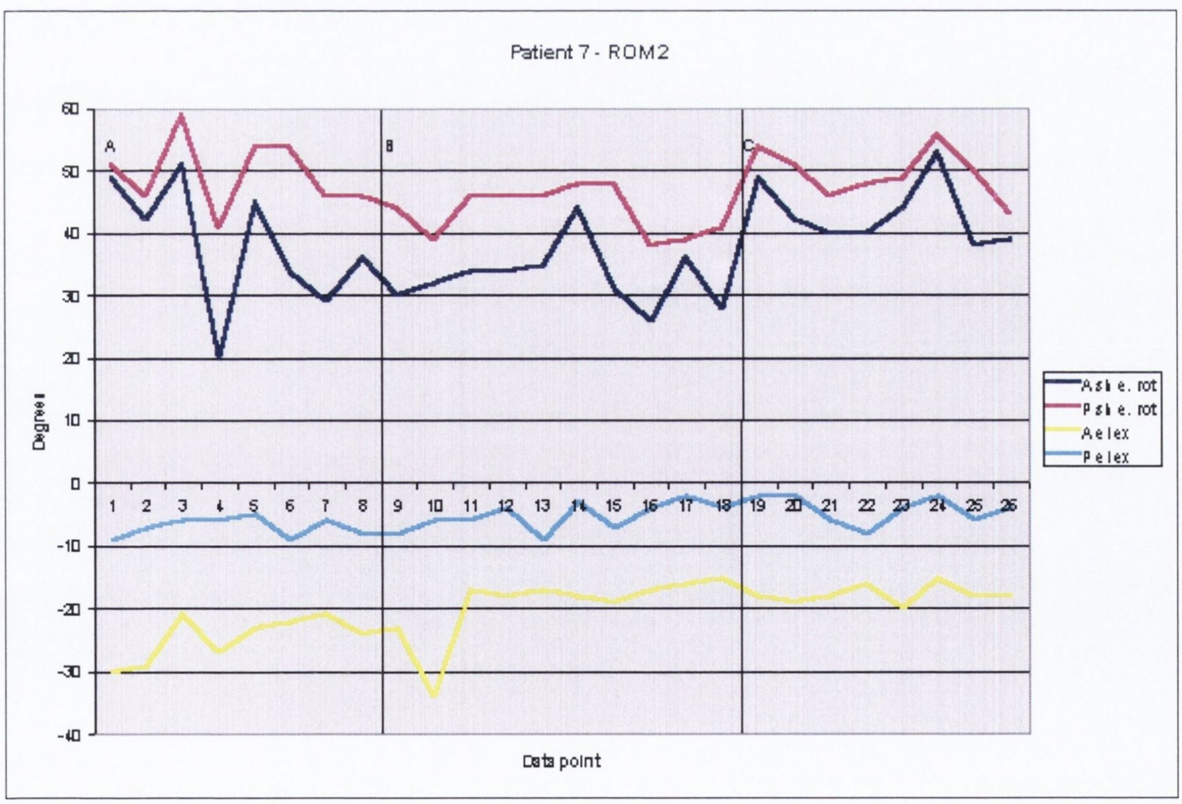

Figure 5-53. Subject 7, ROM 2

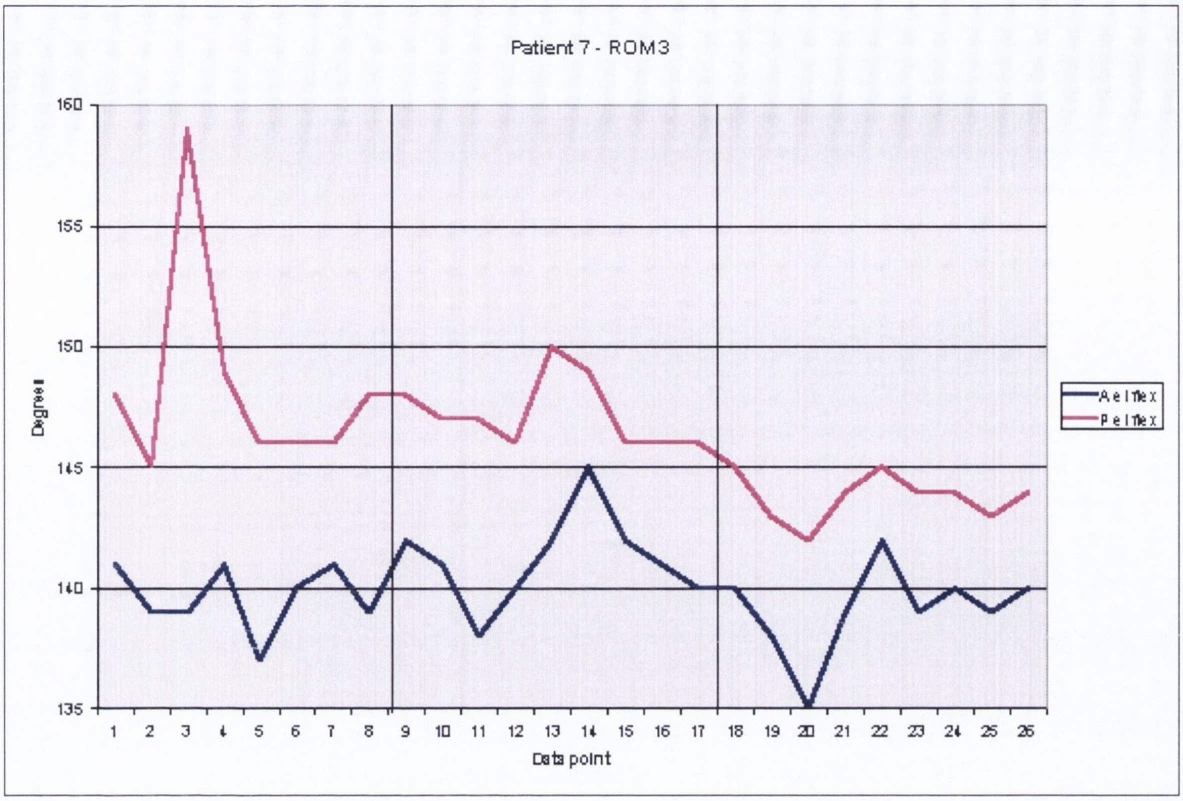

Figure 5-54. Subject 7, ROM 3

Grip Strength

The slope value was greatest during baseline, and lowest during RMT. The plotted raw data shows much fluctuation between measurements.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
Grip	38.52	0.62	-0.25	0.42	-0.87	0.67

Table 5-58. Subject 7, Grip

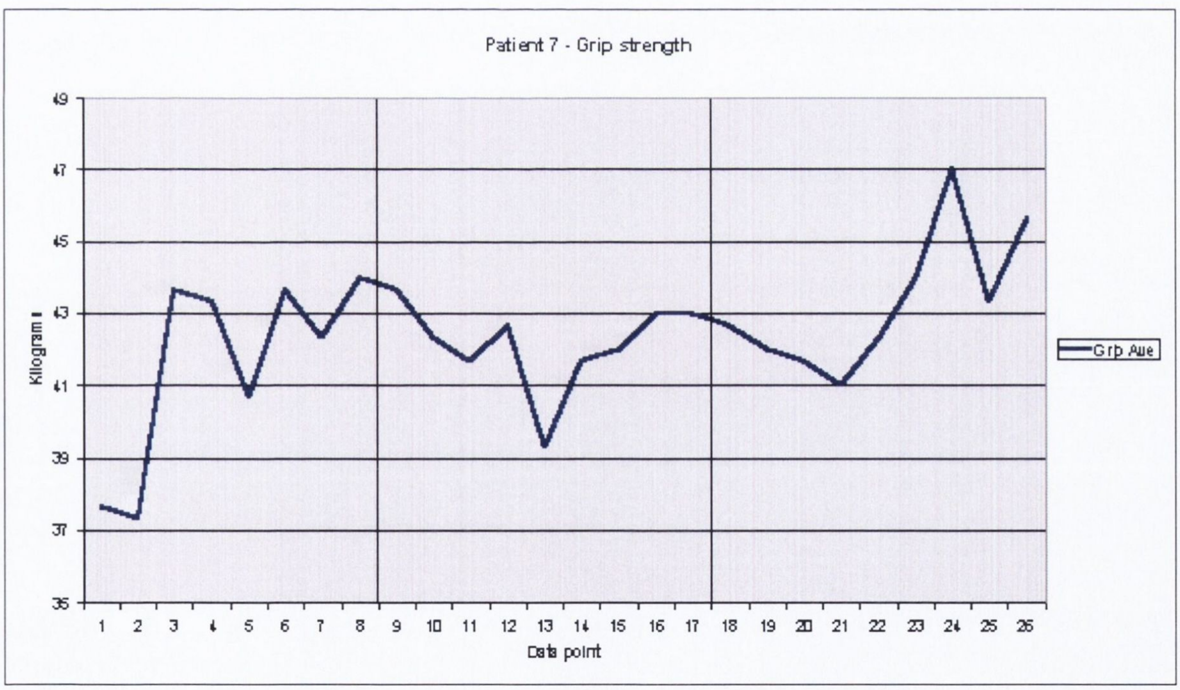

Figure 5-55. Subject 7, Grip

Quality of Life

There is a trend for an increase in score over the baseline and RMT phases and a decrease during the SS phase. The physical health score returns within 1.3% of the original baseline score at the end of the study.

SF-36 Domain	Start	End A	End B	End C
Physical Functioning	40.2	38.1	44.4	38.1
Roles - Physical	27.5	39.7	47.1	39.7
Bodily Pain	62.1	62.1	62.1	62.1
General Health	50.6	52.9	57.7	55.3
Vitality	39.6	52.1	55.2	49
Social Functioning	40.5	56.8	45.9	40.5
Roles - Emotional	36.4	48.1	48.1	52
Mental Health	44.4	50	50	47.2
Physical Health Score	45.5	46.3	52.9	46.8
Mental Health Score	40.2	54.3	49.7	49.4

Table 5-59. Subject 7, SF-36

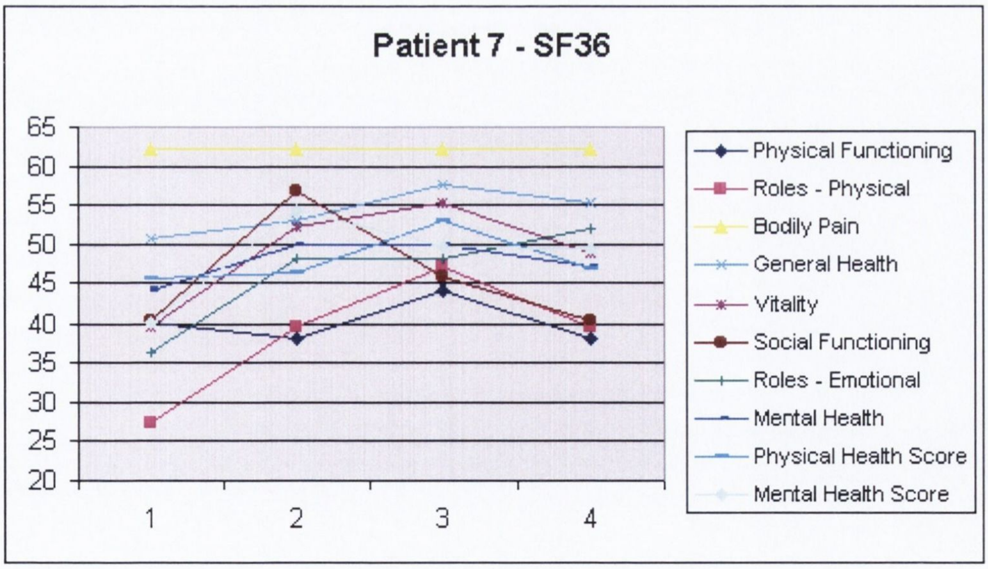

Figure 5-56. Subject 7, SF-36

5.2.8 Subject 8

Mrs. BL was a 70 year old lady who had a right CVA 39 months before the start of the study. Her CT scan showed a right internal capsule infarct.

She lived alone and was on review from Baggot Street Community Hospital stroke unit. Her past medical history included hypertension. She was on carbamazepine for pain relief, and baclofen for high tone.

She was randomized to 8 baseline data points and ACB group. She exercised in passive mode for 1.19%, active assisted for 80.87% and active mode for 17.94% of the time.

Events during course of study

There were no notable events during the course of the study.

Background data

Her star cancellation test was normal and she had no hemianopia. Her pain increased over the baseline phase and decreased most over the SS phase. Her wrist tone decreased over the baseline phase and her elbow tone over the RMT phase. Her sensation score increased to 1 point of maximum after the baseline phase.

Subject 8, Summary	
Age	70
Time post stroke	39 months
Side affected	Left
CT result	Right internal capsule infarct
Current physiotherapy treatment	None
Randomisation	ACB, 8
Exercise mode	P 1.2%, AA 80.9%, A 17.94%

Table 5-60. Subject 8, Summary

BACKGROUND MEASURES	Start A	Start C	Start B	End B
Short Orientation Memory Concentration	28	26	26	28
Star Cancellation L	27	27	27	27
Star Cancellation R	27	27	27	27
Star Cancellation Total	54	54	54	54
Pain	4.65	5.8	3.8	3.95
Hemianopia	0	0	0	0
Tone Wrist	2	1	1	1
Tone Elbow	3	3	3	2
Sensation Light Touch	8	8	8	8
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	8	8	8	8
Sensation Kinaesthesia	8	11	11	11
Sensation Total	32	35	35	35

Table 5-61. Subject 8, Background data

Fugl-Meyer

The rate of recovery during the RMT phase was higher than both baseline and SS for the FMA and FM total sections. The total section had similar rates of recovery for both RMT and SS. The differences in values for the FMB, FMC and FMD scores are extremely small. The rate of recovery in the SS phase is significantly higher than both baseline and RMT for the FMD section.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
FMA	14.86	0.20	0.07	0.36	-0.13	0.28	0.16
FMB	5.52	0.11	0.09	0.01	-0.02	-0.08	-0.10
FMC	10.44	0.08	0.16	0.12	0.09	-0.04	0.04
FMD	2.24	-0.04	0.12	-0.05	0.16	-0.17	0.00
FMT	32.70	0.35	0.45	0.45	0.10	0.00	0.10

Table 5-62. Subject 8, Fugl-Meyer

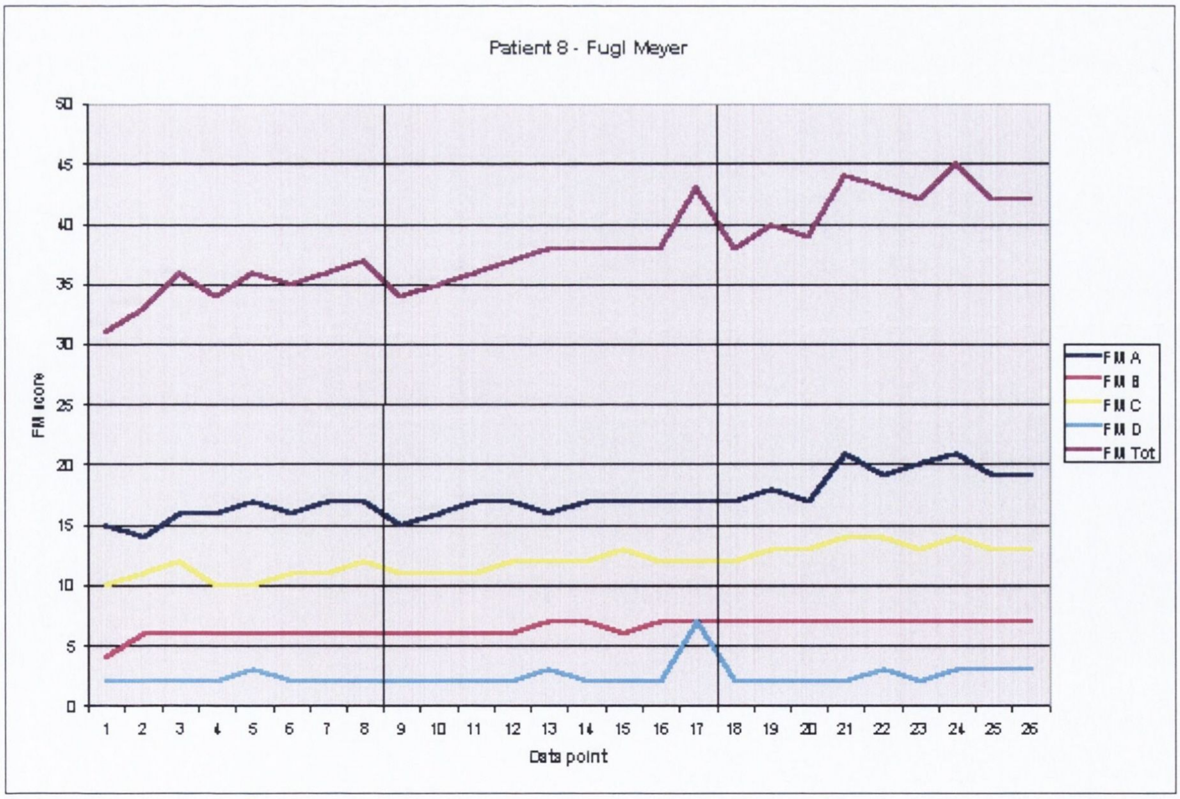

Figure 5-57. Subject 8, Fugl-Meyer

Motor Assessment Scale

The rate of recovery during the RMT phase was greater than both baseline and SS for all but the MASC section. The slope values for this section are negligible indicating essentially no change in this area. The RMT phase was significantly higher than the baseline and SS phases for the MASA and MAS total scores.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
MASA	0.99	0.01	-0.01	0.25	-0.02	0.26	0.24
MASB	4.13	-0.07	0.06	0.07	0.13	0.01	0.14
MASC	1.22	0.00	-0.02	-0.01	-0.02	0.01	-0.01
MAST	6.33	-0.06	0.03	0.31	0.10	0.27	0.37

Table 5-63. Subject 8, MAS

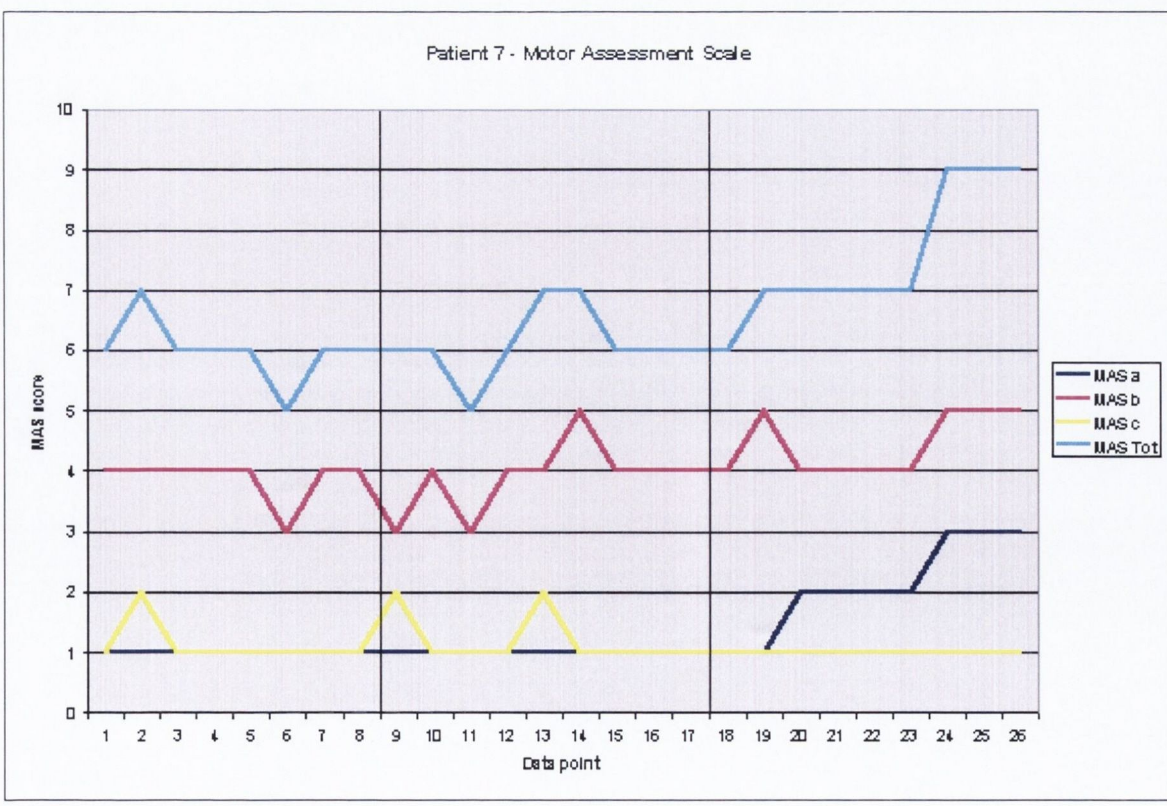

Figure 5-58. Subject 8, MAS

Maximal voluntary isometric contraction

The rate of recovery was greatest during the baseline phase for all 4 muscle groups, with SS the next highest for all but elbow flexion where the slope for RMT was greater than that for SS.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
ElbFlex	7.63	0.74	0.13	0.49	-0.61	0.36	-0.25
ElbExt	4.69	0.75	0.21	0.04	-0.54	-0.18	-0.72
ShoFlex	2.83	0.26	0.17	0.10	-0.09	-0.07	-0.16
ShoExt	9.65	0.61	0.35	-0.01	-0.26	-0.36	-0.62

Table 5-64. Subject 8, MVIC

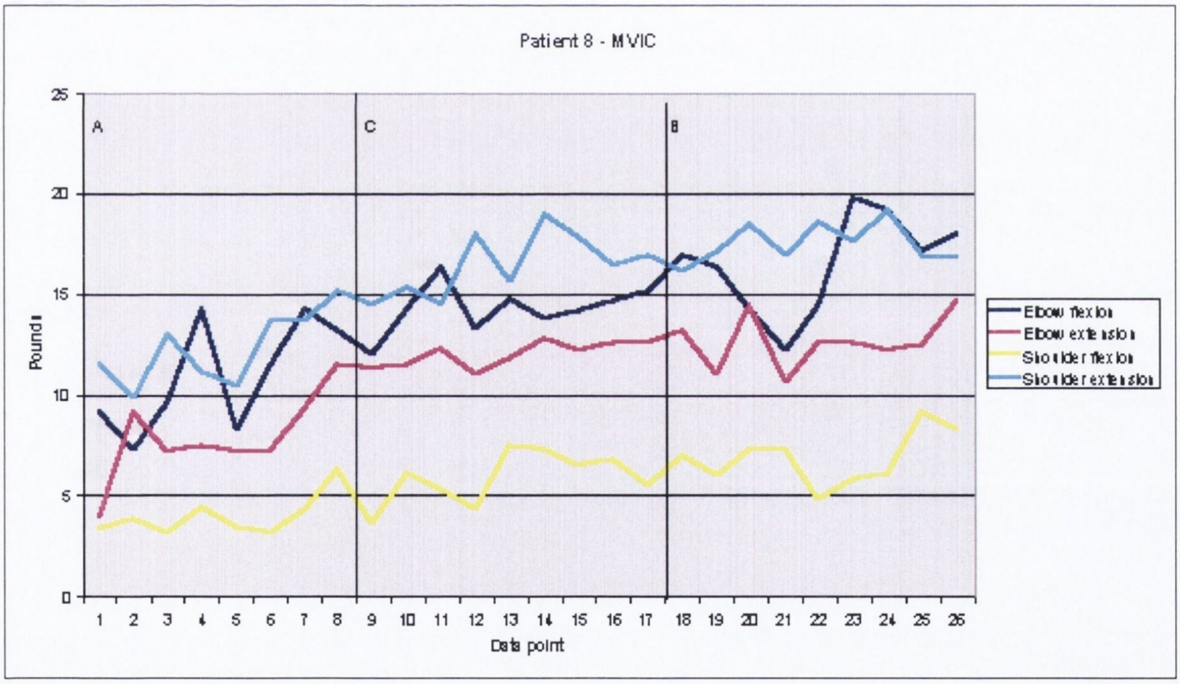

Figure 5-59. Subject 8, MVIC

Range of Motion

The rate of recovery during RMT was greater than SS and baseline for active elbow extension and shoulder abduction, and passive shoulder flexion and passive shoulder external rotation.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
AShFl	57.35	0.95	2.17	1.69	1.21	-0.47	0.74
PShFL	84.21	1.19	-0.08	1.68	-1.27	1.76	0.49
AshA	40.85	0.05	1.18	1.27	1.13	0.08	1.22
PshA	41.75	1.45	1.47	0.18	0.01	-1.28	-1.27
AelX	-48.25	1.05	-0.09	1.57	-1.14	1.67	0.52
PELX	-14.18	1.05	-0.23	0.59	-1.28	0.82	-0.46
AShER	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PShER	-5.36	-0.03	0.50	0.84	0.53	0.34	0.87
AELFl	99.17	1.88	0.46	0.49	-1.42	0.02	-1.40
PELFl	129.20	0.73	-0.09	0.07	-0.83	0.16	-0.67

Table 5-65. Subject 8, ROM

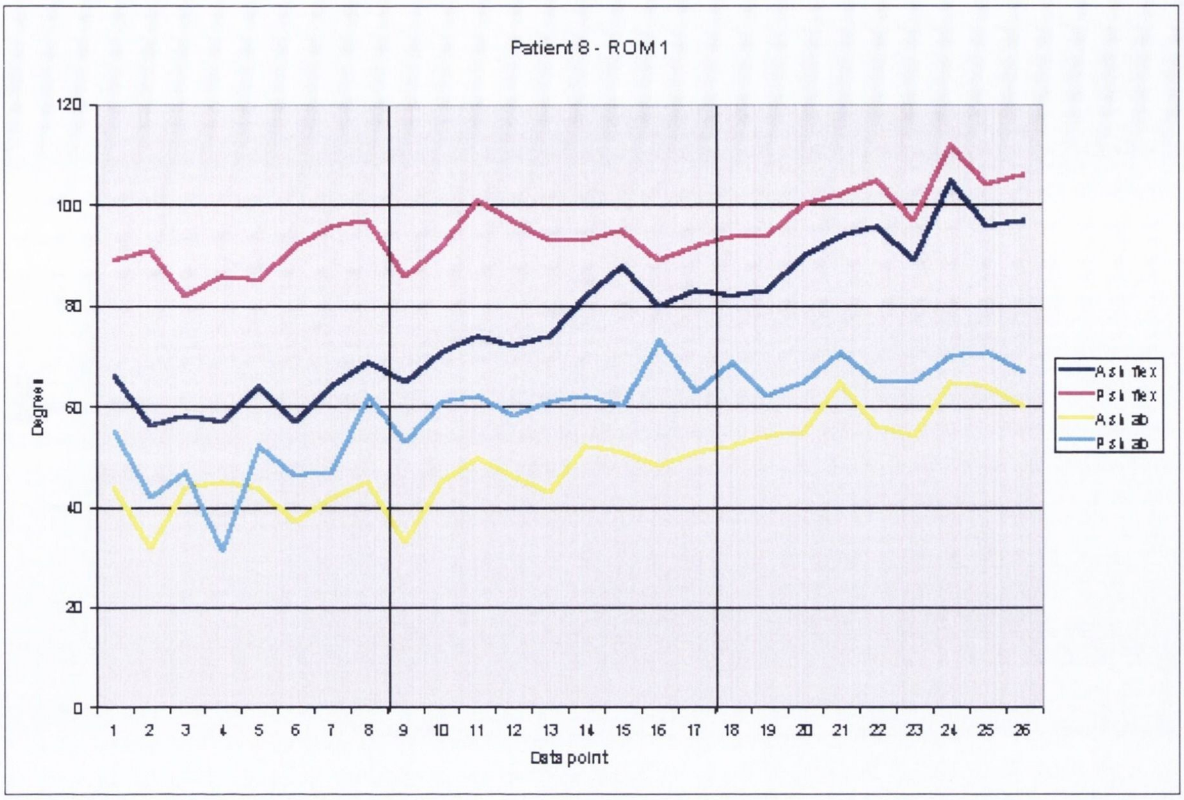

Figure 5-60. Subject 8, ROM 1

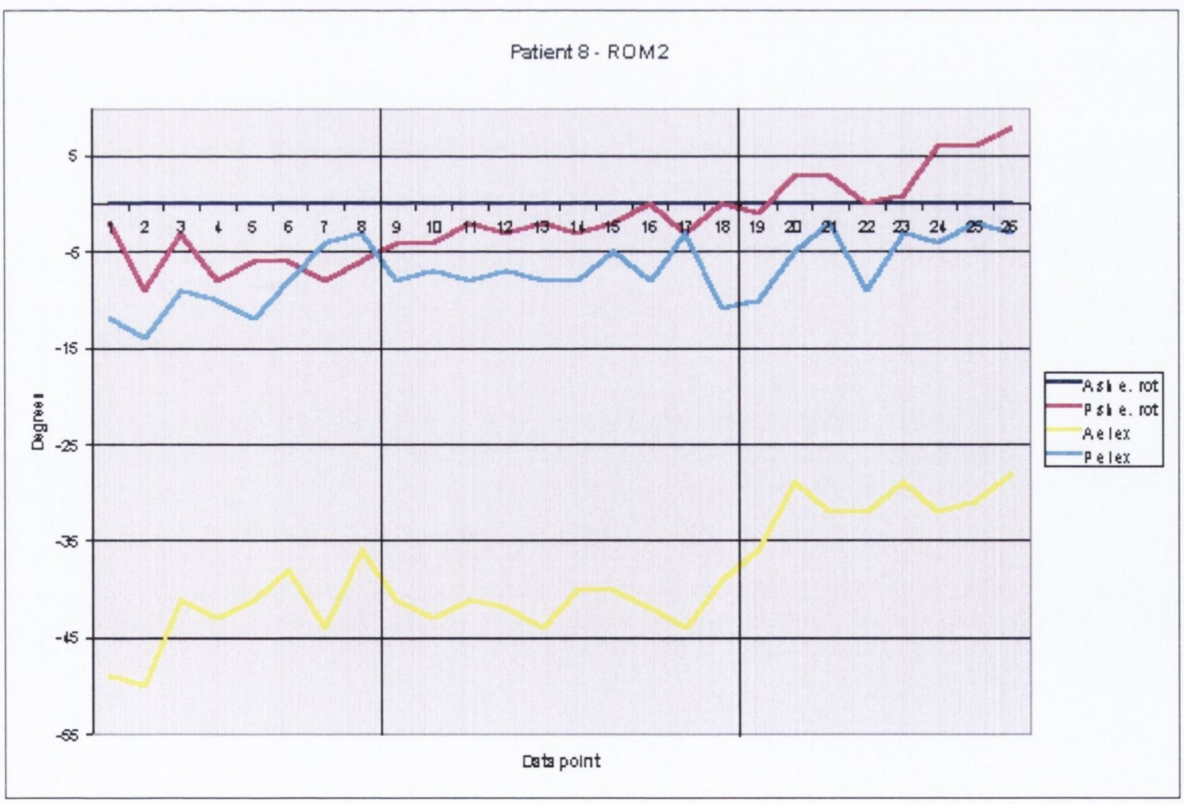

Figure 5-61. Subject 8, ROM 2

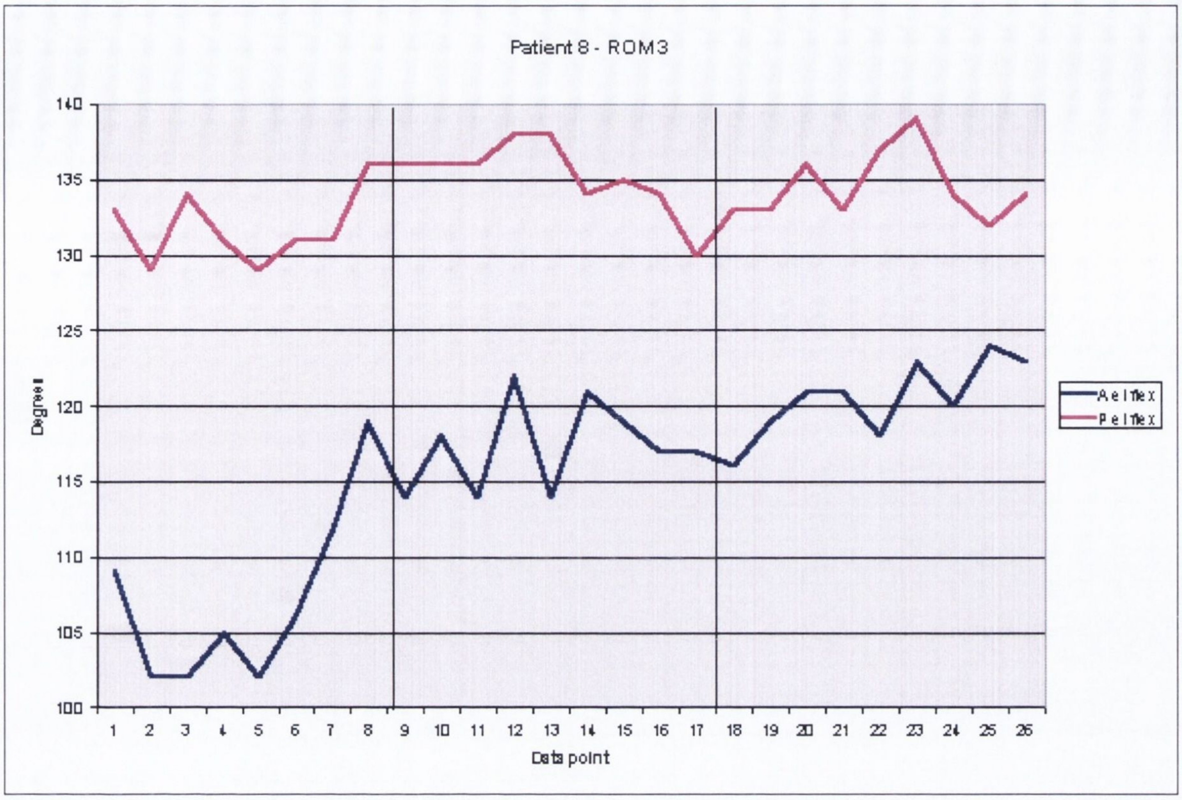

Figure 5-62. Subject 8, ROM 3

Grip Strength

The slope value for the SS phase is the lowest, with the baseline value the highest. The slope in the SS phase was significantly less than that in the baseline phase.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
Grip	5.39	0.31	0.05	0.19	-0.27	0.15	-0.12

Table 5-66. Subject 8, Grip

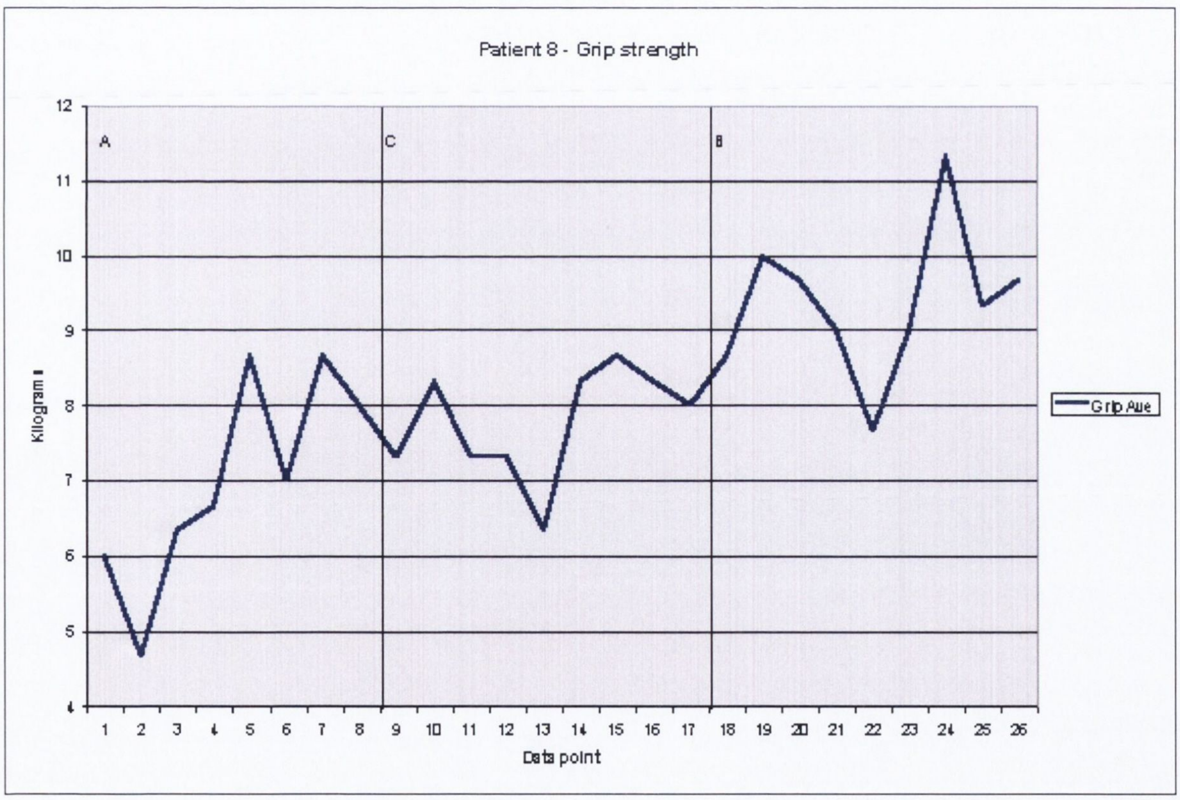

Figure 5-63. Subject 8, Grip

Quality of Life

The plotted data shows a trend for a slight rise in the baseline, followed by a drop in the SS phase and a slight rise in the RMT phase. The physical health score ends only 2% higher than the baseline score.

SF-36 Domain	Start	End A	End C	End B
Physical Functioning	31.8	33.9	33.9	36
Roles - Physical	20.1	29.9	29.9	27.5
Bodily Pain	46.1	33	37.2	41.8
General Health	57.7	50.6	50.6	45.8
Vitality	55.2	61.5	42.7	55.2
Social Functioning	40.5	56.8	24.1	24.1
Roles - Emotional	44.2	48.1	28.7	40.3
Mental Health	55.6	52.8	50	50
Physical Health Score	32.5	30.9	36.3	34.7
Mental Health Score	57	62.9	39.5	46.9

Table 5-67. Subject 8, SF-36

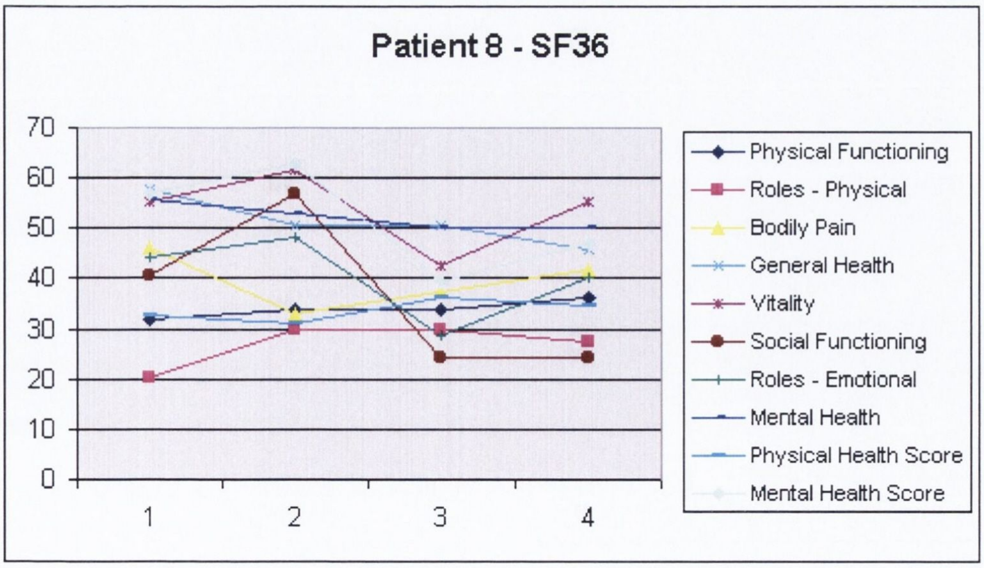

Figure 5-64. Subject 8, SF-36

5.2.9 Subject 9

Mr. MS was a 63 year old man who presented with right weakness 22 months prior to the start of the study. His CT scan showed a large left internal capsule haemorrhage classified as a total anterior circulation infarct (TACI).

His past medical history included peptic ulcer disease and gastritis. His medications were lactulose and centyl k. He was on review from St James's Hospital Day Hospital where he had been receiving physiotherapy once a week. He lived at home with his wife.

He was randomized to the ABC group with a baseline of 10 points. He exercised in passive mode 16.17% of the time, active assisted for 65.85% of the time and active mode for 17.98% of the time.

Events during course of study

Visit 8 - Brother died.

Background data

His SOMCT increased from 26 to 28 over the RMT phase and remained at the maximum score. His star cancellation test was normal throughout the study. He had a minimal amount of pain at the start of the study, which resolved during the baseline and remained absent. His elbow tone as measured by the modified Ashworth scale did not change, his wrist tone decreased over the RMT phase and increased back to its starting score over the SS phase.

Kinaesthesia was the only sensory modality that did not score maximally, it increased by 2 points over the baseline and remained 2 points below maximum for the duration of the study.

Subject 9, Summary	
Age	63
Time post stroke	22 months
Side affected	Right
CT result	Large left internal capsule infarct
Current physiotherapy treatment	None
Randomisation	ABC, 10
Exercise mode	P 16.17% AA 65.85%, A 17.98%

Table 5-68. Subject 9, Summary

	Start A	Start B	Start C	End C
Short Orientation Memory Concentration	26	26	28	28
Star Cancellation L	27	27	27	27
Star Cancellation R	27	27	27	27
Star Cancellation Total	54	54	54	54
Pain	0.3	0	0	0
Hemianopia	0	0	0	0
Tone Wrist	3	3	2	3
Tone Elbow	2	2	2	2
Sensation Light Touch	8	8	8	8
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	8	8	8	8
Sensation Kinaesthesia	8	10	10	10
Sensation Total	32	34	34	34

Table 5-69. Subject 9, Background data

Fugl-Meyer

The rate of recovery during the RMT phase was greater than the baseline and SS phases for the FMA and FM total scores. For the B, C, and D subsections the plotted raw data shows that following an initial increase in the baseline phase, the data remained largely unchanged in the RMT and SS phases, this is reflected by the extremely negligible slope values (a slope value of 0.07 reflects a 0.63 unit change over the 9 visits of that phase).

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
FMA	16.60	-0.08	0.27	-0.07	0.35	-0.34
FMB	1.09	0.06	0.05	-0.01	-0.01	-0.06
FMC	2.50	0.17	-0.03	0.01	-0.21	0.04
FMD	1.38	0.07	-0.01	0.02	-0.09	0.04
FMT	21.56	0.22	0.27	-0.05	0.06	-0.32

Table 5-70. Subject 9, Fugl-Meyer

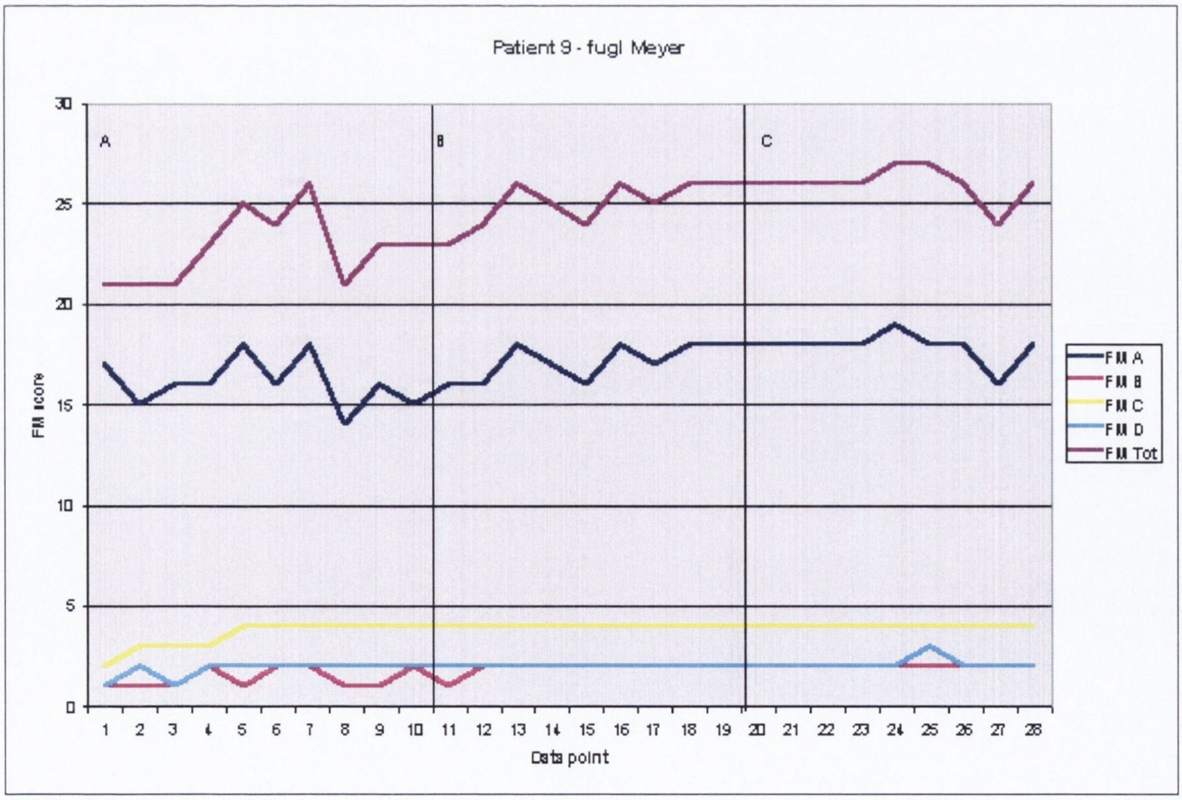

Figure 5-65. Subject 9, Fugl-Meyer

Motor Assessment Scale

The MASA section is responsible solely for the change in the MAS total score. The difference in rate during the baseline and RMT phase is greater than the aMDC, while that for the difference in RMT and SS phases is equal to the aMDC. A difference of 0.18 reflects a rate of recovery of 1.62 units more in the RMT than the baseline phase.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
MASA	1.25	-0.03	0.15	0.08	0.18	-0.07
MASB	0.00	0.00	0.00	0.00	0.00	0.00
MASC	0.00	0.00	0.00	0.00	0.00	0.00
MAST	1.25	-0.03	0.15	0.08	0.18	-0.07

Table 5-71. Subject 9, MAS

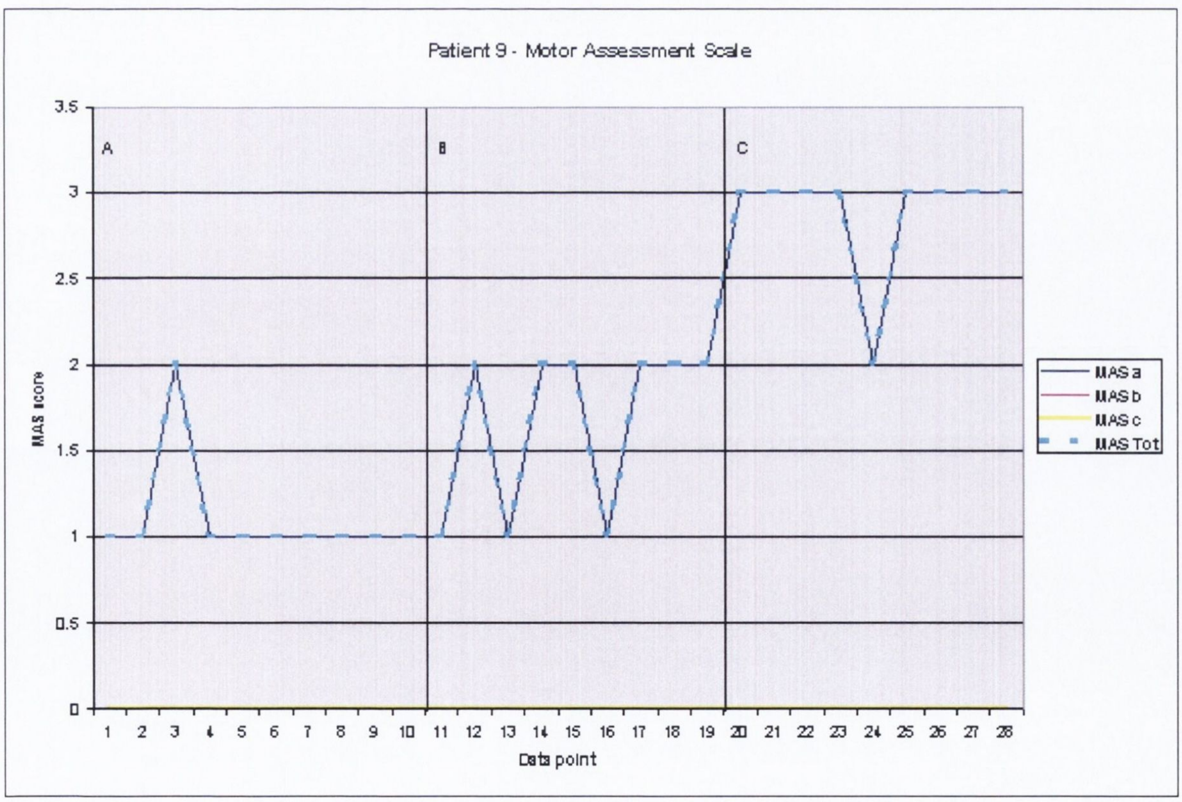

Figure 5-66. Subject 9, MAS

Maximal voluntary isometric contraction

For the two shoulder variables the rate of recovery during the RMT phase is higher than both baseline and SS phases, however this difference cannot be considered more than measurement error as it is not higher than the aMDC value. For elbow flexion the rate is highest in the baseline phase and for elbow extension the rate is highest during the SS phase.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
ElbFlex	7.98	0.30	0.12	0.00	-0.18	-0.12
ElbExt	10.95	0.19	0.08	0.49	-0.10	0.41
ShoFlex	0.07	-0.02	0.12	0.03	0.14	-0.09
ShoExt	12.49	0.13	0.20	0.13	0.07	-0.07

Table 5-72. Subject 9, MVIC

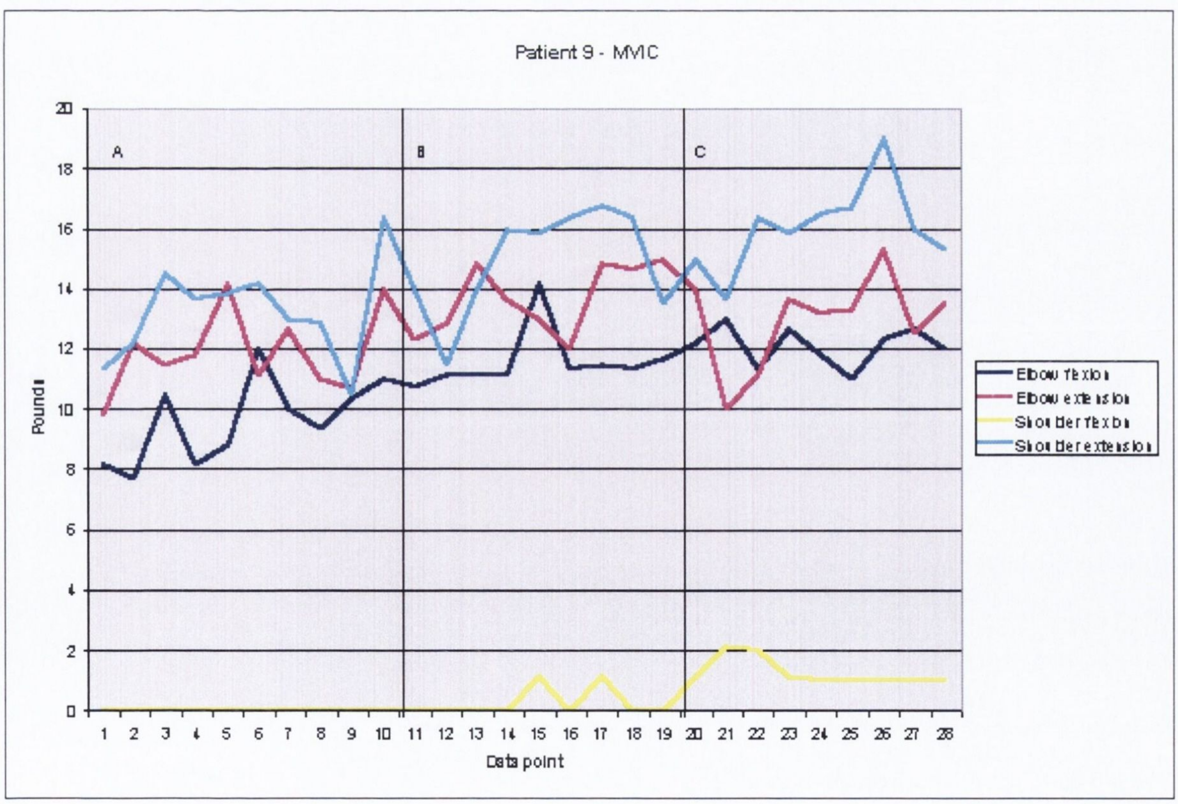

Figure 5-67. Subject 9 MVIC

Range of Motion

The rate of recovery in the RMT phase was higher than both baseline and SS for active elbow extension, active shoulder flexion passive shoulder external rotation, however only the difference between the SS and RMT slopes for active shoulder flexion can be considered significant change as they are greater than the aMDC value.

The rate during the SS phase was higher than both RMT and baseline for passive elbow extension, active and passive shoulder abduction, active shoulder external rotation, however none of these were greater than the aMDC and cannot be considered more than measurement error. The rate of recovery for passive shoulder flexion was greatest in the baseline phase.

The plotted data demonstrates the variable nature of the ROM data with the trends of the significant variables (AShFl, AElX) clearly apparent.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
AShFl	-2.18	0.93	2.40	-0.62	1.47	-3.02
PShFL	92.94	1.65	-0.18	-0.08	-1.83	0.10
AShA	54.77	-0.28	0.55	0.71	0.82	0.16
PShA	68.76	0.45	0.12	0.65	-0.33	0.54
AElX	-34.01	-1.10	1.91	-0.57	3.01	-2.48
PELX	-6.91	0.05	0.05	0.47	-0.01	0.42
AShER	1.08	-0.03	-0.11	0.03	-0.09	0.15
PShER	30.65	-0.16	0.54	0.00	0.69	-0.54
AELFl	102.45	0.87	0.50	0.01	-0.37	-0.49
PELFl	130.14	0.77	0.13	0.00	-0.64	-0.13

Table 5-73. Subject 9, ROM

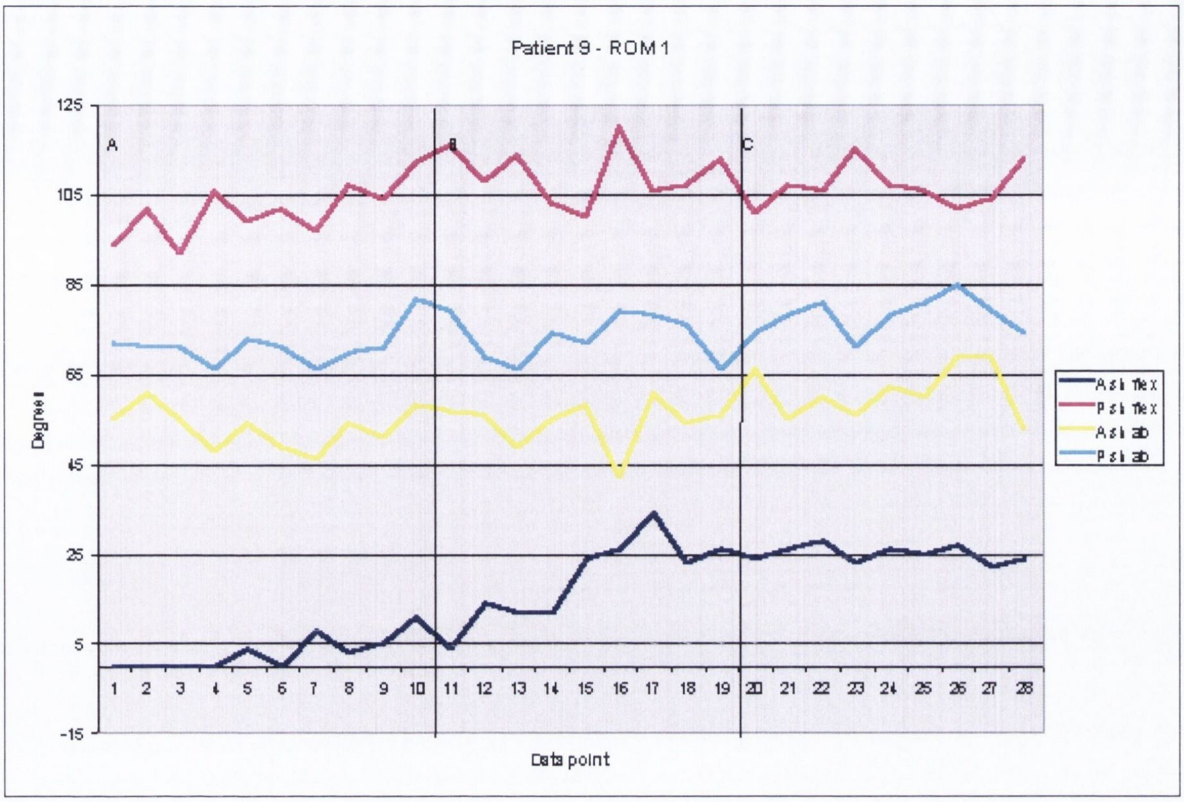

Figure 5-68. Subject 9, ROM 1

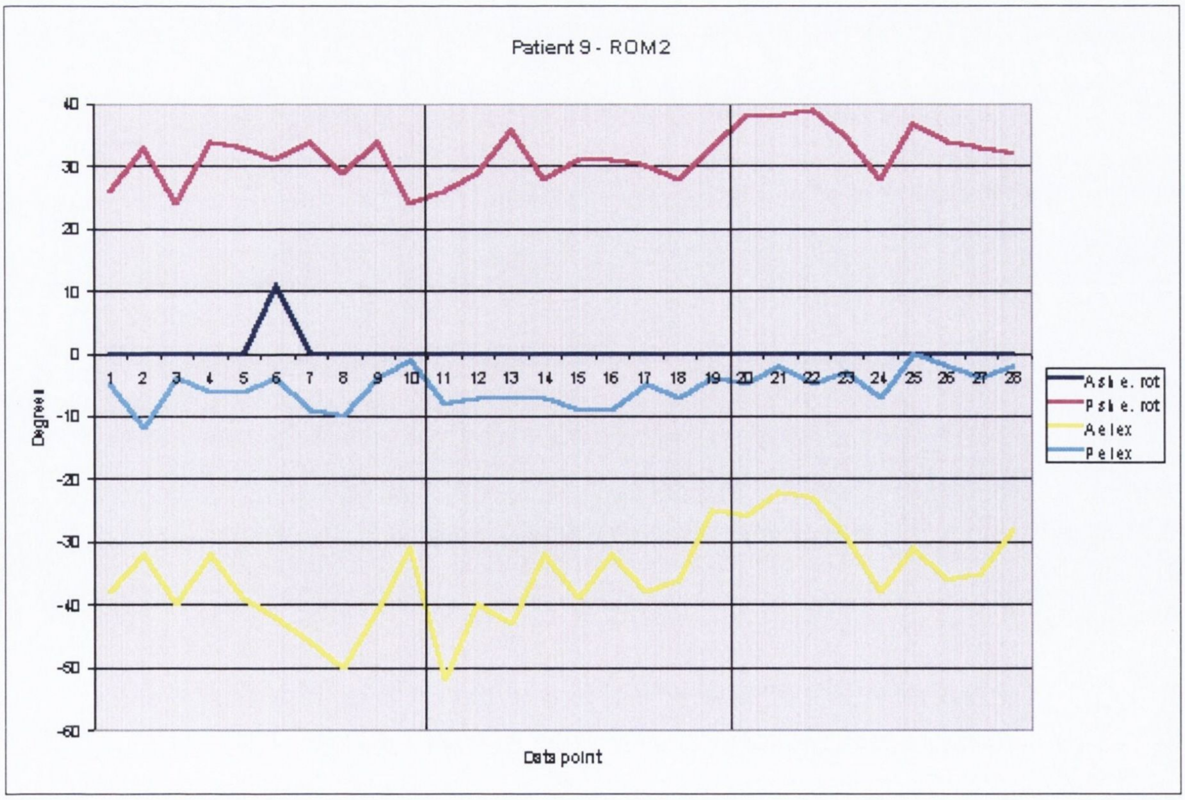

Figure 5-69. Subject 9, ROM 2

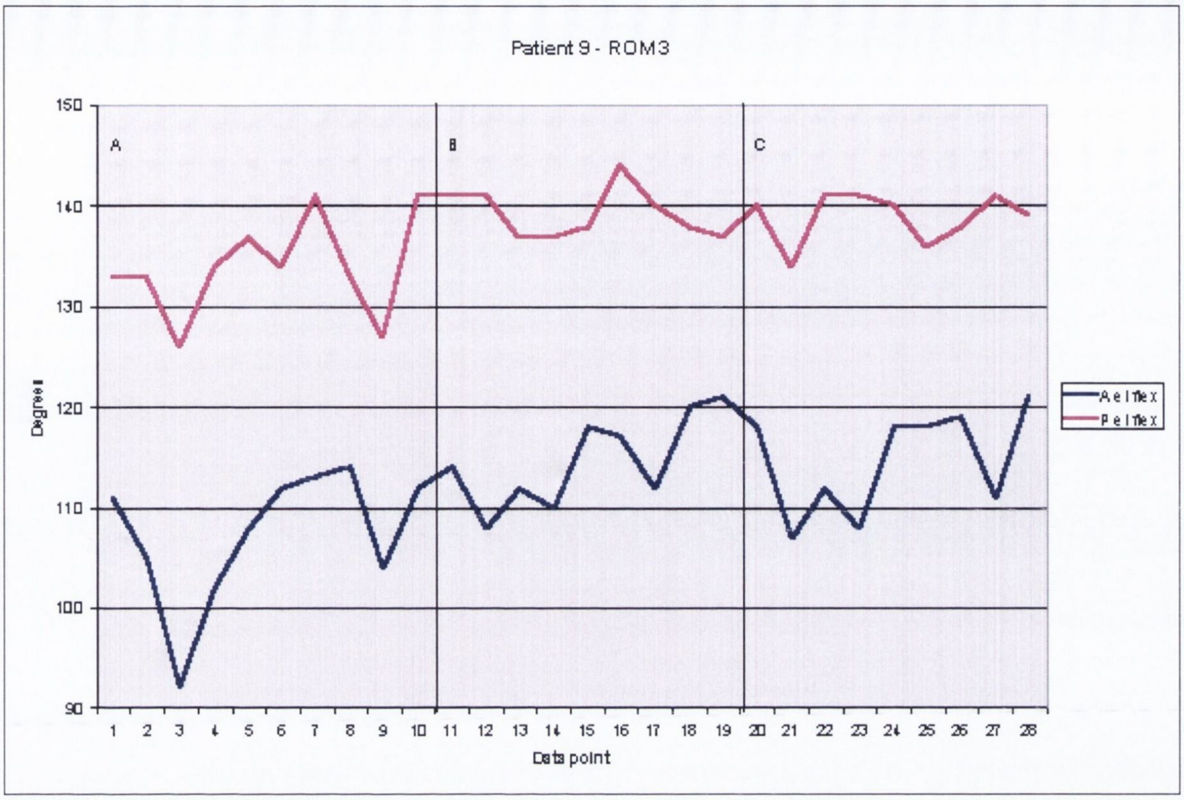

Figure 5-70. Subject 9, ROM 3

Grip Strength

Following an initial rise in the first half of the baseline phase the rate of recovery of grip strength remains fluctuating around 3kg. This is reflected by the fact that none of the differences between phases are higher than the aMDC value for this variable.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
Grip	2.02	0.12	-0.05	0.02	-0.17	0.06

Table 5-74. Subject 9, Grip

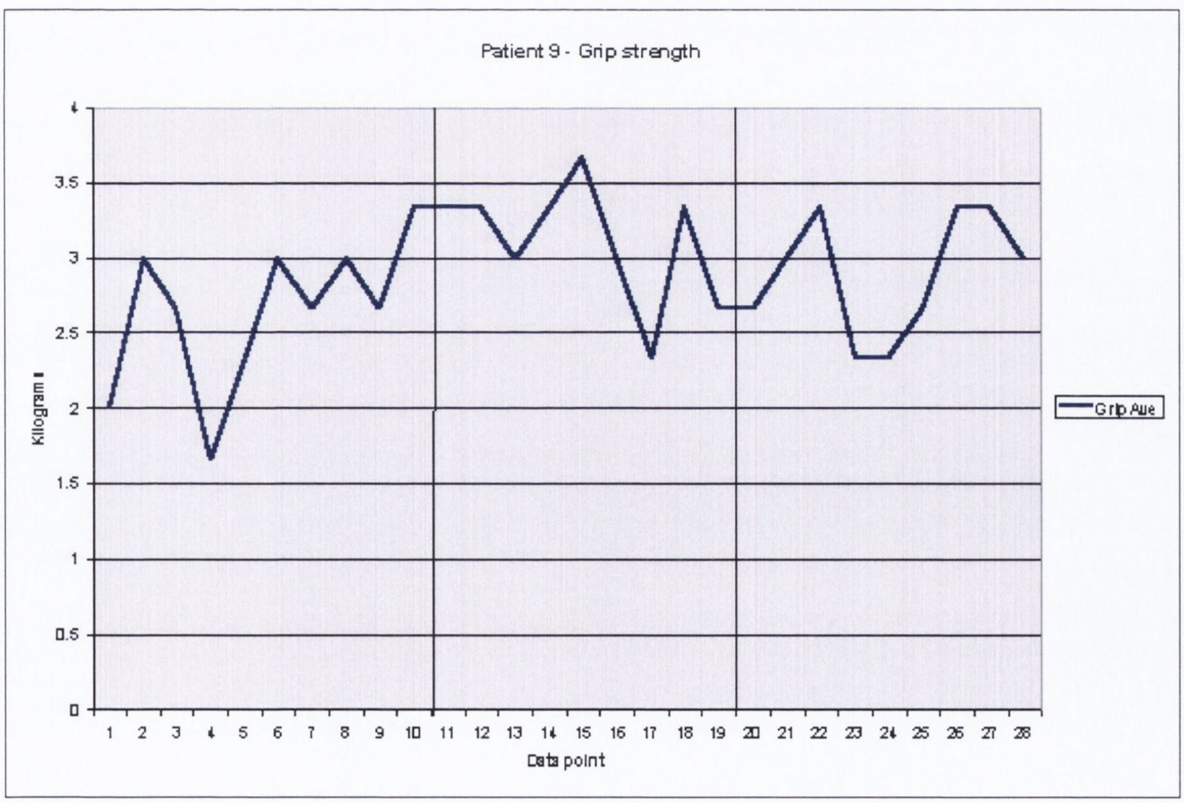

Figure 5-71. Subject 9, Grip

Quality of Life

No clear trend is apparent in the SF-36 data. The physical health score and physical functioning score decreases most over the SS phase, while the mental health score increases.

SF-36 Domain	Start	End A	End B	End C
Physical Functioning	40.2	42.3	44.4	36
Roles - Physical	44.6	42.2	37.3	37.3
Bodily Pain	62.1	62.1	62.1	62.1
General Health	50.6	60.1	62.5	57.7
Vitality	58.3	45.8	49	52.1
Social Functioning	56.8	56.8	56.8	56.8
Roles - Emotional	55.9	55.9	55.9	55.9
Mental Health	52.8	58.5	55.6	64.1
Physical Health Score	46.4	47.2	47.7	41.1
Mental Health Score	59.5	58.9	58.4	65.2

Table 5-75. Subject 9, SF-36

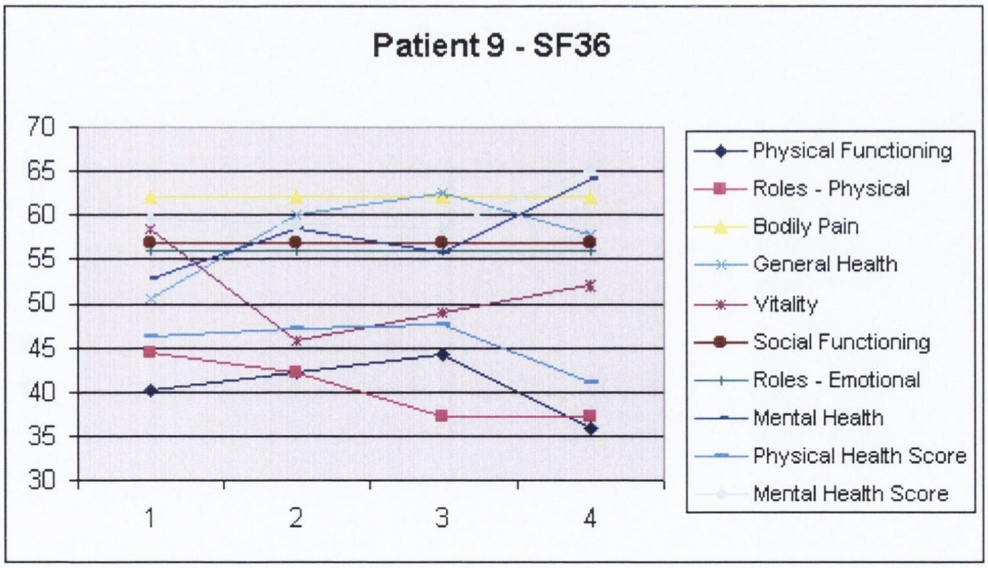

Figure 5-72. Subject 9, SF-36

5.2.10 Subject 10

Mrs. CH was a 73 year old lady who had a left hemiplegia 10 months prior to the start of the study. Her CT scan showed a right internal capsule and right parietal lobe infarct. Her past medical history included hypertension, A-fib and ischemic heart disease. Her medications included amitryptyline, Warfarin, atenolol and lipostat.

She lived at home with a considerable amount of support including care assistant and home help. Her primary mode for mobility was her wheelchair. She was attending the Day Hospital in St James's Hospital twice a week for physiotherapy.

She was randomized to the ACB group with 9 baseline data points. She exercised in passive mode for 87% of the time and active assisted for 13%.

Events during course of study

There were no events of note and she attended for all appointments.

Background data

Her SOMCT decreased by 2 points at the end of the baseline. She had no hemianopia or abnormalities on the star cancellation test and reported no pain for the duration of the study. Her wrist tone decreased over the baseline and RMT phase and increased over the SS phase. Kinaesthesia increased over the SS phase while bilateral simultaneous touch decreased giving a fluctuating sensory score that was highest at the end of the SS phase.

Subject 10, Summary	
Age	73
Time post stroke	10 months
Side affected	Left
CT result	Right internal capsule and parietal lobe infarct
Current physiotherapy treatment	45 minutes twice a week
Randomisation	ABC, 9
Exercise mode	P 87%, AA 13%

Table 5-76. Subject 10, Summary

	Start A	Start C	Start B	End B
Short Orientation Memory Concentration	28	26	28	28
Star Cancellation L	27	27	27	27
Star Cancellation R	27	27	27	27
Star Cancellation Total	54	54	54	54
Pain	0	0	0	0
Hemianopia	0	0	0	0
Tone Wrist	3	1	3	2
Tone Elbow	2	2	2	2
Sensation Light Touch	8	8	8	8
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	8	8	7	7
Sensation Kinaesthesia	9	9	11	9
Sensation Total	33	33	34	32

Table 5-77. Subject 10, Background data

Fugl-Meyer

The FMA section is solely responsible for the change in the FM total score with all other sections remaining at 0 for the duration of the study. While the rate of recovery is greatest during the RMT phase this is not significant as the difference in rates between this and the other phases is not more than the aMDC.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
FMA	4.29	-0.02	0.10	0.16	0.12	0.06	0.18
FMB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FMC	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FMD	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FMT	4.29	-0.02	0.10	0.16	0.12	0.06	0.18

Table 5-78. Subject 10, Fugl-Meyer

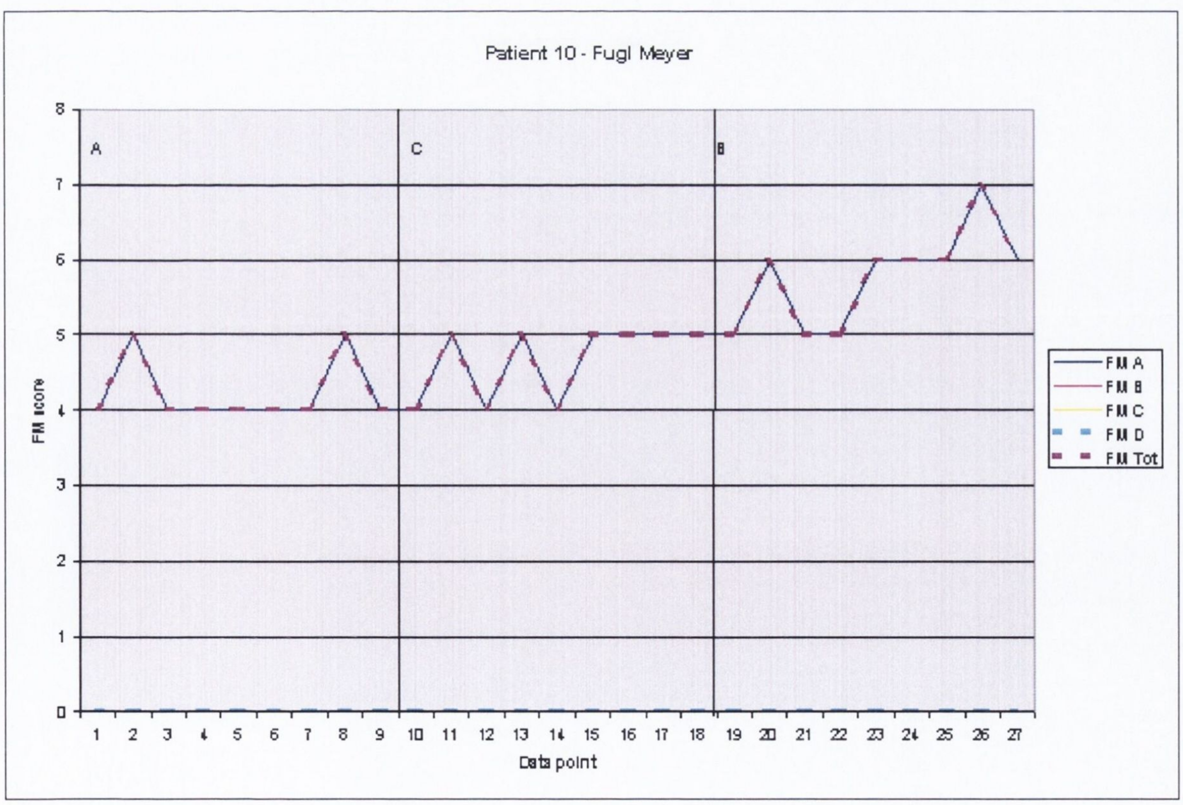

Figure 5-73. Subject 10, Fugl-Meyer

Motor Assessment Scale

Only the MASA section changed (by 1 unit) throughout the study. This caused a significantly higher slope in the SS phase than in either the RMT or baseline phases.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
MASA	-0.02	0.00	0.12	-0.02	0.12	-0.15	-0.03
MASB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MASC	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAST	-0.02	0.01	0.12	-0.02	0.12	-0.15	-0.03

Table 5-79. Subject 10 MAS

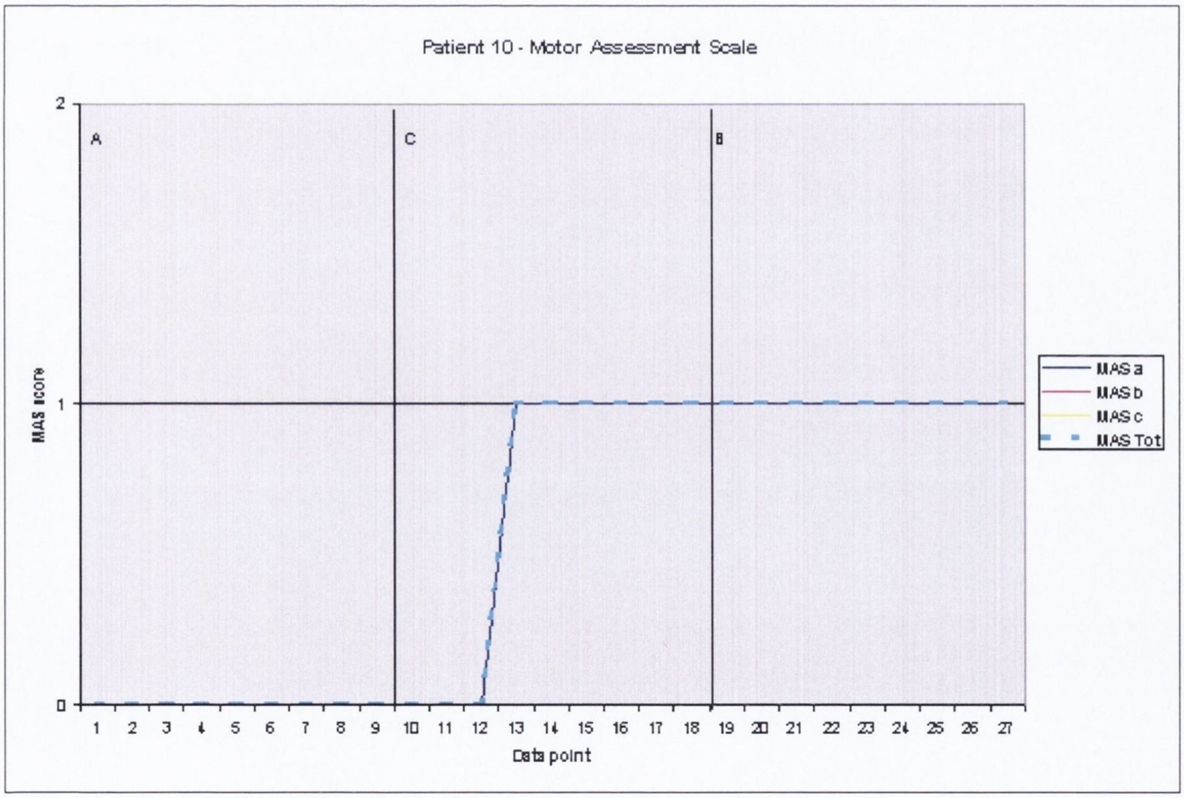

Figure 5-74. Subject 10, MAS

Maximal voluntary isometric contraction

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
ElbFlex	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ElbExt	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ShoFlex	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ShoExt	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5-80. Subject 10 MVIC

All values were at 0 for duration of study therefore graphs are not presented.

Range of Motion

The rate of recovery of active elbow flexion and passive shoulder abduction were greatest during the RMT phase and was significantly so for active elbow flexion. Passive shoulder flexion increased most during the SS phase, while passive shoulder external rotation increased most during the baseline phase. Passive elbow extension increased most during the RMT phase.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
AShFl	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PShFL	94.16	-0.51	1.23	0.25	1.75	-0.98	0.77
AShA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PShA	67.68	-0.26	0.29	1.88	0.55	1.59	2.14
AElX	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PELX	-11.21	0.58	-0.21	0.79	-0.79	1.00	0.21
AShER	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PShER	18.15	0.89	-0.09	0.33	-0.97	0.42	-0.56
AELFl	-1.74	0.52	-1.48	8.29	-2.00	9.76	7.77
PELFl	142.90	-0.03	0.33	-0.24	0.35	-0.57	-0.22

Table 5-81. Subject 10, ROM

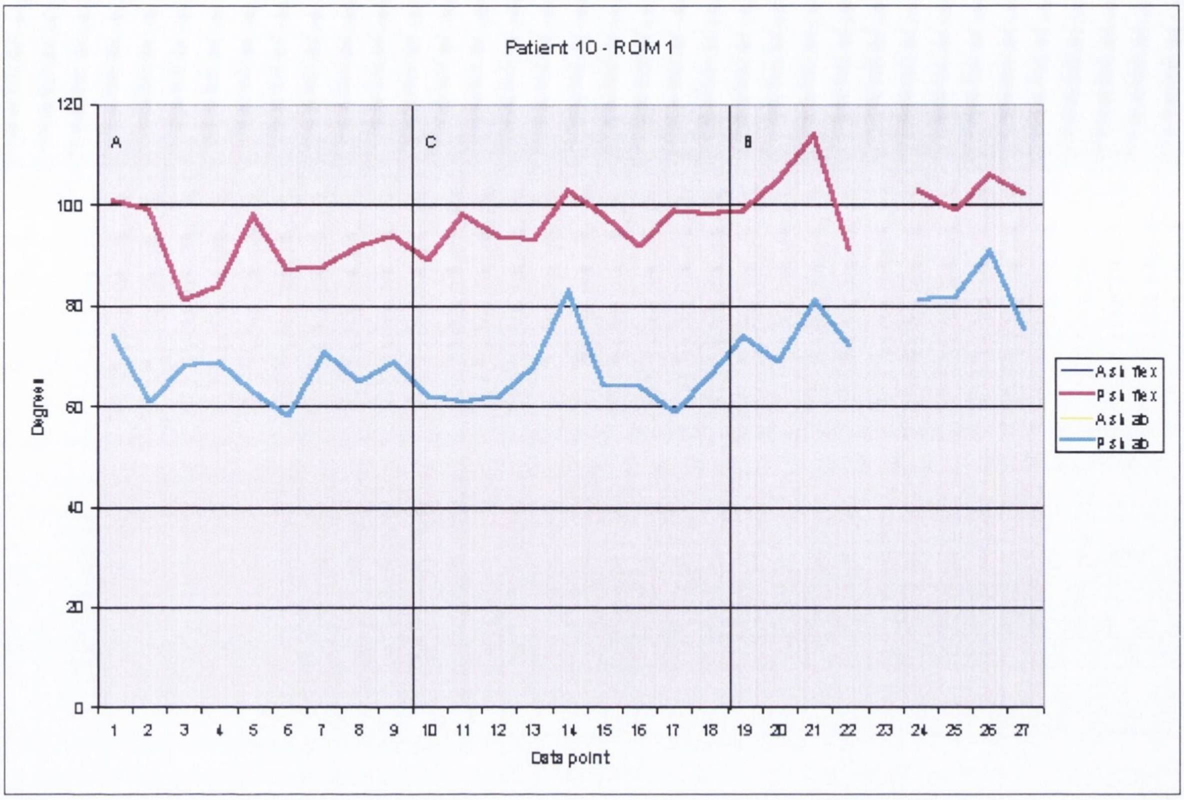

Figure 5-75. Subject 10, ROM 1

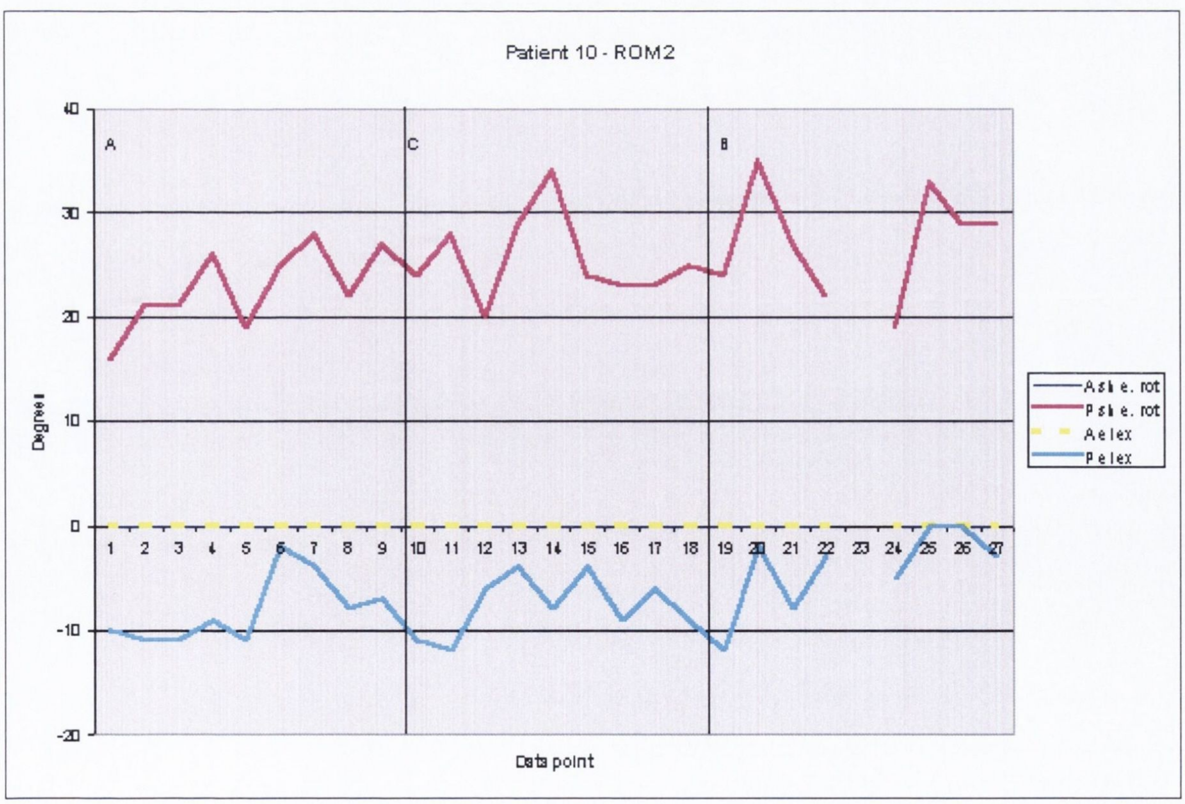

Figure 5-76. Subject 10, ROM 2

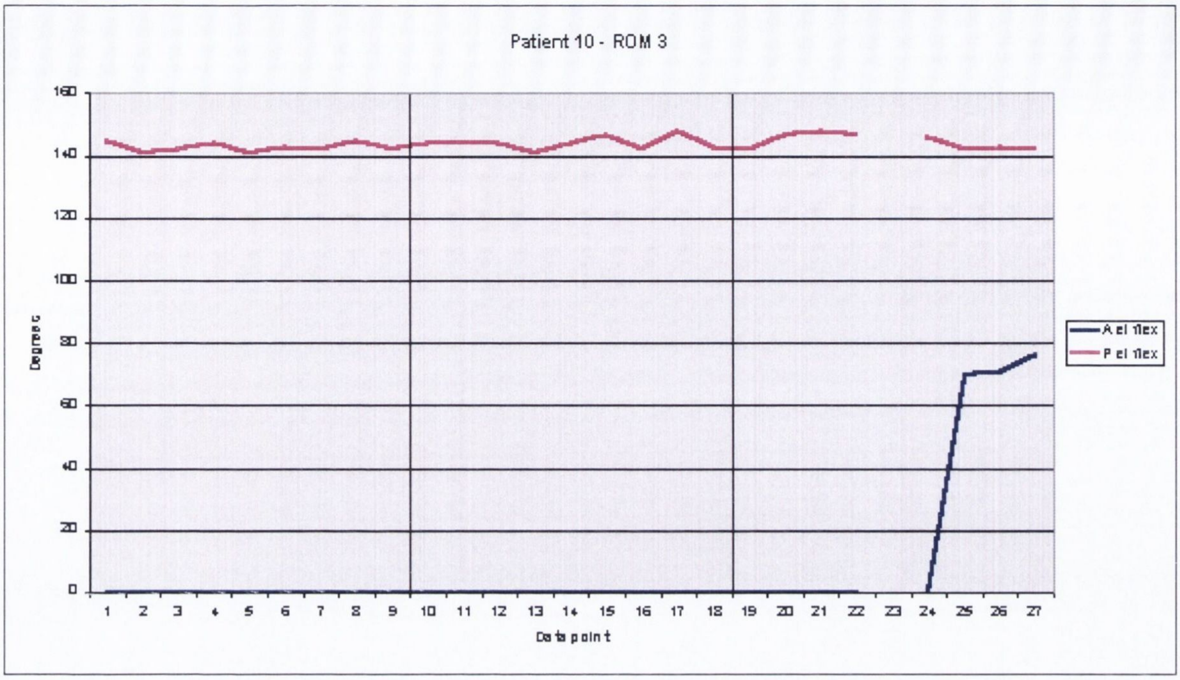

Figure 5-77. Subject 10, ROM 3

Grip Strength

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
Grip	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5-82. Subject 10, Grip

All values were at 0 for duration of study therefore graphs are not presented.

Quality of Life

The data show a trend for an increase across the SS phase and a decrease at the end of the RMT phase. The bodily pain score dropped significantly, suggesting an increase in bodily pain, though this is not reflected in the VAS score which remained at 0 for the arm. Both the physical and mental health summary scores fluctuated and ended lower than the 1st measurement.

SF-36	Start	End A	End C	End B
Physical Functioning	19.2	17	14.9	14.9
Roles – Physical	17.7	29.9	25	17.7
Bodily Pain	62.1	62.1	62.1	29.2
General Health	38.6	43.4	48.2	48.2
Vitality	49	49	49	45.8
Social Functioning	24.1	29.6	35	24.1
Roles – Emotional	24.8	20.9	20.9	13.1
Mental Health	44.4	38.7	52.8	41.6
Physical Health Score	32.8	39.4	34.8	25.7
Mental Health Score	39.2	35.1	44.5	36.1

Table 5-83. Subject 10, SF-36

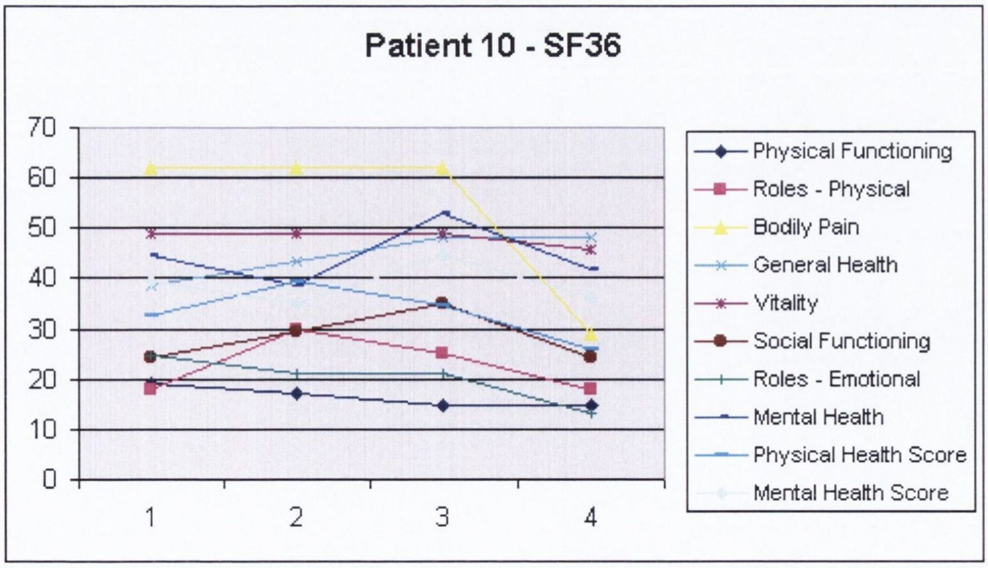

Figure 5-78. Subject 10, SF-36

5.2.11 Subject 11

Ms AF was a 63 year old lady who had a right hemiplegia 25 months prior to the start of the study. Her CT scan showed an atypical infarct in the left middle cerebral artery territory.

Her past medical history included manic depression and oesophagitis. Her medications included lithium and diazepam. She was on review from Baggot Street Community Hospital and was not receiving any intervention at the time of the study.

She lived alone and had good social support. She had expressive aphasia, her speech therapist confirmed her ability to complete the SF36 and to give informed consent for the study.

She was randomized to the ACB group with 8 baseline data points. She exercised in passive mode for 24.19% of the time, active assisted for 74% and active for 2.8% of the time.

Events during course of study

Visit 18 - appeared to have better comprehension of SF 36

Background data

Her SOMCT score was at the borderline level for the duration of the study, and her start cancellation test increased to normal and remained there after baseline. Her pain level increased over the baseline phase, then decreased over the SS phase, increasing slightly over the RMT phase but remaining below her baseline score. She developed some tone in her wrist over the baseline phase which remained over the SS phase and decreased again over the RMT phase. She had a significant deficit in bilateral simultaneous touch, and limitations in kinaesthesia, these domains increased over both of the treatment phases.

Subject 11, Summary	
Age	63
Time post stroke	25 months
Side affected	Right
CT result	Left middle cerebral artery territory
Current physiotherapy treatment	None
Randomisation	ACB, 8
Exercise mode	P 24.19% AA 74% A2.8%

Table 5-84. Subject 11, summary

	Start A	Start C	Start B	End B
Short Orientation Memory Concentration	24	24	24	24
Star Cancellation L	26	27	27	27
Star Cancellation R	26	27	27	27
Star Cancellation Total	52	54	54	54
Pain	3.8	5.4	2.3	3.5
Hemianopia	0	0	0	0
Tone Wrist	0	1	1	0
Tone Elbow	0	2	2	2
Sensation Light Touch	8	8	8	8
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	0	0	5	8
Sensation Kinaesthesia	6	5	7	8
Sensation Total	22	21	28	32

Table 5-85. Subject 11, Background data

Fugl-Meyer

The plotted data show a sharp increase in the FMA scores at the middle of the baseline phase. This is reflected by a higher slope value for the baseline phase for FMA and FMT than in any of the other phases. The only values that were above the aMDC were those that reflected this.

The slope values for the FMB, FMC and FMD sections are small as reflected in the plotted data by relatively unchanging scores.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
FMA	10.02	0.56	0.18	0.11	-0.38	-0.07	-0.44
FMB	-0.18	0.07	0.10	-0.01	0.03	-0.11	-0.08
FMC	1.61	0.06	-0.03	0.08	-0.09	0.11	0.02
FMD	0.57	0.06	0.01	0.04	-0.05	0.03	-0.02
FMT	11.47	0.75	0.26	0.22	-0.49	-0.04	-0.53

Table 5-86. Subject 11, Fugl-Meyer

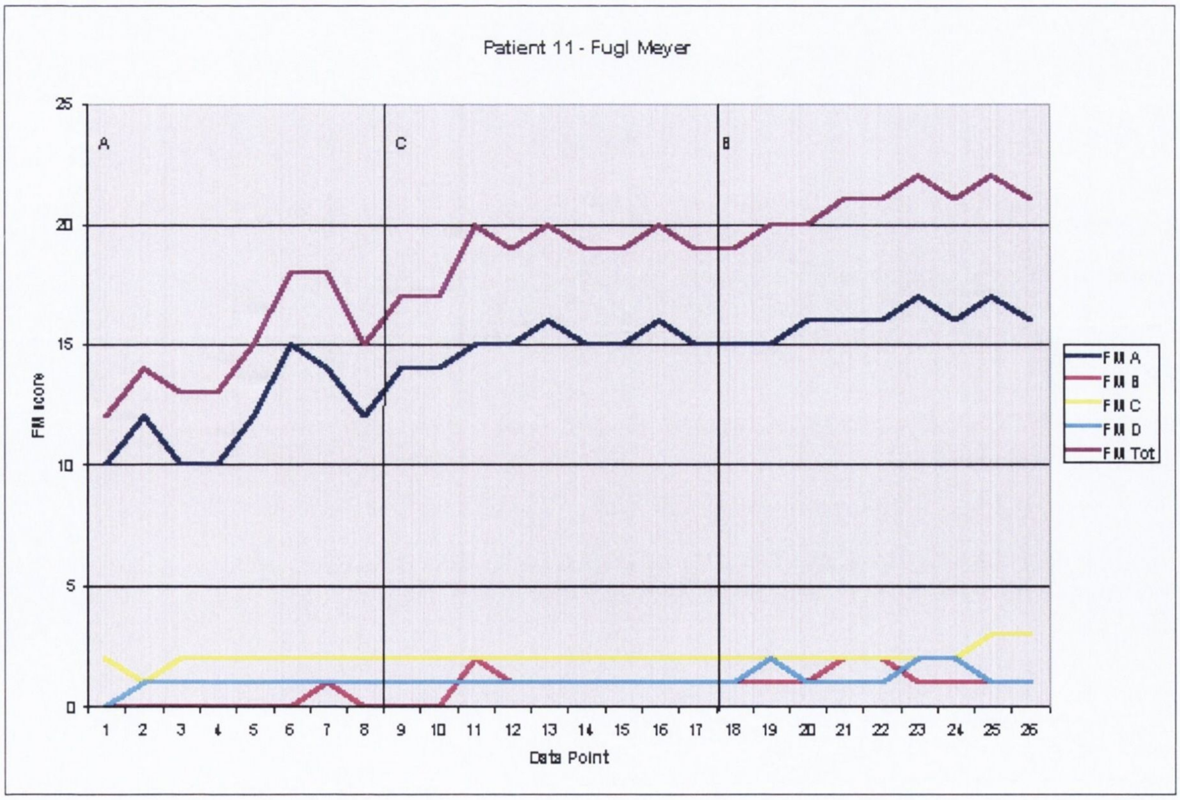

Figure 5-79. Subject 11, Fugl-Meyer

Motor Assessment Scale

Following an initial rise in the baseline phase the MASA section remains unchanged, the only increase is in the MASB section during the RMT phase. This creates significantly higher rates in the baseline phase than both the others for MASA and MAST, and significantly higher rates in the RMT phase than both the others for MASB.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
MASA	1.18	0.12	-0.02	0.01	-0.14	0.02	-0.11
MASB	-0.02	0.01	-0.02	0.14	-0.02	0.15	0.13
MASC	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAST	1.16	0.13	-0.03	0.01	-0.16	0.05	-0.11

Table 5-87. Subject 11, MAS

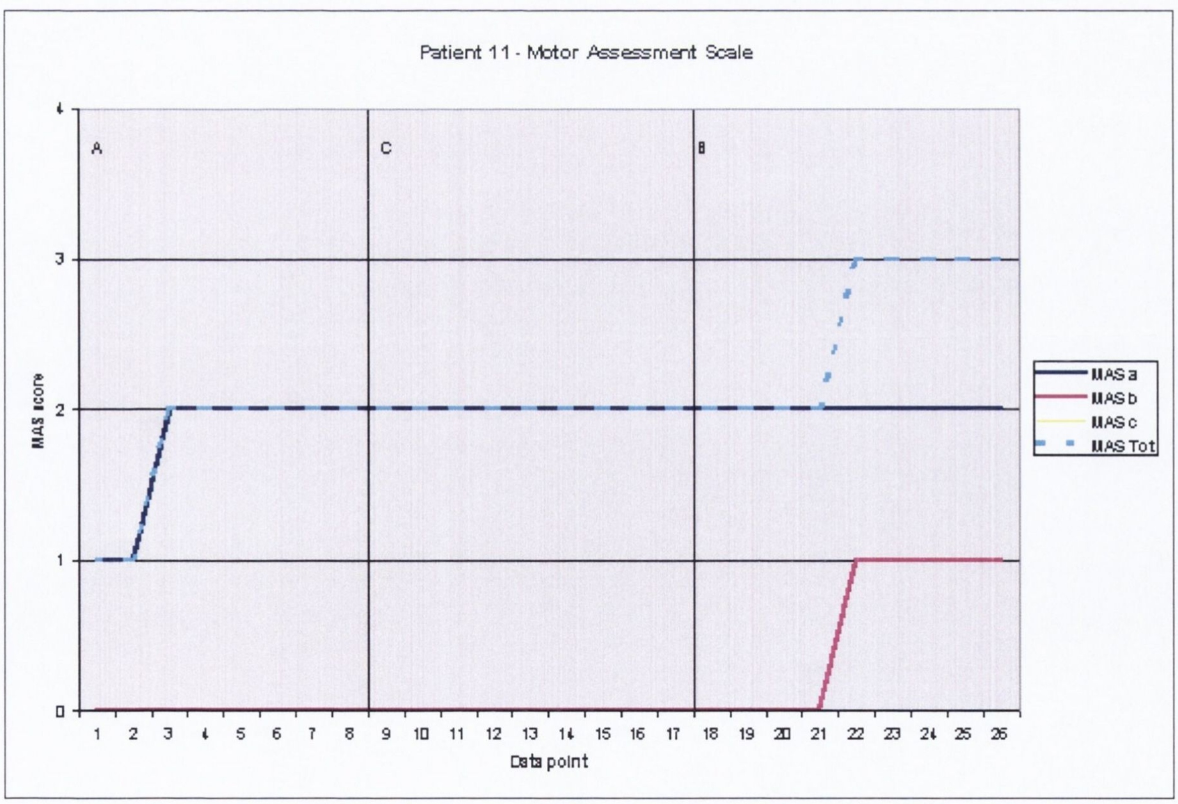

Figure 5-80. Subject 11, MAS

Maximal voluntary isometric contraction

The rate of recovery of MVIC for elbow flexion was greatest in the RMT phase and for elbow extension was greatest in the SS phase. The plotted data shows the variable nature of this measure. There is a trend for the rate of shoulder extension MVIC to be greatest during the SS phase, however this is not significant.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
ElbFlex	0.40	-0.05	-0.01	0.29	0.04	0.30	0.34
ElbExt	10.74	-0.15	0.47	-0.12	0.62	-0.59	0.04
ShoFlex	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ShoExt	10.82	-0.11	0.22	0.00	0.32	-0.21	0.11

Table 5-88. Subject 11, MVIC

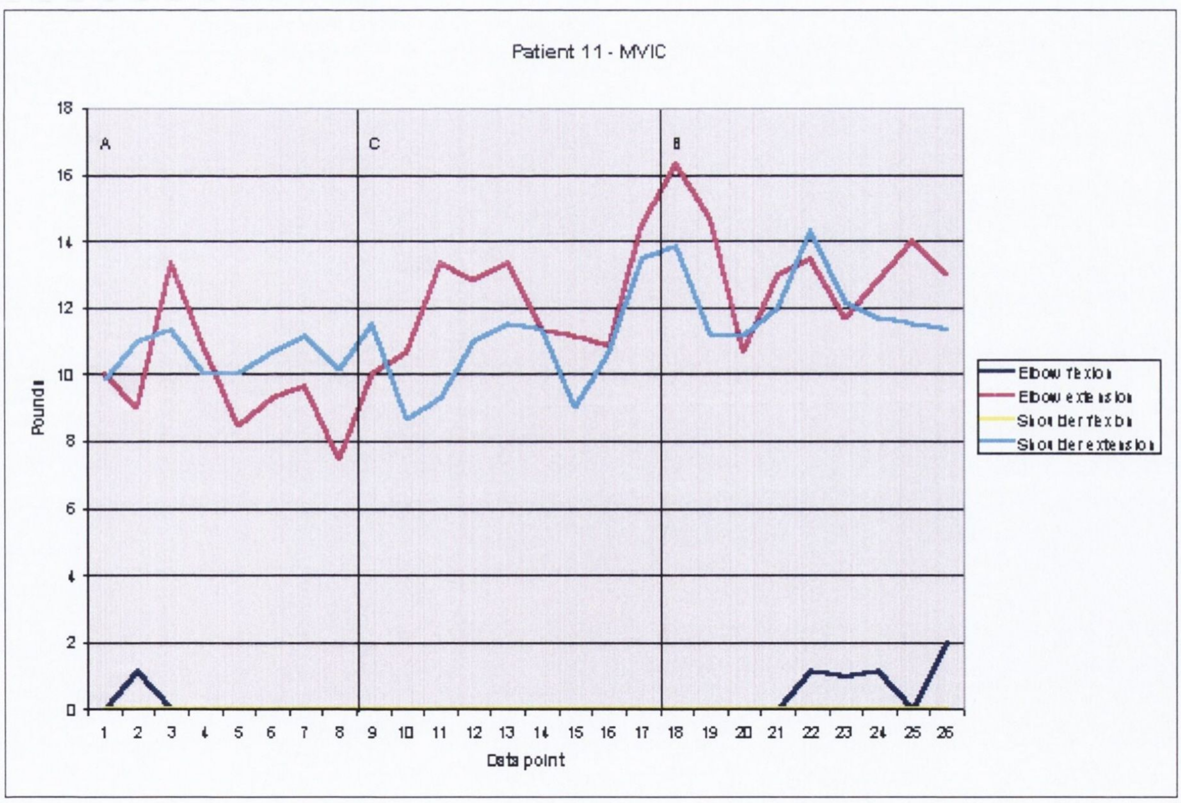

Figure 5-81. Subject 11, MVIC

Range of Motion

The rate of recovery during the RMT phase was significantly greater than that during baseline for passive elbow extension. None of the other differences were greater than the aMDC.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
AShFl	17.71	-0.07	-0.59	0.75	-0.52	1.34	0.82
PShFL	98.95	-0.27	0.69	0.81	0.96	0.11	1.08
AShA	34.42	0.01	-0.27	0.58	-0.28	0.85	0.57
PShA	69.40	-0.28	0.35	0.01	0.63	-0.34	0.28
AElX	-43.40	1.78	0.52	0.83	-1.26	0.31	-0.95
PELX	-2.06	-0.45	0.09	0.48	0.53	0.39	0.92
AShER	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PShER	35.34	0.03	0.18	0.04	0.15	-0.15	0.01
AELFl	73.09	-0.51	-0.11	0.60	0.40	0.71	1.11
PELFl	128.43	0.49	0.35	-0.05	-0.14	-0.40	-0.54

Table 5-89. Subject 11, ROM

The plotted data shows relatively unchanging slopes through variable data.

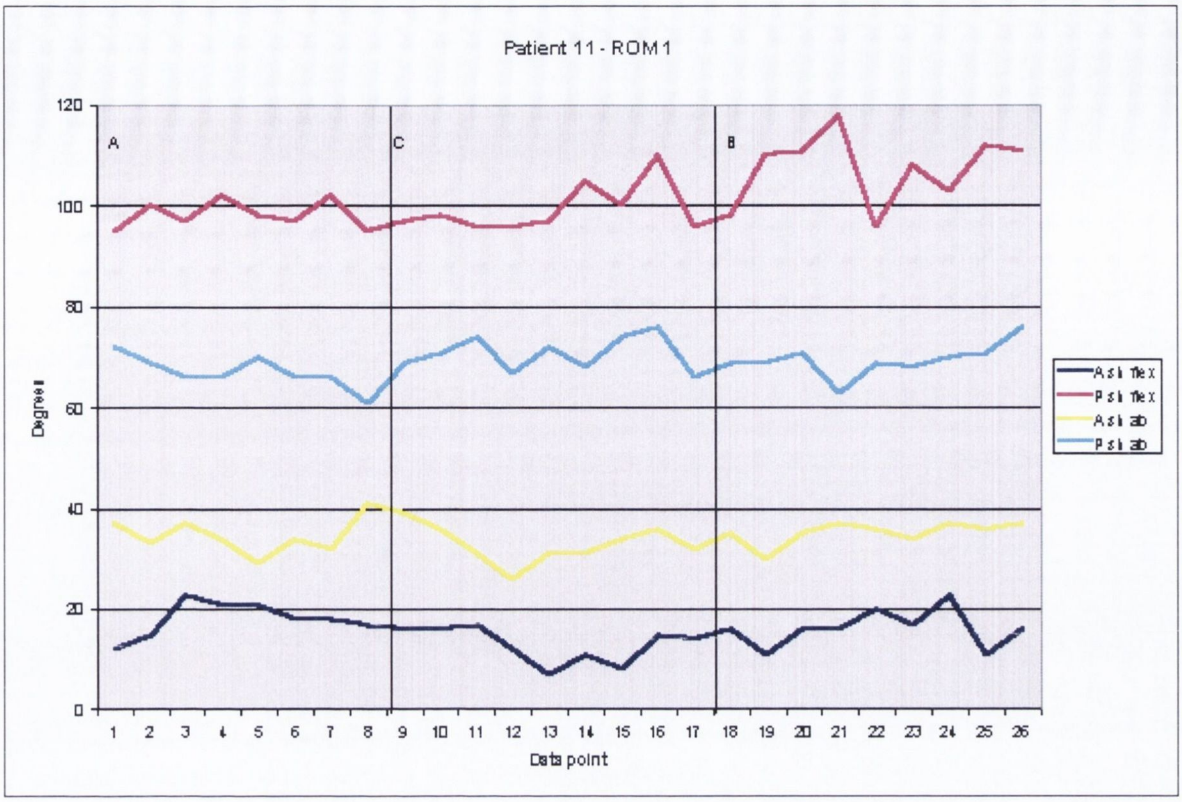

Figure 5-82. Subject 11, ROM 1

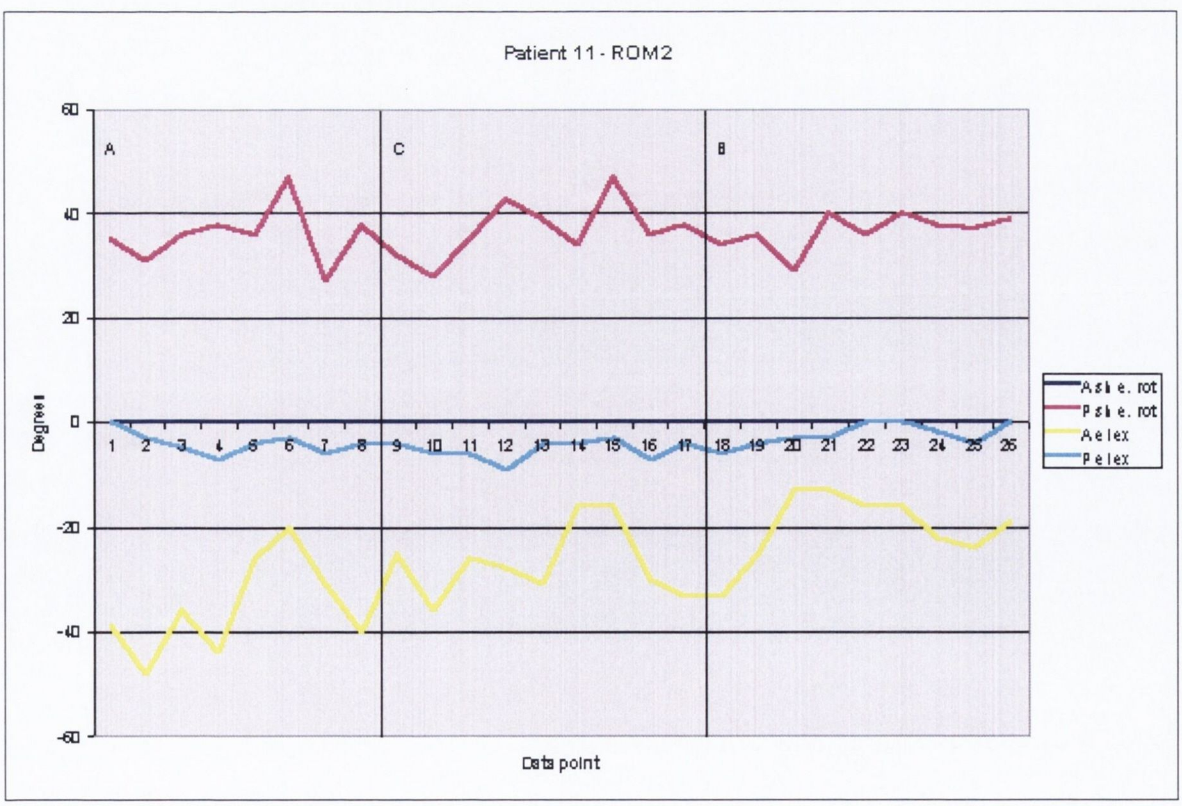

Figure 5-83. Subject 11, ROM 2

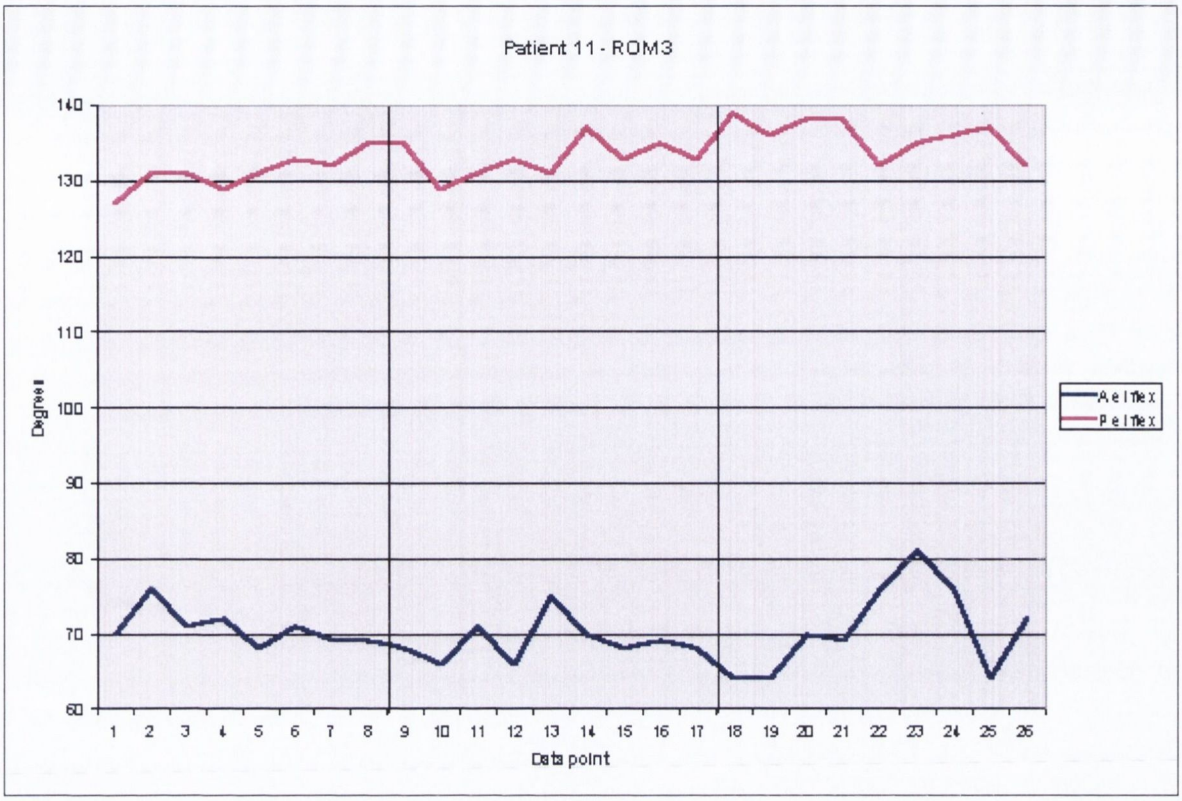

Figure 5-84, Subject 11, ROM 3

Grip Strength

Apart from a peak at measurement 3 this variable remained at 0 throughout the study. This reading caused a negative value in the baseline phase. None of the differences were greater than the aMDC.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
Grip	0.63	-0.08	0.00	0.00	0.09	-0.01	0.08

Table 5-90. Subject 11, Grip

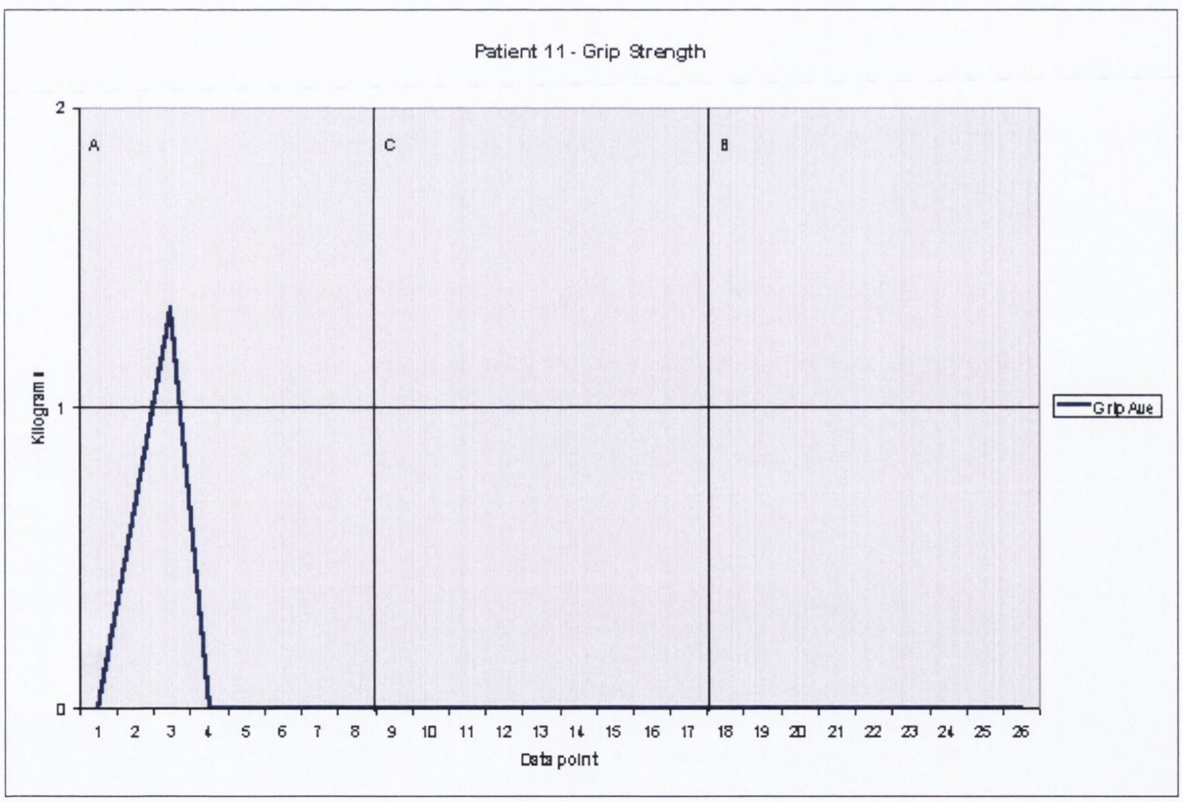

Figure 5-85. Subject 11, Grip

Quality of Life

There is a trend for most subsections to increase at the end of the RMT phase. This includes the physical and mental health sub scores. All sections are at or above their starting level at the end of the study for this subject.

SF-36 Domain	Start	End A	End C	End B
Physical Functioning	25.5	36	27.6	31.8
Roles – Physical	37.3	34.8	27.5	37.3
Bodily Pain	376	46.1	46.1	51.1
General Health	38.6	36.2	40.1	41
Vitality	45.8	45.8	49	58.3
Social Functioning	45.9	35	51.4	45.9
Roles - Emotional	28.7	24.8	17	36.4
Mental Health	38.7	35.9	47.2	38.7
Physical Health Score	34.8	42	35.8	41.3
Mental Health Score	41.8	32.9	42.9	45.3

Table 5-91. Subject 11, SF-36

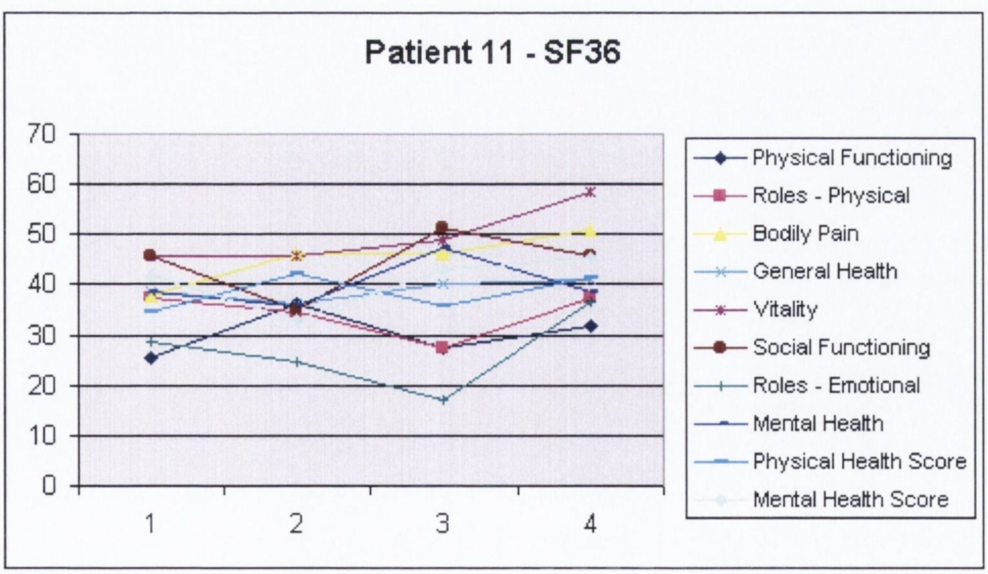

Figure 5-86. Subject 11, SF-36

5.2.12 Subject 12

Mr. MK was a 61 year old man who had a right hemiplegia 34 months prior to the start of the study. His CT scan showed total occlusion of the left carotid artery. He had had extensive rehabilitation up to 6 months post stroke, and at the time of the study was on review at Baggot Street Community hospital.

His past medical history included carotid artery stenosis. He was on Warfarin and lipitor. He was a very active man, who lived with his wife and young daughter, he drove independently.

He was randomized to the ABC group and to a baseline of 9 data points. He exercised in passive mode for 25.8%, active assisted mode for 51.3% and active mode for 22.8% of the time.

Events during course of study

Visit 6 – complained of increased tone

Visit 15 – feeling tired after weekend.

Background data

He had no hemianopia or pain for the duration of the study and his sensory score was within one point of the maximal for the duration of the study. He had increased tone in his elbow and wrist which increased over baseline and decreased over the RMT phase to remain stable.

Subject 12, Summary	
Age	61
Time post stroke	34 months
Side affected	Left
CT result	Occlusion left carotid artery
Current physiotherapy treatment	None
Randomisation	ABC, 9
Exercise mode	P 25.8%, AA 51.3%, A 22.8%

Table 5-92. Subject 12, summary

	Start A	Start B	Start C	End C
Short Orientation Memory Concentration	28	28	26	28
Star Cancellation L	27	27	27	27
Star Cancellation R	27	27	27	27
Star Cancellation Total	54	54	54	54
Pain	0	0	0	0
Hemianopia	0	0	0	0
Tone Wrist	1	1	1	1
Tone Elbow	2	3	2	2
Sensation Light Touch	8	8	8	8
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	8	8	8	8
Sensation Kinaesthesia	11	11	11	11
Sensation Total	35	35	35	35

Table 5-93. Subject 12, Background data

Fugl-Meyer

The rate of recovery during the RMT phase is significantly higher than that during the baseline phase for the FMA, FMB, FMD and FM total score, this is probably due to the negative value of the baseline slope for these 3 variables.

The plotted raw data shows the variable nature of the data, particularly in the FMA and FMB subsections, which appear to contribute most to the total score.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
FMA	16.52	-0.10	0.74	0.34	0.84	-0.40
FMB	2.22	-0.17	0.05	0.19	0.22	0.14
FMC	2.88	0.07	-0.01	0.08	-0.08	0.09
FMD	2.96	-0.07	0.05	0.00	0.13	-0.06
FMT	24.58	-0.27	0.30	0.61	0.57	0.31

Table 5-94. Subject 12, Fugl-Meyer

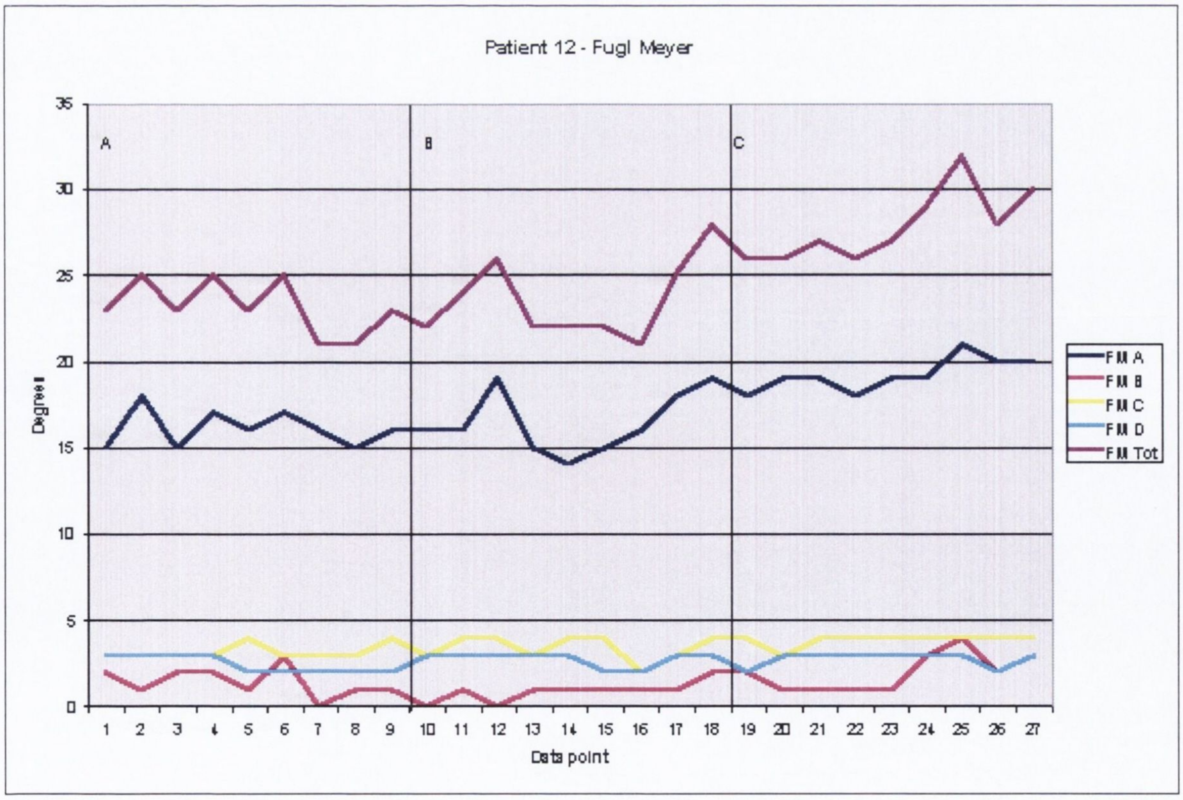

Figure 5-87. Subject 12, Fugl-Meyer

Motor Assessment Scale

The plotted raw data shows an increase in the baseline phase, a stationary RMT phase and an increase in the SS phase. This is reflected in the baseline and SS phase slopes being significantly higher than the RMT phase for the MASB and MAS total scores. For all sections the slope in the baseline phase is the highest.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
MASA	1.10	0.08	0.03	0.06	-0.05	0.03
MASB	0.24	0.10	-0.03	0.05	-0.13	0.08
MASC	0.00	0.00	0.00	0.00	0.00	0.00
MAST	1.35	0.18	0.00	0.11	-0.18	0.11

Table 5-95. Subject 12, MAS

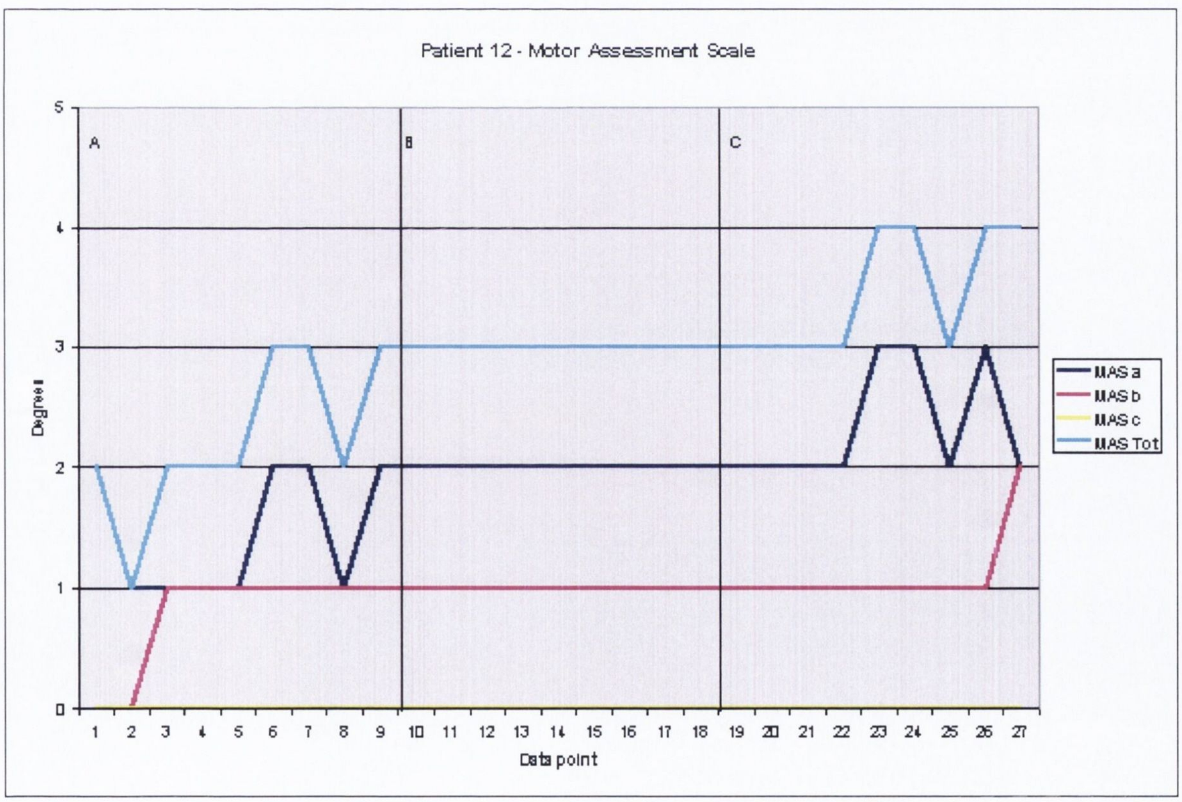

Figure 5-88. Subject 11, MAS

Maximal voluntary isometric contraction

The plotted data shows an increase in the last 1/3rd of the baseline phase. This contributes to the baseline phase slopes being higher than those of the RMT slopes for the two elbow variables.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
ElbFlex	17.07	0.64	0.24	-0.04	-0.41	-0.28
ElbExt	20.15	0.78	0.43	-0.64	-0.35	-1.07
ShoFlex	0.000	0.000	0.000	0.000	0.000	0.000
ShoExt	19.84	0.35	0.18	-0.19	-0.17	-0.37

Table 5-96. Subject 12, MVIC

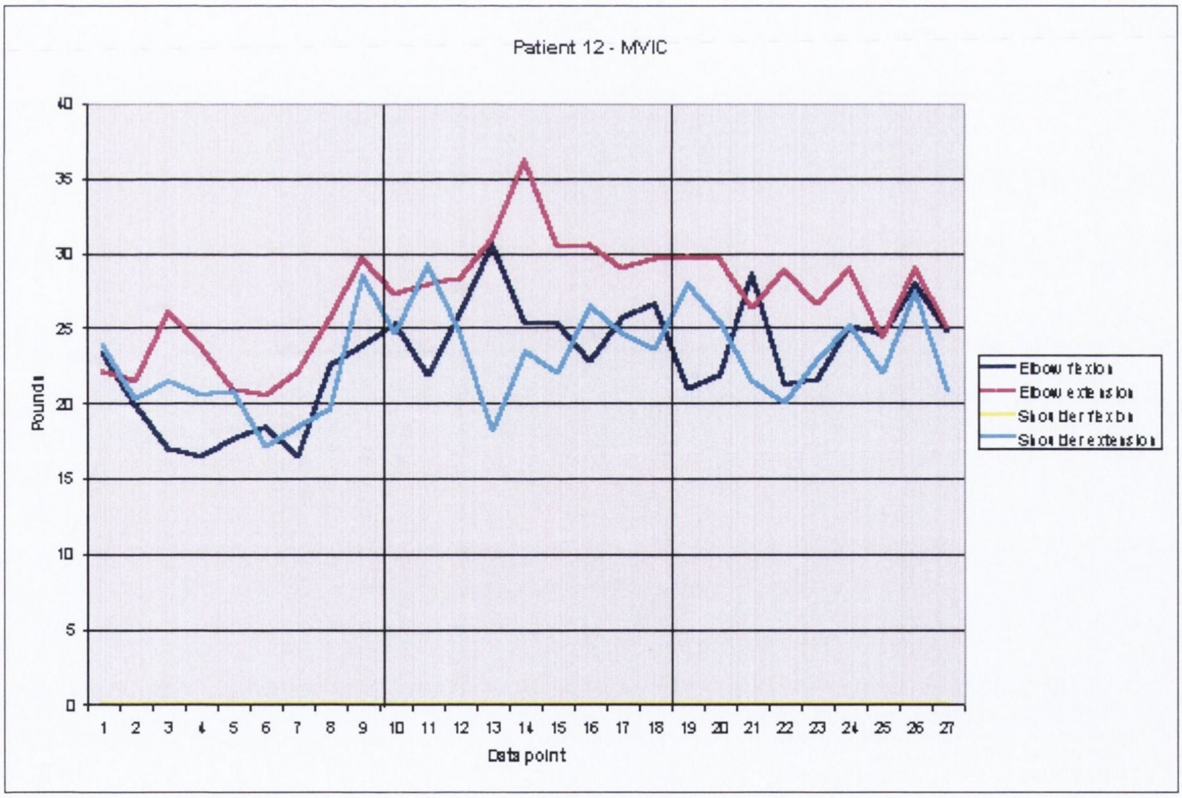

Figure 5-89. Subject 12, MVIC

Range of Motion

The rate of recovery in the RMT phase is significantly higher than that in the baseline phase for active shoulder external rotation and significantly lower for passive shoulder external rotation. The absolute values for the RMT slope are greater than those in the SS and baseline phases for active and passive shoulder abduction and elbow flexion and extension.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
AShFl	24.45	2.13	0.34	1.48	-1.79	1.14
PShFL	108.52	0.03	0.77	1.06	0.74	0.29
AShA	33.96	-1.01	0.63	0.02	1.65	-0.62
PShA	72.06	-0.55	0.55	0.52	1.10	-0.04
AElX	-18.15	-0.44	0.76	-0.24	1.20	-1.00
PELX	-7.09	0.13	0.20	0.47	0.07	0.28
AShER	12.15	-1.34	0.65	0.17	1.99	-0.48
PShER	42.53	0.85	-0.64	0.53	-1.49	1.18
AELFl	130.03	0.22	0.24	-0.02	0.02	-0.26
PELFl	149.28	0.53	-0.05	0.10	-0.59	0.16

Table 5-97. Subject 12, ROM

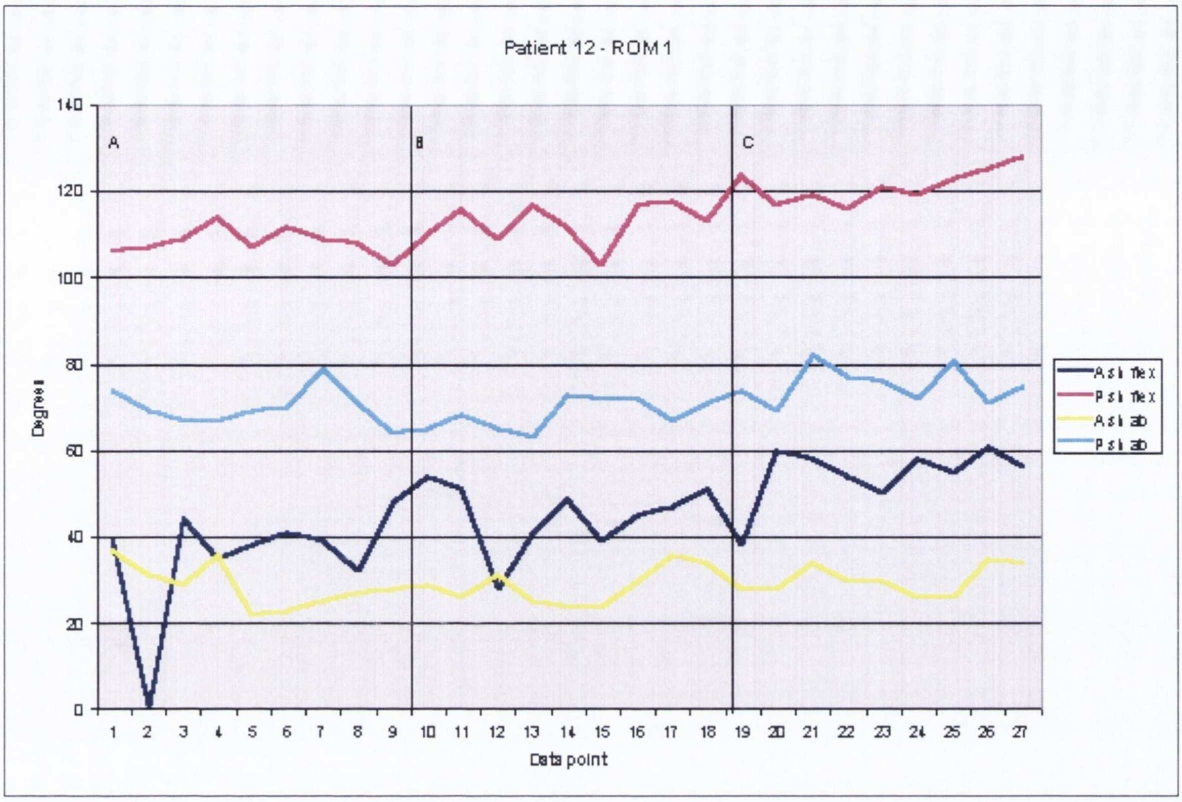

Figure 5-90. Subject 12, ROM 1

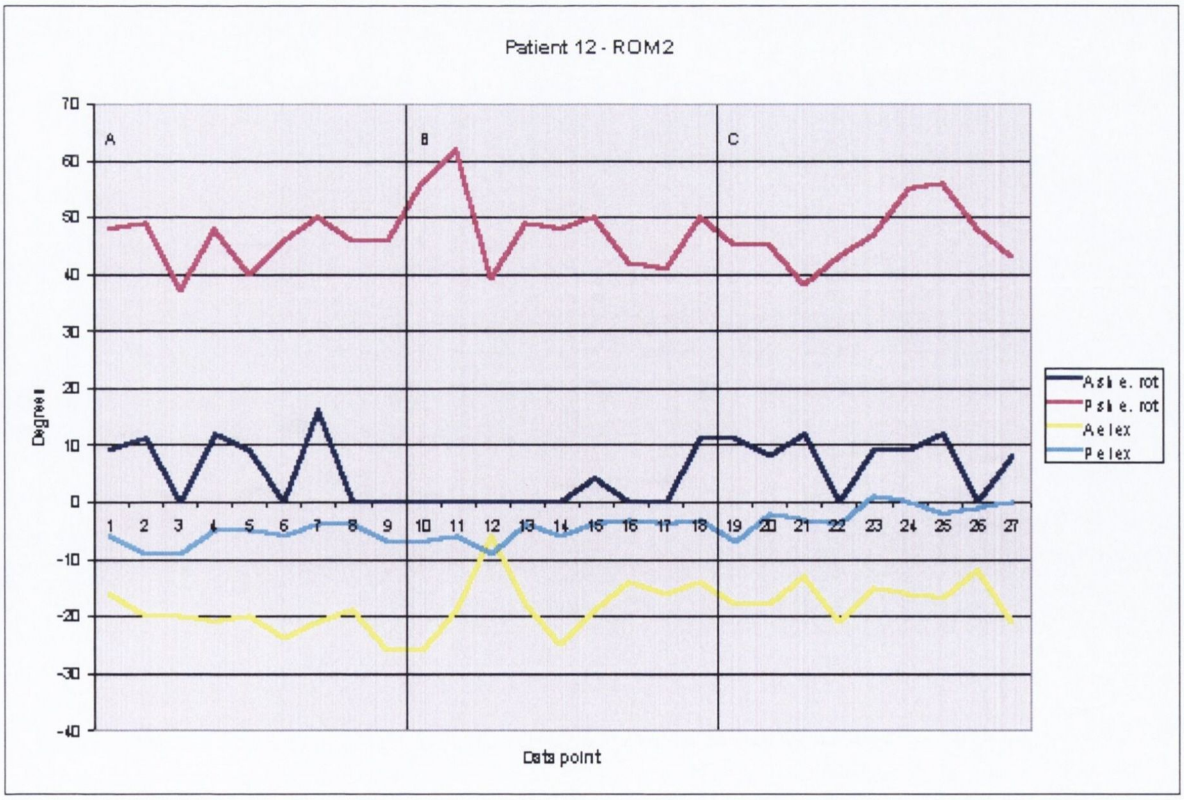

Figure 5-91. Subject 12, ROM 2

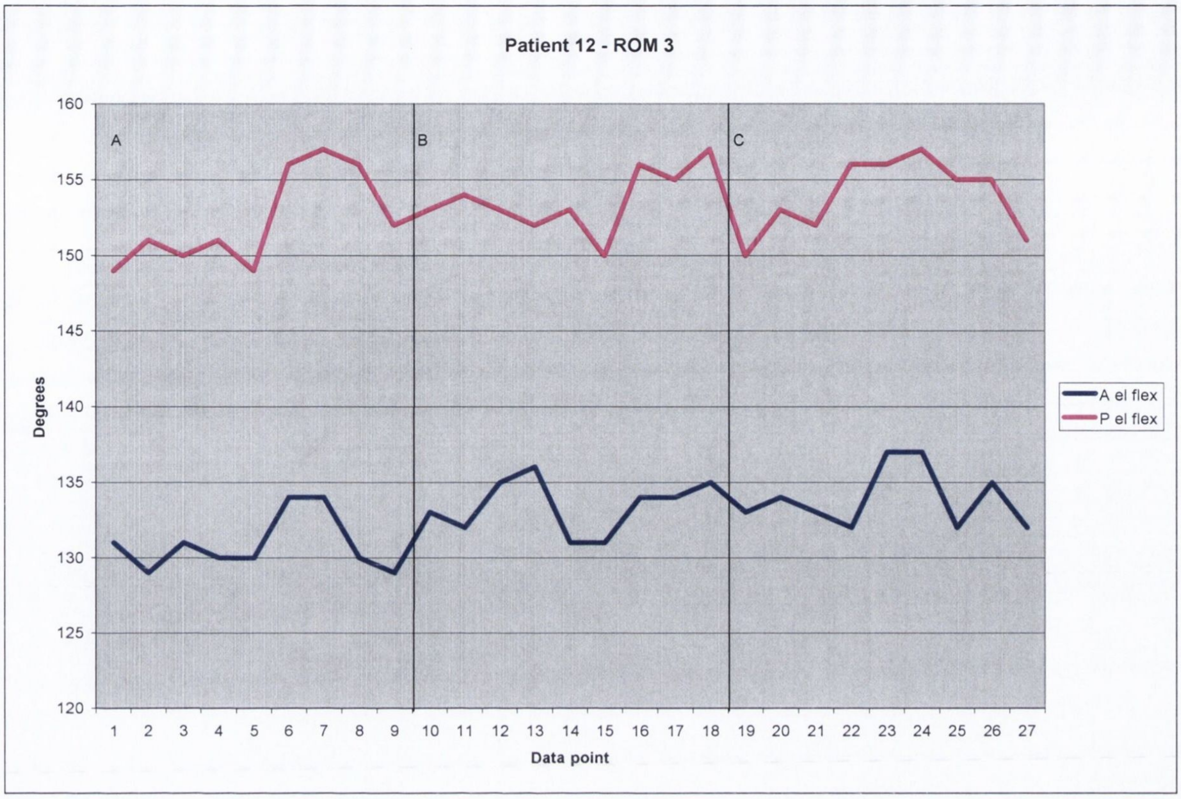

Figure 5-92. Subject 12, ROM 3

Grip Strength

The raw data shows very variable data with a trend for a decrease in the RMT and an increase in the SS phase, however the data is centred around 12kgs. The numerical values for these slopes are significantly different from each other.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
Grip	11.90	0.12	-0.41	0.19	-0.53	0.60

Table 5-98. Subject 12, Grip

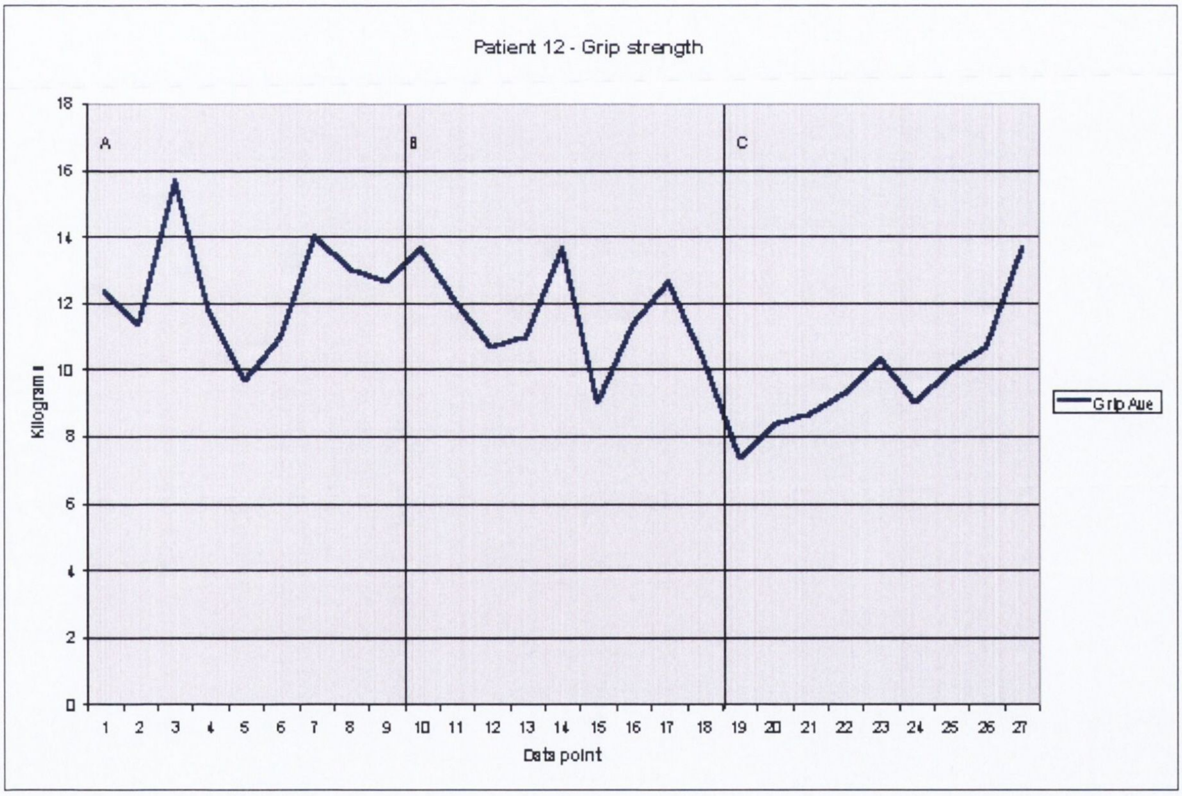

Figure 5-93. Subject 12, Grip

Quality of Life

There is a trend for a decrease over the baseline and RMT phases and a slight increase over the SS phase. Bodily pain is the one section that increases over both treatment phases indicating a decrease in subjective pain levels.

SF-36 Domain	Start	End A	End B	End C
Physical Functioning	14.9	14.9	14.9	14.9
Roles - Physical	27.5	17.7	17.7	17.7
Bodily Pain	55.4	51.1	55.4	62.1
General Health	48.2	44.8	33.9	36.2
Vitality	42.7	42.7	36.5	39.6
Social Functioning	29.6	29.6	24.1	35
Roles - Emotional	28.7	20.9	9.2	13.1
Mental Health	44.4	41.6	41.6	35.9
Physical Health Score	33.7	30.2	31	34.2
Mental Health Score	41.2	38.1	29.8	31.8

Table 5-99. Subject 12, SF-36

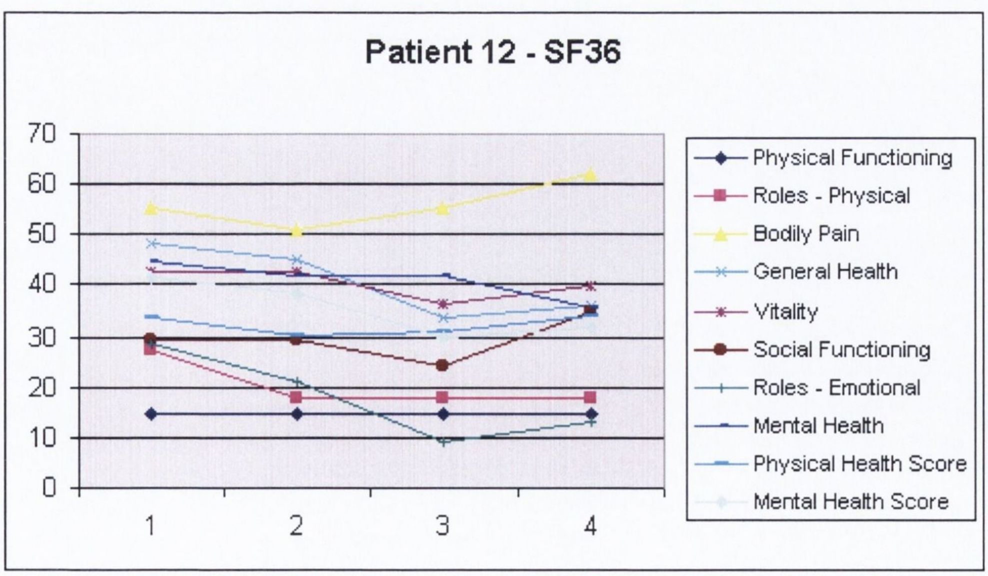

Figure 5-94. Subject 12, SF-36

5.2.13 Subject 13

Mr. CN was a 51 year old man who had a left hemiplegia 21 months prior to the start of the study. His CT scan showed a right middle cerebral artery infarct.

His past medical history included asthma and a transient ischemic attack 7 months prior to his stroke. His medications included aspirin and lipostat. He lived at home with his wife and was on review at Baggot Street Community Hospital at the time of the study.

He was randomized to the ABC group and to a baseline of 8 data points. He exercised in passive mode for 10.7% of the time, active assisted for 0.4% and active for 88.8% of the time.

Events during course of study

Visit 3 – early appointment

Visit 5 - early appointment

Background data

His star cancellation scores showed slight right inattention which fluctuated with the lowest score at the end of the RMT phase. At the first two measurements he demonstrated visual inattention and low bilateral simultaneous touch scores indicating some inattention to the left.

He had no pain for the duration of the study.

Subject 13, Summary	
Age	51
Time post stroke	21 months
Side affected	Left
CT result	Right middle cerebral artery infarct
Current physiotherapy treatment	None
Randomisation	ABC, 8
Exercise mode	P 10.7%, AA 0.4%, A88.8%

Table 5-100. Subject 13, Summary

	Start A	Start B	Start C	End C
Short Orientation Memory Concentration	28	28	28	28
Star Cancellation L	26	27	27	27
Star Cancellation R	27	26	25	27
Star Cancellation Total	53	53	52	54
Pain	0	0	0	0
Hemianopia	1	1	0	0
Tone Wrist	2	1	1	1
Tone Elbow	2	3	2	2
Sensation Light Touch	8	8	8	8
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	2	5	7	8
Sensation Kinaesthesia	10	10	11	11
Sensation Total	28	31	34	35

Table 5-101. Subject 13, Background data

Fugl-Meyer

None of the differences in slope values can be considered true change as they are not greater than the MDC values. The SS phase has the greatest rate of recovery for the baseline and total scores.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
FMA	23.85	0.07	0.07	0.14	-0.01	0.08
FMB	2.58	0.03	0.19	0.10	0.17	-0.09
FMC	3.71	0.04	0.00	0.00	-0.04	0.00
FMD	2.40	0.10	0.04	0.08	-0.06	0.04
FMT	32.54	0.19	0.30	0.32	0.12	0.02

Table 5-102, Subject 13, Fugl-Meyer

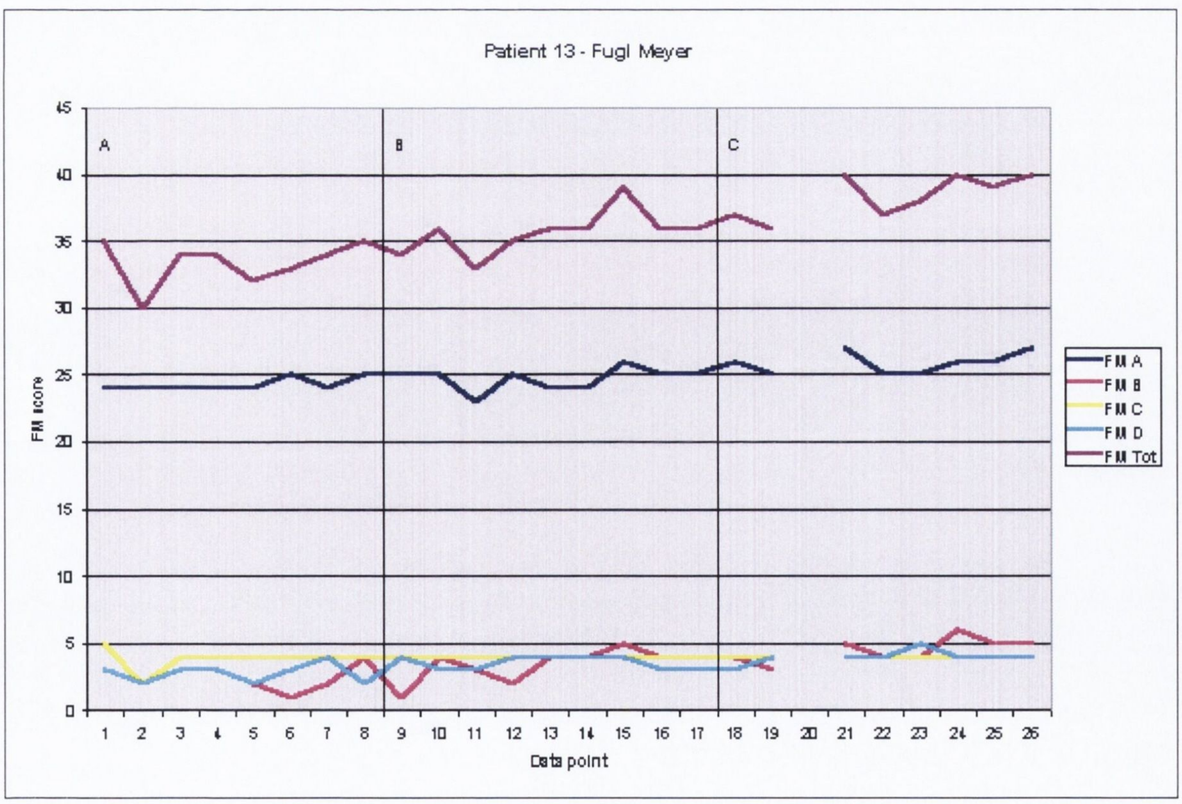

Figure 5-95. Subject 13, Fugl-Meyer

Motor Assessment Scale

The raw data shows little change in the MAS scores. The MASB and total scores increase in the SS phase giving significantly greater slope values than the RMT phase.

This 0.24 unit difference reflects a rate of recovery during SS that is 2.16 units greater than that during the RMT phase.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
MASA	4.00	0.00	0.00	0.00	0.00	0.00
MASB	0.01	0.00	0.01	0.25	0.01	0.24
MASC	0.00	0.00	0.00	0.00	0.00	0.00
MAST	3.99	0.00	0.01	0.25	0.01	0.24

Table 5-103. Subject 13, MAS

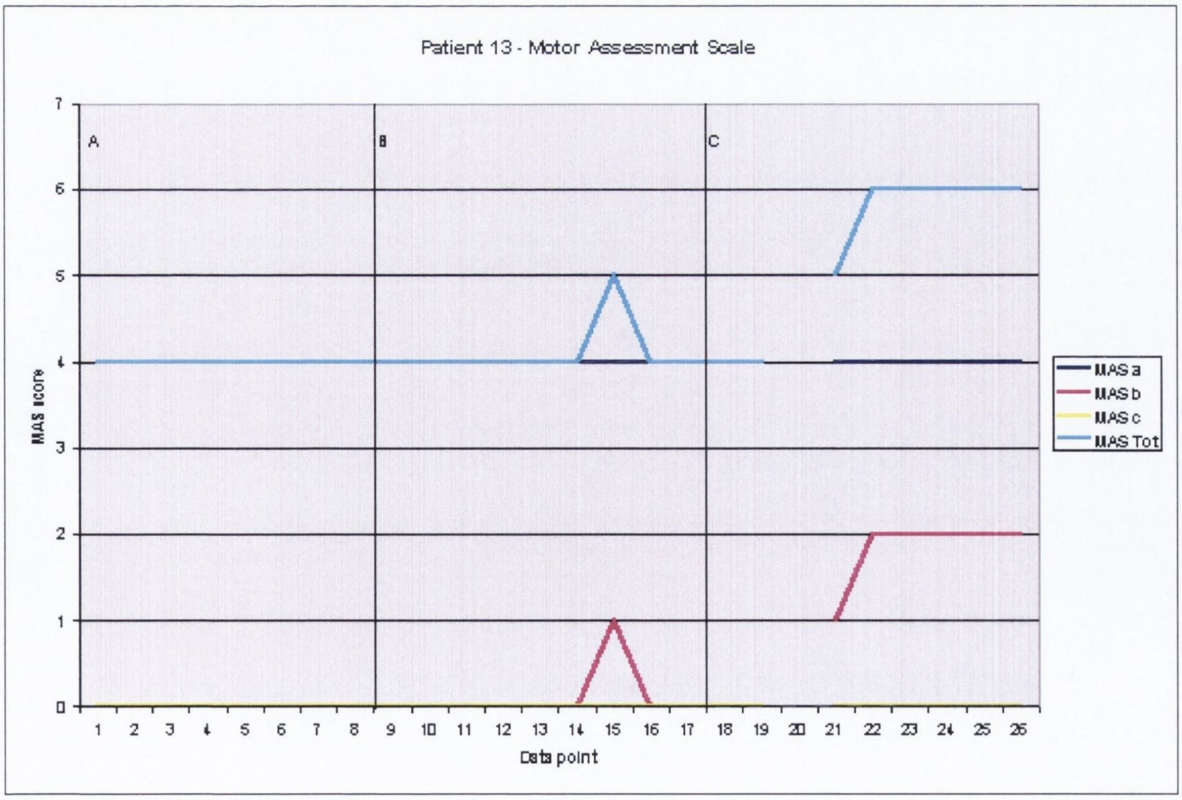

Figure 5-96. Subject 13, MAS

Maximal voluntary isometric contraction

The plotted data shows an increase in slope during the baseline phase that is greater than the RMT phase. This is reflected in the values for the difference in baseline and RMT slopes, which are all significantly in favour of the baseline phase. The RMT phase slope is greater than that of the SS phase for all but shoulder extension, however of these only elbow flexion is significantly so.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
ElbFlex	13.20	1.15	0.33	-0.12	-0.81	-0.45
ElbExt	15.01	0.95	0.41	0.09	-0.54	-0.32
ShoFlex	14.65	1.18	0.39	0.17	-0.79	-0.22
ShoExt	15.39	1.30	0.21	0.34	-1.09	0.13

Table 5-104. Subject 13, MVIC

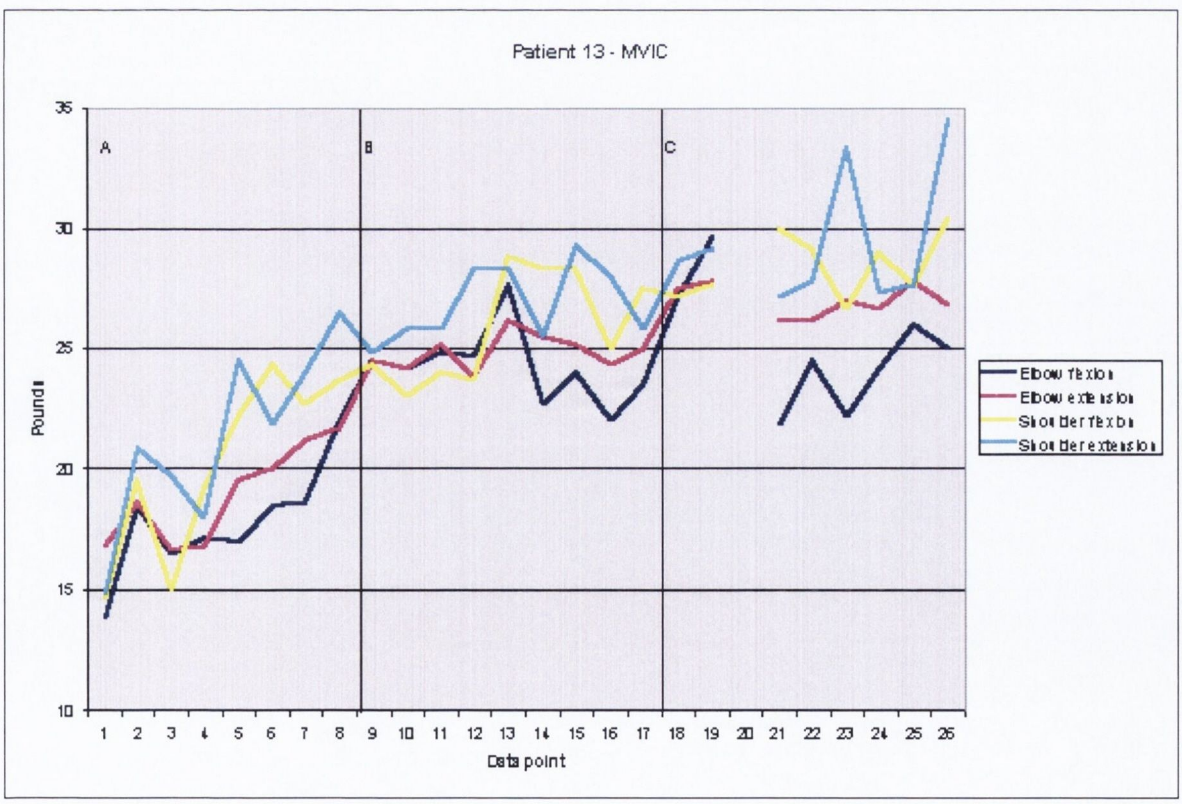

Figure 5-97. Subject 13, MVIC

Range of Motion

The slope values are greater in the RMT phase than the baseline and SS phases for active and passive elbow extension and active and passive shoulder flexion, however the differences are not greater than the MDC for those variables and so they are not considered significant. The RMT phase slope is significantly less than that of the baseline phase for active shoulder abduction and for passive shoulder external rotation. The plotted data shows the highly variable nature of these ROMs.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
AshFl	126.60	0.57	0.61	-0.02	0.04	-0.63
PShFL	136.63	0.40	0.80	-0.59	0.41	-1.39
AshA	87.46	1.41	-2.17	0.03	-3.57	2.20
PshA	103.05	1.85	-0.05	0.05	-1.90	0.10
AelX	-4.86	-0.55	0.34	0.07	0.88	-0.26
PELX	2.79	-0.42	0.20	0.05	0.62	-0.15
AshER	8.28	0.94	0.47	0.33	-0.47	-0.14
PshER	43.66	1.84	-0.45	-0.26	-2.29	0.19
AELFl	140.15	0.25	0.20	-0.19	-0.04	-0.40
PELFl	149.78	0.24	-0.05	-0.02	-0.29	0.03

Table 5-105. Subject 13, ROM

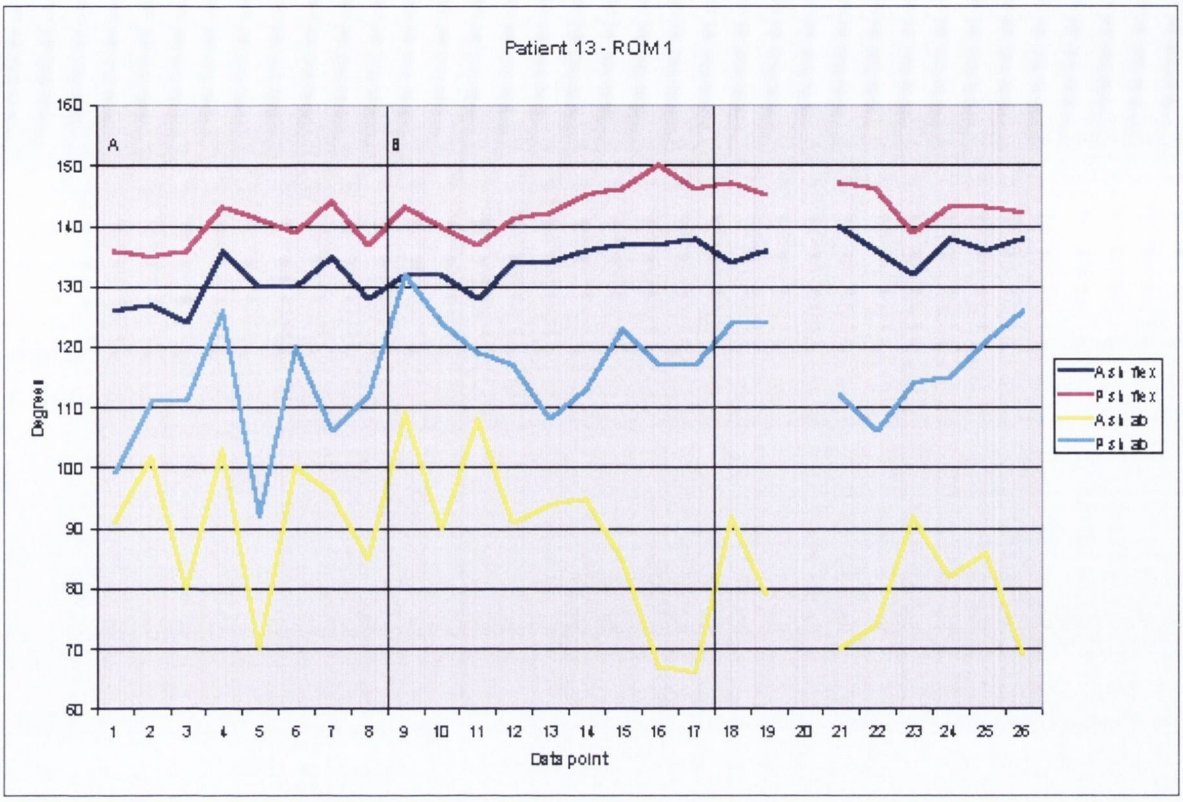

Figure 5-98. Subject 13, ROM 1

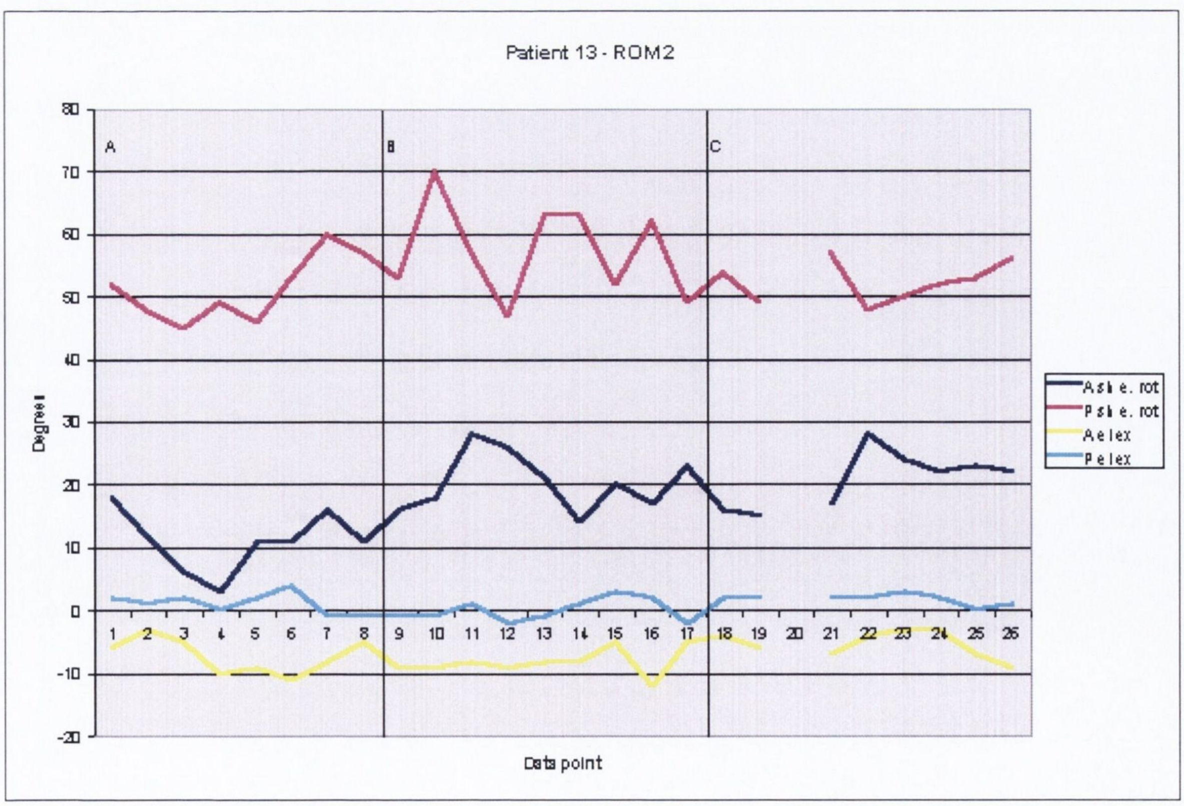

Figure 5-99. Subject 13, ROM 2

Figure 5-100. Subject 13, ROM 3

Grip Strength

The slope for the baseline phase is greater than that of the RMT phase. The plotted data shows that for the treatment phases the data is centred around 15kg with some variability.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
Grip	11.91	0.31	0.06	0.12	-0.25	0.06

Table 5-106. Subject 13, Grip

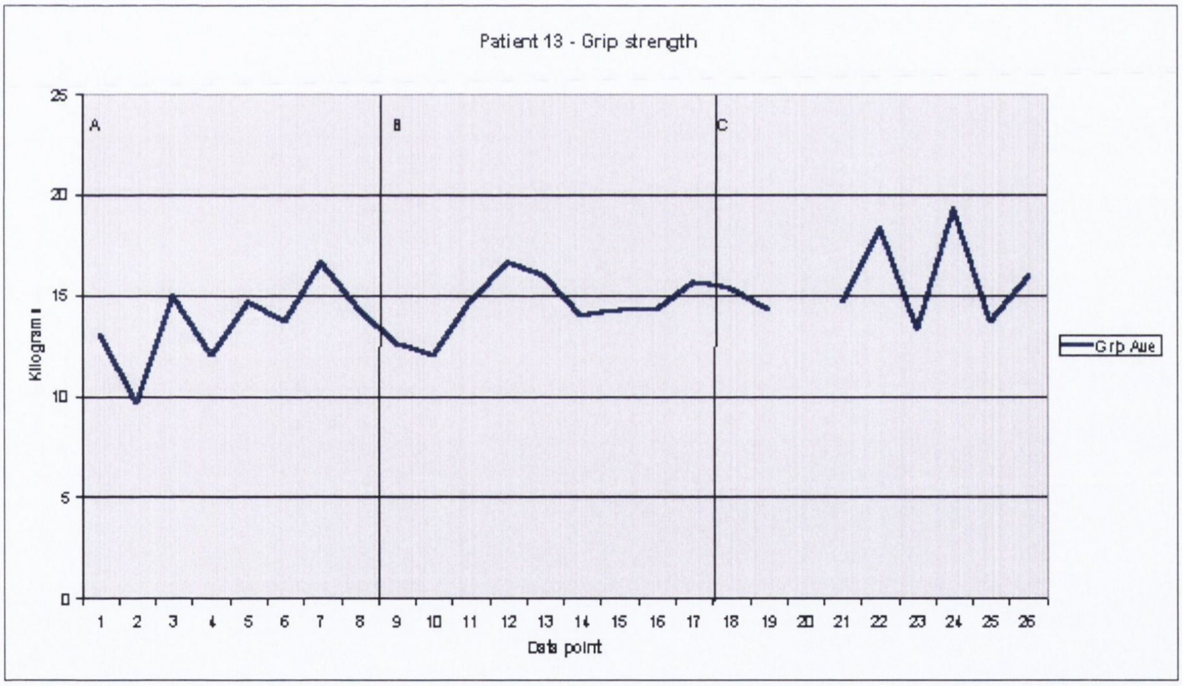

Figure 5-101. Subject 13, Grip

Quality of Life

There is a trend for a decrease or stationary score over the RMT phase and an increase over the SS phase, thought the data fluctuates greatly.

SF-36 Domain	Start	End A	End B	End C
Physical Functioning	44.4	42.3	42.3	48.6
Roles – Physical	42.2	37.3	37.3	49.5
Bodily Pain	62.1	62.1	55.4	62.1
General Health	48.2	45.8	45.8	57.7
Vitality	49	58.3	55.2	61.5
Social Functioning	40.5	51.4	40.5	51.4
Roles - Emotional	55.9	32.6	32.6	55.9
Mental Health	41.6	55.6	55.6	58.5
Physical Health Score	49	47.4	45.2	52.3
Mental Health Score	46.8	49.7	46.7	58.8

Table 5-107. Subject 13, SF-36

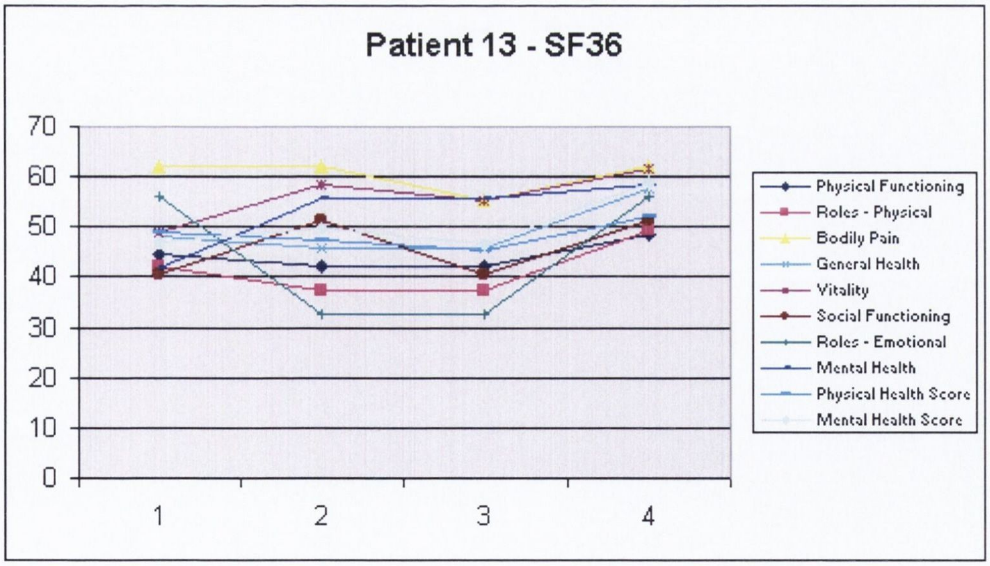

Figure 5-102. Subject 13, SF-36

5.2.14 Subject 14

Mr. PC was a 65 year old man who had a right hemiplegia 3 months prior to the start of the study. His CT result showed a left pontine stroke.

His past medical history included left hip and lumbar spine osteoarthritis. He complained of back pain frequently during the course of the study. He also had non insulin dependent diabetes, angina, hypertension and asthma. His medications included ventolin, glucophage, non steroidal anti inflammatories, and ponstan.

He lived with his wife at home, but as she was an inpatient for surgery was in respite in a nursing home for a portion of the study (see events below). He was receiving treatment once a week at the Day Hospital in AMNCH.

He was randomized to the ACB group and to a baseline of 9 data points. He exercised in passive mode for 1% of the time, active assisted for 84.1% and active for 14.9% of the time.

Events during course of study

Visit 7 – did not attend. In A&E SJH complaining of left hip and left shoulder pain

Visit 8 – moved to respite

Visit 10 – did not attend

Visit 13 – fell yesterday and injured back, complaining of LBP

Visit 14 – feeling "groggy" from pain medication

Visit 16 – complaining of right shoulder pain from "fall" at home

Visit 17 – returned to live at home

Visit 22 – complaining of back and thoracic spine pain, very low mood

Visit 23 – refused treatment, discharged from Day Hospital

Background data

His star cancellation test fluctuated within one point of maximal for the duration of the study. He had no hemianopia and normal bilateral simultaneous sensation scores. Pain in his right arm decreased over baseline and SS and maintained the decrease over the RMT phase.

His tone score for his elbow decreased over the RMT phase. His total sensation score remained within one point of maximal over the treatment phases.

Subject 14, Summary	
Age	65
Time post stroke	3 months
Side affected	Right
CT result	Left pontine stroke
Current physiotherapy treatment	45 minutes once a week
Randomisation	ACB, 9
Exercise mode	AA 26.8%, A 71.1%

Table 5-108. Subject 14, Summary

	Start A	Start C	Start B	End B
Short Orientation Memory Concentration	26	28	28	28
Star Cancellation L	27	27	26	26
Star Cancellation R	27	26	27	27
Star Cancellation Total	54	53	53	53
Pain	4.3	3.9	1.8	1.8
Hemianopia	0	0	0	0
Tone Wrist	1	1	1	1
Tone Elbow	2	2	2	1
Sensation Light Touch	8	8	8	8
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	8	8	8	8
Sensation Kinaesthesia	10	11	11	11
Sensation Total	34	35	35	35

Table 5-109. Subject 14, Background data

Fugl-Meyer

The rate of recovery during the RMT phase was higher than both the baseline and SS phases for all but the FMB section. The RMT phase was significantly greater (i.e. difference greater than aMDC) than both the baseline and SS slopes for the FM total score. The rate of recovery during RMT was significantly greater than baseline for the FMA and significantly greater than the SS phase for FMC.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
FMA	21.96	-0.25	0.35	0.40	0.60	0.05	0.65
FMB	6.29	0.24	-0.01	0.10	-0.25	0.11	-0.14
FMC	10.53	0.09	-0.02	0.20	-0.11	0.23	0.11
FMD	2.89	0.00	0.03	0.11	0.03	0.08	0.11
FMT	41.66	0.07	0.35	0.81	0.28	0.46	0.74

Table 5-110. Subject 14, Fugl-Meyer

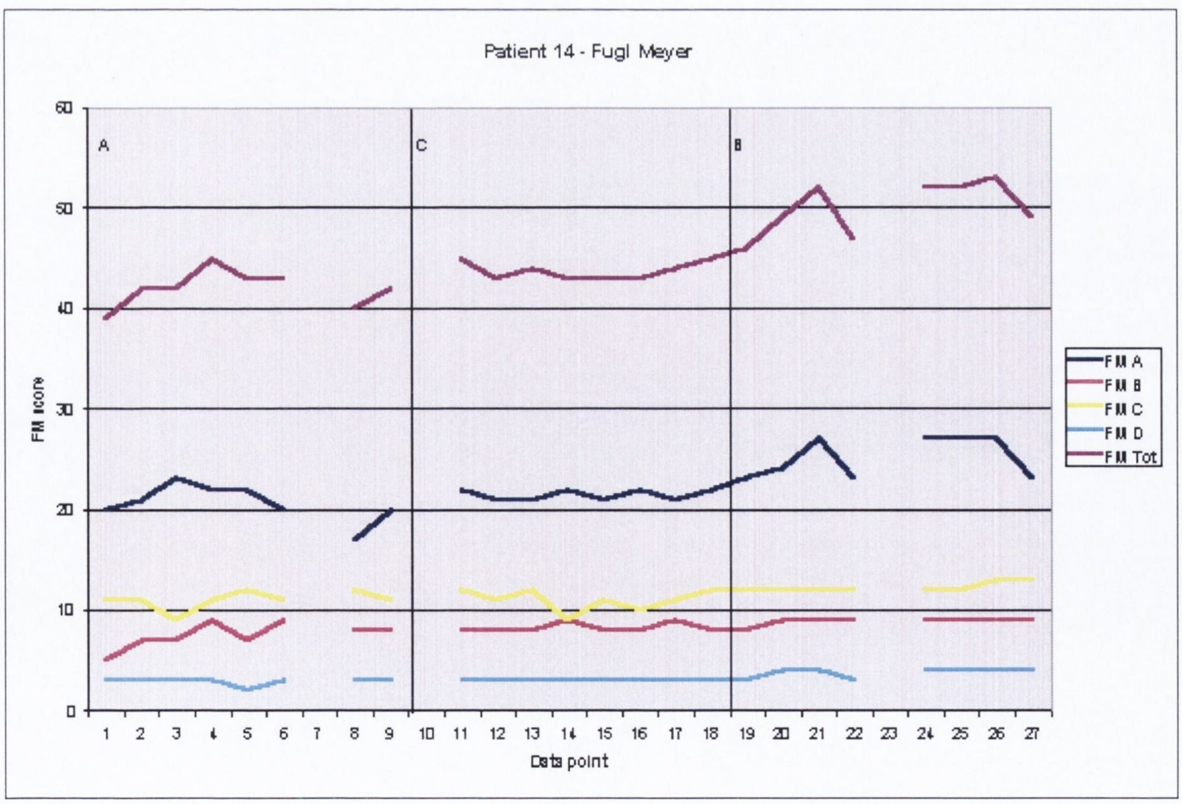

Figure 5-103. Subject 14, Fugl-Meyer

Motor Assessment Scale

The raw data shows an increase in the baseline phase slope which is greater than that of the SS phase. This is reflected in the significantly higher numerical values for the difference in the rates in the baseline and RMT phases. For all sections the RMT phase was greater than the SS phase, and significantly so for the MASA, MASB and total scores.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
MASA	1.99	0.10	-0.01	0.13	-0.10	0.14	0.04
MASB	1.14	0.23	-0.04	0.05	-0.27	0.09	-0.18
MASC	0.04	0.12	-0.02	0.00	-0.13	0.02	-0.11
MAST	3.17	0.45	-0.06	0.19	-0.50	0.25	-0.25

Table 5-111. Subject 14, MAS

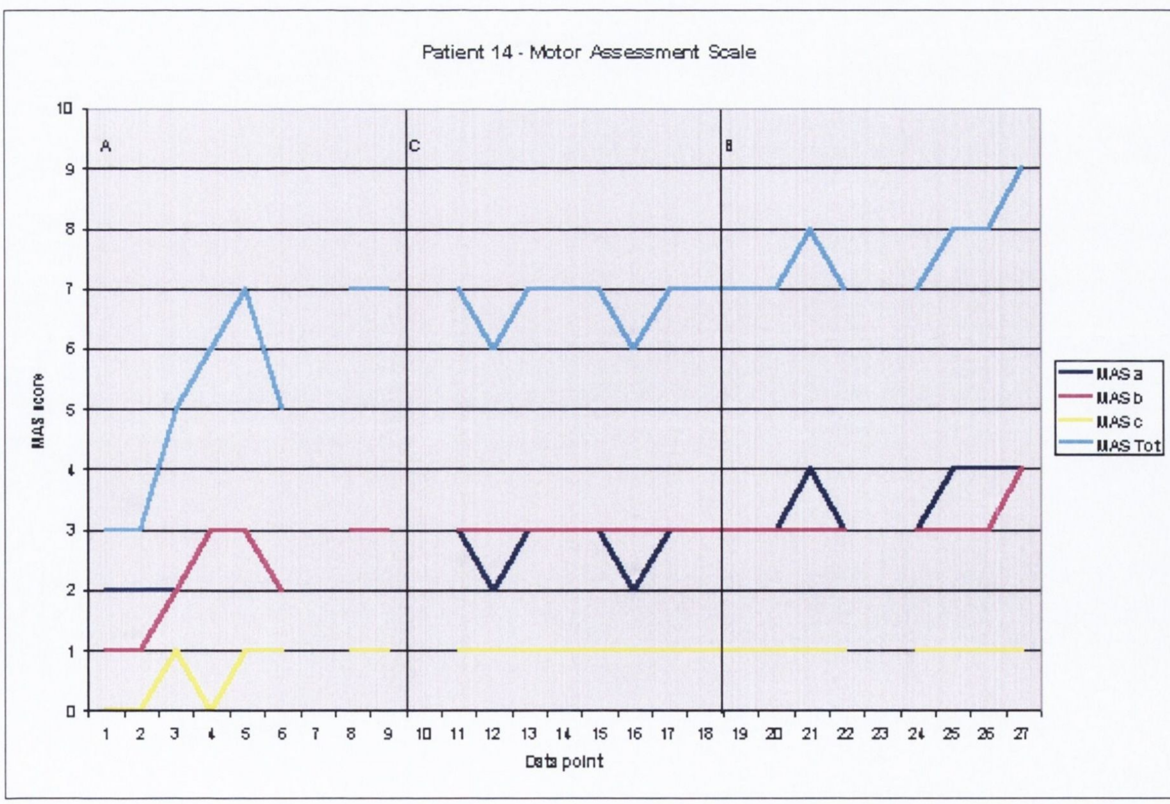

Figure 5-104. Subject 14, MAS

Maximal voluntary isometric contraction

The numerical value for the slope through the RMT phase was higher than that during both other phases for all variables, however this was only significant for the two shoulder variables. It was significantly higher than the SS phase for elbow flexion. The sharp decrease at visit 22 coincides with reports of back pain and low mood.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
ElbFlex	15.59	0.32	0.09	0.58	-0.23	0.49	0.26
ElbExt	13.18	-0.11	0.13	0.31	0.25	0.17	0.42
ShoFlex	5.08	-0.09	-0.22	0.76	-0.13	0.99	0.85
ShoExt	15.61	-0.25	0.13	1.17	0.39	1.04	1.42

Table 5-112. Subject 14, MVIC

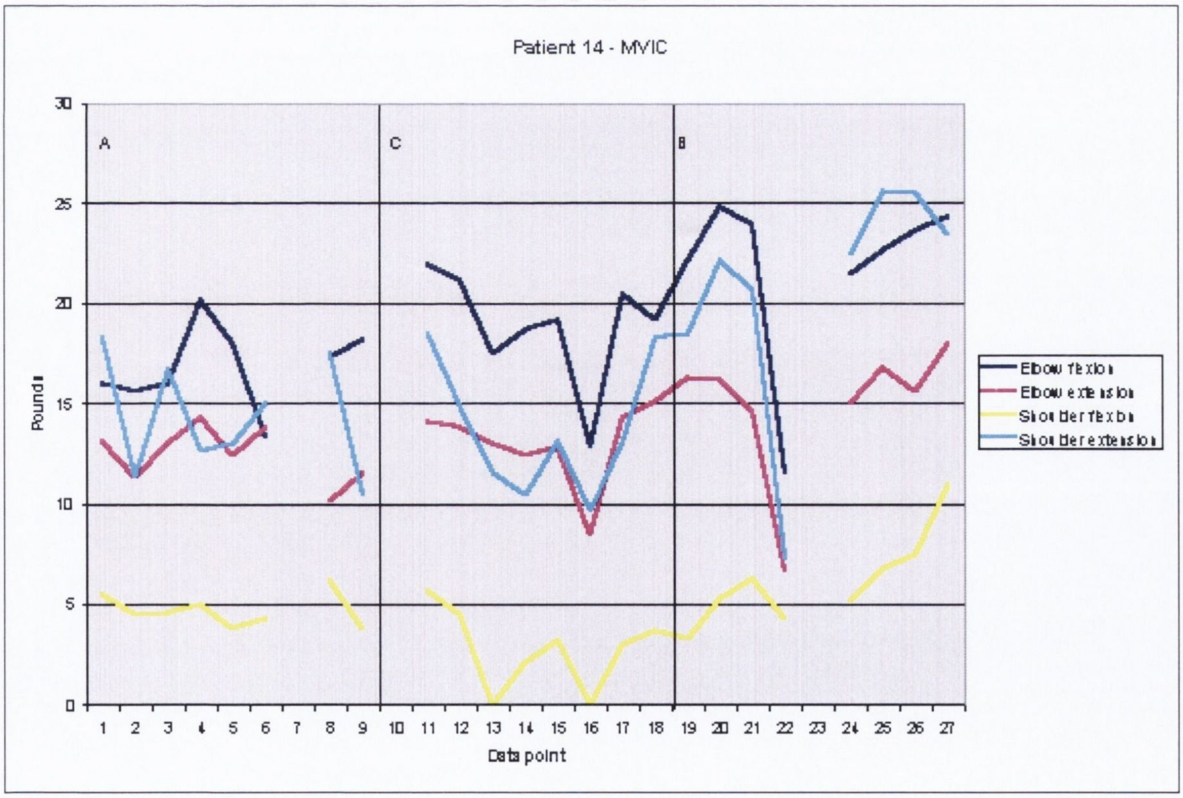

Figure 5-105. Subject 14, MVIC

Range of Motion

The rate of recovery in the RMT phase was greater than that in the baseline and SS phases for active shoulder and elbow flexion and passive elbow extension and shoulder external rotation. None of these differences were above the MDC value. It was higher than just the baseline phase for passive shoulder abduction.

The plotted data indicate the erratic nature of these measures and the missed appointments are highlighted.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
AShFl	43.56	0.96	0.79	2.69	-0.18	1.90	1.72
PShFL	114.60	-1.33	1.05	-0.12	2.39	-1.18	1.21
AShA	58.79	-0.61	0.29	0.23	0.91	-0.06	0.85
PShA	86.90	-1.09	-0.47	0.42	0.63	0.88	1.51
AElX	-27.80	1.02	0.06	0.59	-0.96	0.52	-0.43
PELX	-5.44	0.03	0.09	0.69	0.06	0.61	0.67
AShER	3.16	1.42	-0.08	0.23	-1.50	0.30	-1.20
PShER	33.52	0.28	-0.10	0.65	-0.37	0.75	0.38
AELFl	138.52	-0.27	0.30	0.36	0.57	0.06	0.63
PELFl	150.82	0.59	-0.08	-0.23	-0.67	-0.15	-0.81

Table 5-113. Subject 14, ROM

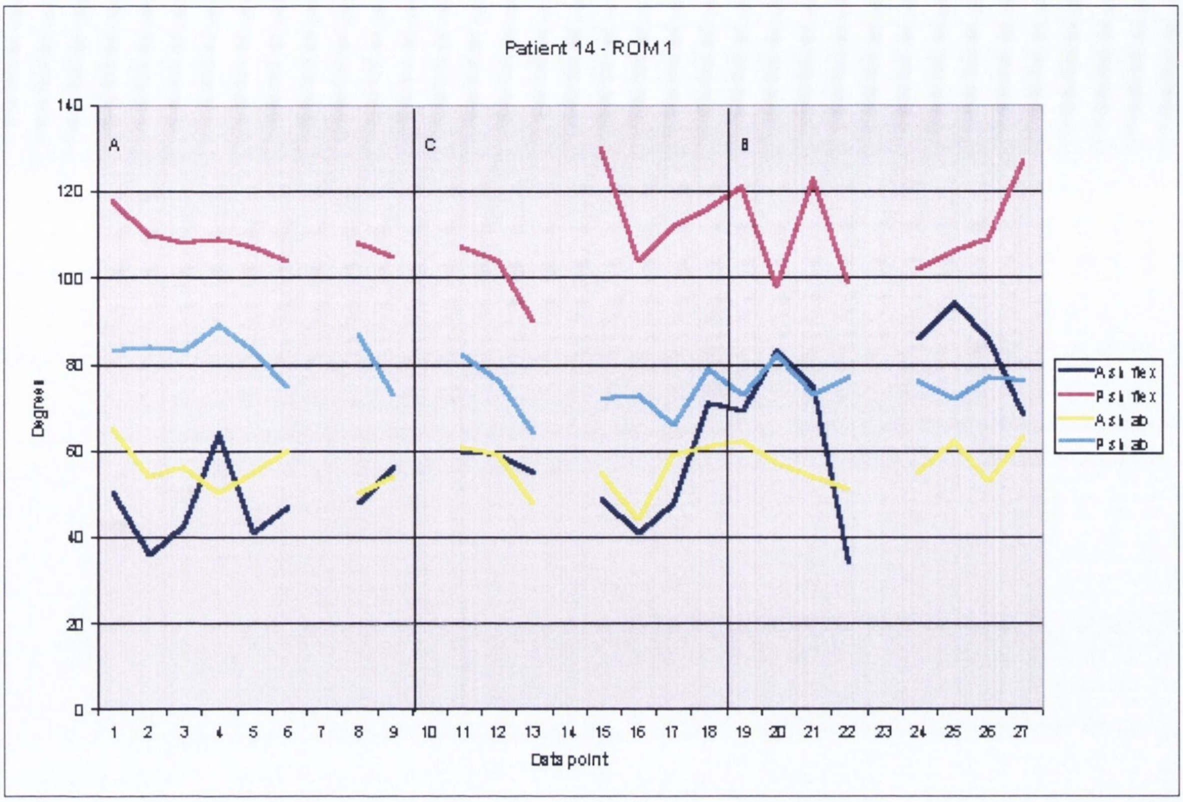

Figure 5-106. Subject 14, ROM 1

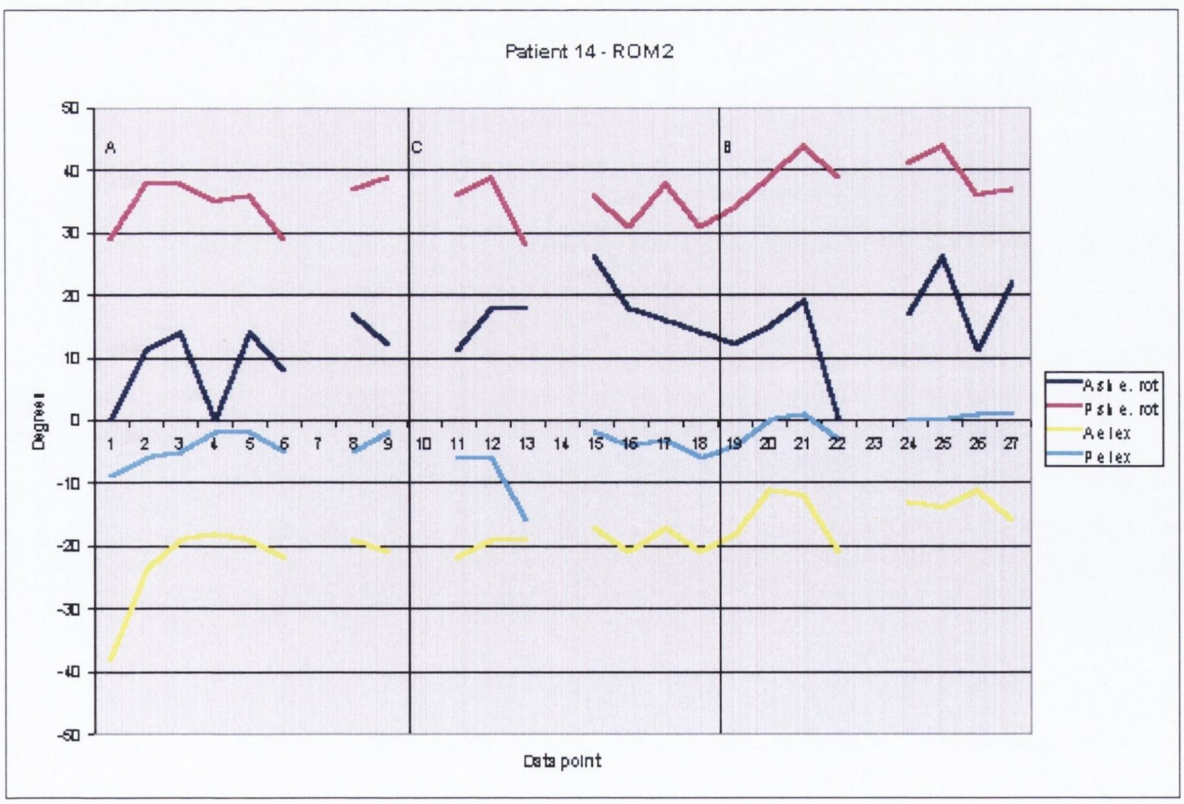

Figure 5-107. Subject 14, ROM 2

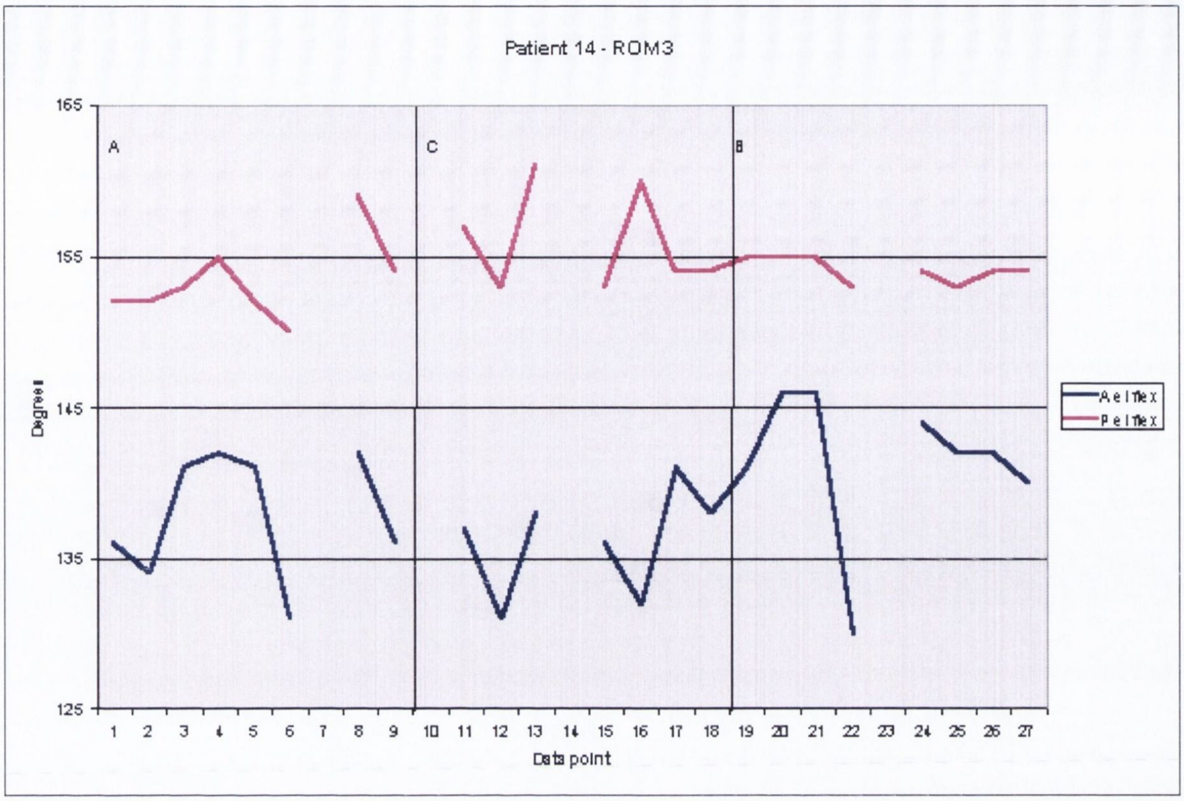

Figure 5-108. Subject 14, ROM 3

Grip Strength

The rate of recovery of grip strength is highest during the RMT phase, and this is significantly different from the SS phase.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
Grip	5.32	0.15	0.04	0.34	-0.11	0.30	0.19

Table 5-114. Subject 14, Grip

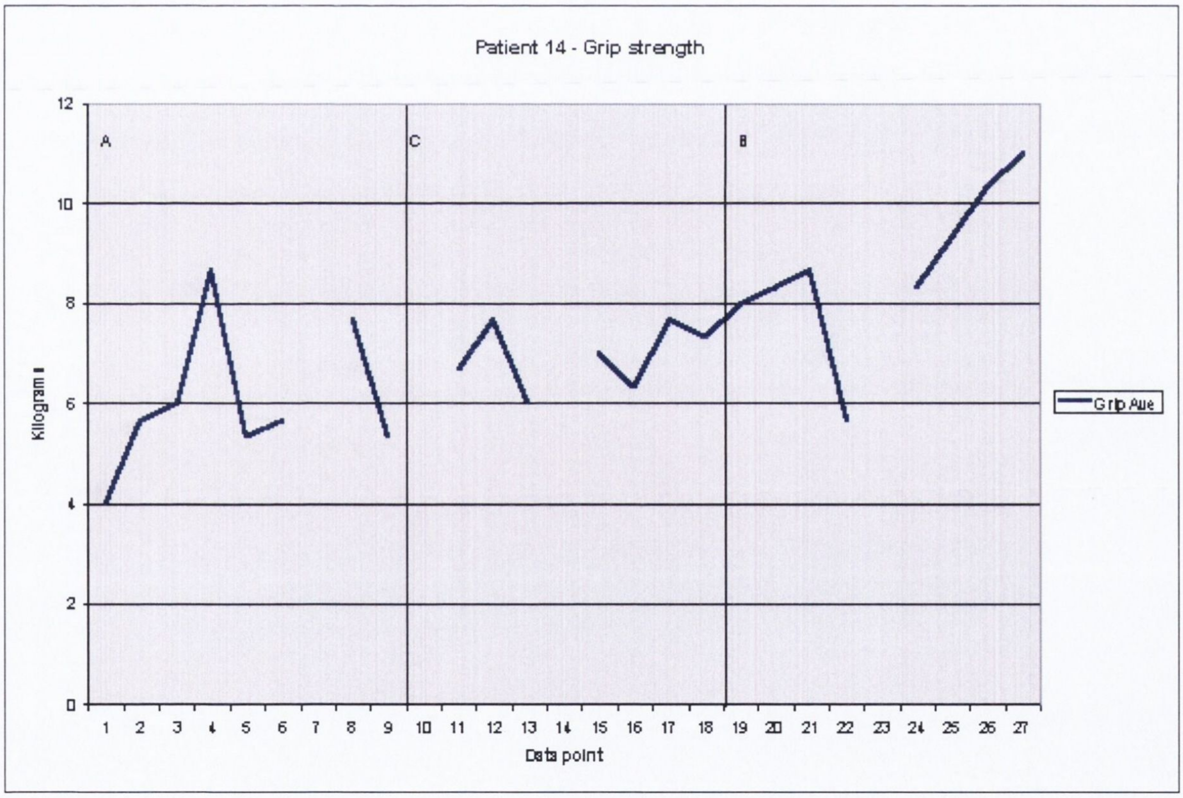

Figure 5-109. Subject 14, Grip

Quality of Life

The data fluctuate with no clear trend emerging. Both the mental and physical health scores return to their baseline at the end of the study.

SF-36 Domain	Start	End A	End C	End B
Physical Functioning	17	17	14.9	14.9
Roles - Physical	17.7	17.7	17.7	17.7
Bodily Pain	19.9	19.9	33	24.9
General Health	28.1	30.5	25.8	28.1
Vitality	36.5	30.2	42.7	30.2
Social Functioning	13.2	13.2	13.2	18.7
Roles - Emotional	13.1	9.2	17	20.9
Mental Health	38.7	33.1	38.7	33.1
Physical Health Score	19.1	21.5	21.2	19.4
Mental Health Score	30.3	24.4	32.7	30.9

Table 5-115. Subject 14, SF-36

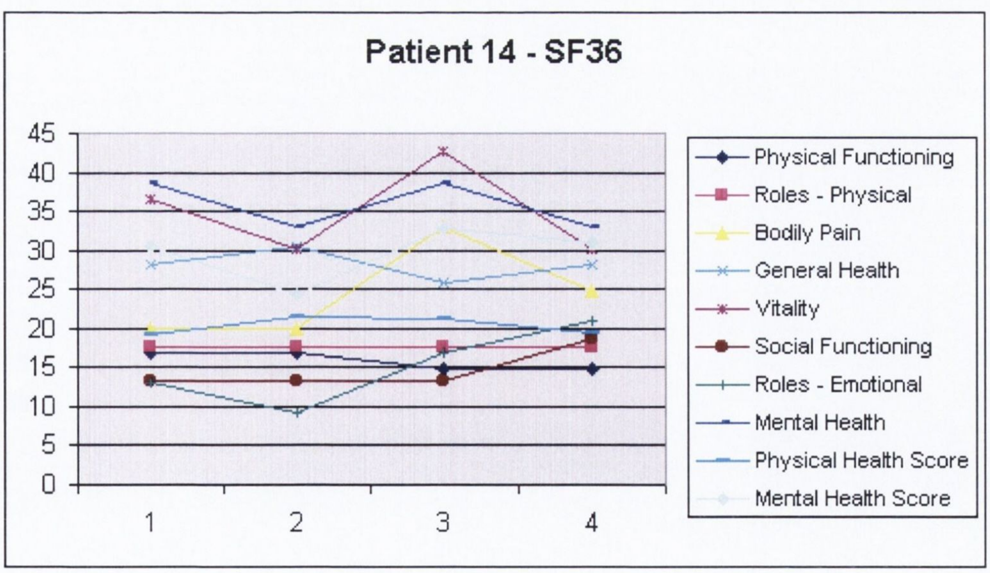

Figure 5-110. Subject 14, SF-36

5.2.15 Subject 15

Mrs. GS was an 85 year old lady who had a left hemiplegia 3 months prior to the start of the study. Her CT scan showed an infarct in the right parietal area, with an extensive right middle cerebral artery infarct. Her past medical history included myocardial infarction 4 years and coronary artery bypass at 3 years prior to the study. She was on aspirin.

She was attending the Day Hospital in AMNCH for physiotherapy twice a week during the study. She lived in a private nursing home and had good support from her family.

She was randomized to the ACB group and to a baseline of 10 data points. She exercised in passive mode for 1.4%, active assisted for 55% and active for 43.6% of the time.

Events during course of study

Visit 12 – complaining of shoulder pain following physiotherapy treatment on day before in Day Hospital

Visit 14 - discharged from physiotherapy

Visit 15 – reports shoulder pain still

Visit 23 – did not attend, feeling unwell

Background data

Her star cancellation test shows left inattention, with her score increasing by 3 points over the SS phase and 4 points over the RMT phase. She also has visual inattention and a marked deficit in bilateral simultaneous touch, which improves after the RMT phase.

Her pain score increased over the SS and decreased over the RMT phase to a level below baseline.

The tone in her elbow and wrist decreased over the baseline and RMT phase, but increased over the SS phase.

Subject 15, Summary	
Age	85
Time post stroke	3 months
Side affected	Left
CT result	Infarct right parietal area
Current physiotherapy treatment	45 minutes twice a week
Randomisation	ACB, 10
Exercise mode	P 1.4%, AA 55%, A 43.6%

Table 5-116. Subject 15, Summary

	Start A	Start C	Start B	End B
Short Orientation Memory Concentration	26	28	25	28
Star Cancellation L	17	16	19	23
Star Cancellation R	27	26	26	26
Star Cancellation Total	44	42	45	49
Pain	6	4	7	5
Hemianopia	1	1	1	1
Tone Wrist	2	0	2	1
Tone Elbow	2	1	3	1
Sensation Light Touch	4	6	3	5
Sensation Pressure	4	8	7	7
Sensation Bilateral Simultaneous	1	0	0	2
Sensation Kinaesthesia	9	7	5	7
Sensation Total	18	21	15	21

Table 5-117. Subject 15, Background data

Fugl-Meyer

The rate of recovery during the RMT phase was greater than both the baseline and SS phases for the FMA and FMC sections. This difference between the RMT and baseline phases was greater than the aMDC for the difference between the RMT and SS phases for the FMC subsection. None of the differences of the FM total score were greater than the aMDC value of 0.32 and therefore cannot be considered more than measurement error.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
FMA	23.37	0.08	0.19	0.40	0.11	0.20	0.32
FMB	1.61	0.36	0.35	-0.03	-0.01	-0.39	-0.40
FMC	3.88	0.14	0.13	0.35	-0.02	0.22	0.20
FMD	2.22	0.01	0.13	0.03	0.12	-0.10	0.02
FMT	31.22	0.60	0.81	0.74	0.21	-0.07	0.14

Table 5-118. Subject 15, Fugl-Meyer

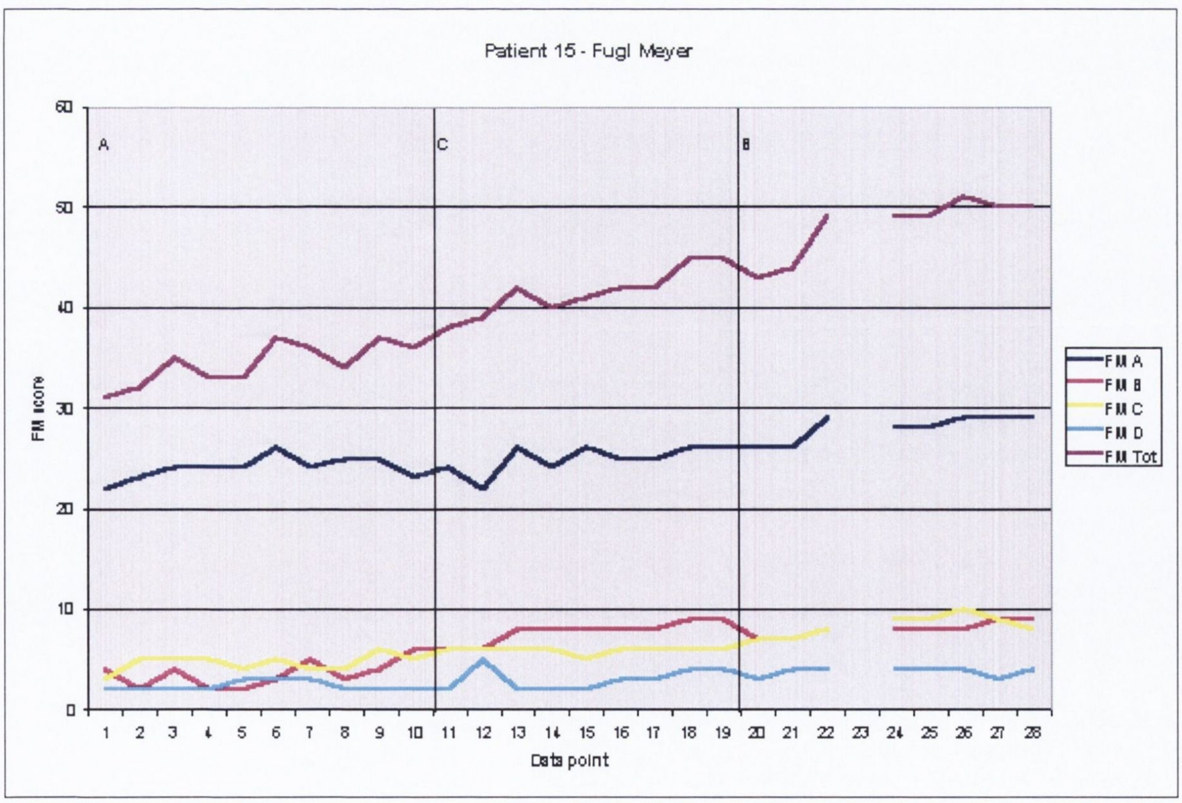

Figure 5-111. Subject 15, Fugl-Meyer

Motor Assessment Scale

The rate of recovery during the MASA and MAS total scores in the RMT phase are significantly higher than those in both the baseline and SS phases. All of the slopes in the SS phase are relatively flat. A slope of 0.39 in the MAST domain in the RMT phase reflects a 3.51 unit change in MAST score over the phase.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
MASA	3.27	-0.03	0.02	0.19	0.05	0.18	0.23
MASB	0.77	0.18	0.00	0.20	-0.18	0.20	0.02
MASC	0.08	0.07	0.03	-0.01	-0.04	-0.04	-0.08
MAST	4.12	0.22	0.05	0.39	-0.17	0.34	0.17

Table 5-119. Subject 15, MAS

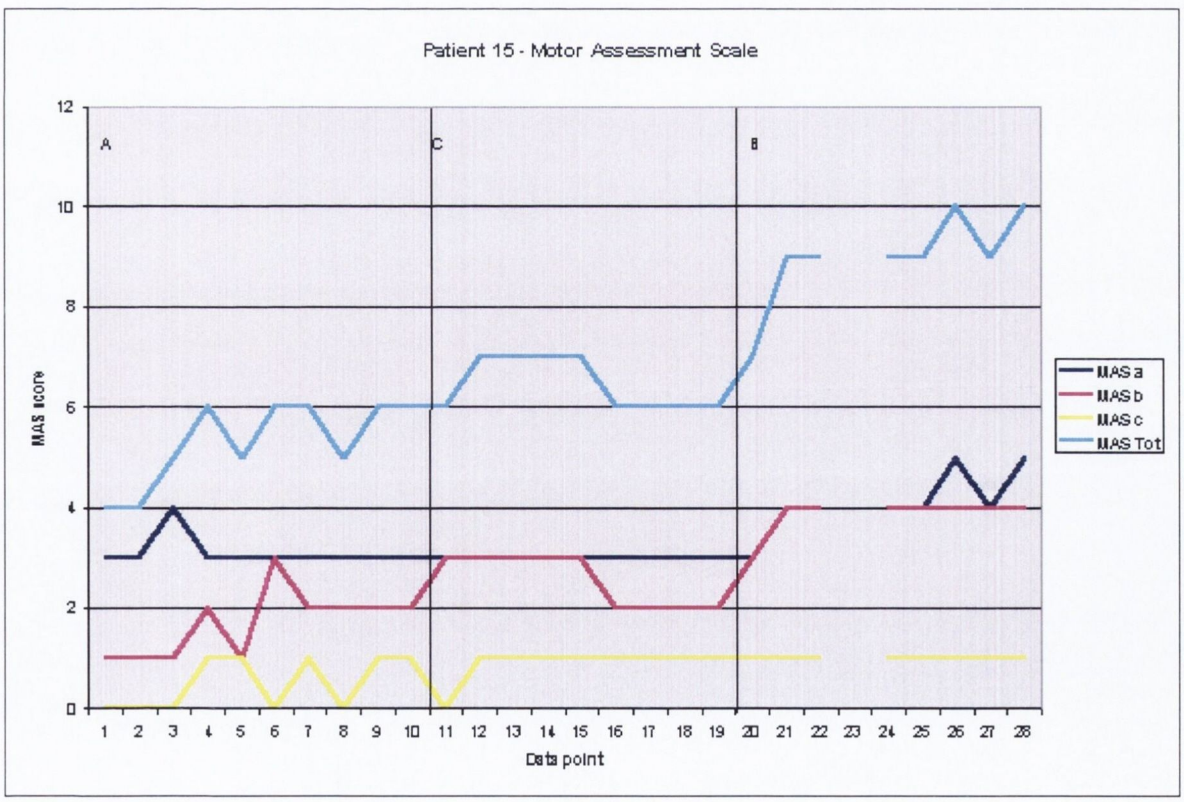

Figure 5-112. Subject 15, MAS

Maximal voluntary isometric contraction

None of the differences in slope value were greater than the aMDC. The plotted raw data shows the variable nature of these measures. Shoulder flexion is the only variable where the slope value is highest in the RMT phase. For the other 3 variables the slope value during RMT is less than that in the baseline phase.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
ElbFlex	3.23	0.35	0.21	0.27	-0.14	0.06	-0.08
ElbExt	7.83	0.01	0.19	-0.01	0.19	-0.20	-0.06
ShoFlex	4.53	0.01	0.12	0.17	0.10	0.05	0.15
ShoExt	9.27	-0.00	0.15	-0.08	0.15	-0.22	-0.07

Table 5-120. Subject 15, MVIC

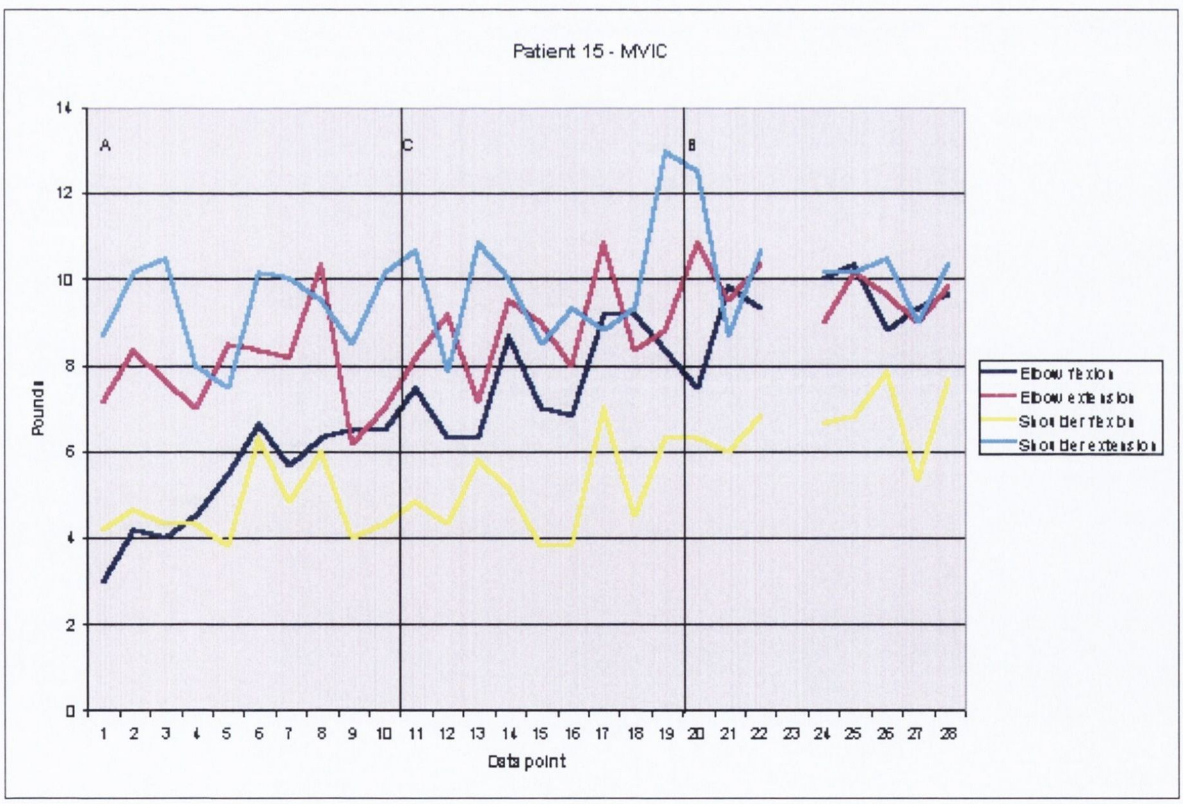

Figure 5-113. Subject 15, MVIC

Range of Motion

The difference between the baseline and RMT and slopes was significantly different for active range of shoulder flexion. The difference in the RMT and SS slope for active external rotation was also significantly different.

The variable nature of the raw data is illustrated in the plotted raw data.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
AShFl	92.61	-0.90	1.27	0.57	2.17	-0.70	1.47
PShFL	109.39	-1.08	0.22	0.79	1.30	0.58	1.88
AShA	64.64	-0.22	0.09	0.24	0.30	0.15	0.45
PShA	79.73	0.41	-0.61	0.11	-1.02	0.72	-0.30
AelX	-28.15	0.98	0.49	0.33	-0.49	-0.17	-0.65
PELX	0.52	0.03	-0.06	-0.06	-0.09	0.00	-0.10
AShER	24.83	1.01	-1.22	1.40	-2.23	2.61	0.38
PShER	49.80	0.87	-1.13	-0.69	-2.00	0.44	-1.57
AELFl	144.71	-0.08	0.01	0.35	0.09	0.34	0.42
PELFl	158.34	-0.06	-0.18	0.20	-0.12	0.38	0.26

Table 5-121. Subject 15, ROM

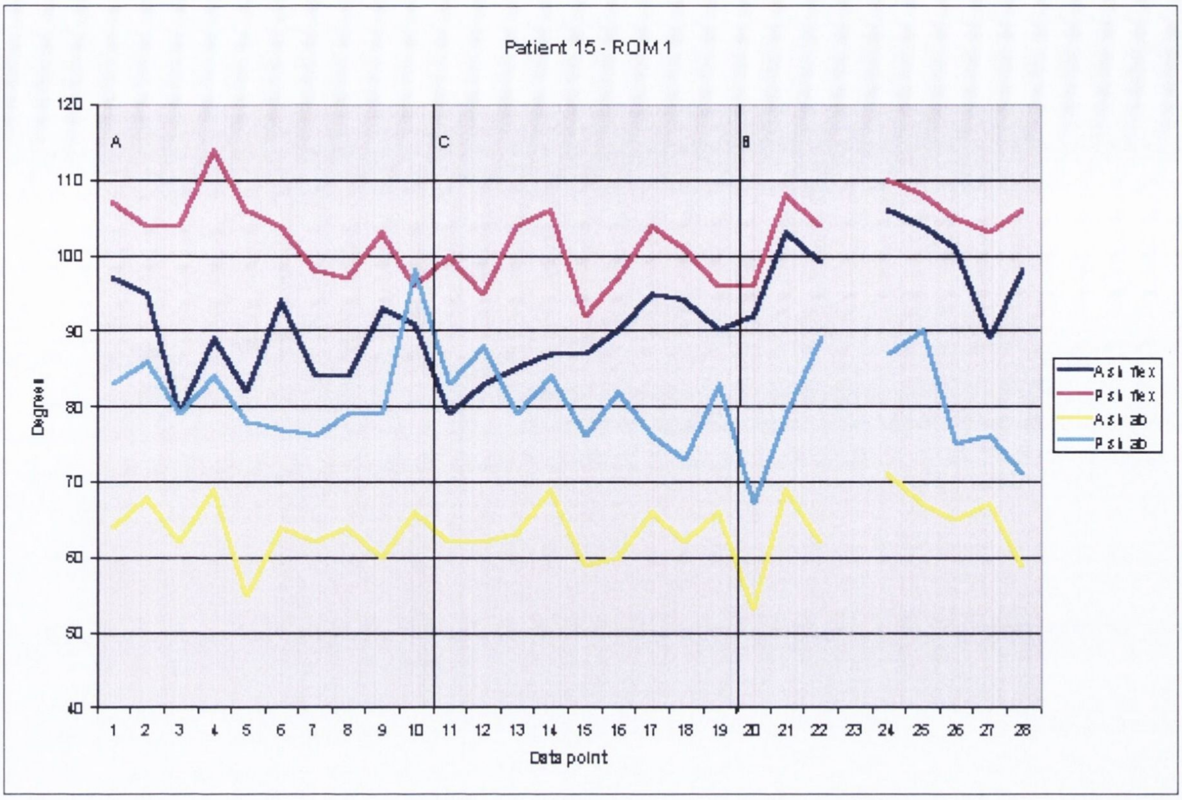

Figure 5-114. Subject 15, ROM 1

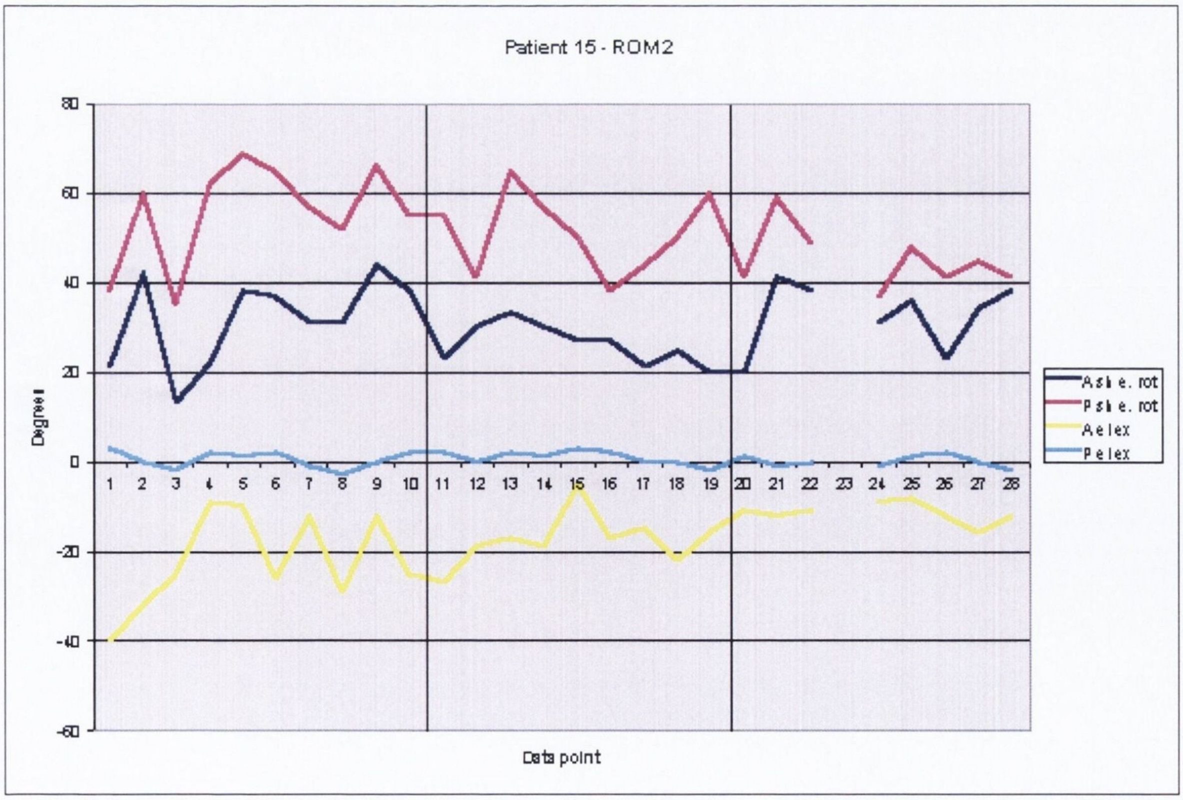

Figure 5-115. Subject 15, ROM 2

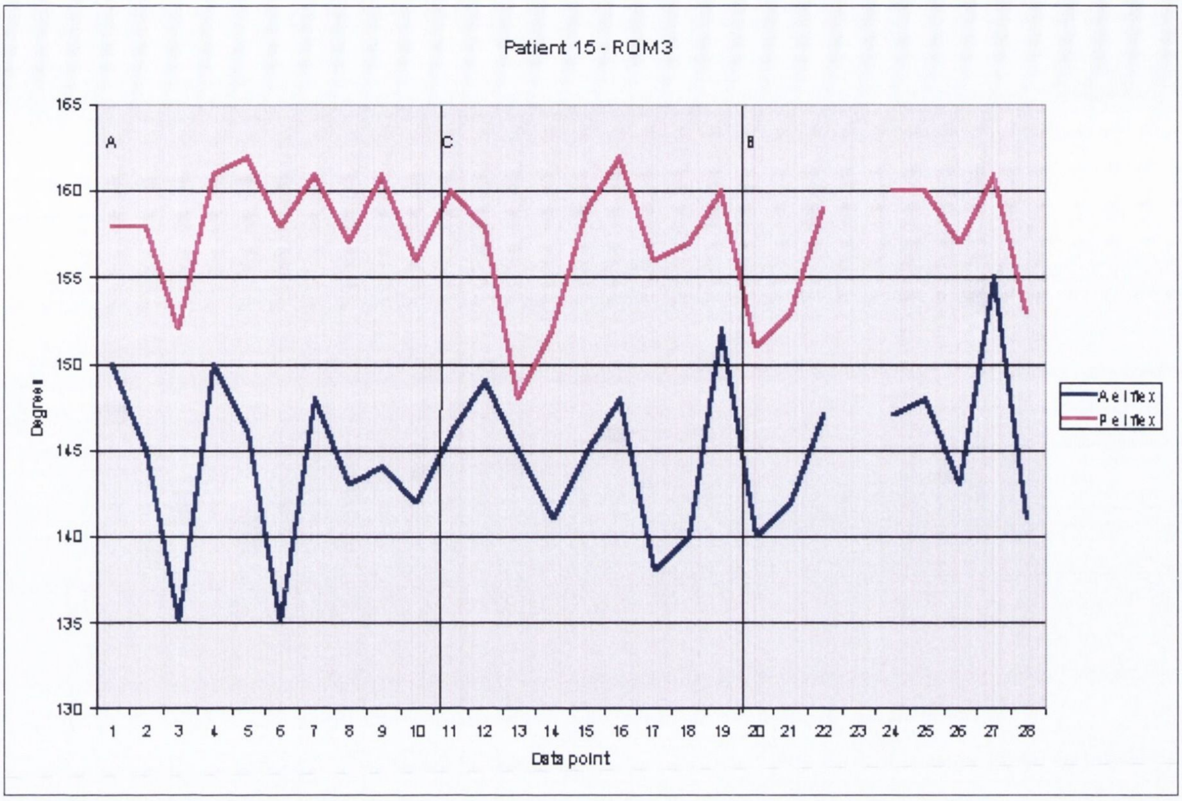

Figure 5-116. Subject 15, ROM 3

Grip Strength

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
Grip	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5-122. Subject 15, Grip

All values remained at 0 for the duration of the study therefore no graph is presented.

Quality of Life

There is no clear trend apparent in the plotted data, with fluctuation in all domains. The physical and mental health sub scores are both below the baseline level at the end of the study.

SF-36 Domain	Start	End A	End C	End B
Physical Functioning	17	21.3	14.9	21.3
Roles - Physical	32.4	17.7	27.5	27.5
Bodily Pain	45.6	45.6	33	41.4
General Health	52	28.1	30.5	30.5
Vitality	39.6	36.5	30.2	39.6
Social Functioning	18.7	13.2	13.2	18.7
Roles - Emotional	36.4	55.9	40.3	20.9
Mental Health	44.4	47.2	44.4	41.6
Physical Health Score	32.7	19	19.8	29.7
Mental Health Score	40.7	49.5	41.3	32.9

Table 5-123. Subject 15, SF-36

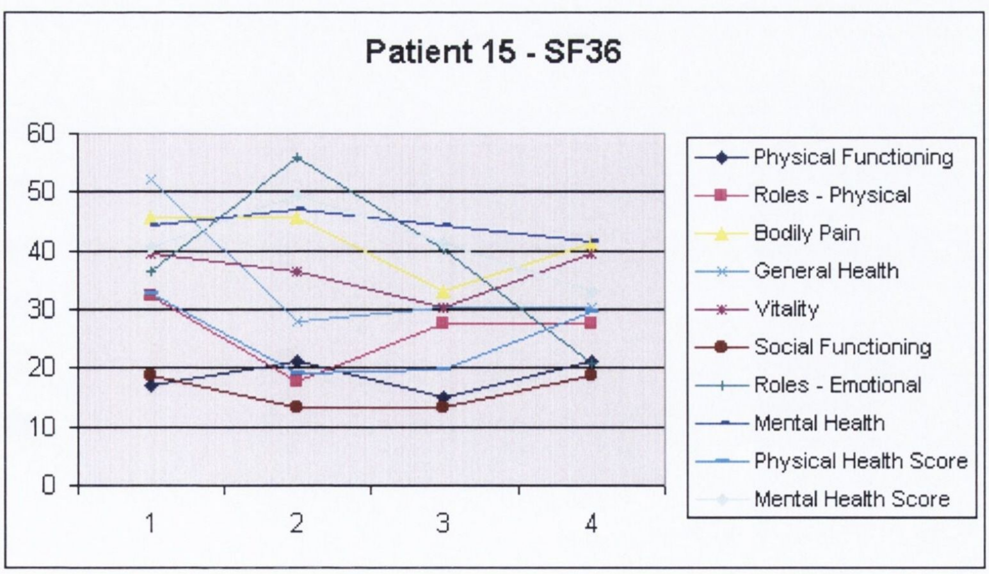

Figure 5-117. Subject 15, SF-36

5.2.16 Subject 16

Mr. JM was a 64 year old man who had a right hemiplegia 4 months prior to the start of the study. His CT scan showed infarction in the left middle cerebral artery territory. His past medical history included OA, an x-ray of his right shoulder showed moderate OA. His medications included aspirin and anti-hypertensives.

He lived alone, with excellent social support from neighbours and family and was attending Naas hospital for physiotherapy once a week.

He was randomized to the ABC group with a baseline of 9 data points. He exercised in passive mode for 52% of the time, active assisted for 35% and active for 13%.

Events during course of study

There were no notable events and all appointments were attended.

Background data

His star cancellation test was normal and he had no hemianopia and normal bilateral simultaneous touch scores.

His pain score increased over the baseline and then decreased across the treatment phases.

Both tone scores decreased over the RMT phase, with the elbow increasing again over the SS phase.

Subject 16, Summary	
Age	64
Time post stroke	4 months
Side affected	Right
CT result	Infarct left middle cerebral artery
Current physiotherapy treatment	45 minutes once a week
Randomisation	ABC, 9
Exercise mode	P 52%, AA 35%, A 13%

Table 5-124. Summary, Subject 16

	Start A	Start B	Start C	End C
Short Orientation Memory Concentration	28	28	28	28
Star Cancellation L	27	27	26	27
Star Cancellation R	27	27	27	27
Star Cancellation Total	54	54	54	54
Pain	0	1.9	0.8	0
Hemianopia	0	0	0	0
Tone Wrist	2	2	1	1
Tone Elbow	3	3	2	3
Sensation Light Touch	8	8	8	8
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	8	8	8	8
Sensation Kinaesthesia	10	10	10	11
Sensation Total	34	34	34	35

Table 5-125. Subject 16, Background data

Fugl-Meyer

The only significantly different slopes are in favour of the baseline and SS phases for the FMC and FMD sections. For the FMA and FMB sections the rate of recovery is highest in the RMT phase though this is not greater than the aMDC value. The total score increases in all phases, but this is greatest in the baseline phase.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
FMA	10.99	0.26	0.40	0.17	0.14	-0.23
FMB	0.97	0.12	0.21	0.20	0.09	-0.01
FMC	4.49	0.13	-0.04	0.11	-0.17	0.15
FMD	-0.21	0.15	-0.01	0.01	-0.15	0.01
FMT	16.25	0.67	0.56	0.49	-0.10	-0.07

Table 5-126. Subject 16, Fugl-Meyer

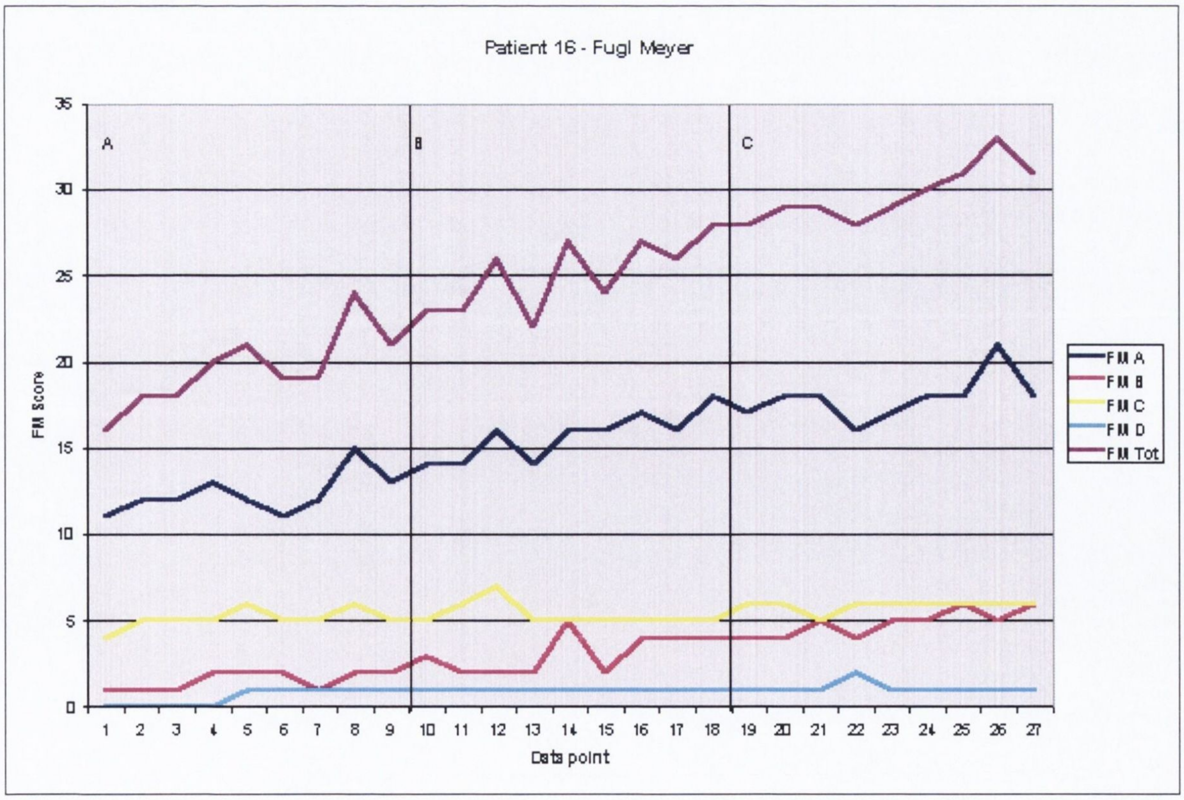

Figure 5-118. Subject 16, Fugl-Meyer

Motor Assessment Scale

The slope in the SS phase was significantly greater than that in the RMT phase for the MASB and MAS total scores and equal for the MASA section. A slope of 0.13 reflects a 1.17 unit change over the phase which clinically is not a large amount.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
MASA	0.99	-0.01	0.02	0.01	0.03	0.01
MASB	1.00	0.00	0.00	0.13	0.00	0.13
MASC	0.00	0.00	0.00	0.00	0.00	0.00
MAST	1.99	-0.01	0.02	0.16	0.03	0.14

Table 5-127. Subject 16, MAS

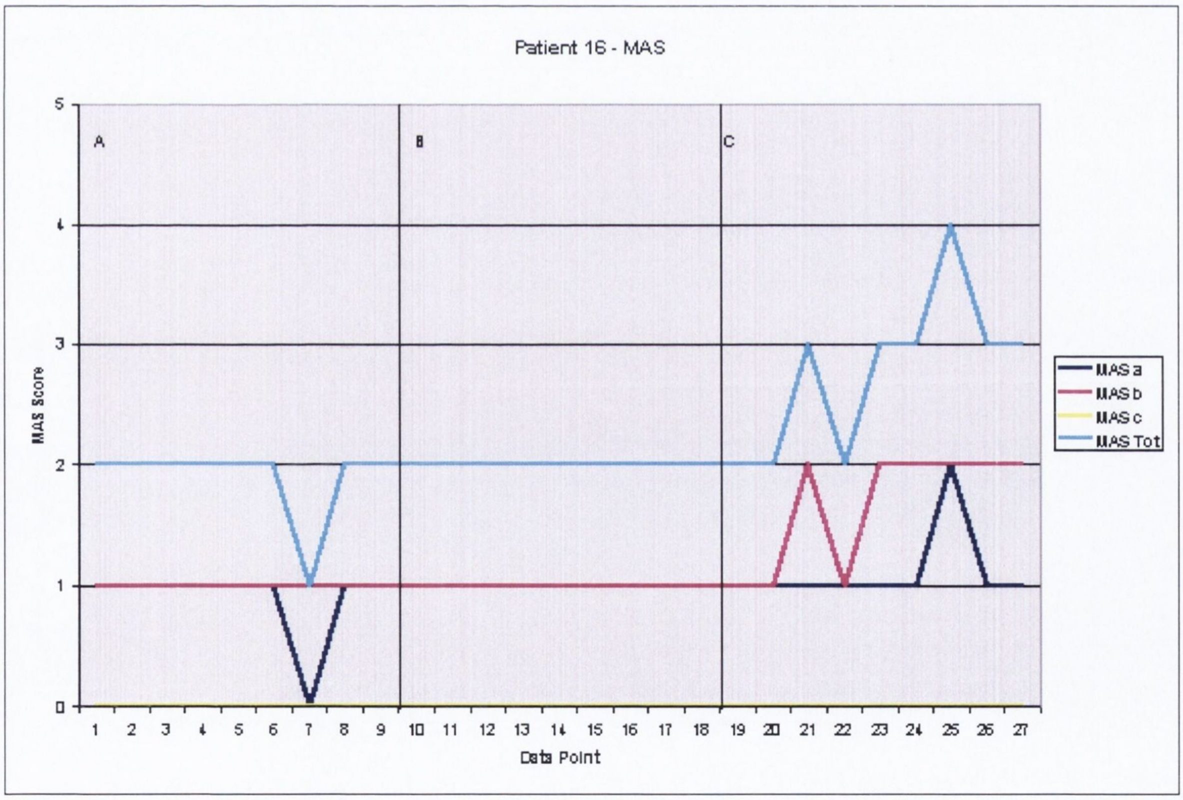

Figure 5-119. Subject 16, MAS

Maximal voluntary isometric contraction

The rate of recovery for elbow and shoulder flexion MVIC is highest in the RMT phase. The rate of recovery during the SS phase is significantly greater than the RMT phase for elbow extension.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
ElbFlex	6.05	0.08	0.44	0.40	0.36	-0.04
ElbExt	3.51	0.09	0.16	0.99	0.07	0.83
ShoFlex	-0.48	0.16	0.35	-0.01	0.20	-0.36
ShoExt	3.45	0.44	0.51	0.57	0.07	0.06

Table 5-128. Subject 16, MVIC

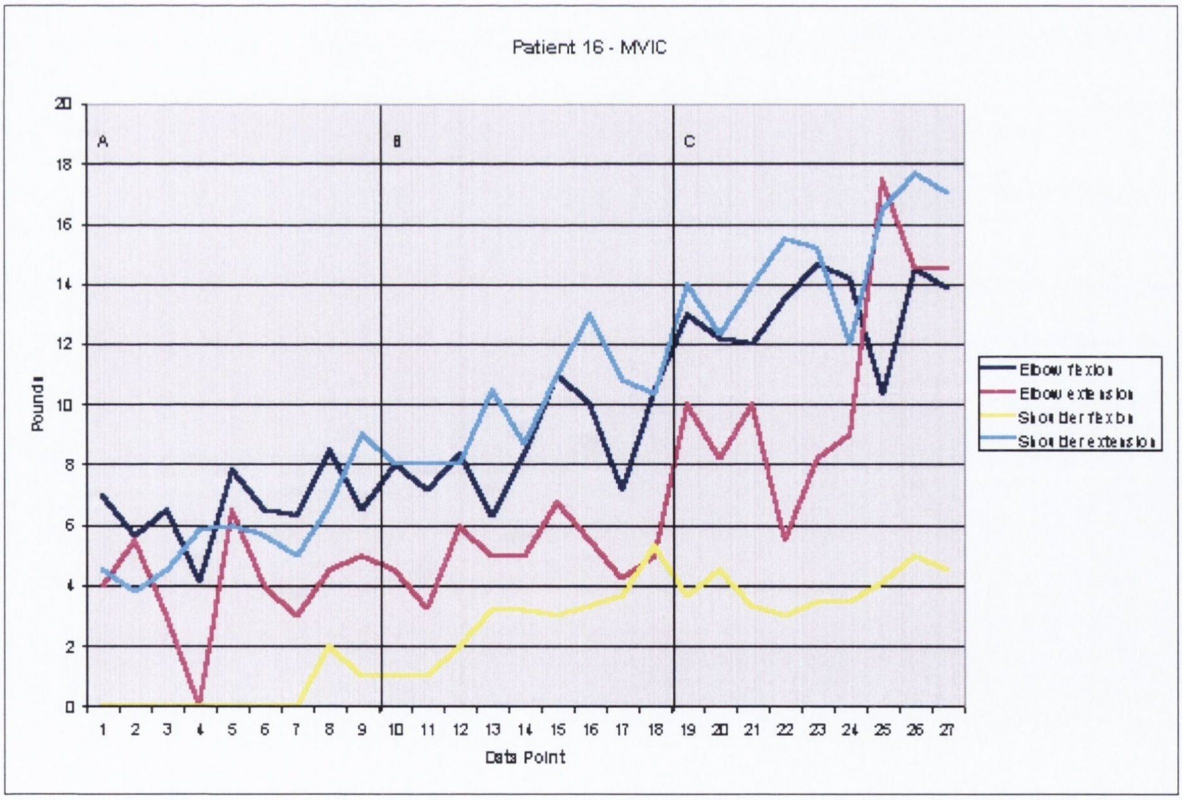

Figure 5-120. Subject 16, MVIC

Range of Motion

The rate of recovery during the RMT phase was significantly greater than that during the baseline and SS phases for shoulder flexion. For active abduction it was significantly greater than baseline only.

Passive shoulder flexion and external rotation had significantly higher rates of recovery during the SS phase.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
AShFl	1.64	0.88	4.42	-0.29	3.54	-4.71
PShFL	112.59	-0.61	-0.09	1.47	0.52	1.56
AShA	40.38	-0.37	1.49	0.71	1.86	-0.77
PShA	58.99	0.77	0.11	0.57	-0.66	0.46
AElX	-79.12	1.49	2.25	1.15	0.77	-1.11
PELX	-12.87	0.08	0.14	0.03	0.07	-0.11
AShER	0.00	0.00	0.00	0.00	0.00	0.00
PShER	25.57	1.14	-0.45	0.98	-1.59	1.43
AELFl	99.95	1.46	2.58	-0.74	1.12	-3.32
PELFl	152.45	-0.04	-0.45	0.21	-0.41	0.66

Table 5-129. Subject 16, ROM

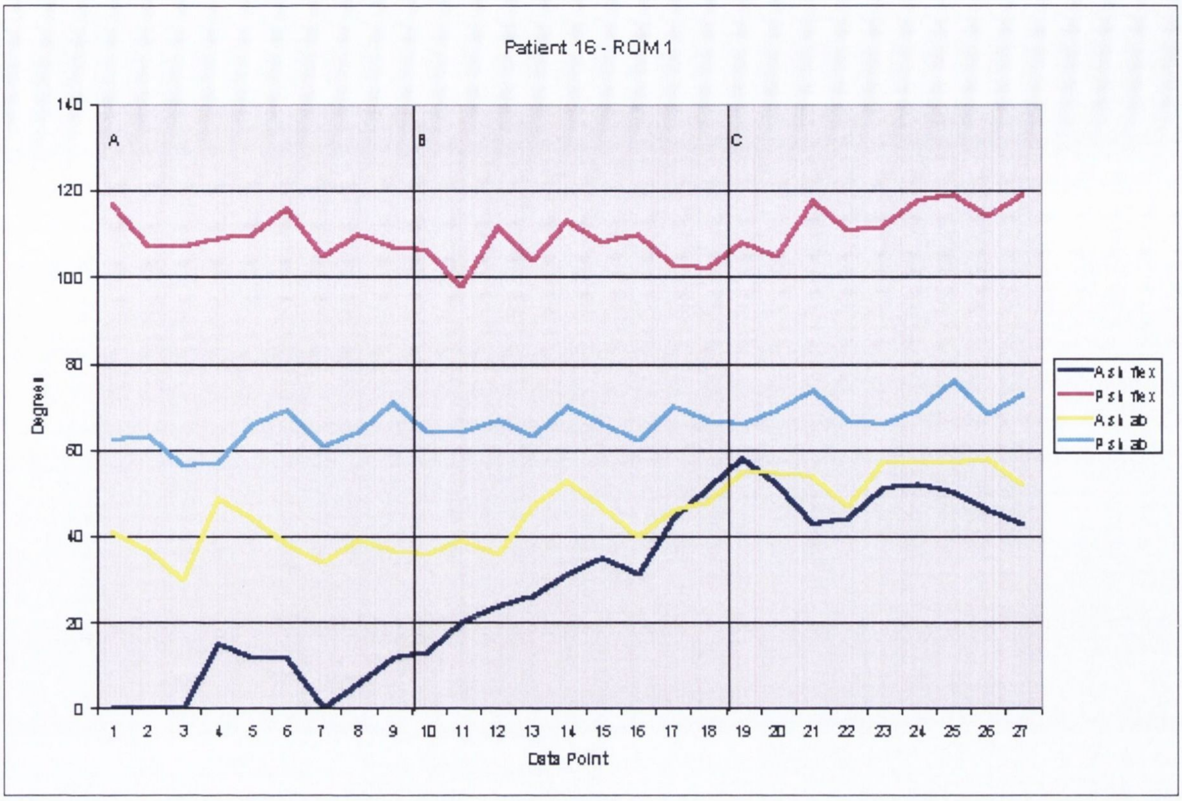

Figure 5-121. Subject 16, ROM 1

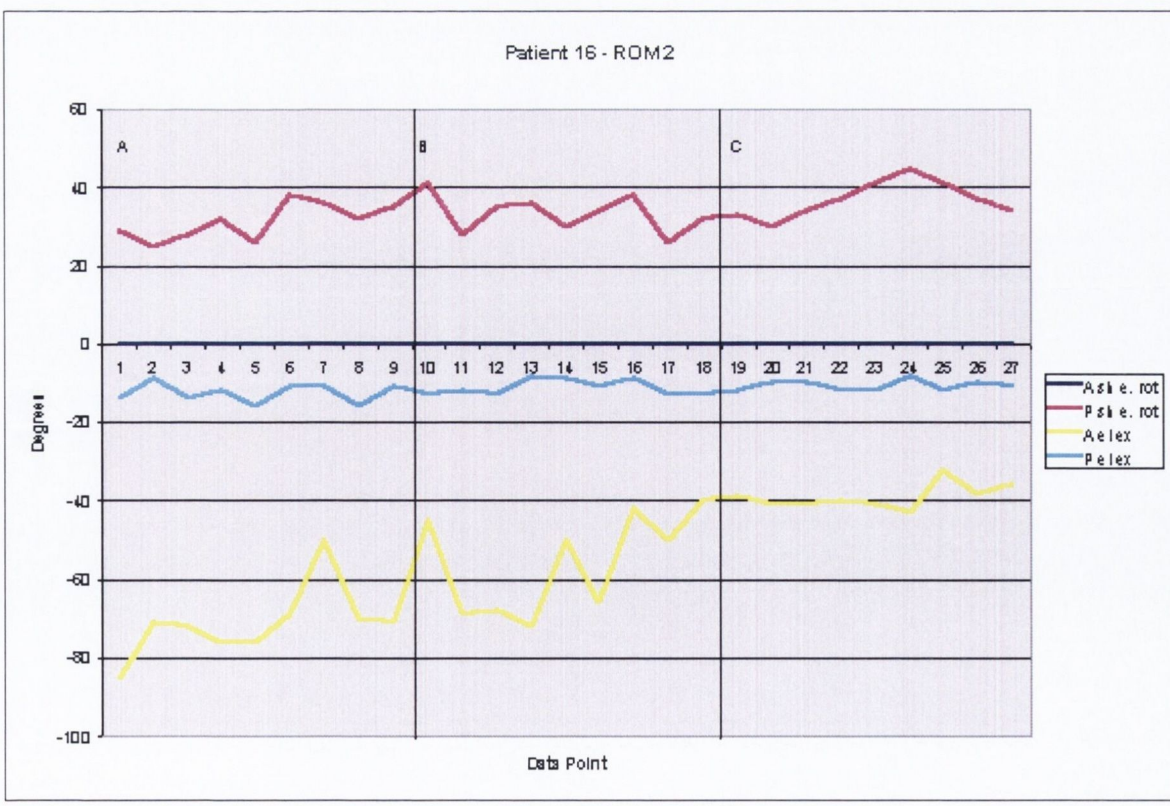

Figure 5-122. Subject 16, ROM 2

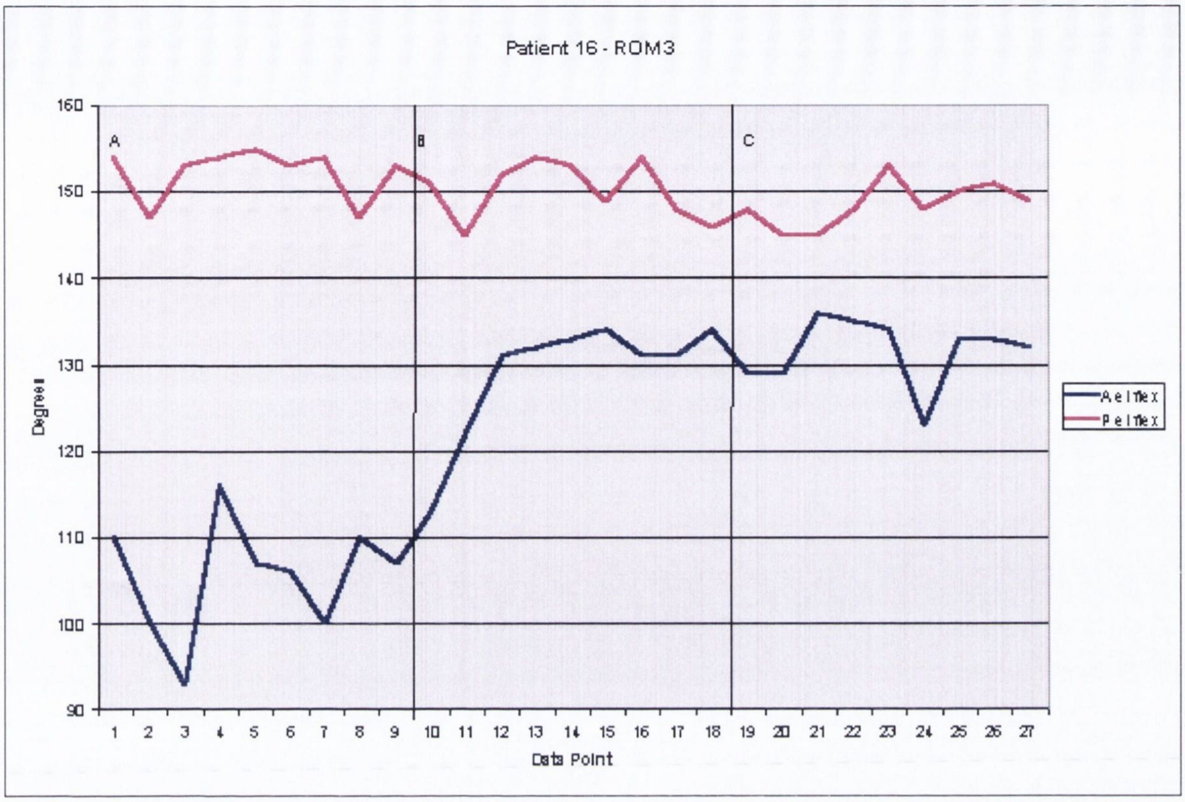

Figure 5-123. Subject 16, ROM 3

Grip Strength

The plotted data shows an increase in this score across all three phases. The differences between the slopes are not statistically different.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
Grip	0.47	0.39	0.16	0.23	-0.22	0.07

Table 5-130. Subject 16, Grip

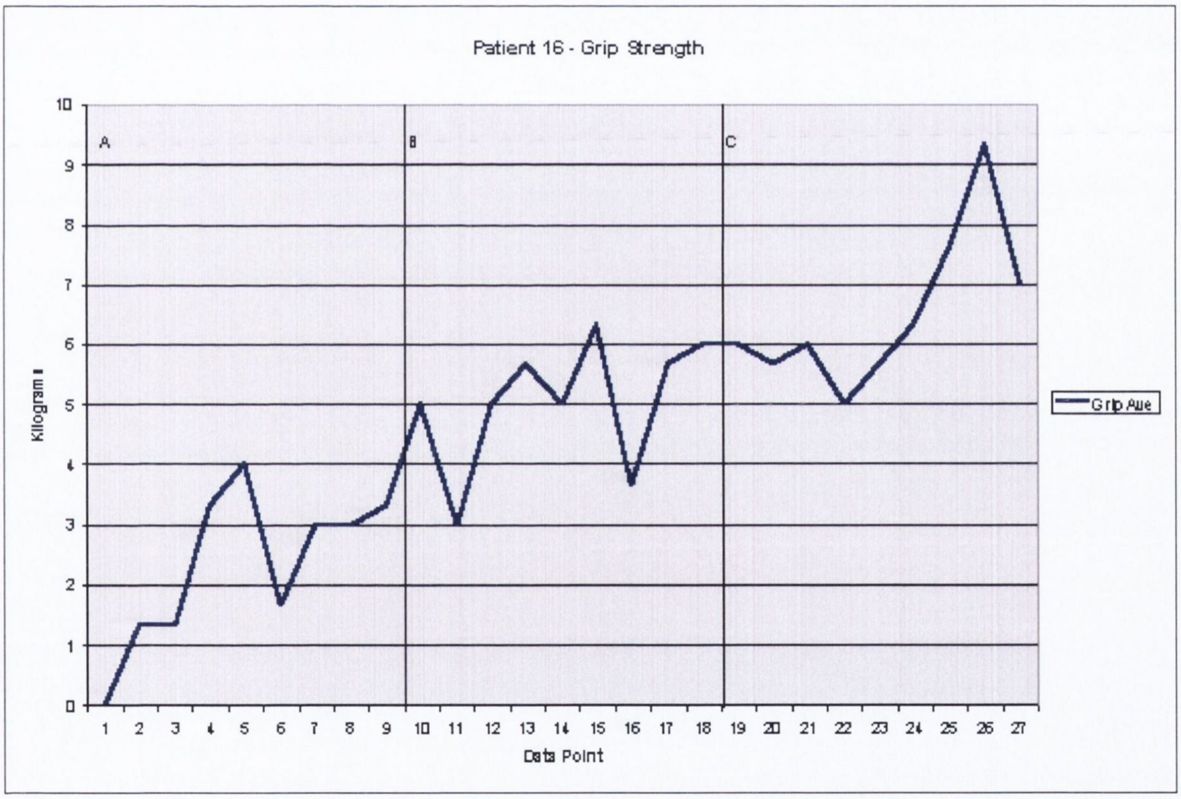

Figure 5-124. Subject 16, Grip

Quality of Life

The physical health score shows a small but steady increase. While the mental health score fluctuates.

SF-36 Domain	Start	End A	End B	End C
Physical Functioning	25.5	25.5	27.6	29.7
Roles - Physical	32.4	27.5	42.2	34.8
Bodily Pain	38.5	41	42.7	53.7
General Health	62.5	60.1	63.9	63.9
Vitality	67.7	61.5	70.8	70.8
Social Functioning	45.9	45.9	56.8	56.8
Roles - Emotional	48.1	20.9	32.6	28.7
Mental Health	52.8	58.5	64.1	52.8
Physical Health Score	33.1	35.4	39.7	44.7
Mental Health Score	62.4	52	62.6	54.8

Table 5-131. Subject 16, SF-36

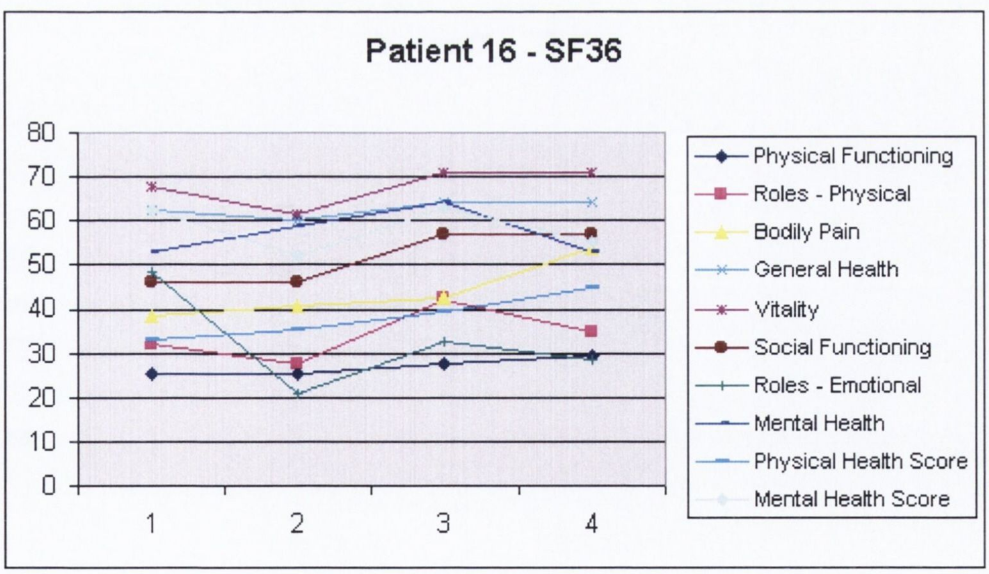

Figure 5-125. Subject 16, SF-36

5.2.17 Subject 17

Mr. DN was a 59 year old man who had a left hemiplegia 12 months prior to the start of the study. His CT scan showed an area of infarction in the right middle cerebral artery territory.

He lived alone and was active in the local golf club. He attended the Day Hospital in SJH once a week for physiotherapy. He had no past medical history of note and was on aspirin and glucophage.

He was randomized to the ABC group and to a baseline length of 10 data points. He exercised in passive mode for 6%, active assisted for 70.3 % active for 23.7% of the time.

Events during course of study

There were no notable events during the study and he attended for all appointments.

Background data

His star cancellation test, hemianopia test and bilateral simultaneous touch were all normal indicating no inattention. His pain scores decreased steadily over the course of the study with the largest decrease in the SS phase (0.8cms).

Subject 17, Summary	
Age	59
Time post stroke	12 months
Side affected	Left
CT result	Infarct right middle cerebral artery
Current physiotherapy treatment	45 minutes once a week
Randomisation	ABC, 10
Exercise mode	P 6%, AA 70.3%, A 23.7%

Table 5-132. Subject 17, Summary

	Start A	Start B	Start C	End C
Short Orientation Memory Concentration	28	28	28	28
Star Cancellation L	27	27	26	27
Star Cancellation R	27	27	27	27
Star Cancellation Total	54	54	53	54
Pain	2.2	2	1.5	0.3
Hemianopia	0	0	0	0
Tone Wrist	3	2	1	2
Tone Elbow	3	3	2	3
Sensation Light Touch	8	8	8	8
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	8	8	8	8
Sensation Kinaesthesia	10	12	9	11
Sensation Total	34	36	33	35

Table 5-133. Subject 17, Background data

Fugl-Meyer

The slope during the baseline phase was greater than that during the RMT phase for all sections. None of the differences in slopes are higher than the MDC value. The increase in scores over the first 4 visits is responsible for the high slope values in the baseline phase.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
FMA	15.98	0.30	0.14	0.09	-0.16	-0.05
FMB	0.15	0.13	0.07	0.01	-0.06	-0.06
FMC	5.35	0.05	0.02	0.03	-0.03	0.01
FMD	-0.29	0.17	0.08	0.12	-0.09	0.04
FMT	21.19	0.65	0.26	0.22	-0.40	-0.03

Table 5-134. Subject 17, Fugl-Meyer

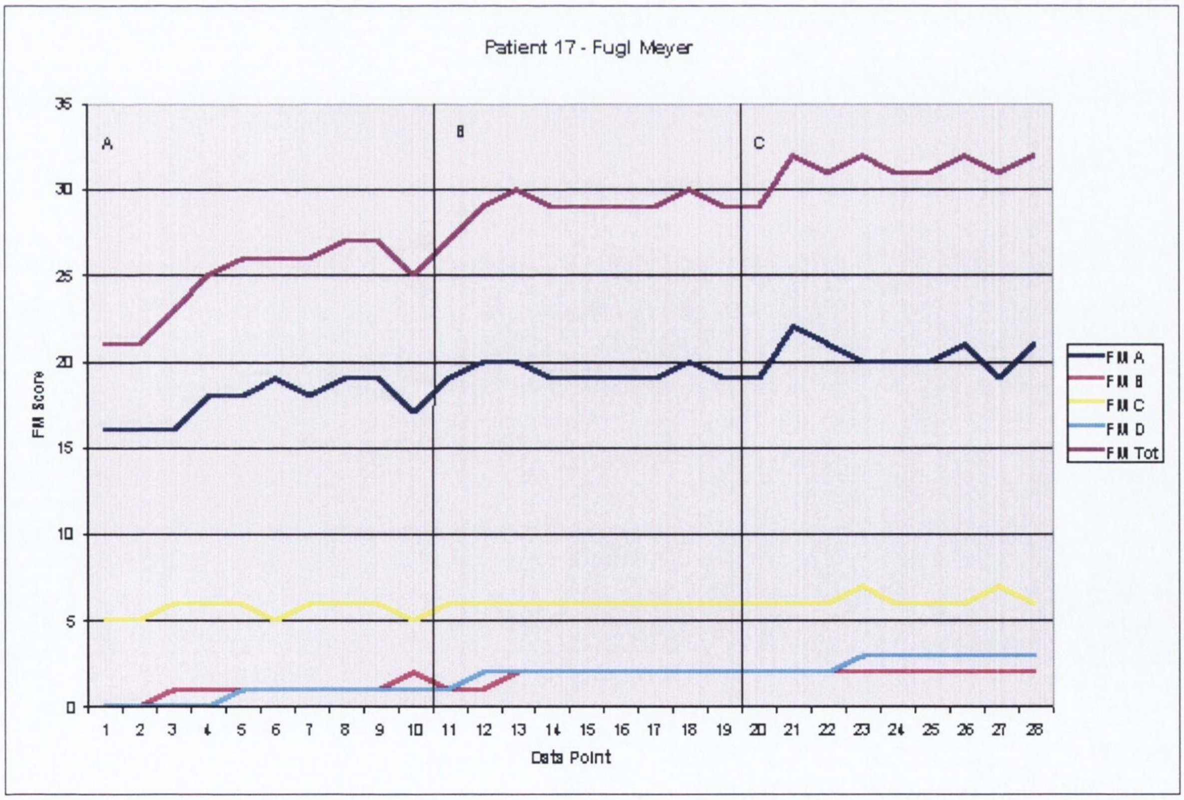

Figure 5-126. Subject 17, Fugl-Meyer

Motor Assessment Scale

The plotted data shows a sharp upward trend in the raw data during the baseline phase. This is reflected in the slope values which show a significantly higher rate of recovery in the baseline phase than in either of the treatment phases.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
MASA	0.68	0.19	0.04	0.09	-0.15	0.05
MASB	0.12	0.10	-0.02	0.01	-0.12	0.02
MASC	0.00	0.00	0.00	0.00	0.00	0.00
MAST	0.80	0.29	0.02	0.10	-0.27	0.07

Table 5-135. Subject 17, MAS

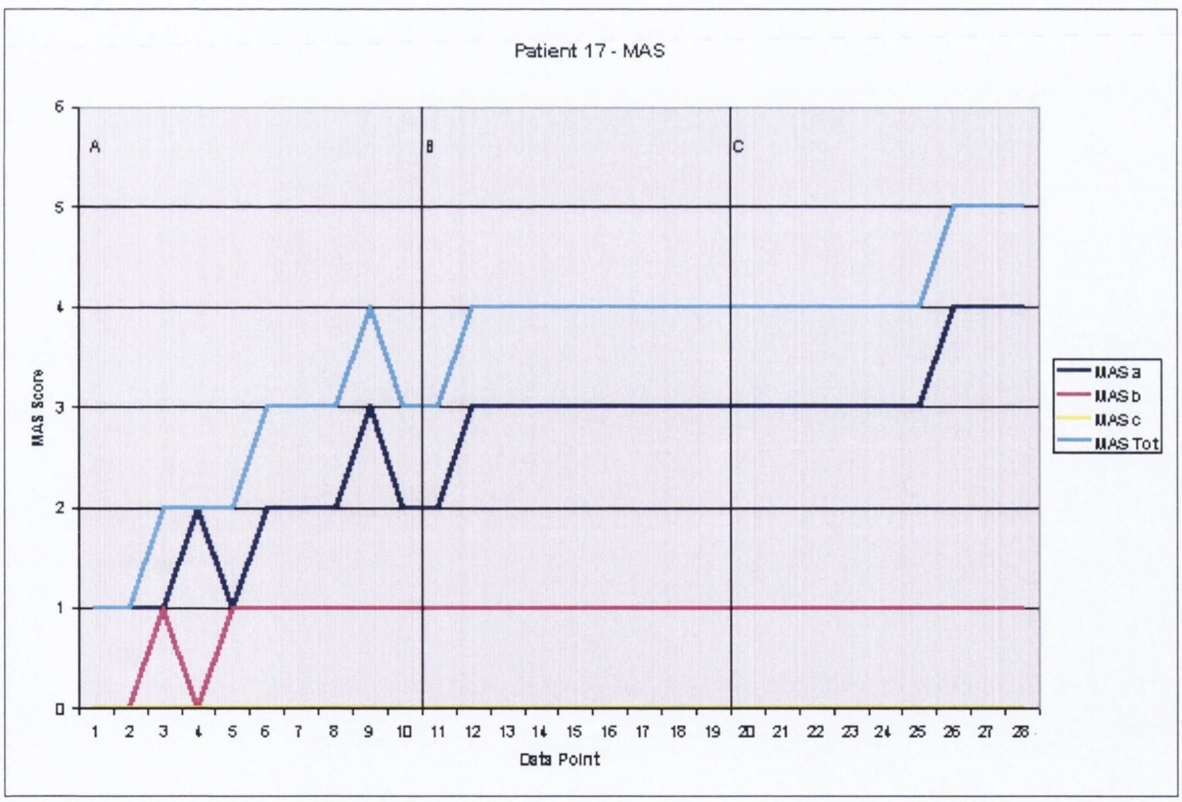

Figure 5-127. Subject 17, MAS

Maximal voluntary isometric contraction

The rate of recovery in the RMT phase was significantly greater than both baseline and SS for the two elbow variables. For both the shoulder variables the rate during the baseline was higher than both other phases, though this was not significant.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
ElbFlex	11.48	0.14	0.85	0.11	0.72	-0.74
ElbExt	17.60	0.22	0.77	-0.14	0.55	-0.92
ShoFlex	0.28	0.40	0.13	0.26	-0.26	0.12
ShoExt	18.18	1.18	0.71	0.23	-0.47	-0.48

Table 5-136. Subject 17, MVIC

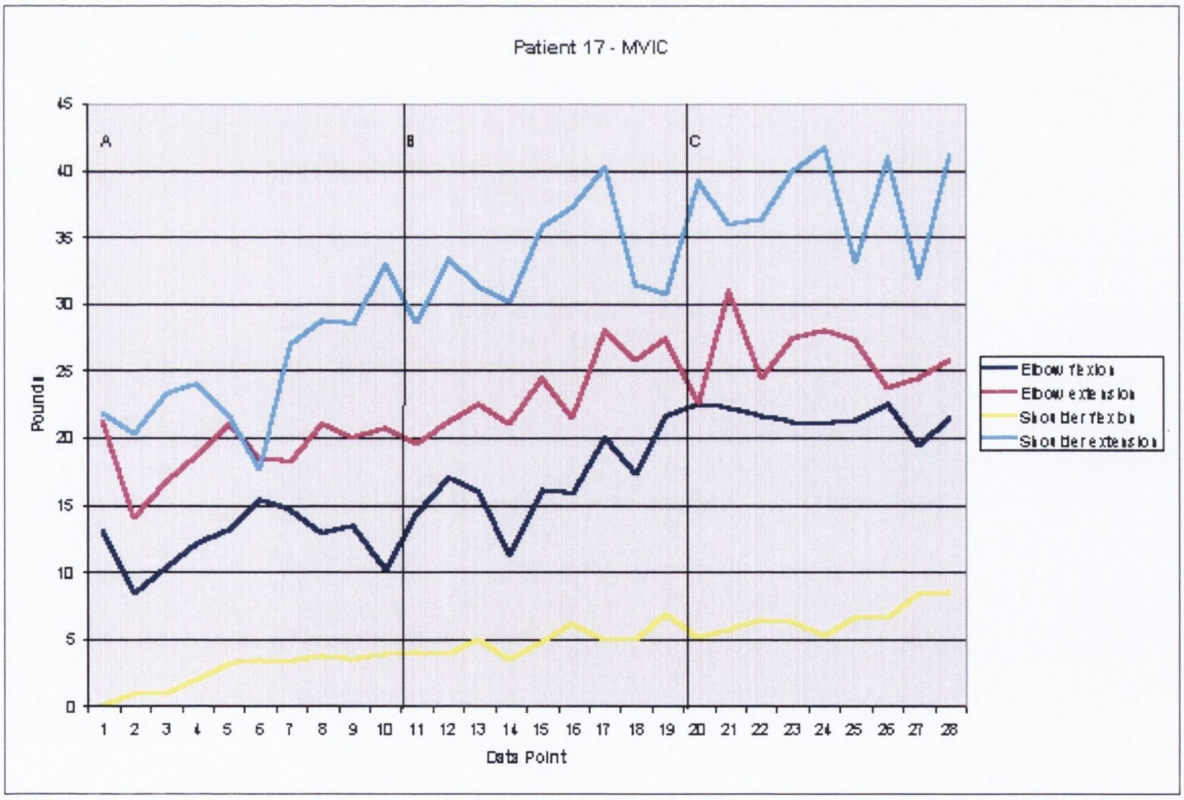

Figure 5-128. Subject 17, MVIC

Range of Motion

Very few of the differences in phases were greater than the aMDC value, this is reflected in the highly variable nature of the plotted raw data. For active and passive elbow extension and passive elbow flexion the rate during RMT was greater than SS and baseline but this was not significant.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
AShFl	41.45	1.51	0.36	1.97	-1.16	1.61
PShFL	96.65	-0.05	0.45	0.55	0.50	0.10
AShA	49.75	0.72	0.39	0.32	-0.33	-0.07
PShA	64.78	0.54	0.00	0.31	-0.54	0.31
AElX	-56.93	0.51	1.38	0.57	0.88	-0.82
PELX	-12.59	0.26	0.65	-0.22	0.39	-0.87
AShER	0.07	-0.02	0.06	0.11	0.08	0.05
PShER	25.30	0.88	0.30	0.55	-0.58	0.25
AELFl	110.21	1.88	0.06	0.07	-1.81	0.01
PELFl	145.41	-0.09	0.03	-0.34	0.12	-0.37

Table 5-137. Subject 17, ROM

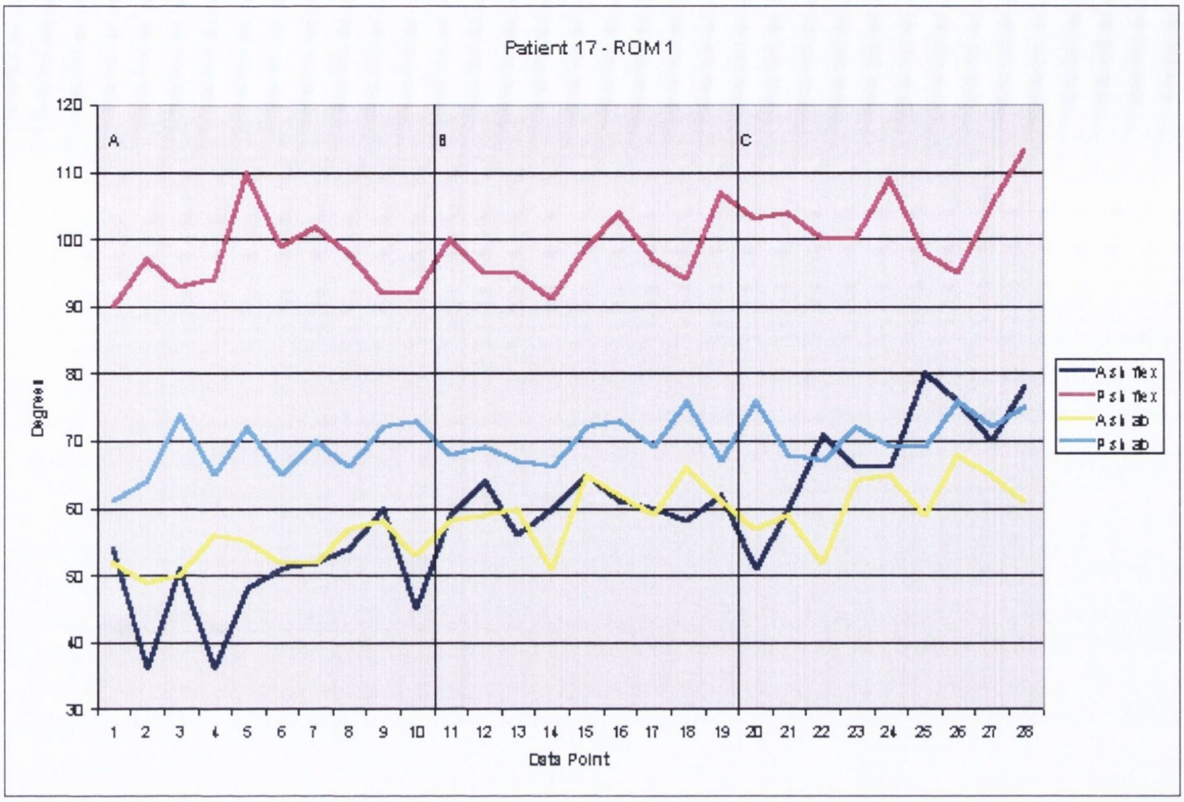

Figure 5-129. Subject 17, ROM 1

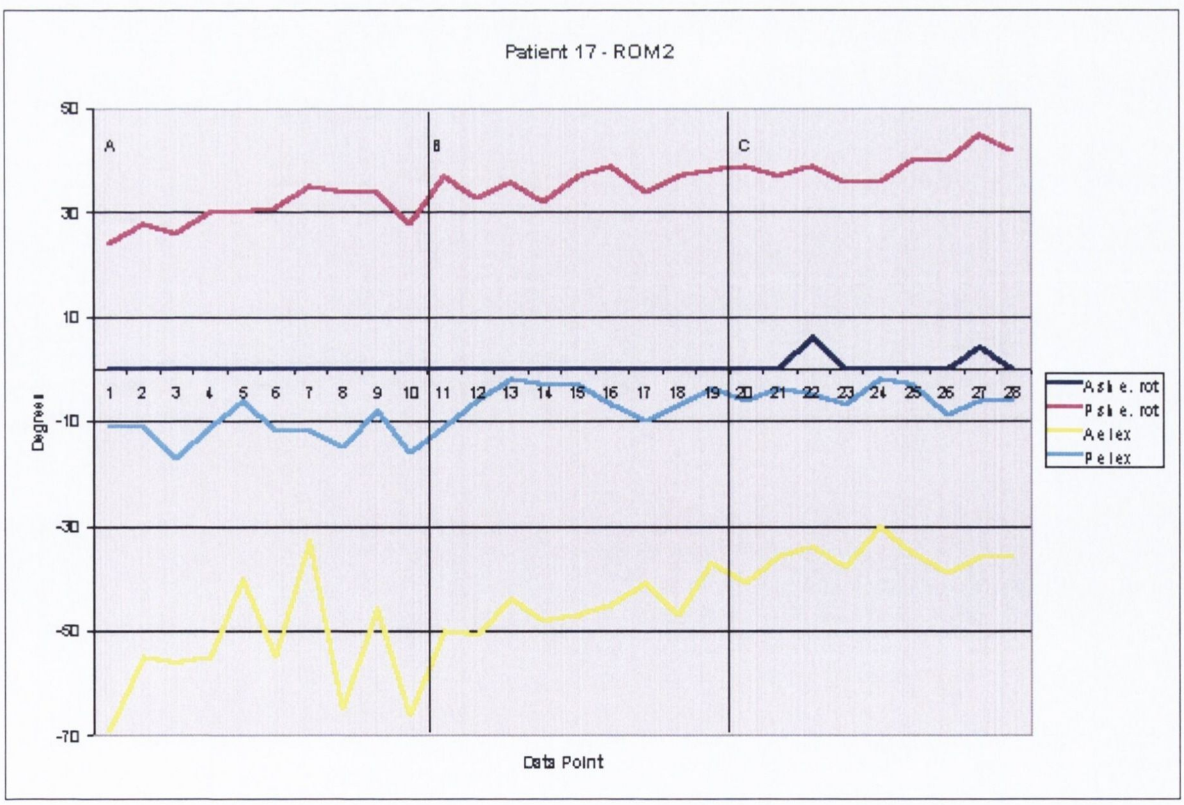

Figure 5-130. Subject 17, ROM 2

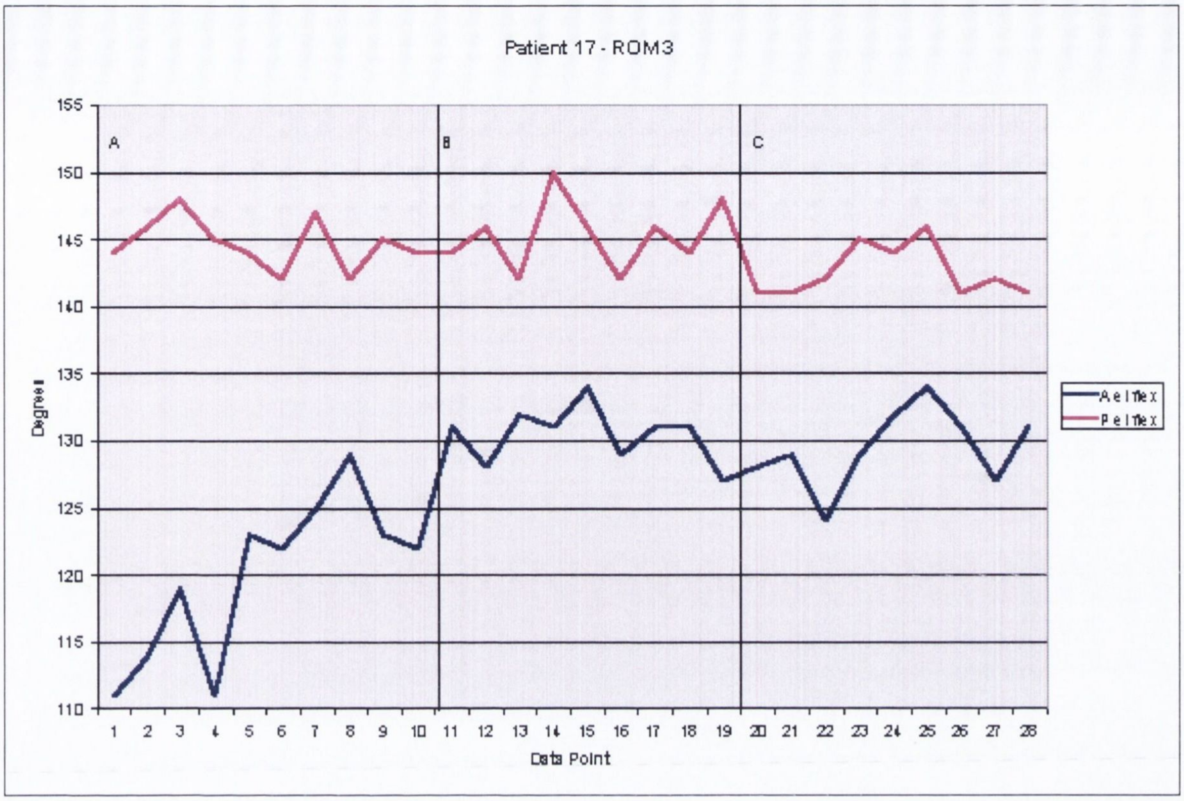

Figure 5-131. Subject 17, ROM 3

Grip Strength

The rate of recovery of grip strength was significantly higher in the RMT phase than the SS phase. However the plotted data suggests that the value of grip strength fluctuated around a score of 10 kgs over the course of the study.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
Grip	10.71	-0.10	0.16	-0.15	0.25	-0.30

Table 5-138. Subject 17, Grip

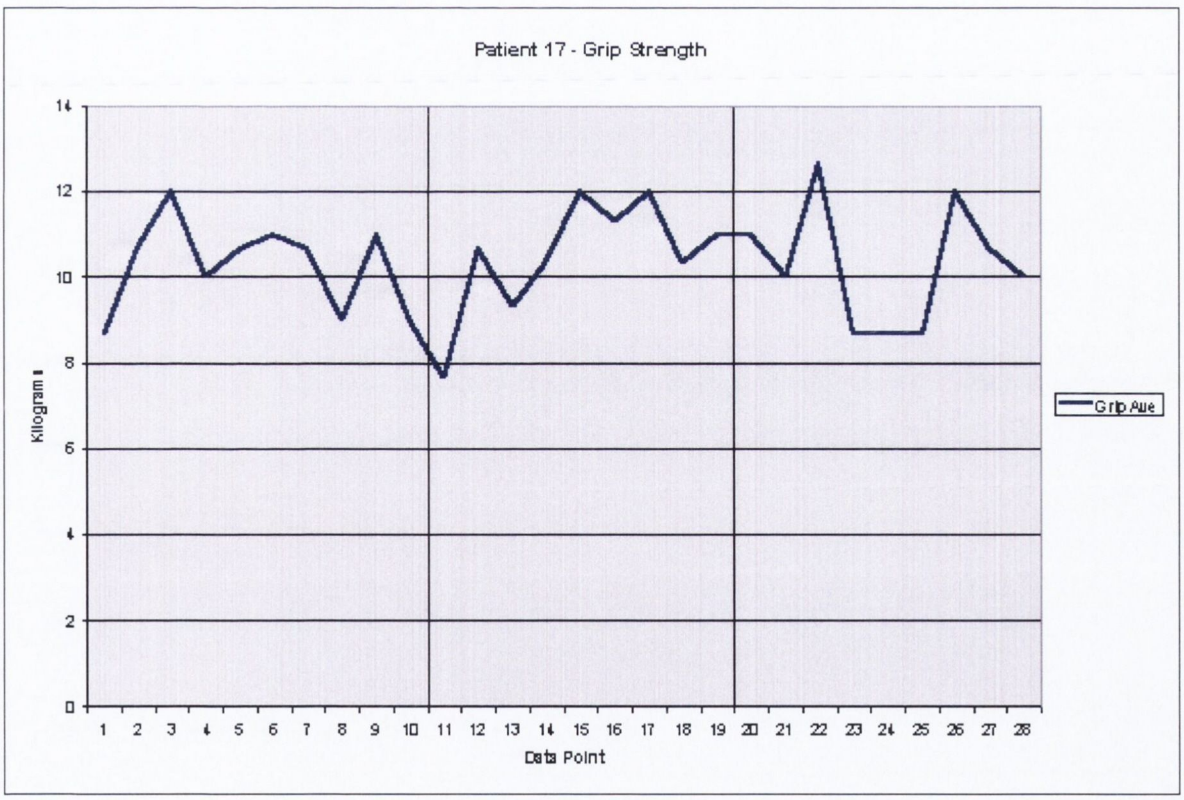

Figure 5-132. Subject 17, Grip

Quality of Life

The plotted data shows a trend for a decrease across the RMT phase and an increase across the SS phase, with the exception of Emotional Roles, which drops sharply over the course of the study.

The physical health domain dropped over the baseline then increased over the two treatment phases to above baseline levels.

SF-36 Domain	Start	End A	End B	End C
Physical Functioning	25.5	23.4	23.4	25.5
Roles - Physical	25	25	22.6	25
Bodily Pain	62.1	50.3	50.3	55.4
General Health	37.7	35.3	32.9	35.3
Vitality	42.7	45.8	39.6	52.1
Social Functioning	24.1	24.1	24.1	29.6
Roles - Emotional	55.9	52	36.4	24.8
Mental Health	50	52.8	41.6	47.2
Physical Health Score	30.5	25.4	29.3	34.5
Mental Health Score	51.6	53.7	40.4	41.1

Table 5-139. Subject 17, SF-36

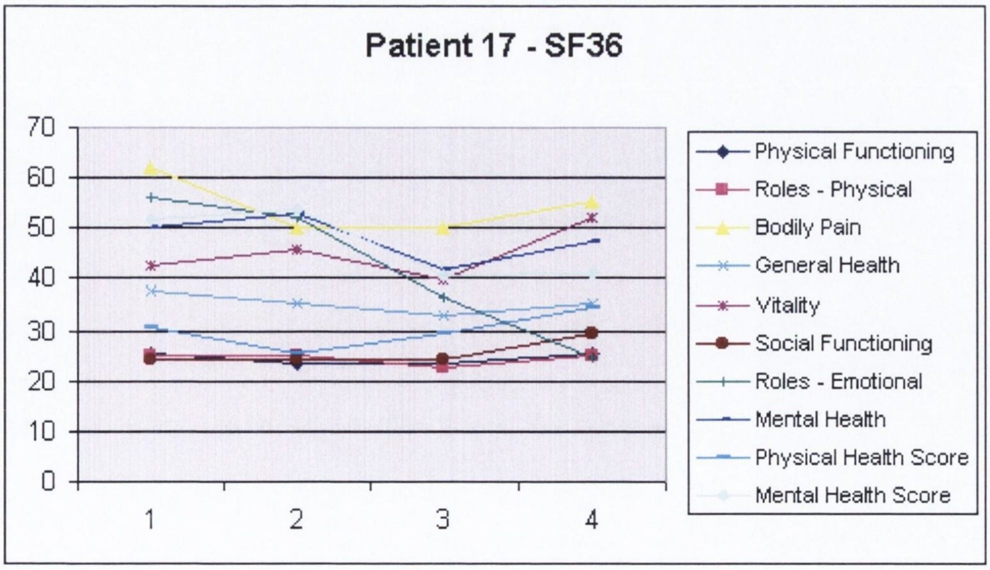

Figure 5-133. Subject 17, SF-36

5.2.18 Subject 18

Mr. PD was a 58 year old man who had a left CVA 19 months prior to the course of the study. His CT showed a right PACI infarct.

His past medical history included alcohol dependency and epilepsy. His medications included phenobarbitone, aspirin, and prostatin.

He lived at home with his mother. At the time of the study he was on review from Baggot Street Community Hospital.

He was randomized to the ACB group with a baseline of 8 measurements. He exercised in passive mode for 24.4% of the time, active assisted for 60.6% and active for 15% of the time.

Events during course of study

Visit 14 – cancelled, feeling unwell.

Visit 26 – study concluded at visit 25 as subject away.

Background data

His SOMCT score was below the 20 mark cut off, however the subject continually expressed interest in participating in the study. Both his treating physician and physiotherapist felt that he was able to give informed consent despite this score. The SF36 was conducted by interview due to his poor literacy.

His star cancellation test was inconsistent with items missed on both sides. He had a visual inattention and impairment in bilateral simultaneous touch, though this was inconsistent.

His tone dropped over the second phase, and he did not report any pain over the duration of the study.

Subject 18, Summary	
Age	58
Time post stroke	19 months
Side affected	Right
CT result	Right PACI infarct
Current physiotherapy treatment	None
Randomisation	ACB, 8
Exercise mode	P 24.4%, AA 60.6%, A 15%

Table 5-140. Subject 18, Summary

	Start A	Start C	Start B	End B
Short Orientation Memory Concentration	14	18	22	24
Star Cancellation L	26	26	25	23
Star Cancellation R	23	22	24	24
Star Cancellation Total	49	48	49	47
Pain	0	0	0	0
Hemianopia	1	1	1	1
Tone Wrist	2	2	1	1
Tone Elbow	2	3	2	2
Sensation Light Touch	8	8	8	8
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	0	6	6	2
Sensation Kinaesthesia	9	7	10	9
Sensation Total	25	29	32	27

Table 5-141. Subject 18, Background data

Fugl-Meyer

None of the differences in the rates of recovery between phases were significant. The slope in the FMA and FMT sections is highest in the baseline phase, with the slope in the RMT phase higher than the SS phase for the total score.

The plotted data illustrates that the fluctuating FMA score is responsible for the most part for the fluctuating FMT score.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
FMA	13.41	0.21	0.11	0.10	-0.09	-0.02	-0.11
FMB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FMC	1.97	0.03	-0.04	0.04	-0.07	0.08	0.01
FMD	1.00	0.00	0.00	0.00	0.00	0.00	0.00
FMT	16.37	0.24	0.07	0.13	-0.17	0.06	-0.10

Table 5-142. Subject 18, Fugl-Meyer

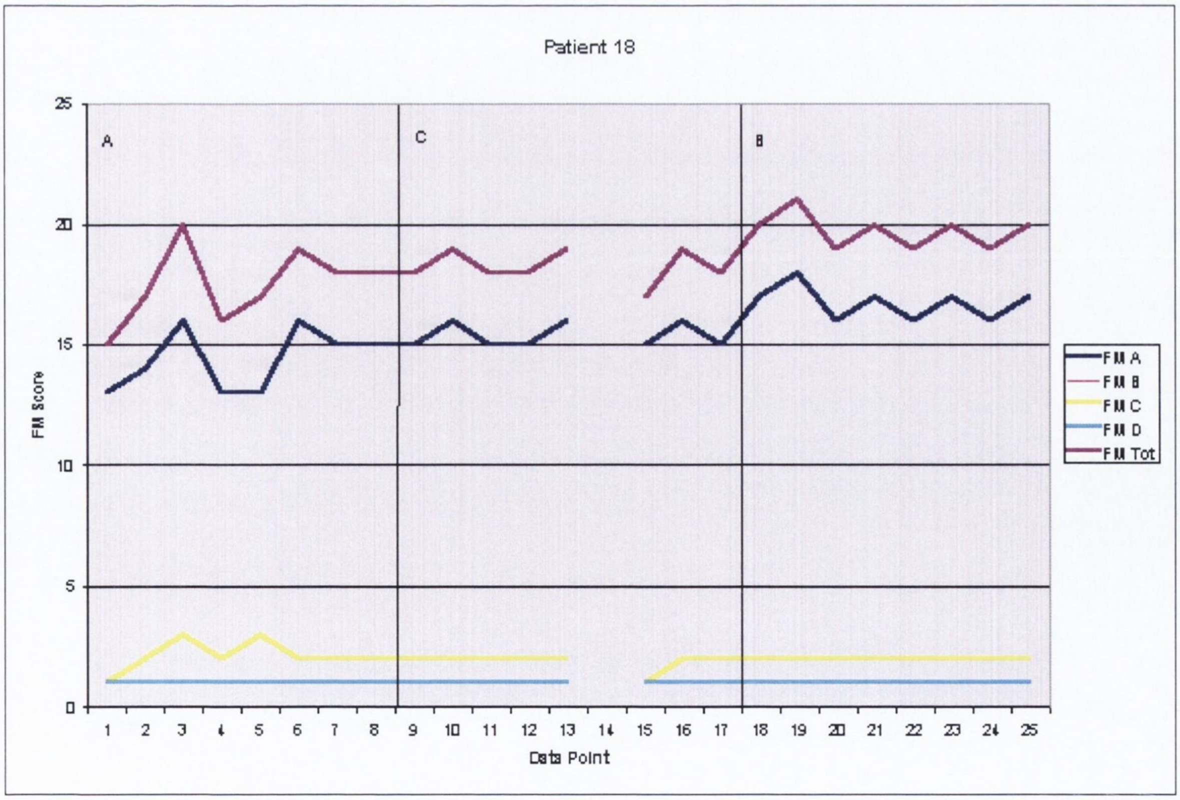

Figure 5-134. Subject 18, Fugl-Meyer

Motor Assessment Scale

The change in baseline phase score contributes solely to the change in the MAST score. While the rate of recovery during the RMT and SS phases do not differ, the RMT phase is significantly greater than the baseline phase.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
MASA	1.87	-0.11	0.09	0.08	0.21	-0.01	0.19
MASB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MASC	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAST	1.87	-0.11	0.14	0.08	0.25	-0.06	0.19

Table 5-143. Subject 18, MAS

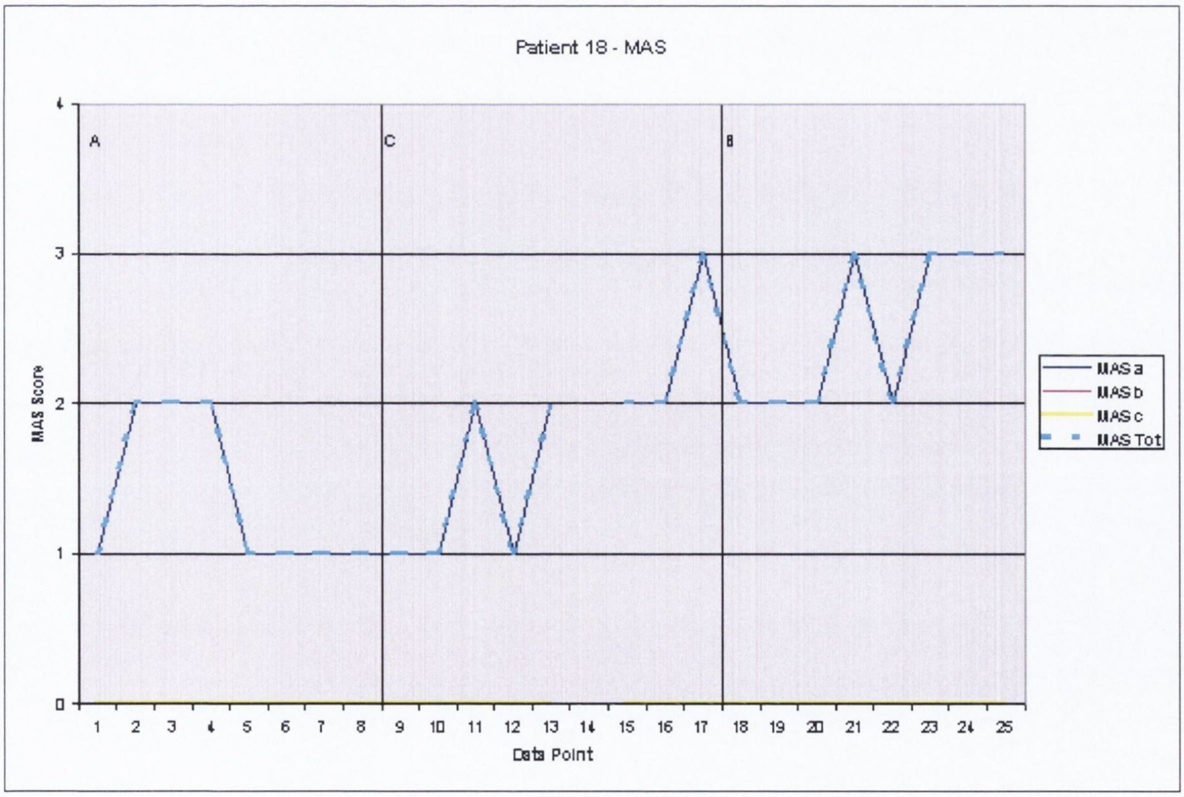

Figure 5-135. Subject 19, MAS

Maximal voluntary isometric contraction

For elbow and shoulder flexion the rate of recovery is highest during the RMT phase, though this is not significant. The slope in the baseline phase is greater than the RMT and SS phase for elbow extension and the RMT phase for shoulder extension. The plotted raw data shows an increase for all variables in the baseline phase.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
ElbFlex	2.46	0.30	0.18	0.32	-0.12	0.14	0.02
ElbExt	6.59	0.59	0.17	0.13	-0.42	-0.04	-0.47
ShoFlex	-0.01	0.01	0.13	0.27	0.13	0.14	0.27
ShoExt	4.72	0.86	0.17	0.49	-0.68	0.32	-0.37

Table 5-144. Subject 18, MVIC

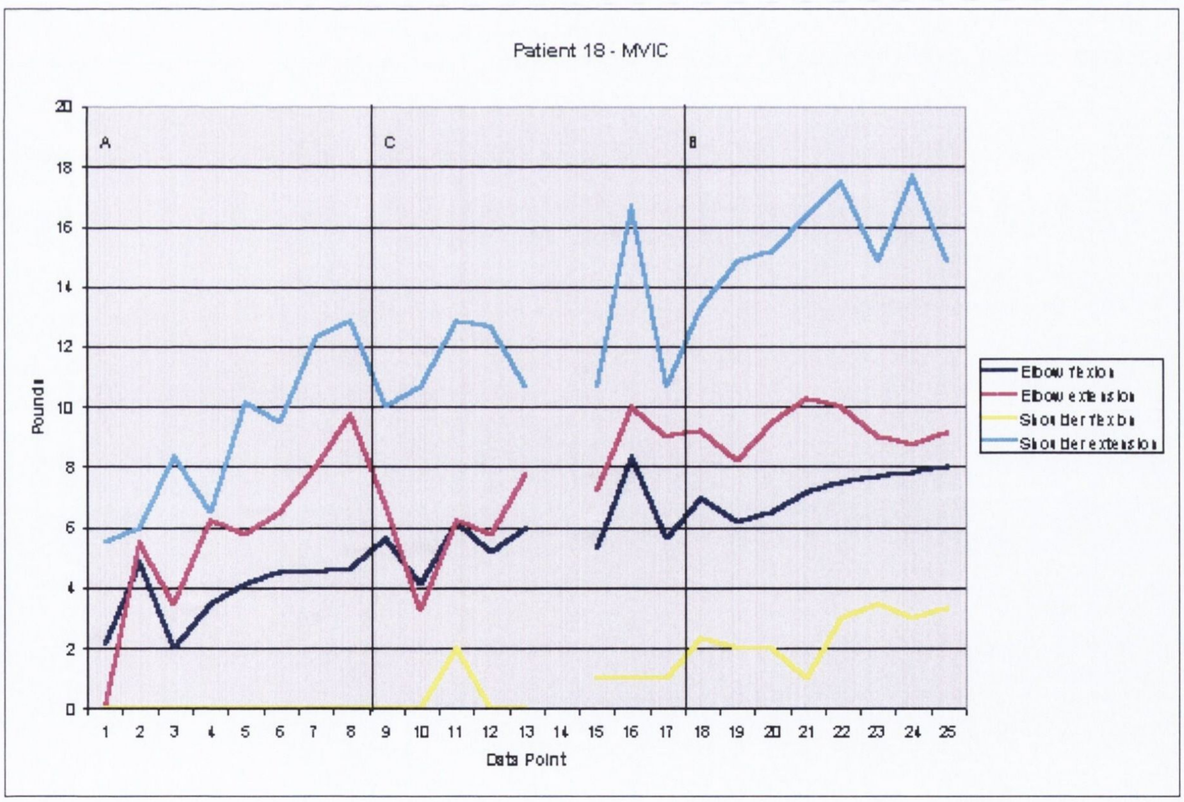

Figure 5-136. Subject 18, MVIC

Range of Motion

The rate of recovery during the SS phase is significantly greater than both baseline and RMT for active elbow flexion and extension and passive elbow flexion.

For active shoulder flexion the RMT slope was significantly higher than both SS and baseline. For passive shoulder external rotation the SS phase slope was significantly less than both the baseline and RMT phases.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
AShFl	42.59	-1.27	1.67	4.54	2.94	2.87	5.81
PShFL	91.19	0.32	-0.19	-0.12	-0.51	0.08	-0.43
AShA	53.74	0.09	-0.28	1.08	-0.36	1.36	0.99
PShA	73.96	-0.46	0.11	-0.44	0.58	-0.55	0.03
AElX	-81.50	0.81	3.78	1.21	2.97	-2.57	0.40
PELX	-2.70	0.51	0.06	0.10	-0.45	0.05	-0.41
AShER	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PShER	25.09	0.83	-0.71	0.87	-1.54	1.58	0.04
AELFl	116.40	-0.23	1.32	0.18	1.55	-1.13	0.41
PELFl	139.96	-1.02	0.75	-0.13	1.77	-0.88	0.89

Table 5-145. Subject 18, ROM

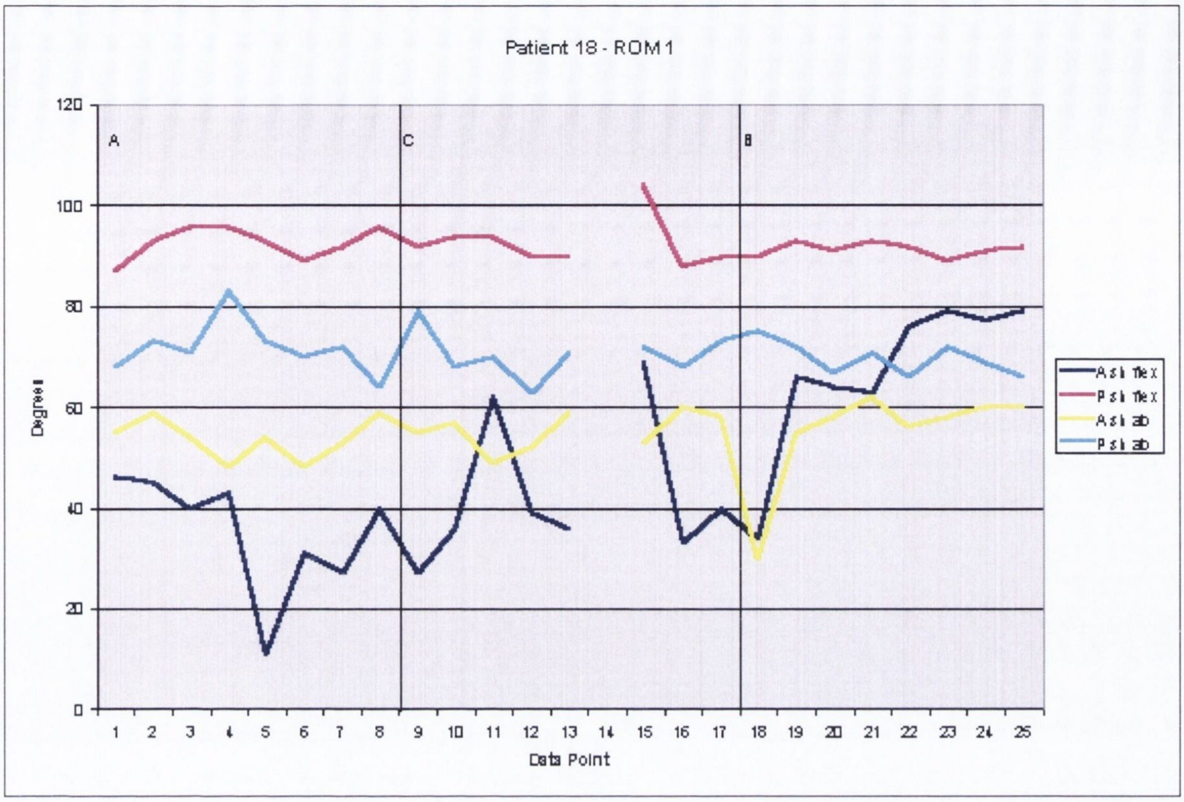

Figure 5-137. Subject 18, ROM 1

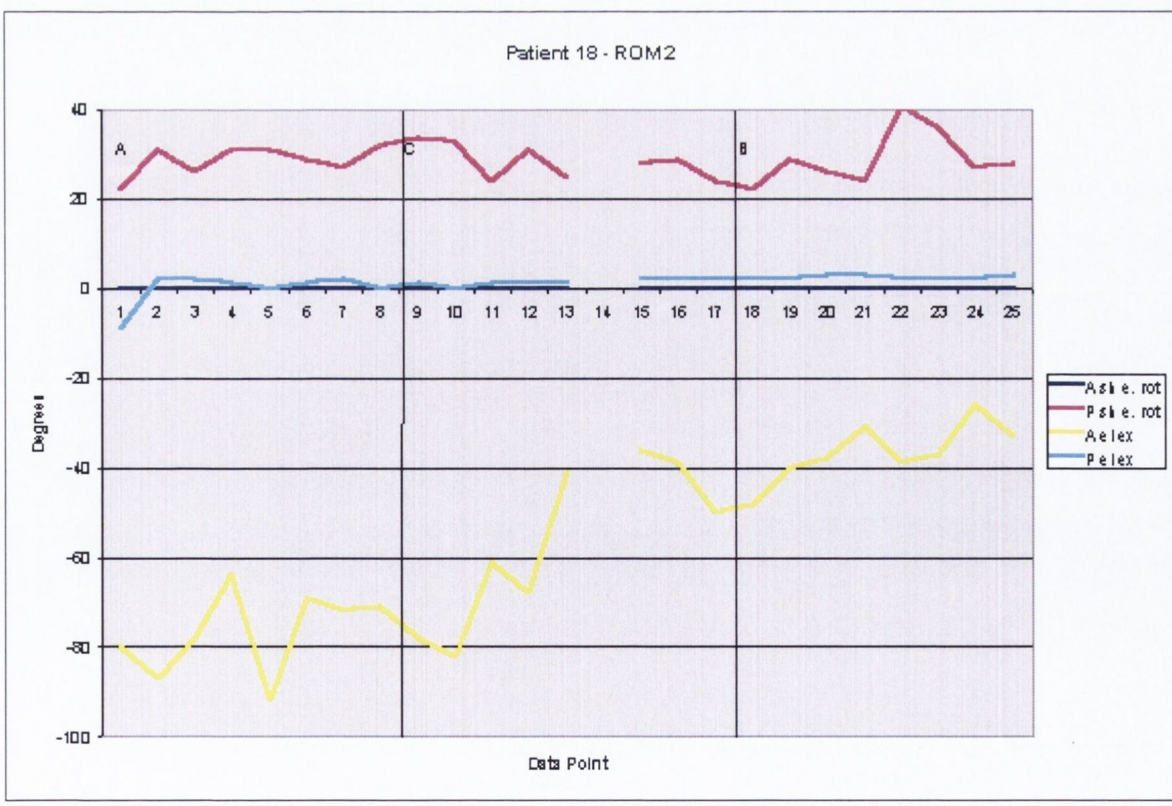

Figure 5-138. Subject 18, ROM 2

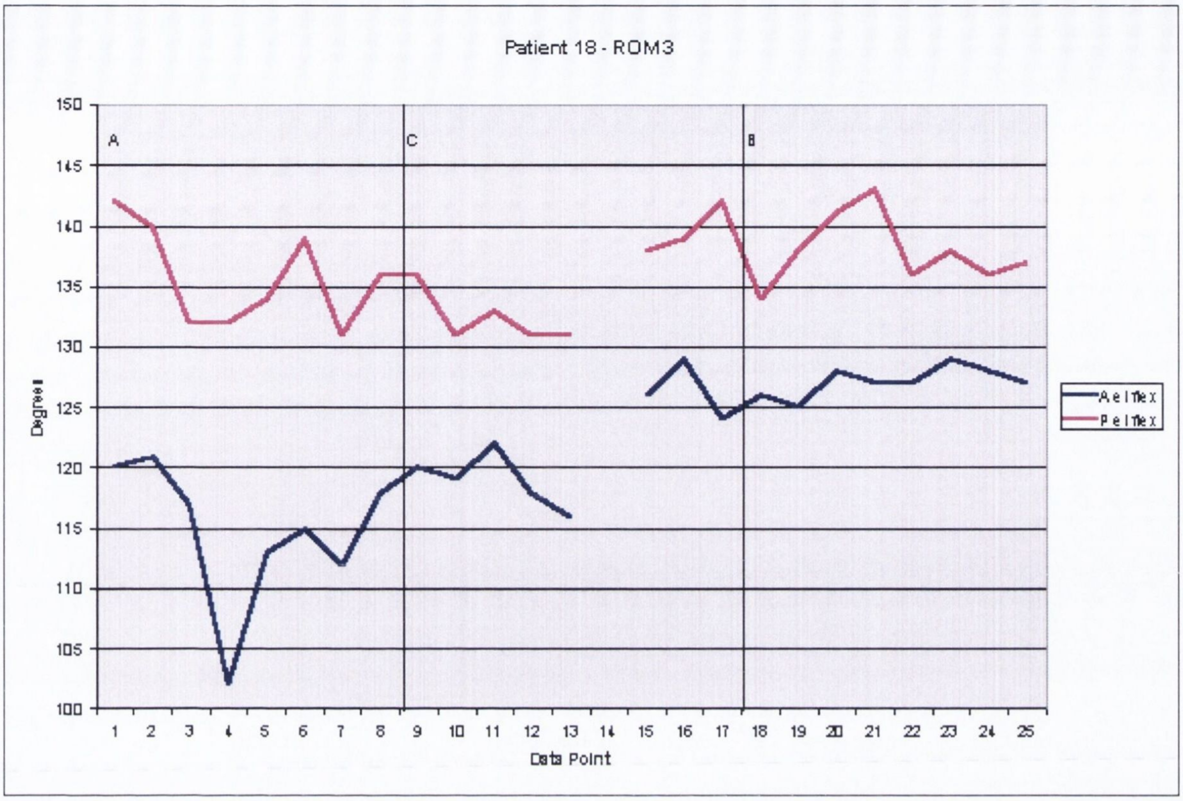

Figure 5-139. Subject 18, ROM 3

Grip Strength

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
Grip	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5-146. Subject 18, Grip

All values remained at 0 for the duration of the study therefore no graph is presented.

Quality of Life

The plotted data does not show a clear trend in the first 2 phases, but demonstrates an increasing trend in the RMT phase.

The physical health score decreases then increases to end above the baseline score.

SF-36 Domain	Start	End A	End C	End B
Physical Functioning	44.4	31.8	40.2	48.6
Roles - Physical	44.6	39.7	42.2	47.1
Bodily Pain	32.5	46.1	46.1	32.5
General Health	45.4	44.8	40.1	44.8
Vitality	39.6	36.5	39.6	45.8
Social Functioning	29.6	40.5	29.6	45.9
Roles - Emotional	32.6	52	36.4	48.1
Mental Health	38.7	27.5	27.5	38.7
Physical Health Score	44	40.4	46.8	44.3
Mental Health Score	32.8	40.1	29	44.1

Table 5-147. Subject 18, SF-36

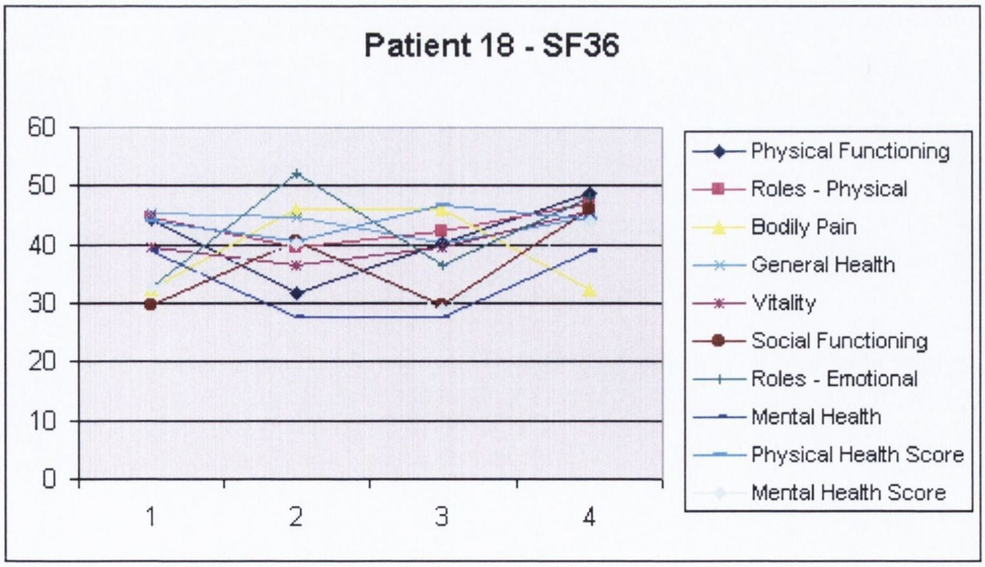

Figure 5-140. Subject 18, SF-36

5.2.19 Subject 19

Mrs. FD was a 74 year old lady who had a left hemiplegia 8 months prior to the start of the study. Her CT scan showed a large infarct in the territory of the middle cerebral artery. Her past medical history included hypertension. She was on lipostat and emcor.

She lived at home with her husband, her mobility was achieved in a wheelchair. She was not receiving any treatment at the time of the study.

She was randomized to the ABC group and to a baseline of 8 data points. She exercise in passive mode for 97.9% of the time and active assisted for 2.1%.

Events during course of study

Visit 18 – reports significant decrease in tone, hand splint easier to put on

Visit 20 – noticed increased tone secondary to bad hay fever.

Background data

While her star cancellation test missed items on both sides, there were a greater number of total errors to the left. She also demonstrated deficits in bilateral simultaneous touch and kinaesthesia. She demonstrated some visual inattention at the final testing only.

Her pain score decreased over baseline and was minimal after the RMT phase. Her tone dropped over the course of the study with the wrist decreasing in the A and SS phase and the elbow in the RMT phase.

Subject 19, Summary	
Age	74
Time post stroke	8 months
Side affected	Right
CT result	Large infarct middle cerebral artery
Current physiotherapy treatment	None
Randomisation	ABC, 8
Exercise mode	P 97.9%, AA 2.1%

Table 5-148. Subject 19, Summary

	Start A	Start B	Start C	End C
Short Orientation Memory Concentration	22	22	26	24
Star Cancellation L	21	24	26	26
Star Cancellation R	22	26	27	26
Star Cancellation Total	43	50	53	52
Pain	1.4	0	0.2	0
Hemianopia	0	0	0	1
Tone Wrist	3	2	2	1
Tone Elbow	2	2	1	1
Sensation Light Touch	8	8	8	8
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	7	6	8	6
Sensation Kinaesthesia	7	8	9	9
Sensation Total	30	30	33	31

Table 5-149. Subject 19, Background data

Fugl-Meyer

All sections remained at 0 apart from the FMA section, which is solely responsible for the FMT score. While none of the differences are significant, the slope is greatest during the SS phase.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
FMA	5.70	-0.22	0.06	0.10	0.28	0.04
FMB	0.00	0.00	0.00	0.00	0.00	0.00
FMC	0.00	0.00	0.00	0.00	0.00	0.00
FMD	0.00	0.00	0.00	0.00	0.00	0.00
FMT	5.70	-0.22	0.06	0.10	0.28	0.04

Table 5-150. Subject 19, Fugl-Meyer

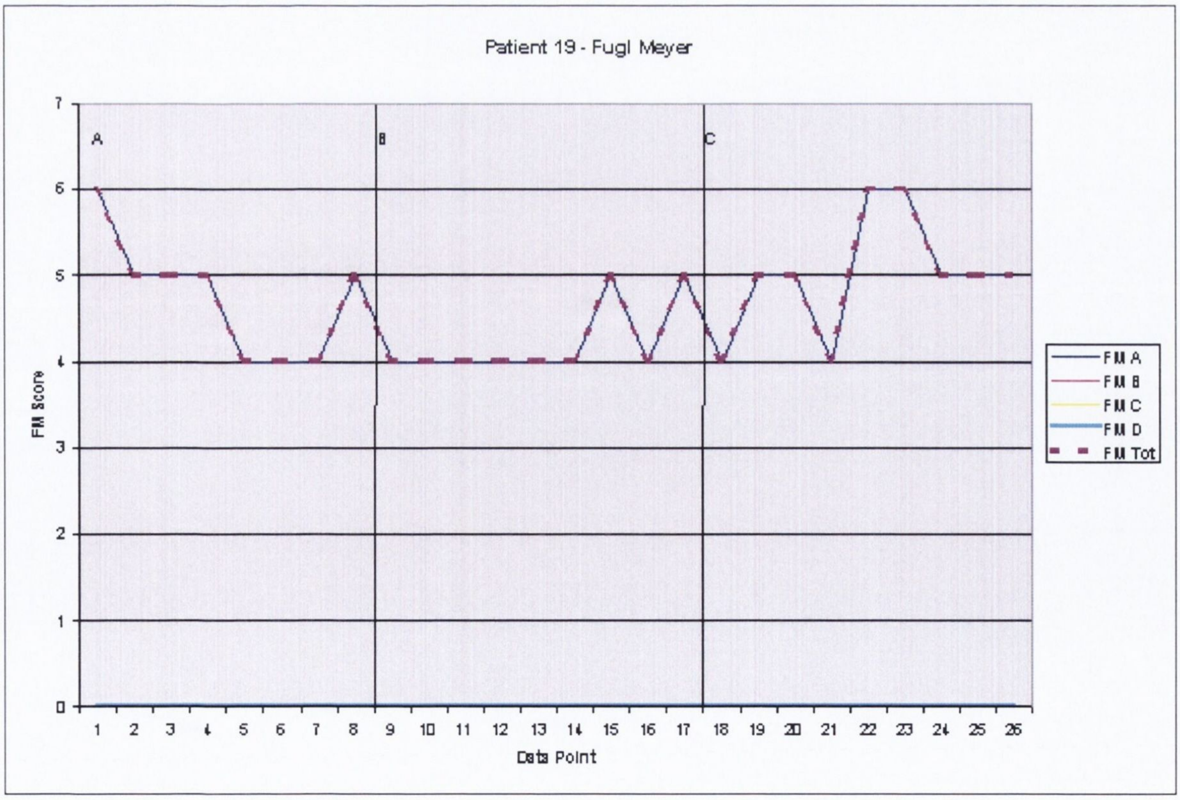

Figure 5-141. Subject 19, Fugl-Meyer

Motor Assessment Scale

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
MASA	0.00	0.00	0.00	0.00	0.00	0.00
MASB	0.00	0.00	0.00	0.00	0.00	0.00
MASC	0.00	0.00	0.00	0.00	0.00	0.00
MAST	0.00	0.00	0.00	0.00	0.00	0.00

Table 5-151. Subject 18, MAS

All values remained at 0 for the duration of the study therefore no graph is presented,

Maximal voluntary isometric contraction

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
ElbFlex	0.00	0.00	0.00	0.00	0.00	0.00
ElbExt	0.00	0.00	0.00	0.00	0.00	0.00
ShoFlex	0.00	0.00	0.00	0.00	0.00	0.00
ShoExt	0.00	0.00	0.00	0.00	0.00	0.00

Table 5-152. Subject 18, MAS

All values remained at 0 for the duration of the study therefore no graph is presented.

Range of Motion

Mrs. FD did not generate any active movement and many of the change in passive values were not significant. The only one that was suggests that the rate during baseline was higher than the RMT phase. The plotted data suggest high variability around central values for all variables for the course of the study.

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
AShFl	0.00	0.00	0.00	0.00	0.00	0.00
PShFL	84.34	0.16	0.10	-0.13	-0.06	-0.23
AShA	0.01	0.00	0.01	0.01	0.01	0.00
PShA	47.88	0.65	-0.26	0.69	-0.91	0.94
AElX	0.00	0.00	0.00	0.00	0.00	0.00
PELX	3.35	-0.33	0.04	0.08	0.37	0.04
AShER	0.00	0.00	0.00	0.00	0.00	0.00
PShER	22.38	1.00	-0.42	0.66	-1.43	1.08
AELFl	0.00	0.00	0.00	0.00	0.00	0.00
PELFl	127.01	0.56	-0.27	0.04	-0.83	0.31

Table 5-153. Subject 19, ROM

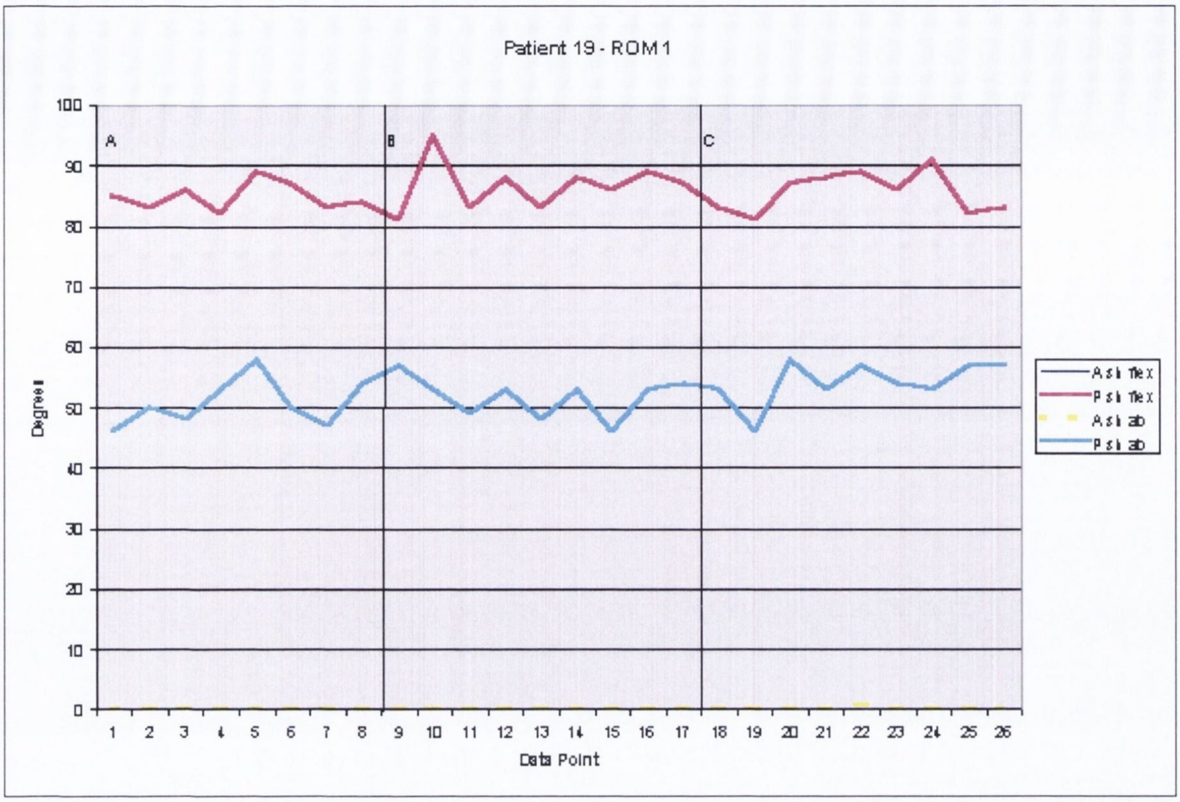

Figure 5-142. Subject 19, ROM 1

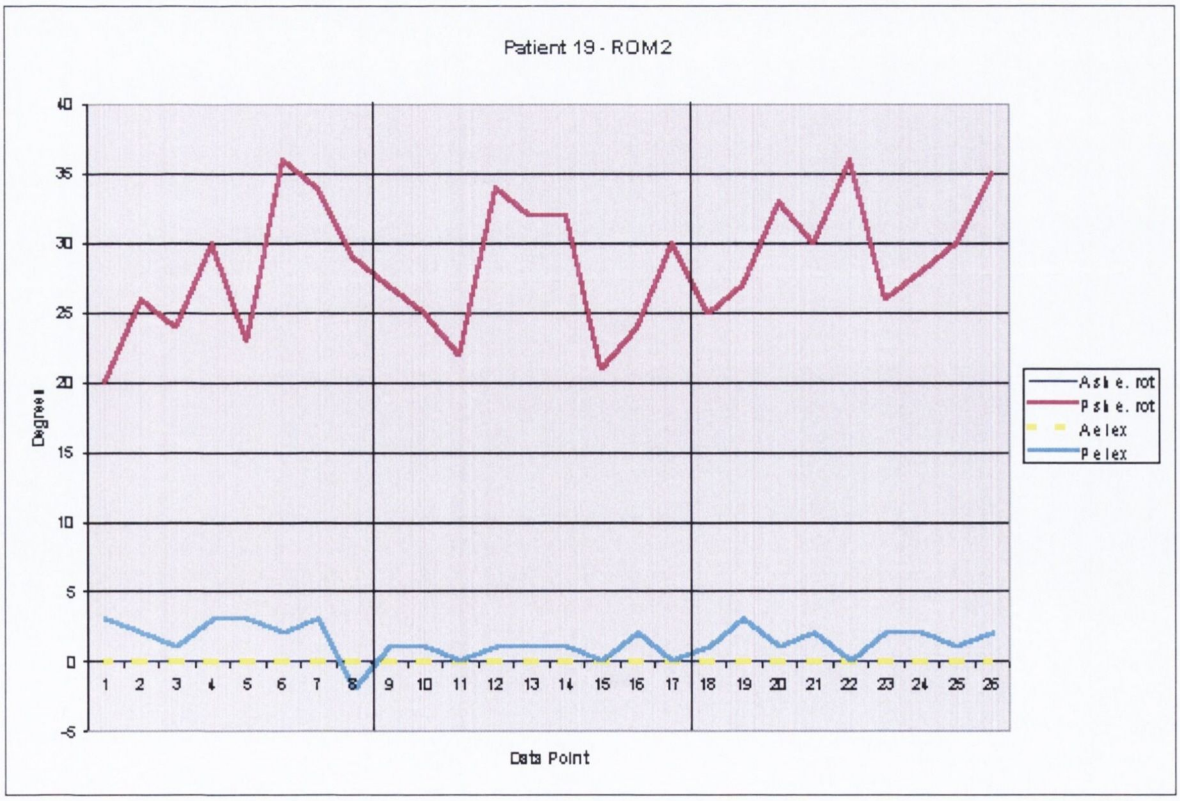

Figure 5-143. Subject 19, ROM 2

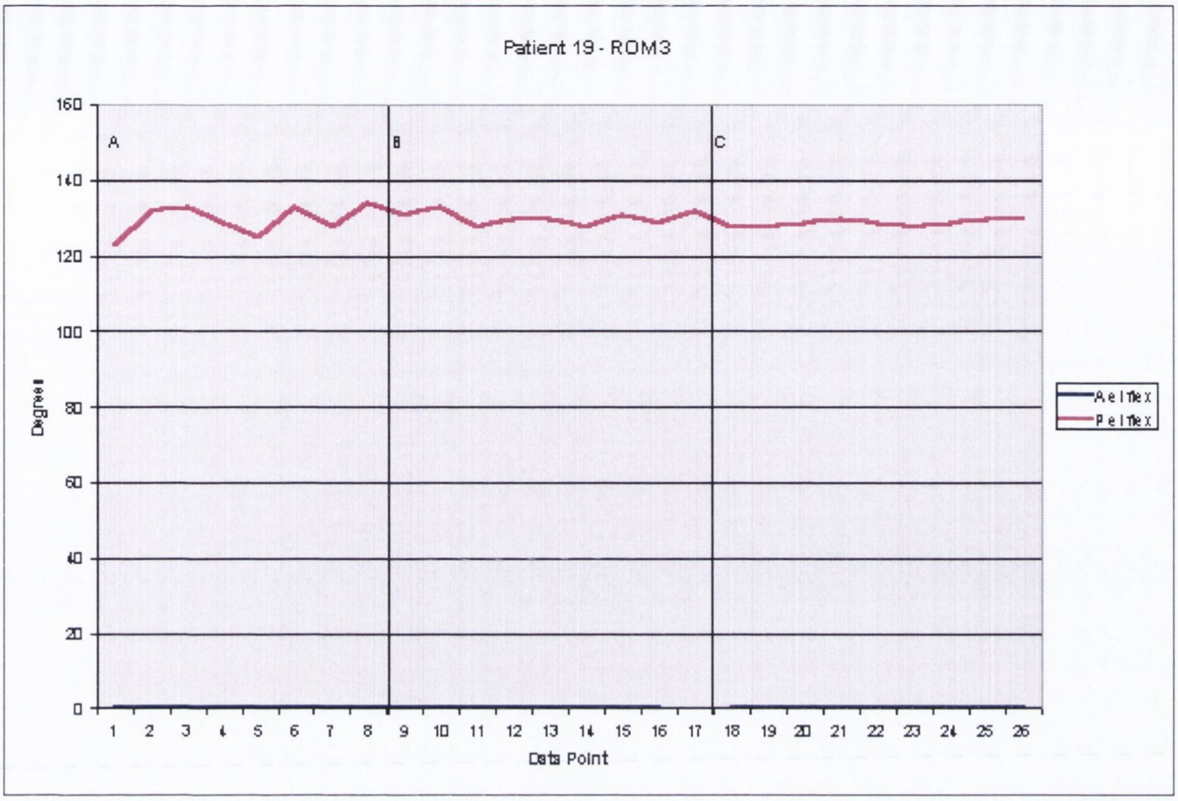

Figure 5-144. Sublect 19, ROM 3

Grip Strength

	Intercept	Slope A	Slope B	Slope C	Slope B-A	Slope C-B
Grip	0.00	0.00	0.00	0.00	0.00	0.00

Table 5-154. Subject 19, Grip

All values remained at 0 for the duration of the study therefore no graphs are presented.

Quality of Life

The plotted data shows fluctuating scores with no clear trend emerging. Both the physical and mental health scores end at a level higher than baseline.

SF-36 Domain	Start	End A	End B	End C
Physical Functioning	17	17	14.9	14.9
Roles - Physical	29.9	42.2	37.3	44.6
Bodily Pain	62.1	62.1	62.1	62.1
General Health	41	45.8	52.9	48.2
Vitality	49	52.1	45.8	45.8
Social Functioning	51.4	51.4	45.9	51.4
Roles - Emotional	28.7	40.3	52	44.2
Mental Health	44.4	41.6	44.4	44.4
Physical Health Score	35.9	39.8	36	38.9
Mental Health Score	47.2	50	54.5	51.7

Table 5-155. Subject 19, SF-36

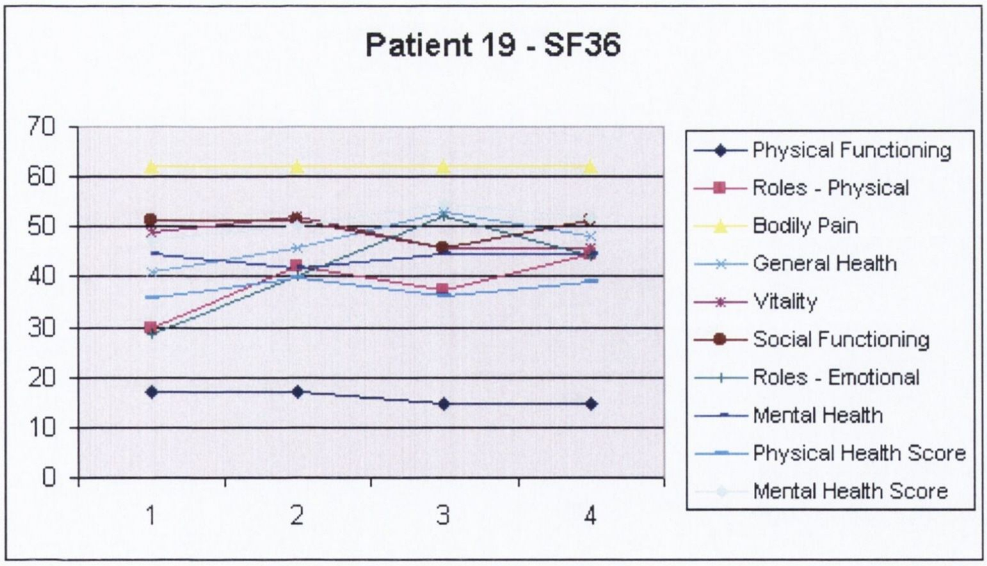

Figure 5-145. Subject 19, SF-36

5.2.20 Subject 20

Mr. HB was a 49 year old man who had a left hemiplegia 75 months prior to the start of the study. His CT scan showed a right intracerebral bleed. His past medical history included angioplasty and a left knee soft tissue injury. His medication included aspirin and Valium.

At the time of the study he lived independently and was not receiving any physiotherapy intervention.

He was randomized to ACB group with 10 baseline data points. He exercised in passive mode for 40% of the time, active assisted for 52% and active for 8% of the time.

Events during course of study

There were no events of note and he attended for all appointments.

Background data

His star cancellation test was normal and he had no visual or somatosensory inattention. His pain levels increased slightly (0.2cms) over each phase of the study.

His wrist tone increased and elbow decreased over the baseline and remained constant for the duration of the study.

Subject 20, Summary	
Age	49
Time post stroke	75 months
Side affected	Left
CT result	Right intracerebral bleed
Current physiotherapy treatment	None
Randomisation	ACB, 10
Exercise mode	P 40%, AA 52%, A 8%

Table 5-156. Subject 20, Summary

	Start A	Start C	Start B	End B
Short Orientation Memory Concentration	28	26	26	28
Star Cancellation L	27	27	27	27
Star Cancellation R	27	27	27	27
Star Cancellation Total	54	54	54	54
Pain	1.9	2.1	2.2	2.4
Hemianopia	0	0	0	0
Tone Wrist	1	2	1	1
Tone Elbow	3	2	2	2
Sensation Light Touch	8	8	8	8
Sensation Pressure	8	8	8	8
Sensation Bilateral Simultaneous	8	8	8	8
Sensation Kinaesthesia	11	11	11	11
Sensation Total	35	35	35	35

Table 5-157. Subject 20, Background data

Fugl-Meyer

For all sections of the FM the slope value was greatest during the baseline phase. They were significantly greater than both the SS and RMT phases for the FMD and FMT scores.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
FMA	14.30	0.50	0.18	0.12	-0.32	-0.07	-0.38
FMB	1.98	0.25	0.20	-0.06	-0.05	-0.26	-0.31
FMC	2.52	0.18	-0.07	0.07	-0.26	0.14	-0.11
FMD	0.68	0.17	0.01	0.06	-0.17	0.05	-0.12
FMT	19.49	1.10	0.32	0.18	-0.79	-0.14	-0.93

Table 5-158. Subject 20, Fugl-Meyer

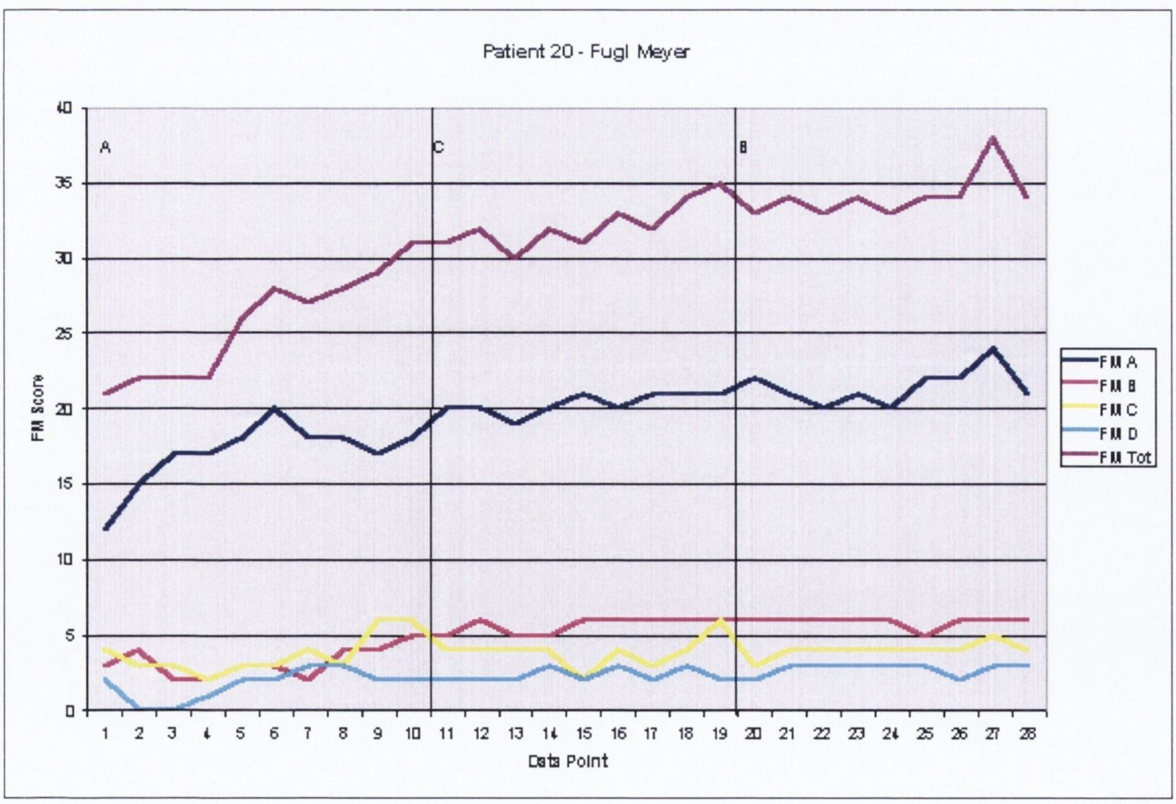

Figure 5-146. Subject 20, Fugl-Meyer

Motor Assessment Scale

For the MASA, MASB and total scores the slopes of the baseline phase are significantly higher than both RMT and SS phases, with the slope of the RMT phase higher than the SS phase.

The raw data shows a sharp increase in the baseline phase with less fluctuation in the RMT than the SS phase.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
MASA	1.54	0.14	-0.04	0.06	-0.18	0.11	-0.80
MASB	0.97	0.12	-0.05	0.04	-0.17	0.09	-0.08
MASC	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAST	2.51	0.26	-0.09	0.10	-0.35	0.20	-0.15

Table 5-159. Subject 20, MAS

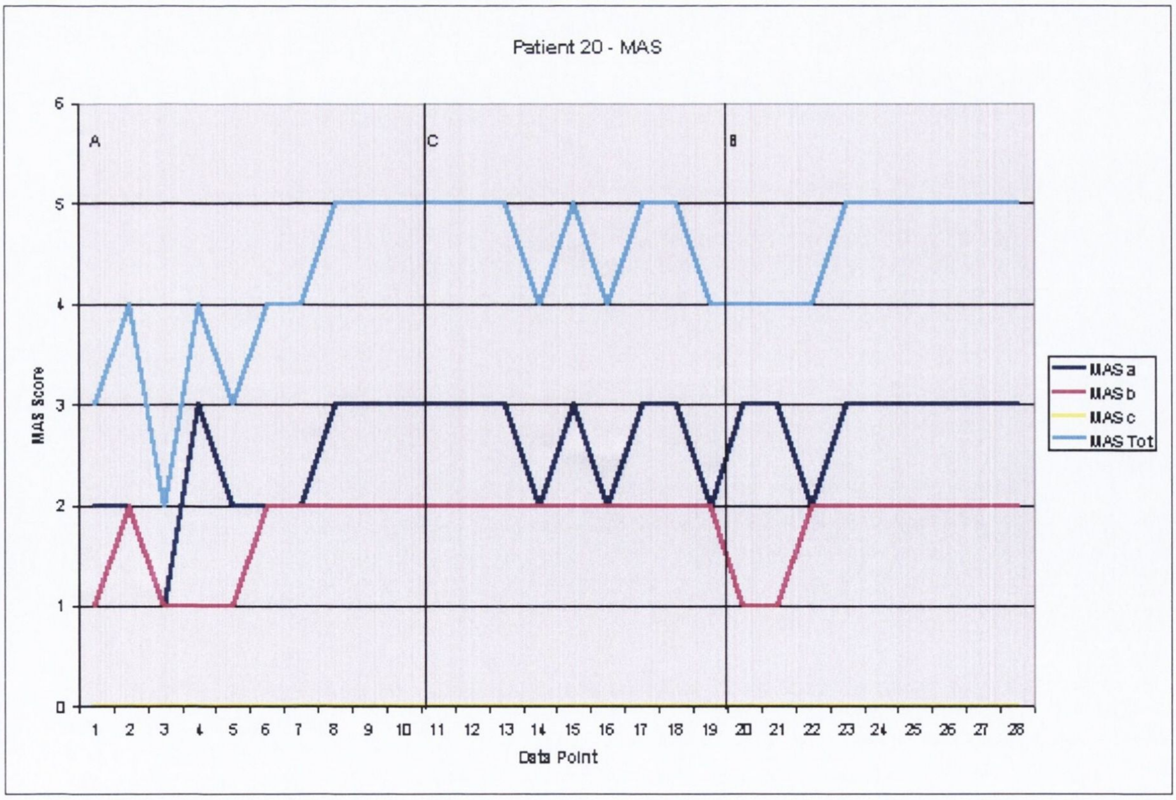

Figure 5-147. Subject 20, MAS

Maximal voluntary isometric contraction

The rate of recovery of elbow flexion MVIC is significantly greater in the SS than the baseline and RMT phases. The high slope values in the baseline phase are significantly higher than the RMT phase for elbow extension and shoulder extension.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
ElbFlex	11.97	-0.13	0.72	0.07	0.85	-0.66	0.20
ElbExt	7.06	0.96	0.26	0.33	-0.70	0.07	-0.63
ShoFlex	3.06	0.15	0.07	0.28	-0.07	0.20	0.13
ShoExt	16.08	1.24	0.77	0.12	-0.47	-0.65	-1.12

Table 5-160. Subject 20, MVIC

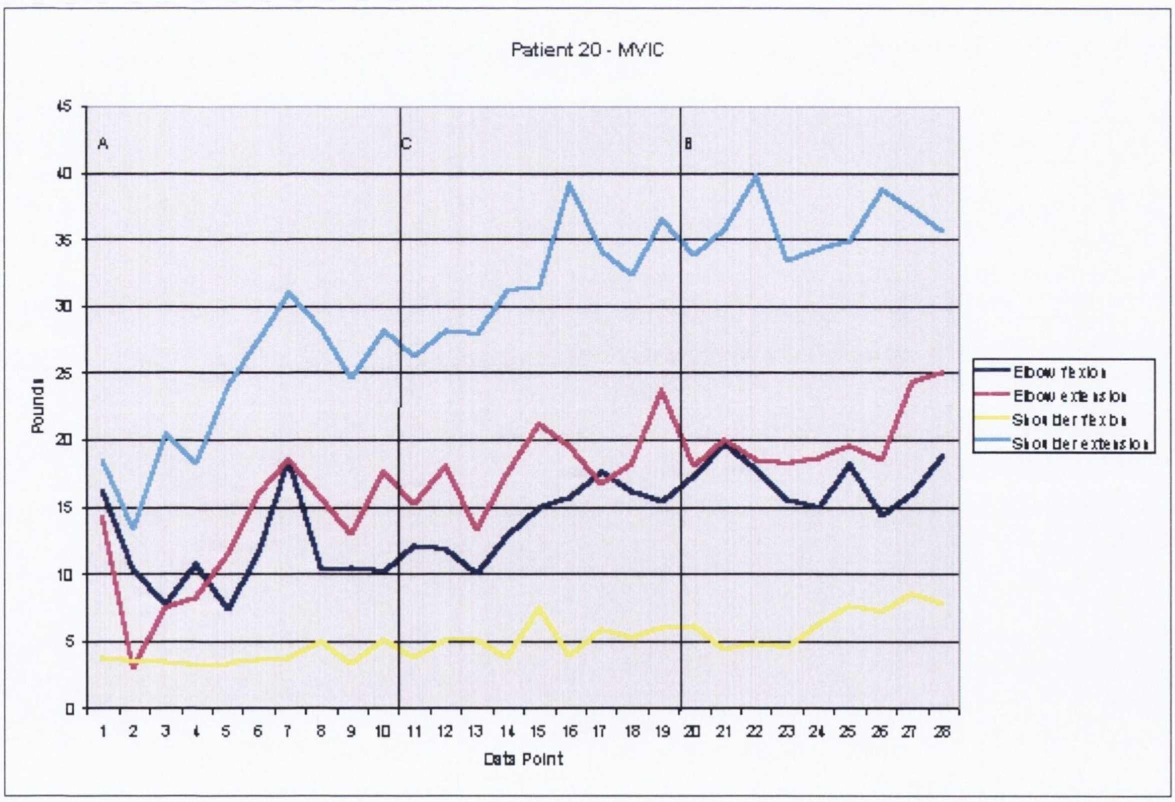

Figure 5-148. Subject 20, MVIC

Range of Motion

The slope through the SS phase was significantly less than the baseline and RMT phases for active elbow extension and significantly greater than them for active elbow flexion and passive shoulder flexion. The slope through the RMT phase was greater than the baseline phase for active shoulder flexion and than the baseline and SS phases for active shoulder abduction.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
AShFl	46.04	-0.19	0.17	1.41	0.35	1.24	1.60
PShFL	109.96	-1.31	0.84	-1.12	2.15	-1.96	0.19
AShA	63.87	-0.42	-0.57	1.79	-0.15	2.36	2.21
PShA	77.78	-0.14	-0.15	0.46	-0.01	0.61	0.60
AElX	-30.43	1.61	-1.08	1.03	-2.69	2.10	-0.59
PELX	1.25	-0.23	0.23	-0.35	0.46	-0.58	-0.13
AShER	-2.94	0.86	0.49	0.06	-0.37	-0.42	-0.79
PShER	42.42	0.00	0.27	-0.58	0.27	-0.85	-0.58
AELFl	130.49	-0.72	1.07	-0.19	1.80	-1.27	0.53
PELFl	157.38	-0.48	0.15	-0.55	0.63	-0.70	-0.07

Table 5-161. Subject 20, ROM

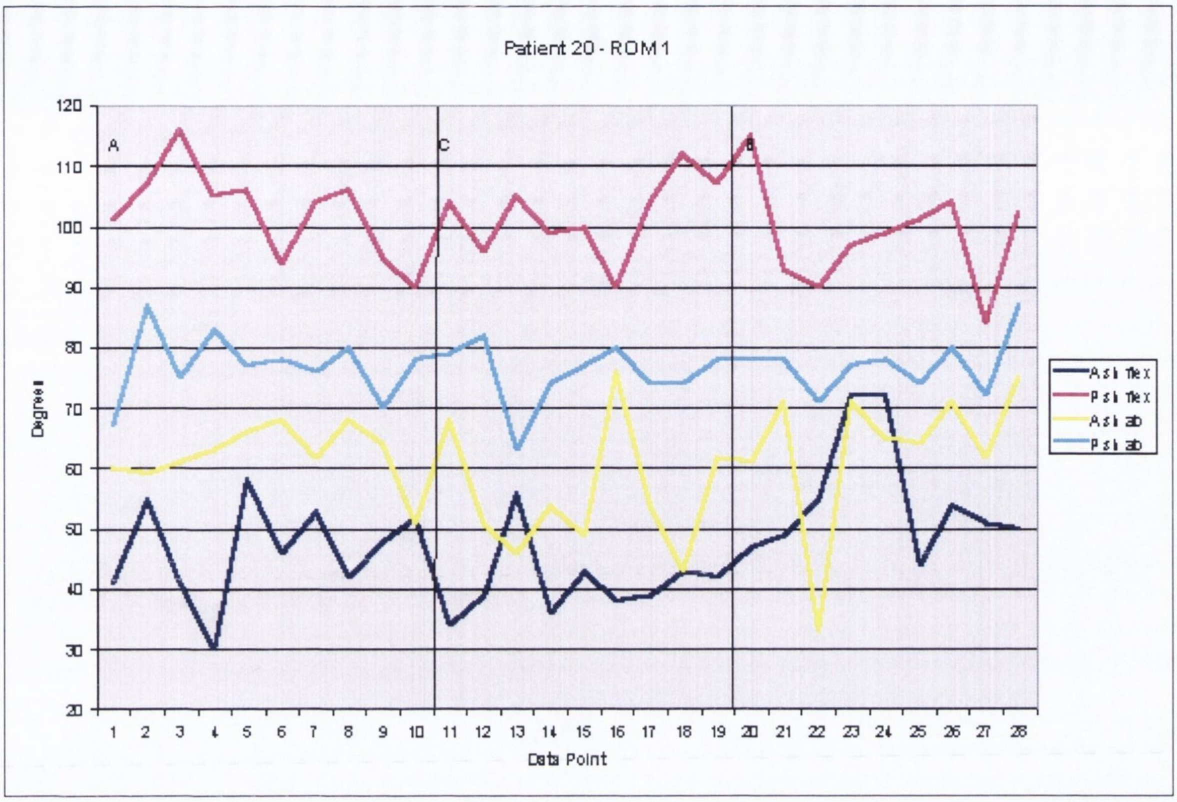

Figure 5-149. Subject 20, ROM 1

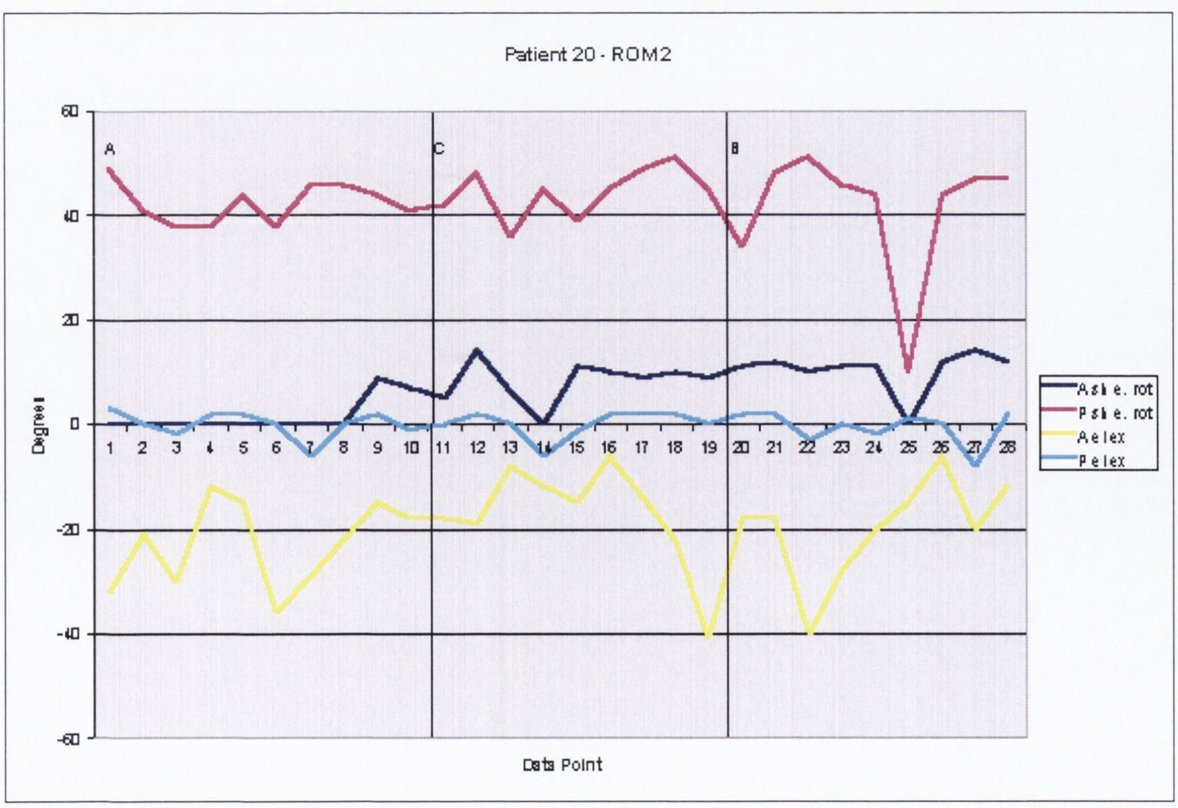

Figure 5-150. Subject 20, ROM 2

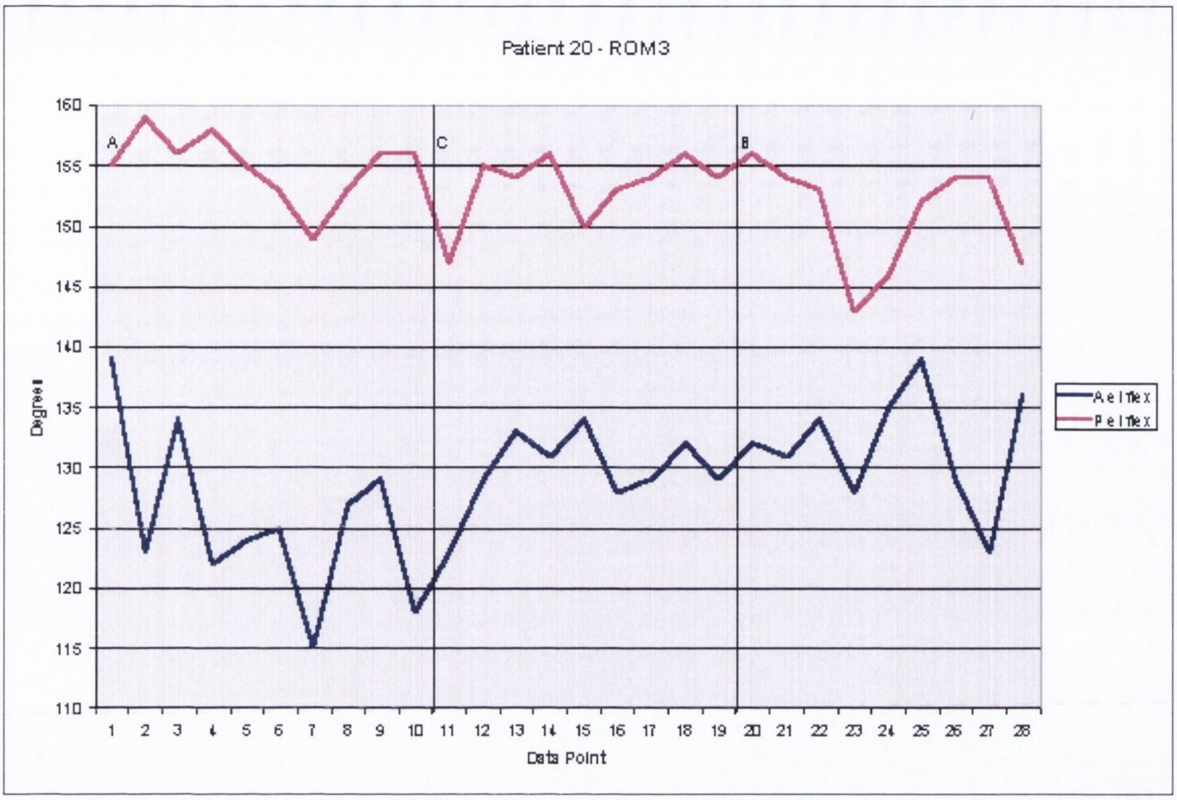

Figure 5-151. Subject 20, ROM 3

Grip Strength

The baseline phase slope is significantly higher than the SS phase. The plotted data shows an initial increase to a value of 8 then fluctuation around this from the 5th to 26th data point.

	Intercept	Slope A	Slope C	Slope B	Slope C-A	Slope B-C	Slope B-A
Grip	5.38	0.29	0.00	0.06	-0.28	0.05	-0.23

Table 5-162. Subject 20, Grip

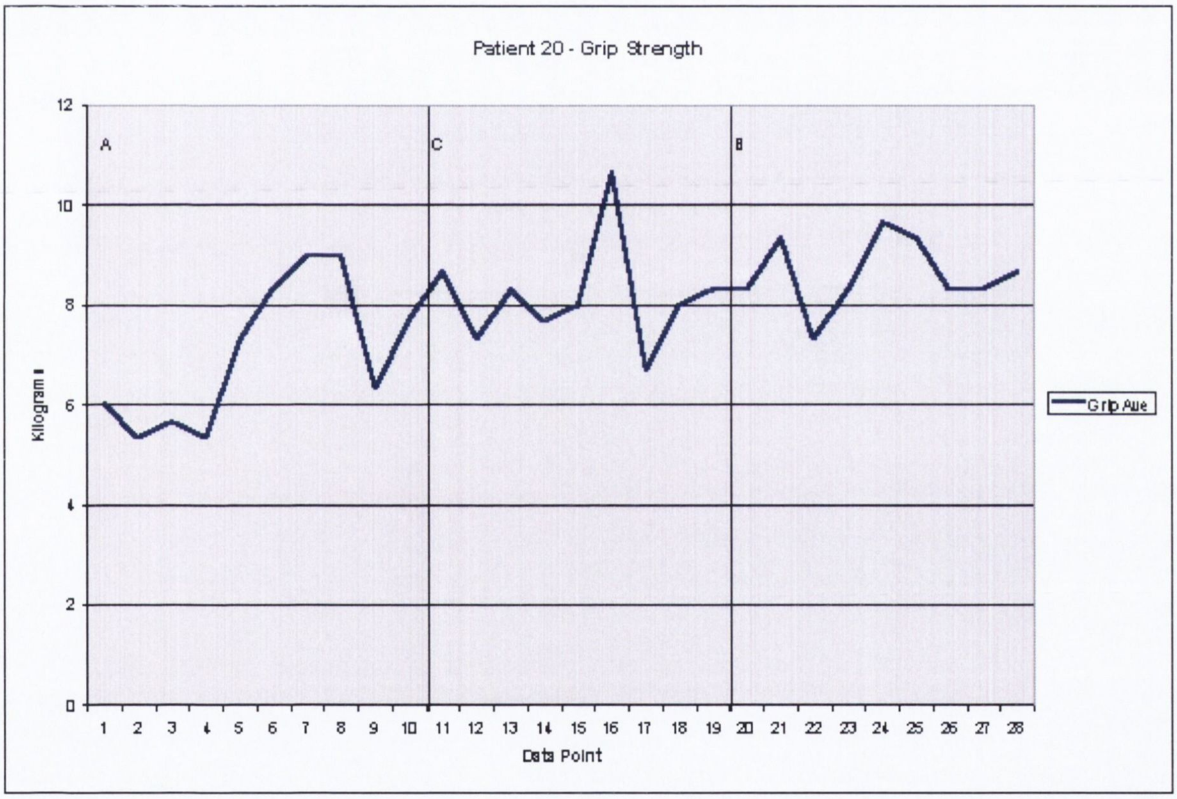

Figure 5-152. Subject 20, Grip

Quality of Life

Bodily pain increased consistently across each phase indicating a decrease in subjective pain. The physical health score showed an increase over the baseline and SS phases and a decrease over the RMT phase. The mental health score shows the exact opposite of this.

SF-36 Domain	Start	End A	End C	End B
Physical Functioning	19.2	29.7	17	27.6
Roles - Physical	20.1	29.9	25	27.5
Bodily Pain	33	33	41.8	46.1
General Health	43.4	48.2	52	60.1
Vitality	45.8	20.9	45.8	33.4
Social Functioning	13.2	18.7	13.2	13.2
Roles - Emotional	13.1	20.9	20.9	20.9
Mental Health	44.4	19	30.3	19
Physical Health Score	27.8	40.3	35.3	46.1
Mental Health Score	32.9	15.9	28.4	16.7

Table 5-163. Subject 20, SF-36

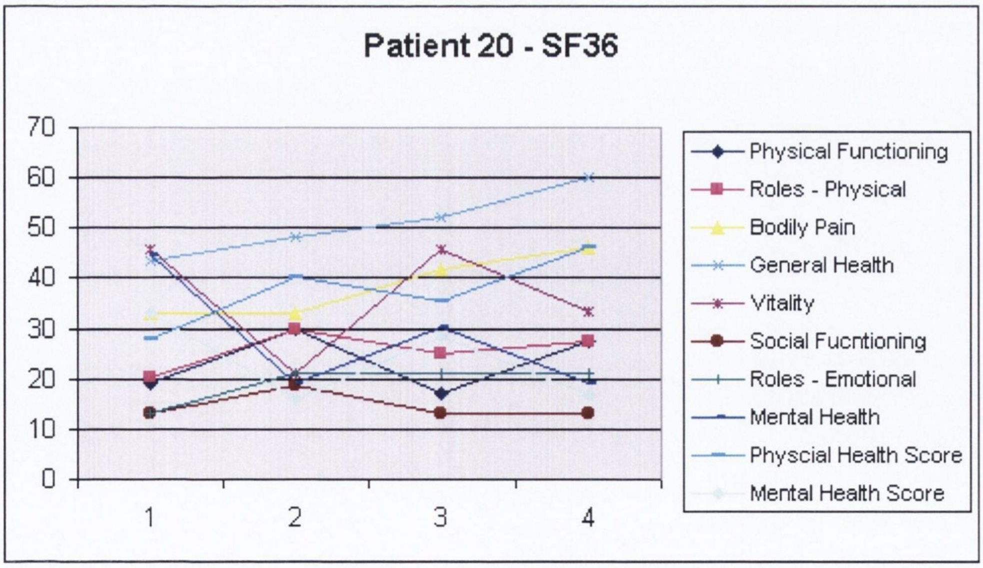

Figure 5-153. Subject 20, SF-36

5.3 Background measures

The previous section presented the results on an individual basis. In order to evaluate the effect of RMT on pain and tone, and quality of life the results for the 10 patients in each group are combined and presented in the following sections.

The pain, tone and SF-36 measures were taken at the start of the study and at the end of each phase (i.e. on four occasions).

In order to assess the effect of RMT on these variables, firstly the significance of the change from the start to the end of each phase is assessed. Secondly the "change over phase" variables (constructed by subtracting the slope values of 2 phases) are then compared to see if the change over one phase was greater than the change over another. This is done using paired, 2-tailed, t-tests for pain and SF-36 measures and using the Wilcoxon signed rank test for the tone measure. Statistically significant p values (α=0.05) are highlighted in yellow, with those nearing statistical significance highlighted in blue.

5.3.1 Pain

Pain was measured with the VAS and is expressed in cm from the left hand end of the line. A score of 0 indicates no pain with 10 representing the worst possible pain.

Group 1 – Pain

The raw data for the pain scores of group 1 are presented in Figure 5-154.

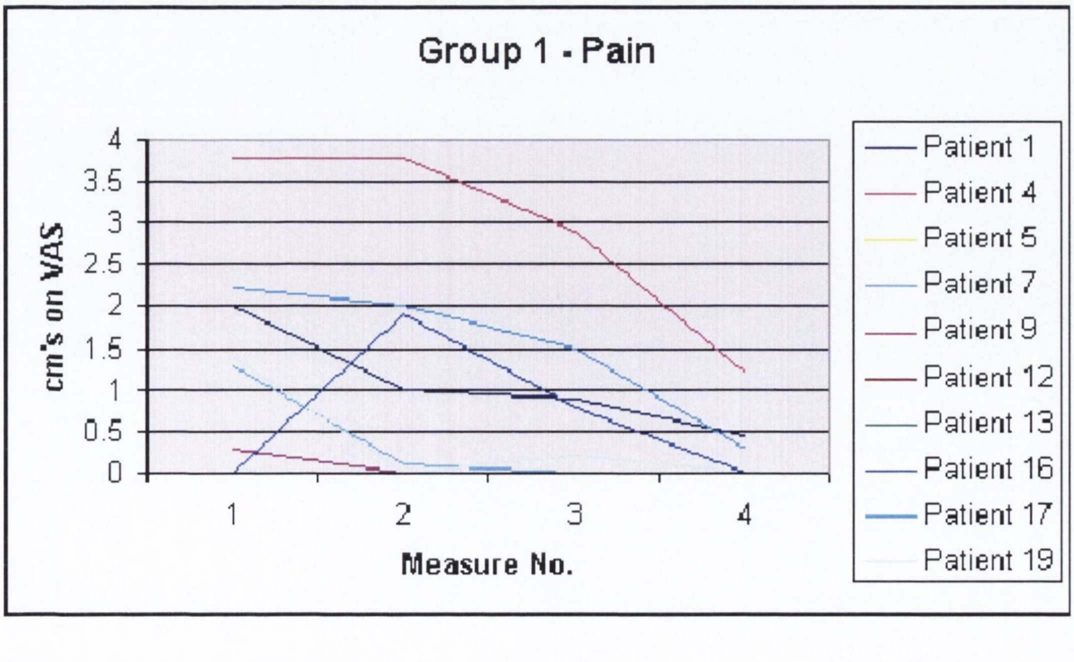

Figure 5-154. Group 1, Pain scores

Table 5-164 presents the mean change in pain score across each phase. While pain, as measured in centimetres on the VAS decreased over all phases, only the decrease in scores over the SS phase was nearing statistical significance.

	Mean difference	95% CI	t-value	p-value
Change over A	-0.22	-0.88, 0.44	0.754	0.470
Change over B	-0.25	-0.56, 0.06	1.186	0.103
Change over C	-0.44	-0.87, 0.00	2.265	0.050

Table 5-164. Group 1, Pain, change over phase

To assess whether the change over one phase was significantly different from another, new "change over phase" variables were constructed and the differences between these assessed. The change over the SS phase was not significantly different to that across any other phase.

	Mean difference	95% CI	t-value	p-value
Change A – Change B	-0.03	-0.94, 0.88	0.075	0.942
Change A – Change C	-0.26	-1.11, 0.68	0.545	0.599
Change B – Change C	-0.19	-0.44, 0.07	1.622	0.139

Table 5-165. Group 1, Pain, difference in change over phase

Group 2 - Pain

Figure 5-155 presents the raw data of the pain scores for group 2.

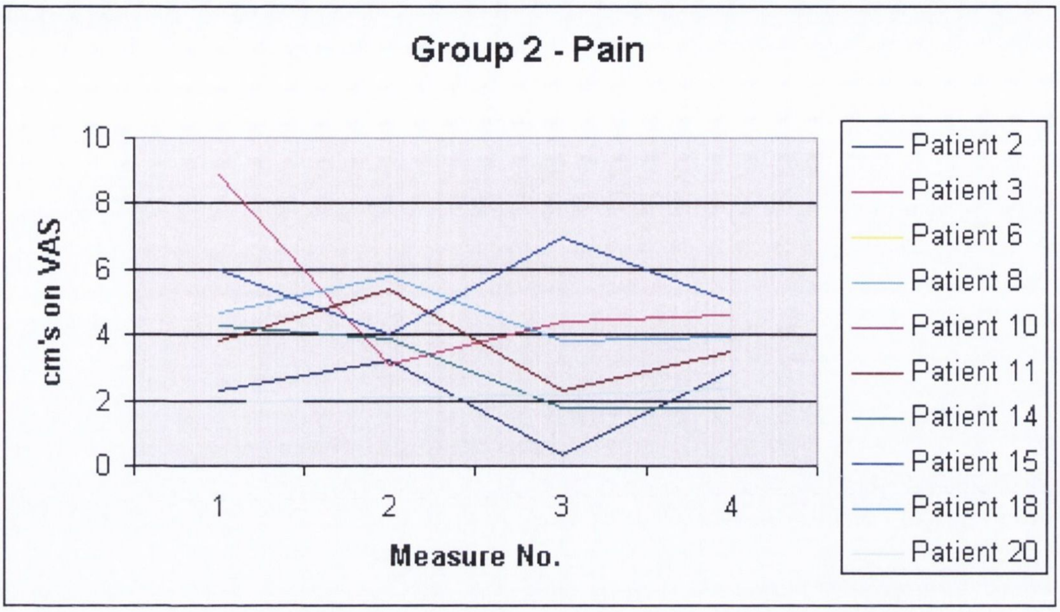

Figure 5-155. Group 2, Pain scores

Table 5-166 presents the mean change in pain scores across the 3 phases for the subjects in group 2. There was a mean increase of 0.24 cm on the VAS during the RMT phase but this increase was not statistically significant.

	Mean difference	95% CI	t-value	p-value
Change over A	-0.44	-1.96, 1.09	0.647	0.534
Change over C	-0.57	-1.96, 0.82	0.929	0.377
Change over B	0.24	-0.58, 1.05	0.650	0.532

Table 5-166, Group 2, Pain change over phase

Table 5-167 presents the results for the differences in the change over one phase compared to the change over another. None of the changes in pain scores over any of the phases was significantly different to that over another phase.

	Mean difference	95% CI	t-value	p-value
Change A – Change B	-0.67	-2.10, 0.76	1.063	0.315
Change A – Change C	-0.14	-2.80, 2.53	0.115	0.911
Change B – Change C	0.81	-1.29, 2.90	0.867	0.408

Table 5-167. Group 2, Pain, difference in change over phase

5.3.2 Tone

Wrist tone

Tone was measured with the Modified Ashworth Scale at the start of the study and at the end of each phase. The Wilcoxon signed rank test was used to assess the difference in the distributions. Two differences were assessed, firstly the difference between the score at the start and the end of the phase, secondly the difference in the "change over phase" variables for each phase. The change over phase variable represents the increase or decrease in score for each subject during that phase.

Group 1

The raw data is plotted in Figure 5-156 and shows a trend for a decrease in tone across the baseline and RMT phases and an increase over the SS phase. The results of the analysis are presented in Table 5-168.

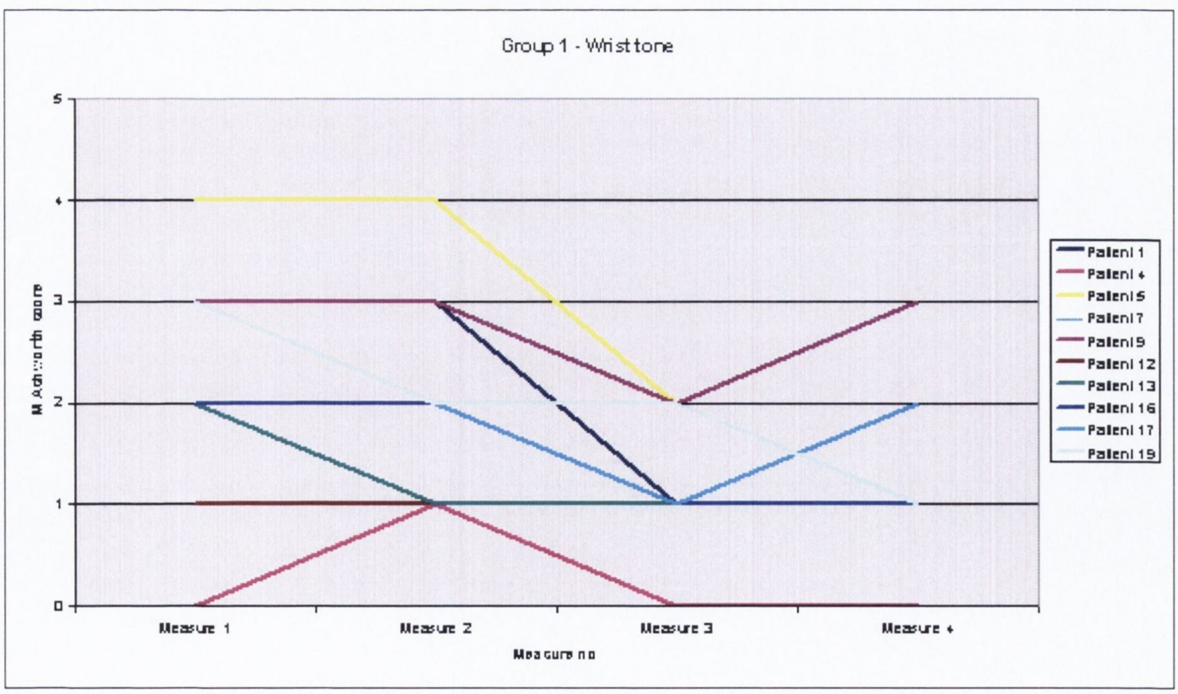

Figure 5-156. Group 1, Wrist tone scores

Difference in Distributions	Negative ranks	Positive Ranks	Equal scores	Z value	Significance
Measures 1 and 2 (Baseline phase)	3	1	6	-1.000	0.317
Measures 2 and 3 (RMT phase)	6	0	4	-2.271	0.023
Measures 3 and 4 (SS phase)	1	3	6	-1.000	0.317

Table 5-168. Group 1, Wrist Tone, change over phase

The decrease in scores over the RMT phase is statistically significant, with no subject demonstrating an increase in tone over the RMT phase. The difference between this change over the RMT phase and that in the SS phases is statistically significant (Table 5-169). Figure 5-157 shows the distribution of the newly constructed change over phase variables.

Difference in Distributions	Negative ranks	Positive Ranks	Equal scores	Z value	Significance
Change over A-Change over B	5	2	3	-1.561	0.119
Change over B-Change over C	1	6	3	-.2.058	0.040
Change over A-Change over C	1	4	5	-1.414	0.157

Table 5-169. Group 1, Wrist tone, difference in change over phase

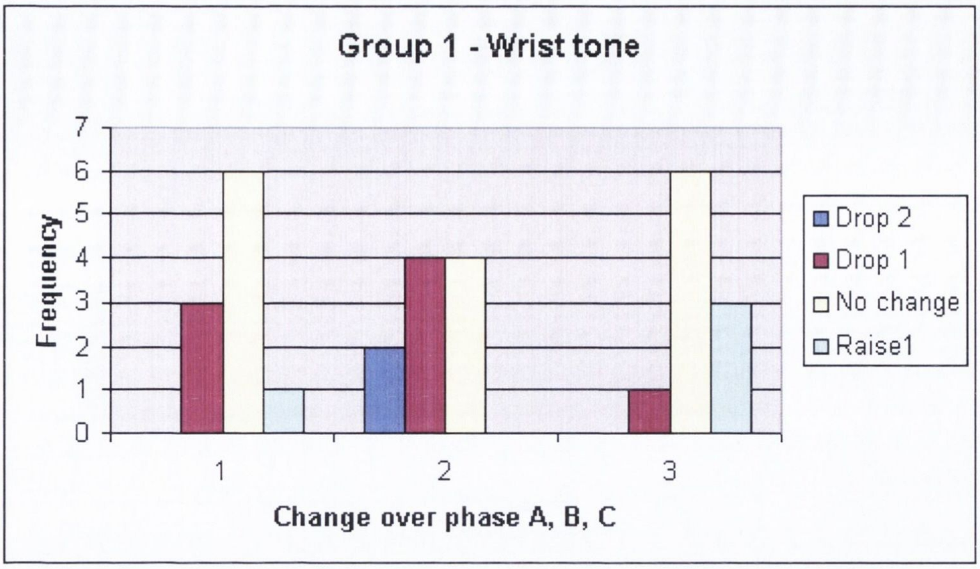

Figure 5-157. Group 1, Change in wrist tone scores

Group 2

The raw data is presented in Figure 5-158 and the results of the analysis of the change over each of the phases in Table 5-170. The changes in scores across each of the 3 phases were not significantly different. The graph shows a trend for a decrease in scores over the RMT phase.

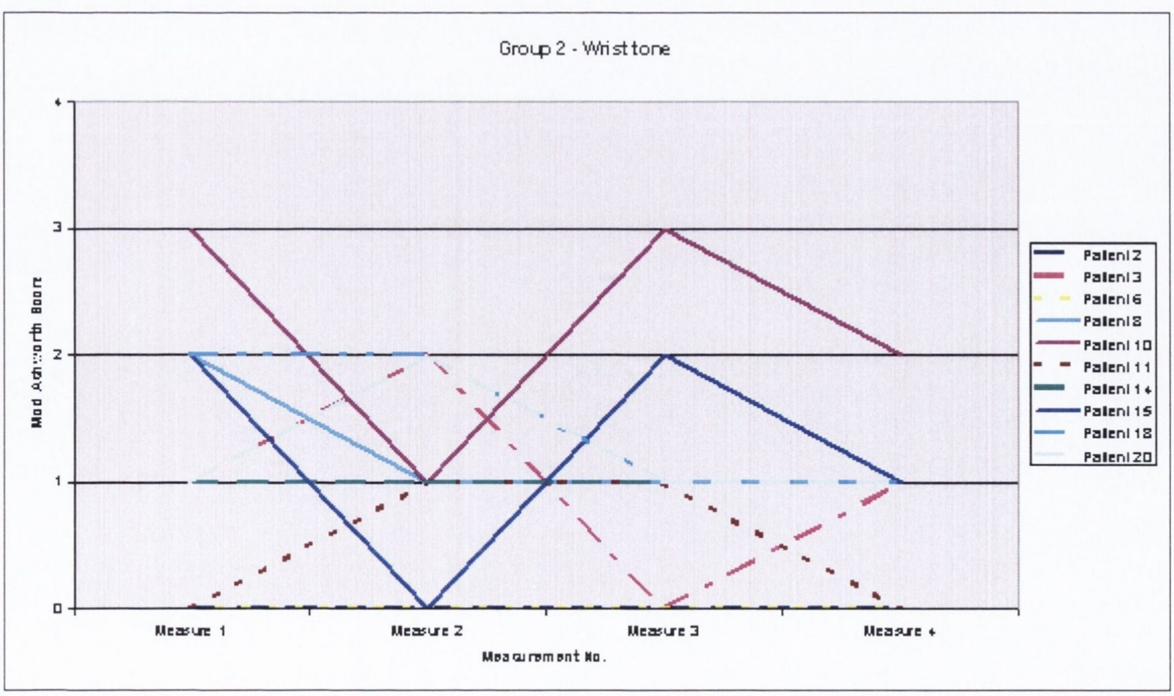

Figure 5-158. Group 2, Wrist tone scores

Difference in Distributions	Negative ranks	Positive Ranks	Equal scores	Z value	Significance
Measures 1 and 2 (Baseline phase)	3	3	4	-0.649	0.516
Measures 2 and 3 (SS phase)	3	2	5	0.138	0.890
Measures 3 and 4 (RMT phase)	3	1	6	-1.000	0.317

Table 5-170. Group 2, Wrist tone, change over phase

There was no statistically significant difference between the change over one phase and another (Table 5-171). The plot of the "change over phase" variables (Figure 5-159) shows a balance in the number of subjects increasing and decreasing scores over the baseline phase, and more decreasing than increasing over the RMT phase.

Difference in Distributions	Negative ranks	Positive Ranks	Equal scores	Z value	Significance
Change over A-Change over C	4	3	3	-0.171	0.865
Change over C-Change over B	3	3	4	-0.322	0.748
Change over A-Change over B	2	3	5	0.000	1.00

Table 5-171. Group 2, Wrist tone, difference in change over phase

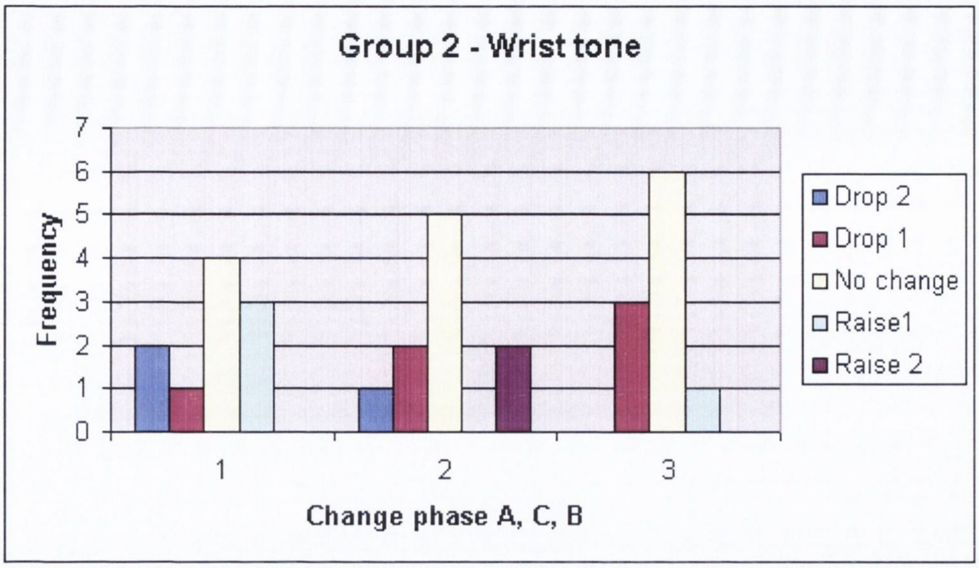

Figure 5-159. Group 2, Change in wrist tone scores

Elbow tone

Group 1

The raw data in Figure 5-160 shows a trend for a decrease in elbow tone score across the RMT phase. The results of the analysis of the change in scores across the phases is presented in Table 5-172 with the decrease across the RMT phase being statistically significant.

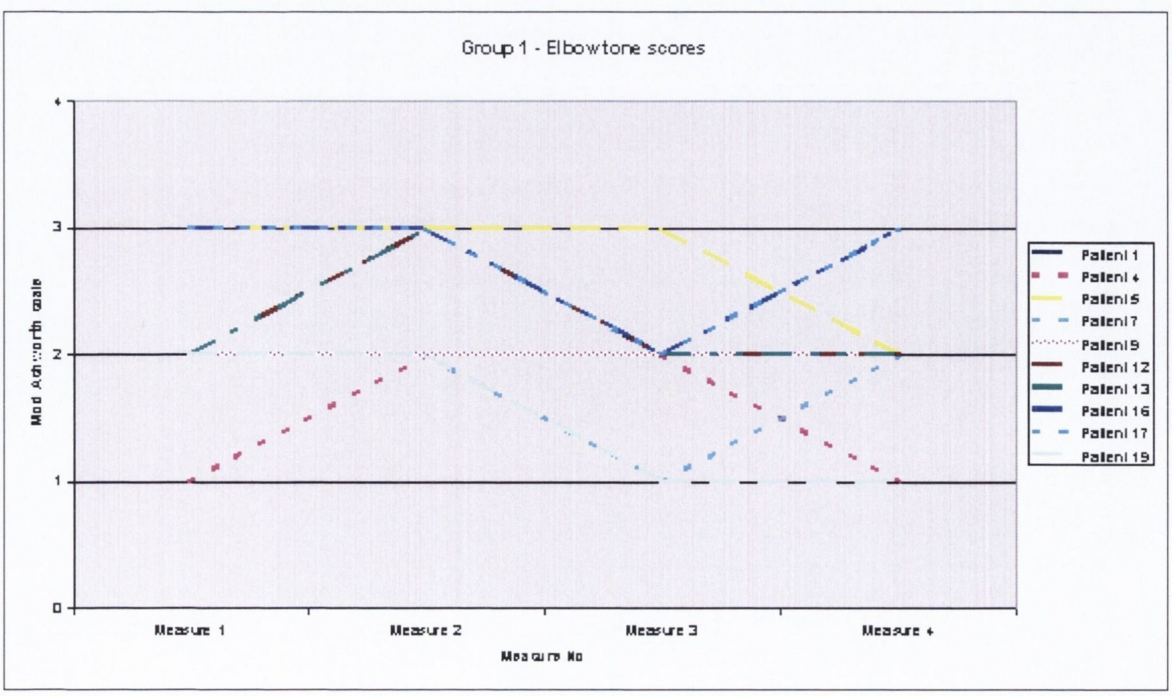

Figure 5-160. Group 1, Elbow tone scores

Difference in Distributions	Negative ranks	Positive Ranks	Equal scores	Z value	Significance
Measures 1 and 2 (Baseline phase)	0	3	7	-1.732	0.083
Measures 2 and 3 (RMT phase)	6	0	4	-2.449	0.014
Measures 3 and 4 (SS phase)	2	3	5	-0.447	0.655

Table 5-172 - Group 1, Elbow Tone, change over phase

The "change over phase" variables are presented in Figure 5-161 and the analysis of this data in Table 5-173. The difference between the change over the RMT phase and that over the baseline phase is statistically significant.

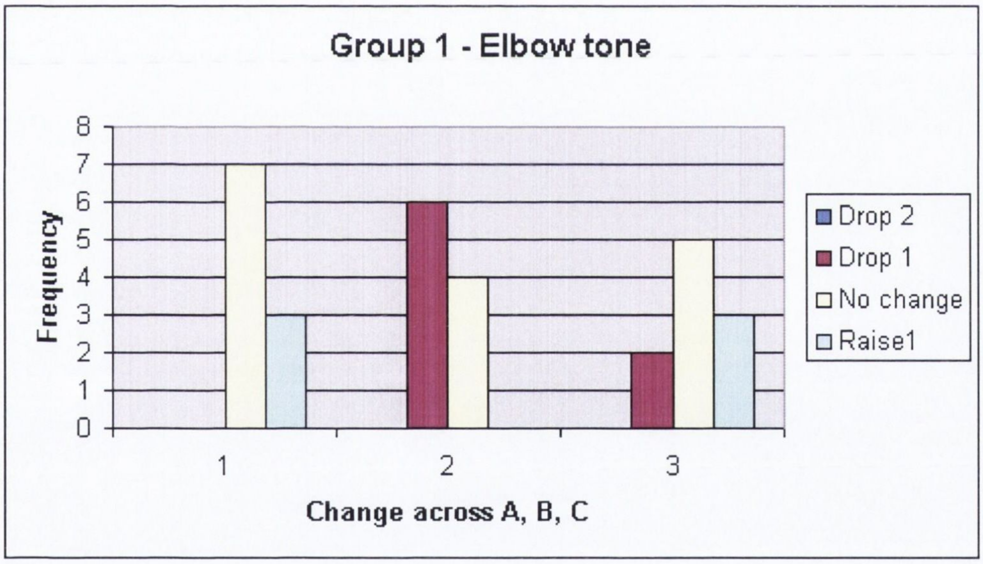

Figure 5-161. Group 1, Change in elbow tone scores

Difference in Distributions	Negative ranks	Positive Ranks	Equal scores	Z value	Significance
Change over A-Change over B	7	0	3	-2.46	0.014
Change over B-Change over C	2	6	2	-1.732	0.083
Change over A-Change over C	4	3	3	-6.32	0.527

Table 5-173. Group 1, Elbow tone, difference in change over phase

Group 2

Figure 5-162 shows the raw data for the elbow tone of group 2. There is a trend towards a decrease between measures 1 and 2 (baseline phase) and measures 3 and 4 which occurred across the RMT phase.

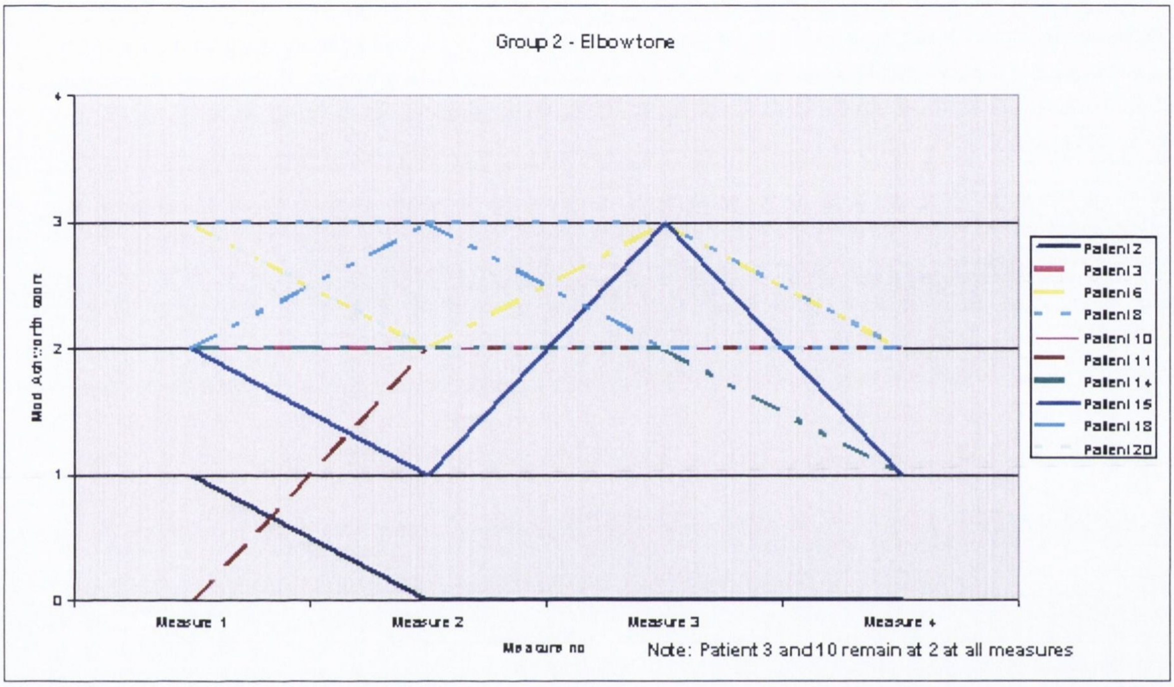

Figure 5-162. Group 2, Elbow tone scores

This analysis of this decrease in score across the RMT phase is presented in Table 5-174. The decrease across the RMT phase is nearing statistical significance.

Difference in Distributions	Negative ranks	Positive Ranks	Equal scores	Z value	Significance
Measures 1 and 2 (Baseline phase)	4	2	4	-0.333	0.739
Measures 2 and 3 (SS phase)	1	2	7	-0.816	0.414
Measures 3 and 4 (RMT phase)	4	0	6	-1.890	0.059

Table 5-174. Group 2, Elbow tone, change over phase

The plotted data of the "change over phase" data in Figure 5-163 shows that there was an overall drop in scores over the baseline and RMT phases. The analysis of this data revealed that the change over one phase was not significantly different to that across another (Table 5-175).

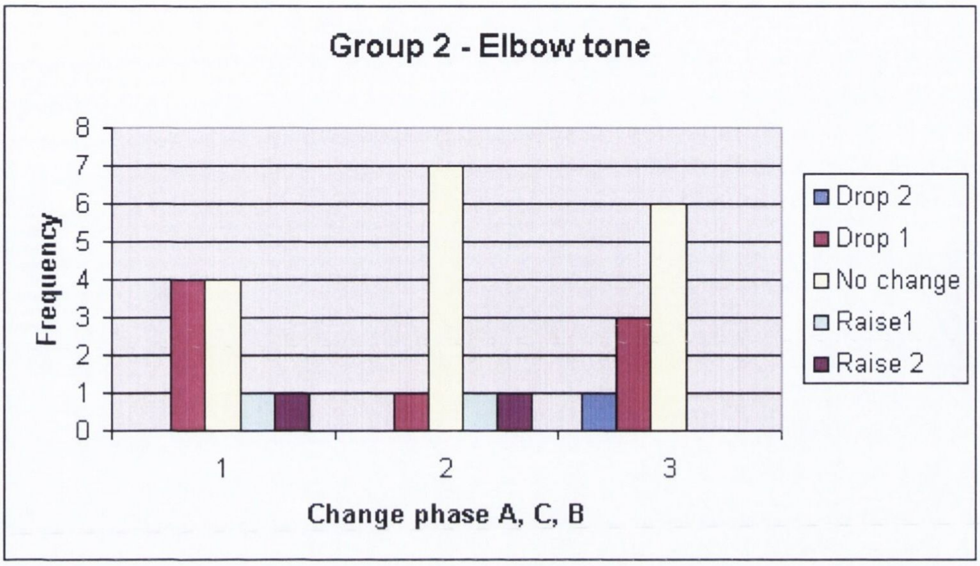

Figure 5-163. Group 2, Change in elbow tone score

Difference in Distributions	Negative ranks	Positive Ranks	Equal scores	Z value	Significance
Change over A-Change over C	2	4	4	-0.531	0.595
Change over C-Change over B	4	1	5	-1.511	0.131
Change over A-Change over B	5	2	3	-1.265	0.206

Table 5-175. Group 2, Elbow tone difference in change over phase

5.3.3 SF-36

Group 1 – SF-36

To investigate whether there was a significant change in score across each phase, the mean score at the start and end of the phase were compared using paired t-tests. The results are presented in Table 5-176. For all mean values a negative number indicates a mean increase over the phase. There was no significant change in any of the ten subsections over any of the phases. The increase over the SS phase for vitality (VT) and the physical composite score (PCS) are nearing statistical significance.

	Phase A			**Phase B**			**Phase C**		
	Mean change A	95%CI change A	p-value changeA	Mean change B	95%CI change B	p-value changeB	Mean change C	95%CI change C	p-value changeC
PF	-1.05	-3.32, 2.71	0.322	0.21	-2.29, 2.71	0.853	-0.63	-4.88, 3.62	0.745
RP	-1.23	-6.47, 4.01	0.608	-0.5	-5.01, 4.01	0.808	-4.38	-10.27, 1.51	0.127
BP	1.84	-1.07, 4.75	0.186	-0.24	-2.27, 1.79	0.795	-2.65	-5.95, 0.65	0.103
GH	-1.08	-4.40, 2.24	0.480	2.15	-2.79, 7.09	0.350	-1.90	-5.82, 2.02	0.301
VT	-0.94	-6.70, 4.82	0.721	0.31	-3.39, 4.01	0.854	-2.81	-6.21, 0.59	0.094
SF	-0.54	-6.47, 5.39	0.841	2.19	-2.74, 7.12	0.341	-2.20	-8.34, 3.94	0.439
RE	4.28	-5.12, 13.77	0.334	1.56	-5.55, 8.67	0.631	-0.79	-9.26, 7.68	0.838
MH	-2.26	-6.36, 1.84	0.244	0.01	-3.40, 3.42	0.995	2.24	-2.68, 7.16	0.330
PCS	-0.92	-3.47, 1.63	0.436	0.06	-2.74, 2.86	0.962	-3.53	-7.79, 0.73	0.094
MCS	0.67	-4.44, 5.78	0.773	1.31	-3.46, 6.08	0.550	0.50	-5.20, 6.20	0.847

Table 5-176. Group 1, SF-36, Mean change over phase

To investigate whether there was a significant difference in the change over one phase compared to another, new change over phase variables were constructed and paired t-tests carried out (Table 5-177). A negative mean difference indicates the change over the second phase was highest. The difference in the change over the SS phase and over the baseline phase was nearing statistical significance for vitality (VT) and mental health (MH) subsections. There was a trend for the change over the SS phase to be greater than the change over the RMT phase.

	Change A – Change B			**Change B – Change C**			**Change A – Change C**		
	Mean A-B	95% CI A-B	p-value A-B	Mean B-C	95% CI B-C	p-value B-C	Mean A-C	95% CI A-C	p-value A-C
PF	1.26	-3.17, 5.69	0.536	-1.89	-7.07, 3.29	0.430	-0.63	-4.17, 2.91	0.697
RP	0.73	-7.07, 8.21	0.830	-3.88	-13.10, 5.34	0.366	-3.15	-0.82, 4.52	0.377
BP	-2.08	-5.95, 1.79	0.256	-2.41	-6.31, 1.49	0.196	-4.49	-9.11, 0.13	0.056
GH	3.23	-2.21, 8.67	0.212	-4.05	-11.95, 3.85	0.267	-0.82	-6.82, 5.18	0.764
VT	1.25	-6.34, 8.84	0.718	-3.12	-9.24, 3.00	0.279	-1.87	-8.93, 5.19	0.564
SF	2.73	-6.86, 12.32	0.535	-4.39	-13.89, 5.11	0.323	-1.66	-9.67, 6.35	0.650
RE	-2.72	-15.31, 9.87	0.637	-2.35	-13.04, 8.34	0.631	-5.07	-20.52, 10.38	0.477
MH	2.27	-3.62, 8.16	0.406	2.23	-5.41, 9.87	0.526	4.50	-0.53, 9.53	0.074
PCS	0.98	-3.66, 5.62	0.644	-3.59	-9.79, 2.61	0.233	-2.61	-7.08, 1.86	0.219
MCS	0.64	-7.86, 9.14	0.869	-0.81	-9.20, 7.58	0.832	-0.17	-7.32, 6.98	0.958

Table 5-177. Group 1, SF-36, Mean difference in change over phase

Group 2 – SF-36

To investigate whether there was a significant change in score across each phase, the mean score at the start and end of the phase were compared using paired t-tests.

The results are presented in Table 5-178. For all mean values a negative number indicates a mean increase over the phase.

There was no significant change in any of the ten subsections over any of the phases. The increase over the RMT phase for physical functioning (PF) and the emotional roles for the baseline phase are nearing statistical significance.

	Phase A			**Phase C**			**Phase B**		
	Mean change A	95% CI change A	p-value change A	Mean change C	95% CI change C	p-value change C	Mean change B	95% CI change B	p-value change B
PF	-0.42	-5.86, 5.02	0.865	1.28	-3.39, 5.95	0.551	-3.59	-7.49, 0.31	0.067
RP	-4.16	-12.43, 4.11	0.285	1.71	-2.67, 6.09	0.400	-1.49	-4.70, 1.72	0.321
BP	-4.24	-11.62, 3.14	0.226	-1.98	-6.85, 2.89	0.382	1.70	-7.77, 11.17	0.694
GH	2.71	-4.05, 9.47	0382	-1.68	-4.70, 1.34	0.236	1.03	-3.36, 5.42	0.609
VT	5.18	-1.49, 11.85	0.111	-2.06	-11.58, 7.47	0.632	-3.43	-12.26, 5.40	0.402
SF	-4.90	-11.38, 1.58	0.121	2.19	-7.04, 11.42	0.604	0.54	-5.94, 7.02	0.855
RE	-5.45	-11.77, 0.87	0.083	9.73	1.30, 18.16	0.028	-4.28	-12.51, 3.95	0.270
MH	5.01	-1.99, 12.01	0.137	1.56	-13.45, 16.56	0.817	-1.40	-14.01, 11.21	0.807
PCS	-2.29	-8.68, 4.11	0.433	-1.30	-6.60, 4.00	0.587	-0.21	-4.99, 4.57	0.923
MCS	1.37	-5.56, 8.29	0.661	3.60	-8.68, 15.88	0.518	-2.38	-10.87, 6.02	0.538

Table 5-178. Group 2, SF-36, Mean change over phase

To investigate whether there was a significant difference in the change over one phase compared to another, new change over phase variables were constructed and paired t-tests carried out (Table 5-179).

A negative mean difference indicates the change over the second phase was highest. The difference in the change over the RMT phase was statistically significantly different from the change over the baseline phase for vitality (VT). The change in emotional role subsection (RE) was significantly greater in the baseline phase than the SS phase. There is no clear trend for the differences in changes across phases.

	Change A – Change B			**Change B – Change C**			**Change A – Change C**		
	Mean A-C	95% CI A-C	p-value A-C	Mean C-B	95% CI C-B	p-value C-B	Mean A-B	95% CI A-B	p-value A-B
PF	1.70	-7.87, 11.27	0.697	-4.87	-11.92, 2.18	0.153	-3.17	-10.33, 3.99	0.343
RP	5.87	-6.07, 17.81	0.295	-3.20	-9.04, 2.64	0.247	2.67	-6.94, 12.28	0.545
BP	2.26	-7.05, 11.57	0.596	3.68	-7.44, 14.80	0.473	5.94	-5.17, 17.05	0.257
GH	-14.3	-37.7, 9.1	0.199	8.31	-8.30, 24.92	0.287	-5.99	-14.57, 2.59	0.149
VT	-14.74	-36.45, 6.97	0.159	3.63	-16.93, 24.19	0.699	-11.11	-20.38, -1.84	0.024
SF	7.09	-7.15, 21.33	0.289	-1.65	-14.90, 11.60	0.785	5.44	-3.75, 14.63	0.213
RE	15.18	2.15, 28.21	0.027	-14.01	-27.40, -0.62	0.042	1.17	-10.34, 12.68	0.823
MH	-10.0	-32.8, 12.8	0.347	1.4	-26.6, 29.3	0.915	-8.66	-20.14, 2.82	0.122
PCS	-9.9	-36.1, 16.3	0.415	6.94	-9.78, 23.66	0.372	-2.95	-15.08, 9.18	0.596
MCS	-4.46	-26.63, 17.71	0.660	-2.24	-22.22, 17.74	0.806	-6.70	-16.42, 3.02	0.153

Table 5-179. Group 2, SF-36, Mean difference in change over phase

5.4 Differences between groups

The groups were compared in terms of their baseline characteristics using 2 sample t-tests.

The estimate for the difference in means of the groups, the 95% confidence interval for the difference and the p-value for the null hypothesis that the difference= 0, are presented. Chi-Squared analysis is applied to the tone data, which is categorical in nature.

The raw data are plotted on box plots, the red dot representing the mean, the shaded area the 2nd and 3rd quartiles, the line through the shaded area the median, and the whiskers the 1st and 4th quartiles. Outliers are represented by an asterix.

Age at entry to study

The estimate for the difference in the means of the groups was -3.11 years, with the 95% CI for difference: (-12.75, 6.52). The p-value was 0.500. While there was no statistically significant difference in the means, on examining the plotted raw data, the spread of group 2 is larger than that of group 1 with group 2 having a greater maximum age.

Figure 5-164. Age at entry to study

Time since stroke

The estimate for the difference in the means is -12.21 months, with the 95% CI for difference: (-32.11, 7.69). The p-value was 0.201. While the difference in means was not statistically significant, an average difference of 12 months is a significant length of time in relation to recovery, also the maximum value for group 2 is much larger with group 2 having greater variability of data.

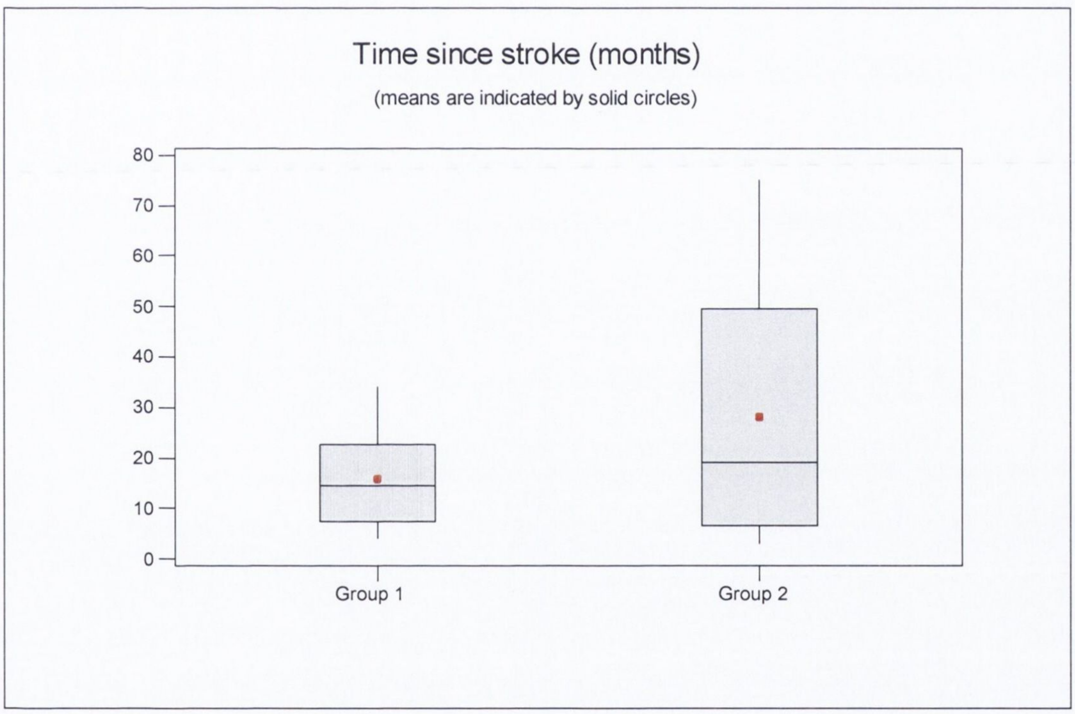

Figure 5-165. Time since stroke

Baseline Fugl Meyer score

The estimate for the difference in means was -0.74 units. With the 95% CI for difference: (-15.27, 13.79). The p-value was 0.915.

In examining the raw data, while both groups are centred on a score of 25, the baseline scores of group 1 are less variable compared to those of group 2. Group 1 also has a higher maximum score.

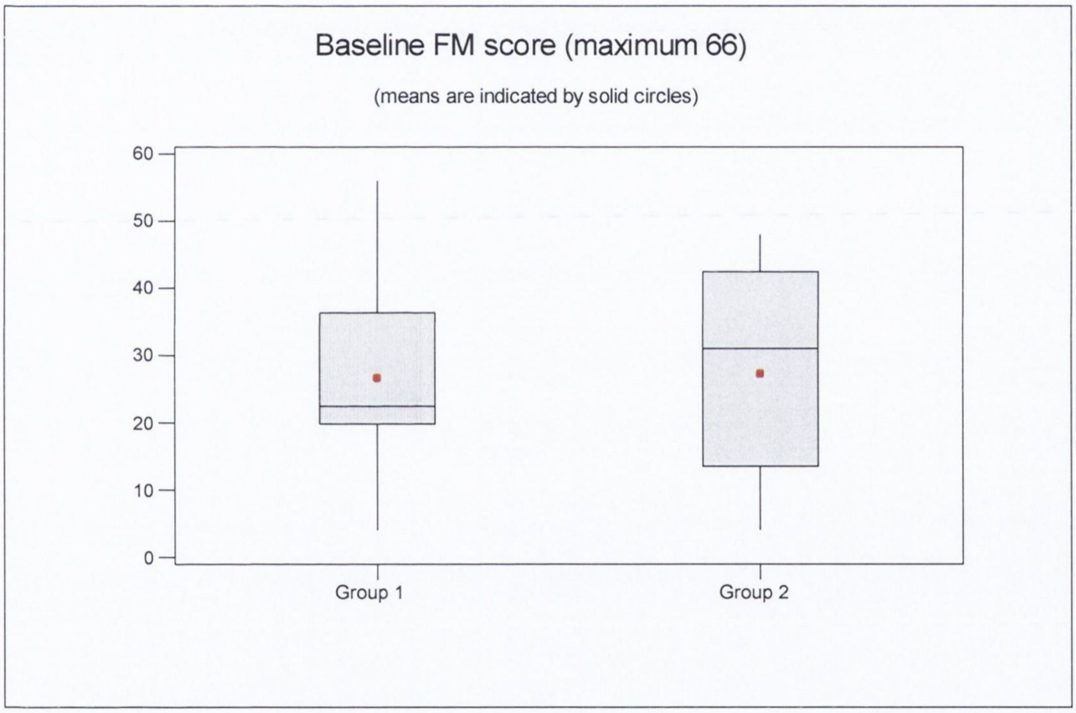

Figure 5-166. Baseline FM score

Sensation

The estimate for the mean difference in sensation score was -0.21, with the 95% CI for difference: (-8.45, 8.03). The p-value was 0.957. The plots of the raw data are similar for both groups, with group 1 having an outlier with a score of 5.

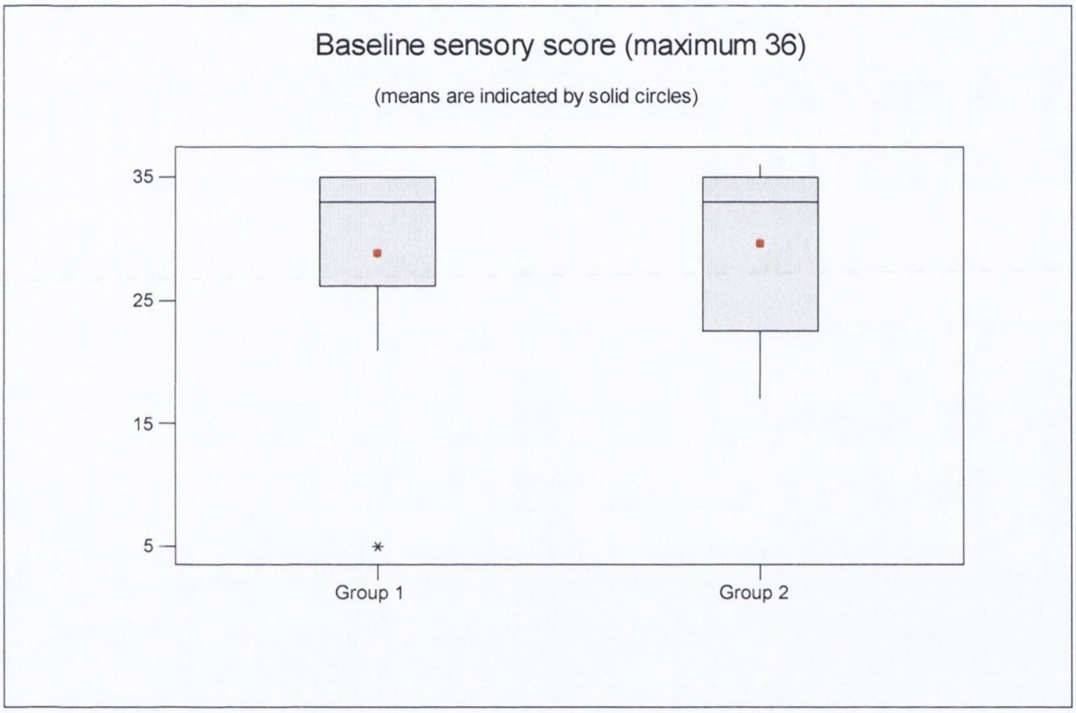

Figure 5-167. Baseline sensory score

Pain score

The estimate for the difference in the means was -2.19cms, with the 95% CI for difference: (-4.66, 0.28). The p-value was 0.076, which is nearing significance at an alpha level of 0.05. In examining the plotted raw data, the mean of group 2 is higher, with group 2 having a higher variability and higher maximum score.

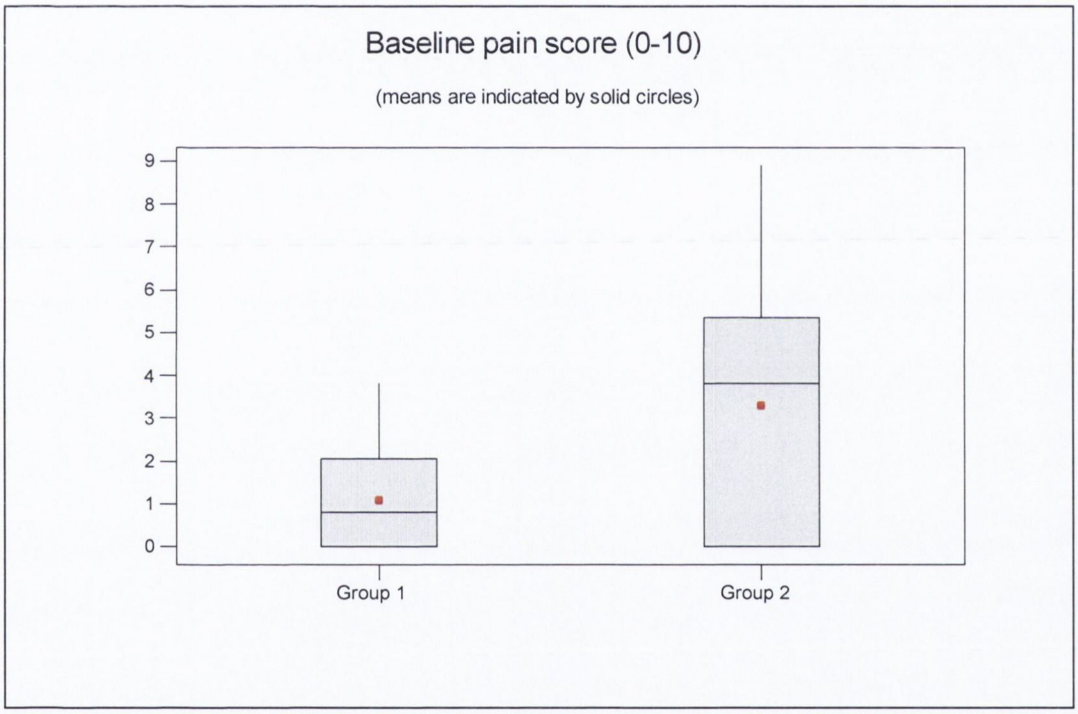

Figure 5-168. Baseline pain score

Tone

The raw data for elbow and wrist tone are plotted on dot plots below. To investigate whether the distribution of tone values across the groups was the same, a Chi-Squared test was applied. There was no difference in the distribution of scores between the groups. (Chi value 8.333, p value 1.000)

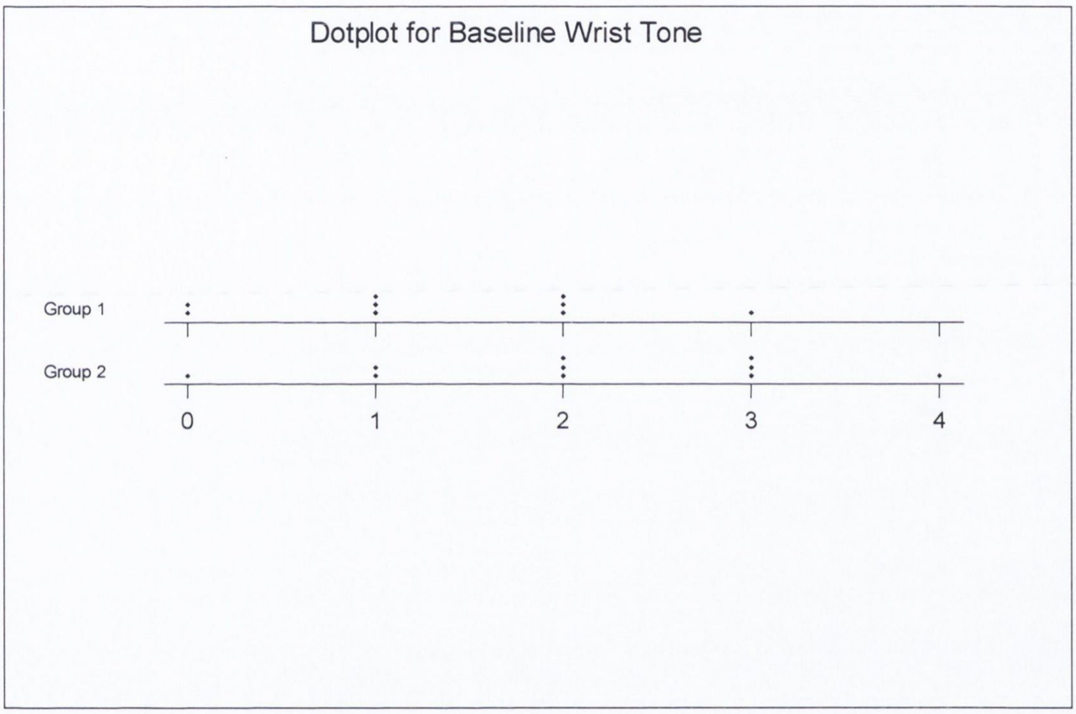

Figure 5-169. Baseline wrist tone

There was no difference in the distribution of baseline elbow tone scores between the groups (Chi value 2.667, p value 1.000)

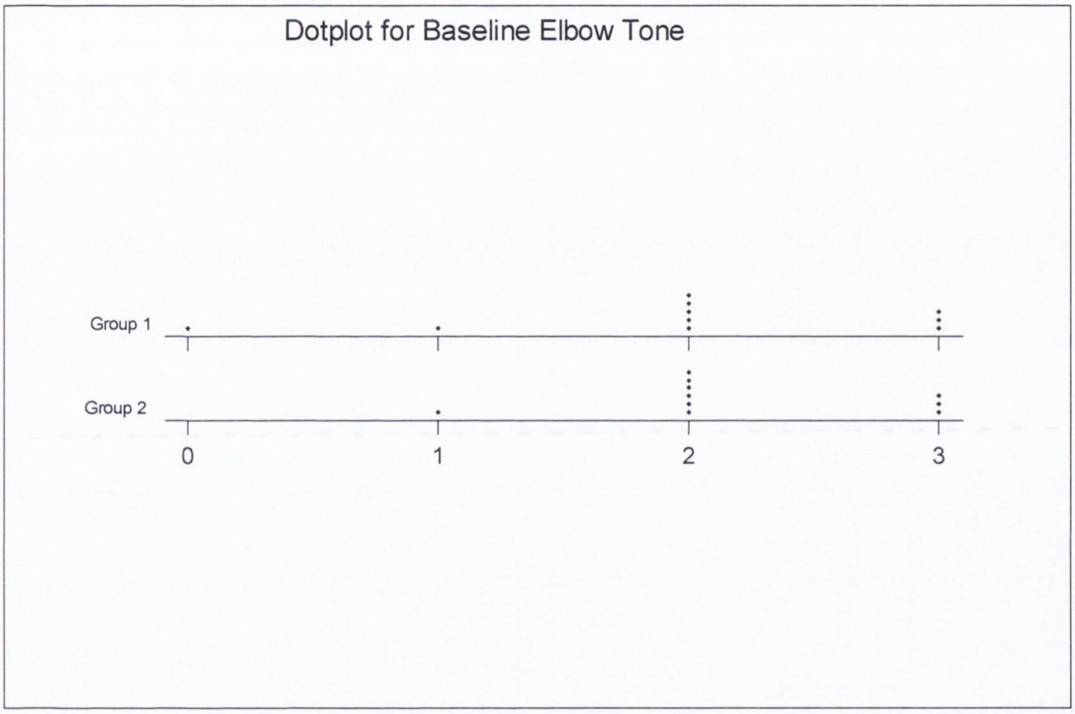

Figure 5-170. Baseline elbow tone

Table 5-180 and Table 5-181 present a summary of the background characteristics of groups 1 and 2.

Subject Number	1	4	5	7	9	12	13	16	17	19	Mean
Gender	M	F	F	M	M	M	M	M	M	F	
Affected side	L	L	R	R	R	R	L	R	L	L	
Age at entry to study (years)	71	70	79	66	63	62	52	64	59	74	66
Time since stroke (months)	5	16	13	24	22	34	21	4	12	8	15.9
FM score /66	22	40	29	56	21	23	35	16	21	4	26.7
Sensory score /36	35	21	5	35	32	35	28	34	34	30	28.9
Star cancellation test /54	54	50	54	54	54	54	53	54	54	43	52.4
Elbow tone 0-5	2	1	3	2	2	2	2	3	3	3	2.3
Wrist tone 0-5	3	0	4	1	3	1	2	2	3	2	2.1
Hemianopia (0=absent, 1=inattention)	0	0	0	0	0	0	1	0	0	0	
Pain score 0-10	2	3.8	0	1.3	0.3	0	0	0	2.2	1.4	1.1

Table 5-180. Background data, Group 1

Subject Number	2	3	6	8	10	11	14	15	18	20	Mean
Gender	M	F	F	F	F	F	M	F	M	M	
Affected side	R	R	L	L	L	R	R	L	L	L	
Age at entry to study (years)	79	80	79	69	73	65	65	84	58	49	69.1
Time since stroke (months)	3	19	60	39	10	25	3	3	19	75	28.1
Baseline FM score /66	57	46	48	31	4	12	39	31	15	21	27.4
Sensory score /36	35	36	33	32	33	24	34	18	17	35	29.1
Star cancellation test /54	54	53	52	54	54	52	54	44	49	54	51.8
Elbow tone 0-5	1	2	3	3	2	0	2	2	2	3	2.1
Wrist tone 0-5	0	1	0	2	3	0	1	2	2	1	1.3
Hemianopia (0=absent, 1=inattention)	0	0	0	0	0	0	0	1	1	0	
Pain score 0-10	2.3	8.9	0	4.7	0	3.8	4.3	6	0	1.9	3.3

Table 5-181. Background data, Group 2

5.5 Summary of results

Twenty subjects took part in the clinical trial. Each subject was measured with 24 study variables and 5 background outcome measures over the course of the trial. Each subject completed 3 phases. As seen in this chapter there is a large quantity of data, the key points of which are summarised below. In order to summarise the results and to allow comparison to other studies in this area the average response of the 10 individuals in each group (ABC, ACB) are also presented in this section.

5.5.1 Individual results

The absolute value of the slope in the RMT phase was higher than both baseline and SS phases for many variables for most subjects. Comparison of the differences in slopes between the phases to the aMDC allowed the distinction between true change and that due to measurement error. There were very few variables for which the differences between the slope values of the phases could be considered greater than measurement error. These differences are described as being significantly higher.

No two subjects had the same response to the intervention. Both the magnitude of the differences in slopes and the outcome variables affected differed between individuals.

Five subjects, 1, 4, 5, 6, and 7, had more than 15 of the 24 variables where the absolute slope value was greatest during the RMT phase.

The subject with the greatest number of variables where the rate of recovery was significantly higher than both the baseline and SS phases was subject 5.

Table 5-182 summarises the absolute results of the 20 subjects. When the absolute value for RMT is greatest it is indicated in red, blue indicates RMT greater than baseline value and purple RMT greater than SS.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FMA		red		red	red	red	red	red	red	red		red		red	red	red	green		blue	
FMB	red	red	blue	green	green	red			green			green	red			red	green			
FMC	red		blue		blue	green		blue			red			red	red			red		green
FMD	red	green	blue	blue	red	green	red				green	red		red	blue					green
FM Total	red	red	blue	red	red	red	red	red	red	red		blue	blue	red	blue	green	green	green	blue	
MASA	blue			red	red	red	red	red	red		green			red	red	red		blue		green
MASB	red	red	blue	red	red	red	green	red			red		blue	green	red					green
MASC	red	green	red	red		red	blue							green						
MAST	red	green	red	red	red	red	red	red	red		green		blue	green	red	blue		blue		green
El Fl	red	red		red		red	red	green	green		red	green	green	red	green	red	red	red		blue
El X	red	red		red	red		red				blue	green	green	red		blue	red			green
Sh Fl	red	red	blue	red	red	red	red		red				green	red	red	red		red		red
Sh X	red	red		red	red	red	green		red		blue	green		red		blue	green			
AshFl	red	green		red	red	red	red	blue	red		red		red	red	blue	red		red		red
PShFl	red	green		red	green	red	red	red		blue	red	blue	red	blue	red		blue	green	green	blue
AshAb	blue		red	red	red	red	red	red	green		red	red		blue	red	red	green	red		red
PshAb			red	green		red	red			red	blue	red		red	green					red
AelX	red	red	blue	red	red	green	red	red	red		green	red	red	green		red	red	blue		green
PelX	red	red	red			green	red	green		red	red	blue	red	red		red	red		blue	
AshER	red	green	red	red	red		blue		blue			red	green	green	red		blue			
PshER		green	green		red	blue	blue	red	red	green	blue			red	green			red		
AelFl	blue		green	green	red	blue	green	green	green	red	red	red	green	red	red	red		blue		blue
PelFl		red	red	green		red	red	green	green						red		red	blue		
Grip	red	red			blue	red		green						red			red			red

Table 5-182. Summary absolute values

Table 5-183 provides a summary of variables where RMT is significantly greater than baseline and SS (red), than baseline only (green) and than SS only (gold).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FMA				● gold	● red	● green						● green		● green						
FMB	● red											● green								
FMC	● green		● green											● gold	● red					
FMD	● green		● green		● red		● gold					● green								
FM Total	● red		● green		● red	● red						● green		● red						
MASA	● gold			● green	● red	● gold	● gold	● red	● green					● gold	● red			● green		● gold
MASB	● green			● red	● red	● gold		● green			● red			● gold	● gold					● gold
MASC	● gold	● gold	● red	● green																
MAST	● red	● gold	● red	● red	● red	● gold	● gold	● red	● green					● gold	● red			● green		● gold
El Fl	● green	● gold		● green		● green	● gold						● gold	● gold			● red			
El X	● green	● green		● red			● red										● red			
Sh Fl	● green	● green					● red							● red						
Sh X	● red			● green										● red						
AshFl	● red			● red			● green		● gold							● red		● red		
PShFl				● red			● green	● gold							● green					
AshAb						● red										● green				● red
PshAb						● red				● red										
AelX	● green			● green					● red											● gold
PelX								● gold		● gold	● green						● gold			
AshER			● green				● green					● green			● gold					
PShER			● gold															● gold		
AelFl	● green									● red						● gold				
PElFl																				
Grip		● red				● gold								● gold			● gold			

Table 5-183. Summary of significant individual variables

Table 5-184 provides a summary of variables for which the values of the baseline slope is highest (blue) and the SS slope is highest (purple).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FMA	blue		blue								blue		purple				blue	blue	purple	blue
FMB			purple	blue	blue			blue	blue		purple	purple		blue	blue		blue			blue
FMC		blue	purple	purple	purple	blue		purple	blue			purple	blue			blue	blue			blue
FMD		blue	purple	purple		blue		purple	blue		blue		blue		purple	blue	blue			blue
FM Total			purple								blue	purple	purple		purple	blue	blue	blue	purple	blue
MASA	purple		purple							purple	blue	blue					blue	purple		blue
MASB			purple				blue					blue	purple	blue		purple	blue			blue
MASC		blue			blue		purple							blue	blue					
MAST		blue								purple	blue	blue	purple	blue		purple	blue	purple		blue
El Fl			purple		blue			blue	blue			blue	blue		blue					purple
El X			purple			blue		blue	purple	purple	purple	blue	blue		purple	purple		blue		blue
Sh Fl								blue					blue				blue			
Sh X			purple				blue	blue			purple	blue	blue		purple	purple	blue	blue		blue
AshFl		blue	purple					purple				blue			purple		purple			
PShFl		blue	purple		blue				blue	purple		purple		purple		purple	purple	blue	blue	purple
AshAb	purple	blue							purple				blue	purple			blue			
PshAb	blue	blue		blue	blue			purple	purple		purple		blue	purple	blue	blue	blue	purple	purple	
AelX			purple			blue					blue			blue	blue			purple		blue
PelX				blue	blue	blue		blue	purple			purple			blue			blue	purple	purple
AshER		blue				purple	purple	purple	purple				blue	blue			purple			blue
PshER	blue	blue	blue	blue		purple	purple			blue	purple	purple	blue		blue	blue	blue		blue	purple
AelFl	purple	purple	blue	blue		purple	blue	blue	blue				blue				blue	purple		purple
PelFl	blue	purple		blue	blue			blue	blue	purple	blue	blue	blue	blue		purple		purple	blue	purple
Grip			purple	blue	purple		blue	blue	blue			purple	blue			blue				

Table 5-184, Summary of baseline and SS slope values highest

Replication of results

Some trends can be seen in the individual results. Subjects 4, 5 and 7 had absolute values of the RMT slope that was greater than that of both the baseline and the SS phase for the A and total section of the Fugl-Meyer, the A and total section of the MAS, the MVIC for shoulder flexion and elbow extension, and for active range of motion of shoulder flexion and elbow extension.

Subject 1 showed the same results except that for the FMA section the slope was greatest during the baseline phase.

Subject 2 showed the same replication, except for the active range of motion shoulder flexion, which was highest in the baseline phase.

Subject 6 showed the same results except that for the MVIC variables the slope was greatest during the baseline phase.

Results in favour of baseline phase

The majority of the variables for subjects 13, 17 and 20 had the highest absolute slope value during the baseline phase.

Results in favour of sling suspension phase

Subject 3 had a high proportion of variables for which the slope was greatest in the SS phase.

Subjects with little or no change

Two subjects showed little or no change in any variables during the study, these were subjects 10 and 19.

Notable individual results by outcome measure

For 11 of the 20 subjects the MASC variable did not change.

For grip strength, only one subject (2) demonstrated a rate of recovery during the RMT phase that was significantly greater than that of the other phases. Only three other subjects had differences in slope values that were statistically significant.

For PROM shoulder abduction, shoulder external rotation and elbow flexion the absolute value of the slope was greatest in the baseline phase in the majority of subjects. For PROM elbow flexion there were no significant differences in the slopes of the three phases.

Background measures

There was a significant decrease in tone scores in the SS phase for group 1. The increase in scores over the SS phase for group 2 was significantly different to the change in scores over the RMT phase. For both groups there was an overall decrease in score over the RMT phase.

Pain decreased over each phase except the RMT phase for group 2 where it increased by on average 0.2 centimetres on the vas. This increase was not significantly different from the decreases in the other phases.

No trends emerged, either positive or negative, in the SF-36 data.

Difference between groups

On average group 2 was three years older and 12 months post stroke later than group 1 and had an average of 2cm more pain on the VAS, though none of these differences were statistically significant.

5.5.2 Average response of group 1 and group 2

The average of the 10 slopes for each subject for each phase are compared using paired t-tests. Where the absolute value of the mean slope in the RMT phase is greater than both the SS and baseline phases the variable name is highlighted in red. Where it is higher than baseline only it is highlighted in blue and than SS only in purple. When the difference in mean slope is statistically significant the p-value is highlighted in yellow, and when nearing statistical significance in blue.

Table 5-185 presents the results for group 1. For 18 of the 24 variables the absolute value of the slope in the RMT phase was greater than that of the baseline and SS phases. This was significantly so for only the active elbow extension measurement. The slope during the RMT phase was significantly greater than the baseline for the total FM score, and was nearing statistical significance for active shoulder flexion.

The values for the difference in slope between the RMT and SS phases for shoulder flexion and extension MVIC and active shoulder flexion were nearing statistical significance in favour of RMT.

For three variables, passive range of shoulder abduction, shoulder external rotation and elbow flexion the slope value was greatest during the baseline period. For two variables FMC and MASB, the rate was highest during the SS phase.

Table 5-186 presents a summary of the results for group 2. For 15 of the 24 variables the absolute value of the slope is greatest during the RMT phase. This was not significant for any variables but was nearing significance for shoulder flexion MVIC.

The difference between the slope values of the RMT and SS phases was statistically significant for MAS total and passive elbow extension. It was nearing significance for MASB, active shoulder abduction, passive shoulder external rotation and grip strength.

For three variables, shoulder flexion MVIC, active and passive shoulder flexion ROM the difference in the slope value between the A and SS phases was nearing significance.

Table 5-185 presents the average response of the 10 individuals in group 1, who followed the ABC order, receiving RMT as their first treatment.

	A	B	C	B-A	C-B	C-A	p B-A	p C-B	p C-A
FMA	0.09	0.31	0.08	0.22	-0.23	-0.01	0.11	0.02	0.87
FMB	0.00	0.11	0.06	0.10	-0.04	0.06	0.18	0.26	0.32
FMC	0.06	0.02	0.06	-0.05	0.04	0.00	0.25	0.12	0.95
FMD	0.04	0.07	0.05	0.03	-0.02	0.01	0.47	0.50	0.69
FMT	0.19	0.44	0.25	0.25	-0.20	0.06	0.06	0.11	0.64
MASA	0.00	0.08	0.05	0.08	-0.03	0.05	0.13	0.42	0.22
MASB	0.04	0.04	0.05	0.00	0.01	0.01	0.88	0.84	0.71
MASC	0.02	0.03	0.01	0.01	-0.02	-0.01	0.72	0.38	0.61
MAST	0.03	0.14	0.10	0.11	-0.04	0.07	0.22	0.57	0.28
ElFl	0.29	0.30	0.11	0.00	-0.18	-0.18	0.99	0.18	0.36
ElX	0.18	0.38	0.11	0.20	-0.27	-0.07	0.24	0.18	0.74
ShFl	0.15	0.25	0.07	0.09	-0.18	-0.09	0.48	0.07	0.49
ShX	0.34	0.37	0.19	0.02	-0.18	-0.16	0.90	0.06	0.34
AShF	0.40	1.67	0.35	1.27	-1.32	-0.05	0.07	0.06	0.89
PShFl	0.21	0.53	0.30	0.32	-0.24	0.08	0.36	0.47	0.84
AShAb	0.03	0.46	0.36	0.43	-0.11	0.33	0.40	0.72	0.24
PShAb	0.63	0.03	0.36	-0.60	0.33	-0.27	0.09	0.15	0.28
AElX	-0.13	1.16	0.14	1.28	-1.01	0.27	0.01	0.00	0.30
PElX	-0.02	0.18	0.08	0.19	-0.10	0.10	0.13	0.47	0.38
AShER	-0.19	0.28	0.14	0.47	-0.14	0.33	0.18	0.21	0.38
PShER	0.73	-0.19	0.36	-0.92	0.55	-0.37	0.03	0.03	0.26
AElFl	0.56	0.58	0.00	0.02	-0.58	-0.56	0.94	0.10	0.11
PElFl	0.26	-0.08	-0.03	-0.34	0.05	-0.29	0.01	0.63	0.01
Grip	0.17	-0.01	0.10	-0.18	0.11	-0.07	0.12	0.26	0.12

Table 5-185. Average response of group 1

Table 5-186 presents the average response of the 10 individuals in group 2 who received SS treatment first.

	A	C	B	C-A	B-C	B-A	p C-A	p B-C	p B-A
FMA	0.13	0.16	0.22	0.03	0.06	0.08	0.78	0.34	0.52
FMB	0.10	0.08	0.01	-0.01	-0.07	-0.09	0.73	0.17	0.11
FMC	0.07	0.05	0.09	-0.01	0.04	0.03	0.87	0.45	0.56
FMD	0.03	0.06	0.05	0.02	-0.01	0.01	0.60	0.71	0.64
FM Total	0.33	0.34	0.39	0.01	0.05	0.05	0.97	0.60	0.73
MASA	0.01	0.02	0.09	0.01	0.07	0.07	0.83	0.13	0.10
MASB	0.06	0.02	0.07	-0.04	0.05	0.02	0.40	0.07	0.57
MASC	0.05	-0.01	0.03	-0.07	0.04	-0.03	0.06	0.21	0.25
MAS Total	0.15	0.03	0.18	-0.12	0.14	0.02	0.14	0.02	0.70
ElFl	0.20	0.16	0.30	-0.04	0.14	0.10	0.78	0.29	0.19
ElX	0.26	0.20	0.16	-0.06	-0.05	-0.11	0.70	0.57	0.47
ShFl	0.01	0.10	0.28	0.08	0.19	0.27	0.47	0.09	0.09
ShX	0.28	0.20	0.30	-0.09	0.10	0.02	0.46	0.55	0.93
AShFl	0.35	0.86	1.49	0.50	0.64	1.18	0.27	0.14	0.08
PShFl	-0.20	0.49	0.33	0.68	-0.16	0.53	0.13	0.67	0.08
AShAb	-0.02	0.04	0.92	0.06	0.88	0.94	0.85	0.07	0.16
PShAb	0.15	0.10	0.65	-0.04	0.55	0.50	0.84	0.22	0.31
AElX	0.76	0.42	0.72	-0.35	0.30	-0.05	0.54	0.49	0.86
PElX	0.20	0.02	0.34	-0.19	0.32	0.14	0.38	0.05	0.41
AShER	0.41	0.00	0.23	-0.40	0.22	-0.18	0.24	0.47	0.44
PShER	0.43	-0.18	0.27	-0.61	0.45	-0.16	0.08	0.09	0.48
AelFl	0.04	0.30	1.04	0.26	0.75	1.00	0.52	0.48	0.23
PElFl	0.03	0.17	-0.05	0.14	-0.22	-0.07	0.58	0.22	0.66
Grip	0.10	0.05	0.15	-0.05	0.10	0.05	0.32	0.08	0.47

Table 5-186. Average response of Group 2

6 Chapter 6 - Discussion

6.1 Introduction

The proportion of recovery of function in the hemiplegic UE is considerably less than that of the lower extremity and the residual deficits make a large contribution to the decreased ability to function at home and in society and also to decreased well being post stroke.

While there has been much research exploring physiotherapy treatments post stroke, a review of the literature revealed little evidence to support any one of the many forms of intervention for the UE. This concurs with a recent systematic review that described the "lack of evidence to guide current practice" (Pomeroy & Tallis 2000).

Physiotherapy research in the last decade has attempted to follow the path of "unpacking the black box" that is physiotherapy post stroke (Edwards et al 1990) to identify which of the many components are responsible for the improvements seen. The evidence emerging from the literature is that exercise based interventions show positive treatment effects (Pomeroy & Tallis 2000, Coote & Stokes 2001) and that a higher dosage of intervention improves the outcome (Kwakkel et al 1997, Langhorne et al 1996).

It has been suggested that a complimentary research approach would be to develop therapies based on our emerging understanding of neuroscience and to comprehensively evaluate these (Pomeroy & Tallis 2002). Studies on animal and human brains suggest that repeated practice of meaningful movements has a positive effect on cortical reorganisation (Nudo et al 1996, Liepert et al 2000). In animals, when these movements require skill and are challenging, the degree of cortical reorganisation is optimised (Plautz et al 2000).

The outputs of both these research strands are combined to form the principles behind RMT. The GENTLE/s system is capable of delivering a higher intensity of exercise based intervention that is repetitious, challenging and engaging. The virtual representation of the task on screen coupled with the haptic feedback provided by the robot builds on the systems previously evaluated in the USA that were found to have positive treatment effects (Volpe et al 2000, Lum et al 2002).

This study examined the effect of a period of treatment with RMT on the hemiplegic UE and compared it to a baseline measurement phase and to a period of treatment with sling suspension (SS) in 20 individuals. The order of treatment and length of baseline were randomised. The outcome was measured at the level of impairment of body structures, activity limitations and participation restrictions. In addition the presence and/or level of coexisting impairments that may influence the rate of recovery were recorded. The data for the primary outcomes was analysed by using a general linear model to estimate the slope of a line through the data, the slope value representing the unit increase per treatment or the rate of recovery during that phase. As the number of subjects and outcomes produced a large quantity of data that did not show a consistent result, the data for the 10 subjects in group 1 and in group 2 are averaged to examine the overall trends in the data and to allow comparison to other studies of UE treatments.

By comparing the slope in the RMT phase to that of the baseline it was possible to evaluate whether RMT delivered by the GENTLE/s system had a positive treatment effect. As RMT only trained movement of the shoulder and elbow it was expected that the rate of recovery of these variables might be influenced by RMT. The following discussion begins with the comparison of the baseline and RMT phases.

Comparing the slope during the SS phase to that of the RMT phase allowed the comparison of treatment with RMT to a similar duration of another intervention based on repetition in a de-weighted environment. The differences in rates of recovery during these phases may be attributed to the differing content of the interventions, namely the addition of feedback through virtual representation of the movement on screen and through haptic feedback from the RMT system. The second section of this chapter discusses the comparison of these two phases.

Several coexisting impairments are reported by authors to have an influence on the recovery of UE motor function and activities, the association between these and the individual outcomes are discussed. In the subsequent section the results of this study are compared to those of US researchers of RMT systems. The chapter continues with a discussion of the validity and limitations of this study and recommendations for future research. The thesis closes with the conclusions.

6.2 Comparison of baseline and RMT phases

The baseline measurement phase aims to capture any changes in the outcome measure due to natural recovery, the learning effect of the outcome measures and any increase in outcome purely due to attention to the UE and participation in a therapy environment. By comparing the rate of recovery during this phase to that during the phase in which RMT was added, the effect of RMT on the UE can be evaluated. Should RMT have a positive treatment effect the slope value in the RMT phase would be higher than that in the baseline phase. For the individual case studies this difference can be considered significantly different when it exceeds the criteria for change greater than measurement error, which in this study is the aMDC.

It was hypothesised that RMT would only have a treatment effect on those areas that were trained during treatment. Movement of the UE was guided from the wrist and the exercises completed all involved components of shoulder flexion and elbow extension. Therefore the variables expected to increase would be the A section of the FM, the A section of the MAS (and possibly therefore their total scores) and the active ROM of shoulder flexion and elbow extension. For those exercising in active or active assisted mode an increase in shoulder flexion and elbow extension MVIC was also possible. As RMT did not aim to affect movement of the hand and did not move the subjects UE to the end of range of any movements other than elbow extension an increase in the hand sections of the FM and MAS and in the PROM variables was not expected during the RMT phase.

The results suggest that for the majority of subjects for these trained variables the absolute value of the slope in the RMT phase was greater than that in the baseline phase, supporting the above hypothesis. Subjects 1, 2, 4, 5, 6, and 7 exercised in active or active assisted mode and demonstrated RMT slopes greatest for all but one of the expected measures. However few of the differences in slope value can be considered more than measurement error and therefore are not significantly different. Only subject 5 had a rate of recovery that was significantly greater in the RMT phase in the expected components of the FM and MAS. When considering the average response to RMT the difference in the rates of the baseline and RMT phases are statistically significant for active elbow extension ROM for group 1 and nearing statistical significance for the active ROM shoulder flexion variable for both groups. Shoulder flexion MVIC and passive ROM shoulder flexion for group 2 and FM total score for group 1 are also nearing statistical significance.

This suggests a trend for a positive treatment effect at the level of body functions and at the level of activity that does not appear to translate into a treatment effect at the level of participation as measured by the SF-36. The lack of significant differences and lack of effect at the level of participation are considered below.

6.2.1 Lack of significant differences

There are several possible reasons why significant differences were not seen. Statistically significant differences are obtained when there is a large difference in scores coupled with low variability. In this study some of the actual differences between the rates of recovery in the phases were not large. For group 2 for example, the average difference between the slopes in the A and B phases for FMA was 0.05, which represents a difference of 0.45 FM units between the phases. Similarly the difference between the A and B slopes for the MASA variable for this group was only 0.07 or 0.63 MAS units between phases. Greater changes are needed in order to effect change in the subjects status that is either clinically or statistically significant.

Insufficient dosage

It is possible that these small differences between the rates of recovery in the baseline and treatment phases can be attributed to an insufficient treatment dosage. The total treatment time in the B and C phases was 4.5 hours each representing an additional 1.5 hours per week. While this reflects the dosage that might be available in current clinical practice, over a three week period this represents an extremely small proportion of the subjects' waking hours. Authors have suggested that the small doses of intervention such as those found in current practice can be only be considered "homeopathic" (Pomeroy & Tallis 2002a) and that greater doses of intervention are required to bring about the plastic changes at brain level that contribute to functional improvements.

The intensity of treatment in the standard protocol of CIMT is 60 hours over 2 weeks, considerably greater than in this study and this intensity appears to bring about significant change (Taub et al 1993, Kunkel et al 1999, Miltner et al 1999), as different outcome measures were used in these studies a direct comparison is not possible. The modified CIMT protocol consisting of 30 hours over 10 weeks represents double the treatment time per week of this study over a longer time course and brought about an average difference of 5.5 FM units between baseline and treatment phases in two subjects 5 months post CVA (Page et al 2001). This is over 10 times the average difference in this study and would be considered significantly different using the MDC criteria. This would suggest that increasing the duration and or intensity of treatment with the GENTLE/s system may bring about change that can be considered significant.

The study by Sunderland et al (1992) suggested that in the acute phase an additional 1.25 hours of treatment per week produces significantly greater recovery at the level of impairment and activities, and Kwakkel et al (1999) suggest that 2.5 hours of additional treatment brings about significantly greater improvement at activities level. While the intensity of the additional treatment in this study was of similar duration to these two studies the subjects in this study were not in the acute phase where most recovery takes place. Therefore greater intensities of treatment than were given may be required to effect change of sufficient magnitude to produce treatment effects that are both clinically and statistically significant in these sub acute and chronic subjects.

The lack of consistent or significant change in the SF-36 measure may also be attributed to an insufficient dosage. It is possible that far greater change at the level of body functions and activities are required before any impact is made on quality of life. The lack of consideration of this domain in previous research prohibits comparison of these results to other studies. It is also possible that the change produced was not detected by the SF-36. Two subjects reported significant positive changes during the treatment phases of the study, one (Subject 4) was able to pick up her grandchild for the first time, another (Subject 13) reported being able to open the kitchen door with his hemiplegic arm. Both these events were reported to have made significant positive improvements in the subjects' life, but were not captured by the SF-36 measure.

High variability

To achieve differences between the slope values that are statistically significant a large difference in scores and/or a low degree of variability must be present. In the case of the individual results the MDC was used as the measure of variability. It is calculated from the standard error of the measurement, which reflects the variation between two sequential measurements (Finch et al 2002). A high degree of test-retest variability would lead to a high MDC and hence the need for a greater difference in score in order to achieve a significant difference.

In the case of the average results t-tests were used to assess the significance of the change occurring. The t-value obtained is a ratio between the degree of change and the variability, in this case the standard deviation. The level of significance is higher if the standard deviation is lower, if the difference is greater or if the number of cases is larger. A high degree of inter individual variability (and hence standard deviation) was present in the analysis of the average response thus requiring greater differences in order to achieve statistical significance. As the study was a series of single case studies it did not set out to obtain similar groups but rather to evaluate the effect of RMT on subjects with wide ranging characteristics, the average response was calculated purely to ease interpretation of results.

For some outcome measures the standard error of the measure (SEM) is high, this is especially true for the range of motion variables where the high SEM values resulted in high aMDC criteria. The high variability of these measures is illustrated clearly in the plots of the raw data. These variables demonstrated SEM values of between 2.35^0 (AROM shoulder abduction) and 6.58^0 (AROM shoulder flexion). This suggests that a minimum change of 18.24^0 (MDC value) in AROM shoulder flexion should be seen before the change can be attributed to more than measurement variability.

This value is considerably higher than the criteria for change suggested by Boone et al (1978) and Mayerson and Milano (1984) who suggested 5^0 of change was necessary. It is considerably less than the values of SEM reported by Hayes et al (2001) who evaluated test-retest measurements for an orthopaedic surgeon. They reported SEM values of 17^0 for shoulder flexion. It is possible that the values in this study may be lower than those reported by Hayes et al (2001) who used two initial measurements, because the SEM in this study was calculated from the last two measures taken by a physiotherapist in the baseline phase when the learning effect had possibly stabilised. No other studies on goniometric reliability have published SEM values so comparison is not possible.

Sanford et al (1993) in a study of interrater reliability estimated the SEM of the UE portion of the FM as 3.6 units. The value calculated from the last two measures in the baseline phase of this study was 1.47. As Sanford et al (1993) were measuring the reliability between raters, and in this study the reliability was between test occasions, their value can be expected to be greater and is therefore not directly comparable. No other studies reported SEM values for the FM or for the MAS.

Boissy et al (1999) estimated the SEM for grip strength (using a dynamometer) as 25N or 2.5kg, whereas in this study the SEM was estimated as 0.83kg, which is considerably lower. While both studies evaluated subjects with stroke the measurements in the study by Boissy et al (1999) were taken 1 week apart, where improvement may have been occurring, whereas in this study the measures were 2 days apart at the end of the baseline where any learning effect should have been eliminated and the test procedure was extremely familiar to both subject and rater hence reducing variability between test occasions. As several subjects did not have any grip ability and scored 0 on both occasions this may also have falsely lowered the SEM value for this study.

Further evidence of increased variability between measurements is demonstrated in the plots of the raw data and in the form of negative slope values, especially for the ROM and MVIC variables. On occasions the slope values in the baseline (and treatment) phases are negative while other measures considering the same movement components have positive slopes. This does not make clinical sense and visual analysis of the raw data reveals high measurement variability, which probably contributes to the decreasing scores as opposed to a true clinical decrease.

6.2.2 Trend for positive treatment effect

For the majority of trained variables for the majority of subjects the absolute rate of recovery was greater in the RMT than the baseline phase. This trend suggests that RMT may have a positive treatment effect at the level of impairment and activities. This result concurs with the results of the meta-analyses (Kwakkel et al 1997, Langhorne et al 1996), which suggest that higher intensities of rehabilitation result in improvements in impairments of body functions and activity limitations. This result also concurs with the results of a systematic review of exercise therapy by van der Lee et al (2001), which also suggested that more intensive exercise therapy may be beneficial in improving outcome of the UE.

6.2.3 Order effect

Generally the differences between the baseline and RMT slopes were of smaller magnitude for group 2 than for group 1. It is possible that the confounding factor of the SS phase between the baseline and RMT phases contributed to this difference in outcome. However while there are no statistically significant differences between the groups, group 2 was 12 months post stroke later and had an average of 2cm more pain on the VAS, both factors which may also have contributed to a poorer recovery and could explain the differences in outcome.

Other studies suggest that an order effect may have a role to play in this result. Lum et al (2002) found in their study that the majority of change in outcome occurred over the first and not the second month of intervention. Wang et al (2002) also found that in their second intervention phase in an ABA design, the effect of treatment (second A phase) was not of similar quantity to that in the first intervention phase (first A phase).

It may be that there is a saturation point after which the additional intervention fails to produce a significant treatment effect or that the potential for recovery has been exhausted. Lum et al (2002) also noticed that their control group did not show any significant change with additional dosage of the intervention they had been receiving. They suggest that after a time point the benefits of one mode of intervention may be exhausted and simply changing the modality may produce an effect for a only a certain time interval.

The smaller magnitude of difference between the baseline and RMT slopes for group 2 might be attributable to either the difference in groups or to the order effect of treatment and it is not possible to draw definite conclusions as to the order effect from the results of this study.

6.2.4 Baseline slope greater than RMT slope

The slope values were not always highest during the treatment phases and on occasions the baseline slope was greater than both treatment phases. This is particularly true for the passive range of motion of shoulder abduction for 8/20 subjects and external rotation and elbow flexion for 10/20 subjects. On average the rate of increase in PROM of shoulder external rotation and elbow flexion in the baseline phase were significantly higher than the first treatment phase for group 1 and nearing statistical significance for PROM shoulder external rotation for group 2. This result suggests that simply moving the UE to the extremes of the range for measurement purposes has a positive effect on that movement.

While bringing the joint the end of the PROM is a treatment method for increasing PROM, completing this once daily three times a week was not expected to produce such an effect.

This effect of repeated measurement is the learning effect of the outcome measure, which in RCTs is controlled for as it occurs in both groups. Ideally in single case studies the baseline measures should have a stable trend prior to the introduction of treatment. The lack of stabilisation of the baseline phase for these variables before the introduction of the treatment phase may negate the positive effect of treatment on these variables, as the increase due to treatment is indistinguishable from that due to the learning effect of the measurement.

Another possible explanation for baseline slopes that were higher than those during the intervention phases is that there was an "unmasking of learned non use". This phenomenon first described by Taub (1980) suggests that compensation with the unaffected limb masks the abilities of the affected limb and that with practice subjects can maximise the use of the hidden potentials of movement. This would seem to be true for subjects 13, 17 and 20 where the majority of the variables showed the highest rate of recovery during the baseline phase. Had these higher slope values been due to underlying natural recovery, the effect would have continued at, at least, the same rate during the treatment phases, as this was not the case it suggests that "unmasking of learned non-use" was responsible. All three subjects had a left hemiplegia and were greater than one year post stroke suggesting that learned non-use is a plausible explanation for these results.

In summary the comparison of baseline and RMT slopes showed a trend for an increase in rate of recovery during the RMT phase which was for the most part not greater than measurement error and on average was only statistically significant for 1 variable. This suggests that RMT may have a positive treatment effect and concurs with studies suggesting that exercise based interventions have a positive treatment effect and that increasing the dosage of physiotherapy intervention produces improved outcome. It is possible that greater intensities of intervention are required to bring about change that is statistically significant.

6.3 Comparison of RMT and SS phases

The comparison of the RMT and baseline phases sought to establish whether RMT had a positive treatment effect but did not control for the effect of additional therapy producing improved outcomes. The rate of recovery during the RMT phase was compared to that during the SS phase to compare the effect to that of another intervention of similar duration. As SS and RMT contain the common components of repetition in a de-weighted environment the comparison of the rates of recovery allowed the addition of the robotic assistance (or resistance) visual feedback, and motivational component of the GENTLE/s system to be evaluated. This comparison helps to evaluate which specific components of the black box of RMT are responsible for the improvements seen.

The positive, but for the most part not statistically significant, response to both interventions suggests a trend indicating that exercise based interventions involving repetitious movements show positive treatment effects at the level of body functions and activities. This concurs with animal studies (Nudo et al 1996) and with physiotherapy studies involving interventions based on repetition (Feys et al 1998, Bütefisch et al 1995, Taub et al 1993, Miltner et al 1999, Kunkel et al 1999).

6.3.1 Trend for superior effect of RMT

The comparison of the RMT and SS phase allows the specific components of the intervention responsible for the treatment effect to be evaluated. The treatments differ principally in the fact that SS involves single plane, non-functional movements with no visual feedback, whereas RMT involves the repeated practice of functional, meaningful, challenging movements. In general, there were higher rates of recovery during the RMT phase than the SS phase suggesting that adding visual feedback through virtual reality and the assistance of the robot does improve outcome. This concurs with the results of Plautz et al (2000) who found that cortical reorganisation in monkeys was optimised when the skill practiced was challenging and engaging. It is also possible that the completion of virtual reality tasks, as opposed to single planar movements, increased attention a factor that is important for motor learning post stroke (Robertson et al 1997). This result also concurs with the findings of the literature concerning exercise based interventions, where the only intervention not involving functional, task oriented movements did not show a positive treatment effect (Woldag et al 2003).

6.3.2 Lack of significant differences

The similarity of the interventions is one reason why there are few differences that can be considered significant. RMT and SS share significant common elements and were implemented for similar durations of intervention. As with the differences between baseline and RMT it is possible that a longer duration and higher intensity of interventions is required to establish significant differences between the two interventions.

One of the important differences between RMT and SS is the amount of direct intervention required by the therapist. For those subjects who exercised for some time in passive or active assisted modes in the RMT phase (n=17) direct input from the therapist was required during SS to perform the assistance that was completed by the robot. This has significant implications in terms of therapists' time and hence costs of the intervention, factors which were not considered in this trial.

6.3.3 SS slope greater than RMT slope

The SS treatment phase involved exercises that brought the subject to the end of range of shoulder flexion, which was outside the movement range of the GENTLE/s system. This may explain the higher average value for the slope of the passive shoulder and elbow flexion variable during the SS phase for group 2 and for PROM shoulder abduction and external rotation for group 1. In order to increase the range of motion at a joint it must be brought to the end of the range, hence an increase in these variables during the RMT phase would not be expected as the initial PROM for all subjects was greater than the movement range of the GENTLE/s system (with the exception of PROM shoulder external rotation which was brought to end range and which was, for three subjects, significantly higher in the RMT than baseline phase).

Subject 3 has 12 variables for which the absolute value of the SS phase is greatest. As SS was her first treatment it is possible that her recovery potential was exhausted by the SS intervention and further recovery beyond that i.e. during the RMT phase, was not possible. This would concur with the findings of Lum et al (2002) and Wang et al (2002) who reported greater responses to the first period of intervention than the second. However the variables in which this was demonstrated included those in which change was not expected during the RMT phase, and in general the degree of difference is extremely small possibly suggesting that measurement error was a considerable factor in this result.

In summary the trend for a greater rate of recovery in the RMT than the SS phase for the trained variables is consistent with research suggesting that interventions that involve task oriented, challenging exercises, as opposed to those that are purely repetitious, have a superior treatment effect. The lack of significant differences may be due to the similarities of the interventions and a lack of sufficient intensity to bring about change in outcome.

6.4 Effect of RMT on pain and tone

Treatment with the GENTLE/s system did not have an adverse effect on the tone of the UE of the subjects in the study (as measured using the modified Ashworth scale). Therapists using the Bobath concept, who make up the majority of treating therapists in the UK (Sackley & Lincoln 1996) and Ireland (Coote & Stokes 2003) place special emphasis on the normalisation of tone (Lennon et al 2001) and effortful activities such as strength training are strongly discouraged (Edwards 1996).

The results of this study would suggest that RMT, which for some subjects involved resisted exercise, significantly decreased wrist and elbow tone for group 1 and produced a decrease nearing statistical significance for elbow tone in group 2. This concurs with the findings of Bütefisch et al (1996) who also found a reduction in tone following resisted exercises.

RMT did not have an adverse effect on the levels of pain in the affected UE, and on average resulted in a small decrease in pain (-0.25cm) for the subjects in group 1 and a small increase (mean increase of 0.25cm) for group 2 though neither of these changes was statistically significant. Given the association between pain and motor outcome (Wanklyn et al 1996, Roy et al 1995) any reduction is in pain is positive. One subject (3) reported an increase in pain one week after cessation of the study. Generally her pain levels at the end of the study were reported as being less than those at the start, the mechanism for this is not apparent though may have been due to her pre-existing injury.

6.5 Influence of background measures

One of the aims of the study was to investigate which sub group of subjects with what background characteristics would benefit most from the intervention. For this reason the level and presence of pain, sensory deficit, visuospatial neglect, hemianopia, tone and motor deficit for all subjects was measured. The effect of these confounding factors on the response to treatment is explored in this section.

6.5.1 Pain

Shoulder pain was present in 12/20 subjects, (1, 2, 3, 4, 7, 8, 11, 14, 15, 17, 19, 20). Of those 12, four (1, 2, 4, 7) are considered to have had a positive treatment effect where the absolute slope value of RMT was greater than baseline and SS for the trained variables. For the other 8 subjects it is possible that the presence of shoulder pain influenced their response to treatment. Roy el (1995) found that pain on movement was significantly associated with poor Frenchay arm test score on discharge and Wanklyn et al (1996) found that shoulder pain was strongly associated with reduced shoulder shrug and pinch grip on discharge.

The association between pain and external rotation suggested by Bohannon et al (1986) is replicated in this study as 8 of the 12 subjects with shoulder pain had a PROM of external shoulder rotation less than 45^0. Of interest only 2/20 subjects (2, 7) had an AROM of external rotation that was greater than 45^0 at initial measurement, the association between this variable and recovery of motor function warrants further exploration.

6.5.2 Sensory loss

Several authors have suggested a link between sensory impairment and poorer motor recovery (Parker et al 1986, Feys et al 2000, Rand et al 1999). Of the subjects in this trial only one (3) had maximum scores on the Nottingham sensory assessment (NSA) at the initial assessment. Therefore it is possible that the presence of sensory impairment was responsible for the small amounts of recovery demonstrated by subjects in the trial leading to lack of significant outcome.

When considering those with scores of less than 50% of the scale (<18) (subjects 5, 15, and 18) no conclusive link to response to RMT is apparent. Subject 5 has the lowest score on the NSA and greatest number of variables for which the rate of recovery during RMT is significantly greater than both baseline and SS, while subject 15 demonstrated recovery rates only in MASA and MAST variables that were significantly greater than both baseline and SS. Subject 18 however demonstrated little change in the trained variables with only AROM shoulder flexion being significantly greater than both baseline and RMT. The positive treatment effect of RMT for the individual with a large degree of sensory loss concurs with the results of the study by van der Lee et al (1999) whose results suggest that CIMT, which also involves high level of repetition of task based exercises, has a particular benefit over NDT based intervention for those subjects with severe sensory loss.

Of the six subjects who demonstrated a positive effect of RMT in the trained variables (1, 2, 4, 5, 6, and 7) two scored less than 35 (4, 5), which does not suggest a clear link between sensory deficit and benefit of RMT.

6.5.3 Visuospatial neglect

Several authors have suggested that the presence of visuospatial neglect has a negative effect on the outcome of rehabilitation (Katz et al 1999, Friedman 1992, Cherney et al 2001, Appelros 2002) and the star cancellation test has been validated as a measure of this domain. However, there is considerable debate as to what constitutes an abnormal star cancellation score. The maximum score is 54, i.e. 27 stars on each side, some authors have proposed that a score less than 38 is abnormal (Stone et al 1991) while others have suggested scores of 51 or 44 (Friedman 1992). A study by Friedman (1992) suggested that the score of 44 was more specific than that of 51 (84.4% compared to 46.2%) but less sensitive, in detecting those subjects with visuospatial neglect. Only one subject in this study can be classified as having visuospatial neglect (subject 19) with a cut-off of 44 stars. As her motor abilities were extremely limited and she did not demonstrate any significant change on any of the variables it is difficult to distinguish whether her lack of improvement was due to visuospatial neglect or due to her poor motor abilities, which are also a predictor of poor outcome (Feys et al 2000, Loewen & Anderson 1990). If 51 is considered as the cut-off point then subjects 4, 15, 18 and 19 could be considered to have visuospatial neglect. No clear link between this deficit and the effect of RMT is apparent when these subjects are considered as the results suggest varying treatment effects for all four subjects.

Some physiotherapeutic interventions have demonstrated a particularly positive treatment effect for those subjects with hemineglect, for instance the effect of the repetitious weight bearing exercise in the study by Feys et al (1998) and the benefit of CIMT over NDT based therapy seen by van der Lee et al (1999). The positive response of subject 4 to RMT might be as explained as a result of the repetitious task based exercises that are the specific components of RMT.

6.5.4 Hemianopia and neglect

None of the subjects had a hemianopia, however three demonstrated visual inattention (13, 15, 18). The presence of this deficit did not prohibit the use of RMT. When considering hemianopia in the three part screening for neglect along with abnormal star cancellation test and abnormal bilateral simultaneous touch, subjects 15 and 18 have abnormal scores in all three domains. Both subjects demonstrated rates of recovery during the RMT phase that were significantly greater than the baseline phase for the MASA and MAS total score, with subject 15 also being significantly greater than the SS phase also. This result suggests that RMT has a positive treatment effect on shoulder activities, but not shoulder/elbow impairments, for those with neglect.

6.5.5 Tone

While a search of the literature did not reveal any studies that investigated the associated between high tone and poor motor outcome therapists in the UK and Ireland, who for the most part use the Bobath concept in treatment, are likely to put a special emphasis on the need to reduce tone before treating movement deficits in the UE. In this study no differentiation in treatment was made between those with no, mild or moderate increases in tone.

When considering those with a marked increase in tone in their elbow (modified Ashworth score ≥3) seven subjects fall into this category (5, 6, 8, 16, 17, 19, 20). Subjects 5 and 6 are among those demonstrating a trend for a positive response to RMT in the treated variables, while 17 and 20 had high baseline rates of recovery for most variables, and 19 had little change at all. Thus while RMT appears to be effective in reducing tone in the UE there does not appear to be a direct link between the presence of a marked increase in tone and the response to RMT.

While the modified Ashworth scale is widely reported and represents one of the only clinically used measures of tone, its limitations as a valid and reliable quantification of tone are acknowledged. This result should therefore be interpreted with caution.

6.5.6 Motor deficit

Sunderland et al (1992) and Parry et al (1999) suggest that the benefit of additional therapy is most apparent in those subjects with milder deficits. When considering the subjects that demonstrated an increase in those trained variables in the treatment phases, subjects 1, 2, 4, 5, 6, and 7 demonstrated positive findings in the treated variables. All of these subjects scored in the upper 2/3rd of the FM scale, supporting the findings of the above studies.

The lack of response in the treatment phases of the two subjects (10 and 19) with poor initial motor scores (4/66 on FM) is consistent with the findings that those with lower levels of initial motor impairment have a poorer motor recovery (Loewen & Anderson 1990, Feys et al 2000). Feys et al (1998, 2004) found that their repetitive intervention formed the basis for training, which only became significant at follow up, and was particularly beneficial for those with severe deficit and hemianopia. It is therefore possible that for these two subjects with severe motor loss (10 and 19) that the response to RMT was delayed and may have become apparent should a follow up measurement have been taken.

While the higher motor scores are consistent with the findings of Sunderland et al (1992) and Parry et al (1999) who demonstrated that the greatest benefit of additional therapy was for those with higher motor abilities, as not every subject in this bracket had a similar response, it is possible that another unmeasured element was responsible. Ohlsson and Johansson (1995) demonstrated in rats that the environment before and after the lesion has a significant effect on outcome. It is possible that a factor such as this contributed to the differing responses to the interventions.

6.5.7 Lesion location

Studies have suggested that subjects with lesions affecting both the cortex and subcortex demonstrate less potential for recovery than those with purely cortical lesions. The subjects were recruited from various centres in Dublin who used different classifications and detail of CT reporting. This was unfortunately insufficient to allow classification of the subjects into cortical and subcortical areas of lesion therefore the investigation of this potentially confounding factor is not possible.

In summary, it is possible that the presence of pain and sensory impairment had a negative influence on the outcome of treatment with RMT. It is also possible that RMT may positively affect the UE at the level of activities for those with unilateral neglect, but no clear link between visuospatial neglect and effect of RMT is apparent. While RMT had a positive effect on tone, the presence of a marked increase in tone does not have a clear link to the effect of RMT. Consistent with studies investigating the effect of an increased intensity of intervention, RMT has the most positive effect for those who score in the top

2/3^{rds} of the FM scale. For all of the above results, given the small magnitude of change and the lack of significant findings, differences that are not apparent in this study may become so should the study be repeated with a higher intensity of intervention and/or longer treatment phases.

6.6 Comparison of results to US studies

The MIME and MIT-Manus systems have completed clinical trials that are reported in the medical literature. This section compares their results to those of this study. The positive effect of RMT on the treated variables seen in the US studies whose results also suggest a significant improvement in the shoulder and elbow variables (Volpe et al 2000, Lum et al 2002) is replicated in this study. In this study the mean change in total FM score over the RMT phase was 3.96 for group 1 and 3.51 for group 2 following 4.5 hours of treatment. This mean change in score is only slightly less than that found by Lum et al (2002) who found a mean change of 4.7 on the FM after 24 hours of treatment. Volpe et al (2000) found a mean change of 6.0 after 25 hours of treatment. While the subjects were at differing times post stroke, (those of Lum et al were 30 months post CVA and those of Volpe et al were three weeks) the changes elicited were similar in all three studies despite the greatly differing durations. The unit increase per hour treatment is 0.83 for this study, 0.11 for the MIME study and 0.20 for the MIT-Manus study. While this would suggest that treatment with the GENTLE/s system may have a superior effect to that of the other RMT systems, caution should be exercised in interpreting this result as the increase in scores across treatment phases combines actual change with that due to measurement error, natural recovery (though this should be minimal for this study as all subjects are in the subacute or chronic stage of recovery) and other factors.

While all three RMT systems share the common elements of repeated practice of exercises delivered by robotic systems, there are inherent differences in the systems. The MIME system does not provide visual feedback on screen, instead objects such as cones are used as the target. The MIT-Manus system uses visual feedback of computer game like environments, while the GENTLE/s system uses virtual representation of the real world environment. The more positive effect of exercising in an environment representing the real world is supported by work by Wu et al (2000) who found that the kinematics of reaching with the affected UE improved when a meaningful object was present as opposed to reaching into space, this may explain some of the differences between the results of the three studies.

The workspace of the GENTLE/s system is similar to that of the MIME system, but considerably larger than that of the MIT-Manus system, which only has two degrees of freedom and does not allow elevation at the shoulder.

Thus the GENTLE/s system has advantages over MIT-Manus in terms of workspace and over MIME in terms of visual feedback. It is possible that there are other differences in the content of the interventions that are not fully described in reports of these studies that may account for the difference in the magnitude of the treatment effect.

It is interesting to note that when there was less variability within the study groups of Lum et al (2002) and Volpe et al (2000) changes of similar magnitude to those of this study became statistically significant for the other study groups. This supports the suggestion that the results of this study lack statistical significance due to high inter-subject variability and high variability of the measures leading to high MDC criteria.

The above studies measured changes at the level of activity limitations using the Barthel index (BI) (Lum et al 2002) and the functional independence measure (FIM) (Volpe et el al 2000). Both of these outcome measures contain sections other than those considering the UE and studies have shown that increases in these measures can be brought about without any change in the status of the affected limb (Nakayama 1994a, Williams et al 2001). This study directly measured the activity limitations arising from the deficits of the affected UE using the MAS. The results indicate that the positive effects at impairment level are also present at the level of activities. However, the increases over the treatment phases are small and few of the differences are statistically or clinically of sufficient magnitude. It may be that greater dosages are needed to bring about changes of body functions that are of sufficient size to affect activity limitations.

In summary, it is possible that the additional features of the GENTLE/s system, the virtual representation of the real world and the haptic feedback from the robot, may have an additional benefit to that of the other RMT systems. However additional studies are required comparing this in well matched control and treatment groups.

6.7 Validity

The methodology applied to this study aimed to improve the internal validity of the study by several means, namely the use of multiple/non concurrent baselines, the use of long phases with continued measurement and the comparison of the results to a control variable.

6.7.1 Multiple baselines

The multiple baseline design has the highest internal validity of the single case study designs (Sunderland 1990). As every subject started treatment at a different time post stroke, if the improvement in rate of recovery of every subject began after the initiation of treatment, the effect could be attributed to the treatment and not to another concurrent event. For those variables with high variability (ROM, MVIC and strength) and for some individuals this is not apparent from the visual plots. For those subjects where there were significant differences in rates (e.g. subject 1, 5, 6, 7) the plots of the raw FM and MAS data show that the rate of recovery increases when RMT is introduced. There were no concurrent events documented for any subject that may have accounted for the increase in recovery rate. This supports the hypothesis that it was RMT and not a concurrent event that was responsible for the increase in rate of recovery during the RMT phase.

6.7.2 Length of phases

Both Backman and Harris (1999) and Sunderland (1990) suggested that 10 data points per phase was optimal in order to allow the comparison of trends during the phases. In order to be consistent with treatment three times a week for three weeks, this study used a similar number of 9 points per phase.

While for some measures this length of phase was sufficient to allow the trend to stabilise during the baseline phase (e.g. FM and MAS), for others this was not the case. The PROM variables of shoulder external rotation and elbow flexion in the baseline phase were significantly higher than the first treatment phase for group 1 and nearing statistical significance for PROM shoulder external rotation for group 2. This suggested that the learning effect of repeated measurement had not stabilised before the introduction of the treatment. This is apparent also for the MVIC plots for subjects 18 and 20 for the MAS for subject 17 and ROM 1 for subject 2. The sharp increase in the baseline phases (which occur at different times post stroke for all subjects and therefore can be attributed to the practice of repeated measurement) do not stabilise prior to the introduction of the treatment and comparison of the effect of treatment to the baseline is therefore not possible.

Some authors have used two measurements prior to treatment (Page et al 2001b, Miltner et al 1999), or have compared the measurements at the start and end of phases (Bütefisch et al 1995). The variability and learning effect in the impairment measures in this study would suggest that these two points would not accurately represent the natural rate of recovery, as is assumed in the above studies. Their results should therefore be interpreted with caution.

6.7.3 Comparison to control variable

The measurement of grip strength was used as the control variable for this study. As RMT did not train grip strength, and grip strength is an indicator of UE recovery (Sunderland 1989), it was hypothesised that this variable would not demonstrate a rate of recovery in the RMT phase that was greater than the baseline phase. For 12 subjects this was the case suggesting that any improvement in scores in the other measures could be attributed to RMT and not to natural recovery. For the subjects who did demonstrate an higher rate of recovery in grip strength during the RMT phase (1, 2, 5, 6, 8, 14, 17, 20) it is possible that by improving their proximal abilities they were able to interact more with the environment during ADLs and hence may have improved their grip strength in this manner.

From the results it became apparent that the MASC variable, which considers advanced hand activities, was also unaffected by RMT. For 12 of the 20 subjects there was no change in this variable in the RMT phase. The same is also true for 10 subjects for the FMC variable, which considers hand movements. These results support the specificity of treatment with the GENTLE/s RMT system and strengthen the internal validity of the study design. This result also supports the findings of the MIME (Lum et al 2002) and MIT-Manus (Volpe et al 2000) studies which demonstrated significant improvements in those areas trained by the systems.

The lack of consistency of this result across all individuals reflects the fact that UE function incorporates coordinated movements of many joints and that improving proximal stability and control may enable the hand to be used more to interact with the environment, therefore having an indirect treatment effect.

6.7.4 Replication of positive treatment effect

While the external validity of one single case study is limited, the replication of a treatment effect across individuals greatly improves the external validity of a study (Kazdin 1982, Barlow & Hersen 1984). In this study the non significant trend for improvements in the treated variables was replicated in subjects 1, 2, 4, 5, 6, and 7. The common feature of these subjects was a FM score in the upper 2/3^{rds} of the measure and a lack of hemianopia. This result suggests that for other individuals with these characteristics RMT may have a positive treatment effect.

The lack of replication in the other 14 subjects may be due to the presence of pain and sensory disorders, high baseline slopes due to a learning effect of the measure or learned non use, poor recovery potential due to low motor scores, and possibly due to other unmeasured characteristics. It is interesting to note that the first 9 subjects had the most improvements in either treatment phase. This study used a sample of convenience and therapists forwarded the names of suitable subjects for the study. It became difficult to recruit subjects after the first 10 subjects. There may be other characteristics apparent to the therapists that were not measured in this trial that prompted them to put forward the subjects.

6.8 Limitations

The main limitation of this study is the lack of change that could be considered greater than measurement error for the majority of subjects and variables. The high variability of measures coupled with insufficient intensity of treatment, leading to insufficient change, and the presence of background characteristics that have a negative effect on outcome all may have contributed to this effect.

6.8.1 Study design

The results of single case studies are not considered as robust as those of RCTs, which are the 'gold standard' in medical research. However, one of the most striking features of the results is that no two subjects had the same response to the interventions. This reinforces the fact that stroke patients are inherently heterogeneous, a feature which does not lend itself to evaluation using randomised controlled trials (RCT) (Domholt 2000). In order to source sufficient numbers of subjects to generate treatment and control groups with similar characteristics significant amounts of time (and funding) are required. As a result the RCTs available have numbers that are too small to provide reliable answers (Ottenbacher & Jannell 1993). This is one possible reason why the trials to date have not yielded clear answers (DeWeerdt & Feys 2002).

RCTs and single case studies answer essentially two very different questions. RCTs are best placed to evaluate general rehabilitation policies (Langhorne et al 2002, Sim 1995, Evans 1994) whereas single case studies can answer whether a specific treatment should be used for an individual patient (Zhan & Ottenbacher 2001, Riddoch & Lennon 1991). Both levels of information are needed for clinical decision making at the various levels of service provision, and is has been suggested that the evidence needs to be replicated at both levels before that treatment method can be confidently adopted (Robertson 1994). As physiotherapists are more likely to ask what treatment they should use with a certain individual with unique characteristics it may be that single case studies are in a better position to answer that question.

The effect of rehabilitative interventions should not only be considered over the short term, but also on a longer term basis. This study did not follow up the patients at a later date to investigate whether the improvements seen during the study were maintained, therefore there is currently no evidence to support the positive benefits of RMT delivered by the GENTLE/s system on the UE over a time period greater than the intervention periods.

This study compared the effect of RMT to sling suspension (SS) that is not routinely used in clinical practice, and not to the conventional therapy (i.e. Bobath). Pomeroy and Tallis (2000) recommended that therapies for which there is a significant body of evidence (exercise based interventions) should be compared to the most widely used treatment approach (Bobath) to investigate the superiority of one over the other. In the absence of a concrete definition of the Bobath approach this research is difficult to complete. This study therefore followed the advice of researchers who suggested that the way forward for research in physiotherapy post stroke is to unpack the "black box" that is the poorly defined components of this intervention and to investigate which components are responsible for the improvements seen. Comparison of the rates of recovery with RMT, SS and baseline periods revealed differences in response that can be attributed for the most part to the components of the interventions.

6.8.2 Study sample

The sample of subjects with stroke included in this study consisted largely of subjects over the age of 65 and at a minimum of three months post stroke. The youngest subject to take part in the study was 49 years old and the effect of RMT on patients under this age was not considered. The results are therefore not directly applicable to younger subjects.

While the inclusion criteria for this study were broad, it did not include those with cognitive deficits and those with significant communication deficits as the measures used required a certain level of comprehension (either verbal or written). The validity of the results from this study may be limited when applied to these patients with stroke. This is however the case for the majority of studies of the effect of rehabilitation as informed consent and the majority of the outcome measures used require a high level of comprehension, cognition and communication abilities.

Many studies have suggested that the greatest amount of recovery occurs in the first 12 weeks following stroke (Sunderland et al 1989, Skilbeck et al 1983). While recent studies have shown that the potential for recovery exists beyond this time frame (Lum et al 2002, van der Lee et al 1999) and that recovery is not limited to this time period, it is still widely accepted that the maximum rate of recovery happens during this period. Turton and Pomeroy (2002) in a review of neurophysiology suggest that intensive therapy should be initiated after the first week after stroke. One limitation of this study is that it did not examine the effect of a period of additional RMT during this optimal recovery window or during the first three months post stroke. Exposure to an increased dosage of repetitious, challenging and engaging therapy at this time may capitalise on the recovery potential of the neurological system and result in greater outcomes for rehabilitation and this should be explored in future studies.

6.8.3 Outcome measures

This study aimed to evaluate the effect of RMT at the level of body functions, activities and participation. The outcome measures used were chosen as studies reported high test retest reliability and responsiveness to small changes and they did not have significant floor and ceiling effects which allowed them to be used with a wide range of subjects. The impairment measures however demonstrated considerable variability leading to high SEM values and hence high criteria for change greater than measurement error (MDC). The variability meant that visual analysis of the trend through the data was not possible on many occasions, and the statistical analysis on occasion gave estimates of negative slopes which were inconsistent with other variables of the same movement.

The ROM and on occasion MVIC variables demonstrated a significant learning effect, with the average baseline slope being greater than that of the treatment phases for some variables. This property necessitates longer baseline phases in order for this effect to stabilise prior to the introduction of the treatment, which was not done in this study. Sunderland (1990) suggests that the baseline length should be determined only once stable measurements have been achieved, and this should be considered for future studies using these measures.

The trend for the positive effect of RMT at the body function level was replicated at the activity level as measured by the MAS, but not at the level of participation as measured by the SF-36. Given the low mean increase across the treatment phases at the activity level it is possible that there was insufficient change (probably due to insufficient dosage) to affect the subjects' participation levels. It is also possible that concurring events captured by this measure negated any effect of treatment.

Few studies of physiotherapy interventions consider the effect of treatment on the restrictions in participation in the subjects desired lifestyle. The SF36 was chosen to measure quality of life. While it is validated as a measure of the deficits associated with health related quality of life, it has not to date been used to evaluate the effect of a period of intervention. No trends in the scores of this measure, either positive or negative, emerged over the course of the study. It is possible that the duration of intervention and the resultant changes in activity limitations were not of sufficient magnitude to affect this measure. It is also possible that many of the other confounding factors in this complex domain were interacting with the individuals' participation levels during the time of the study and hence negated any influence the study intervention had on the score of the measure.

6.8.4 Data analysis

The use of a general linear model to estimate the recovery rate across phases in rehabilitation studies has not been reported previously, however it has been suggested in statistical literature (Dobson 2001, Everitt 1995). The assumptions for a regression analysis were met, and the fitted model compared well to the raw data.

The use of a criterion for change greater than measurement error as opposed to statistical significance has been used in stroke rehabilitation studies (Kwakkel et al 2002). It would appear from the other RMT studies that change of similar magnitude to this study was statistically significant when it was not greater than the MDC value obtained for the FM in this or other (Sanford et al 1993) studies. The criteria for significant change in this study may therefore have been higher than those in studies using statistical significance and may have contributed to the lack of significance. Few rehabilitation studies consider clinical significance or significance of results in relation to the error of the measurement, these properties should warrant more attention.

7 Chapter 7 - Conclusion and recommendations

In recent years there has been a significant increase in the number of studies investigating treatments specifically for the upper extremity post stroke. Despite this a large number of questions remain unanswered. The literature suggests that an increase in the amount of intervention the UE receives produces a more positive treatment effect, however the direct relationship between dosage and response is still uncertain. Also unanswered is the question of which components of the interventions that produce the most positive treatment effect are responsible for the improvements seen. Studies that deliver additional treatment with interventions ranging from additional sensory stimulation, mental practice, RMT, and electrotherapy all suggest that outcome improves when you add additional therapy. The key question that will require significantly more research is; which components of this poorly described "black box" of intervention are responsible for bringing about the change in patients and at what stage in the rehabilitation process these should be introduced?

One theme emerging from the literature is that exercise based interventions involving repetition show positive treatment effects. This concurs with the results of studies involving imaging of the human brain through functional magnetic resonance imaging, positron emission tomography and transcranial magnetic stimulation. These techniques have the potential to provide a window into the recovering brain to allow significant insight into the mechanisms of recovery. Collaboration involving clinical and neurophysiological researchers has the potential to make significant inroads into the understanding of the mechanisms of recovery and hence enable clinicians to tailor treatments to maximise this process.

There is a significant amount to be learned from the output of this study, combined with the literature mentioned in previous chapters that will guide future researchers in designing studies that will enable us to maximise the recovery of every individual partaking in the process of rehabilitation.

Need for well designed randomised controlled trials

The comparison of the baseline and RMT phases in this study suggests that RMT has a positive treatment effect, however further high level evidence is needed before this novel treatment can be incorporated into every day practice. RCTs are considered to be the gold standard in the medical literature and well designed RCTs have the potential to provide high levels of quality evidence for both the service provider and the clinician treating individual patients. For RCTs to be useful to the treating physiotherapist, they must however provide clear descriptions of the types of patient for whom the treatment is effective or not effective. In addition to considering the average effect of the treatment on a number of patients, the output of RCTs should include sub group analysis to consider background characteristics, such as the presence of a sensory, perceptual, visual, or cognitive deficit, and how these affect the response to treatment. The results of this series of single case studies highlights the differing responses of individuals post stroke to a standardised treatment and supports the widespread acknowledgement that heterogeneity of patients post stroke is a factor that must be considered by researchers.

In order to produce such results the use of multi-centre trials to source the numbers of patients needed to produce similar control and treatment groups is recommended. The measurement of the factors known to predict and affect recovery must be considered when assessing the similarity of control and treatment groups in addition to considering the relationship between these background characteristics and response to treatment.

It is possible that an unmeasured characteristic was responsible for the many and varied responses to the treatment seen in this study or that the presence of pain and sensory loss, which are negative predictors of UE recovery, contributed to the small treatment effect. Those who demonstrated the most positive treatment effect had initial scores in the upper $2/3^{rds}$ of the Fugl Meyer scale supporting research that suggests that those with lesser motor impairments benefit most from the effect of additional intervention. Researchers should therefore consider the effect of these factors on response to treatment and also consider other factors such as occupation before stroke and environment after stroke in order to predict which patients might benefit most from that specific treatment intervention.

Need to establish dose/outcome response

The trend for rates of recovery during the RMT phase that are greater than the baseline phase supports research suggesting that increasing the duration of intervention improves outcome. While this treatment effect was seen in the measures of impairment of body functions and activity restrictions, it was not seen at the level of participation.

The lack of statistical significance and small magnitude of change seen in the outcome measures in this study would suggest that Pomeroy and Tallis (2002a) are correct in suggesting that the dosages currently delivered in physiotherapy are indeed homeopathic. While 90 minutes per week represents the dosage seen in clinical practice it represents a tiny proportion of the patients day. It is possible that greater dosages would bring about a level of change that was statistically significant and of sufficient magnitude to affect quality of life. It is therefore recommended that future studies of the GENTLE/s RMT system consider studying the dose/outcome relationship to evaluate what the optimum intensity of intervention might be.

Another important consideration is at what stage of recovery this additional intervention should be targeted. A review of the neurophysiological and physiotherapeutic literature suggests that intervention should be maximised between one and twelve weeks post stroke (Turton & Pomeroy 2002). None of the patients in this study were within this time frame and further research to assess the affect of additional RMT at this point in the recovery process is recommended.

Need to compare to current physiotherapy practice

The lack of description of the content of "conventional" physiotherapy makes it difficult to assess whether novel treatments such as RMT have a more positive treatment effect than current practice. Pomeroy and Tallis (2000) suggested that research comparing exercise based interventions to the Bobath approach is needed, and future studies should aim to address this. However it cannot be completed until the most widely used concept (Bobath, Coote & Stokes 2003, Davidson & Waters 2000) has been described. This is further confounded by the fact that the majority of physiotherapists in the UK and Ireland now use an eclectic approach of one or more concepts, a factor that makes description even more difficult. The transition from traditional to evidence based practice in stroke rehabilitation requires evidence that suggests which approach (e.g. Bobath, eclectic or exercise based) produces the most positive treatment effect. This is currently largely hampered by the lack of research into and description of these traditional methods, namely the Bobath approach.

While RMT delivered by the GENTLE/s system has not yet been compared to "conventional" therapy, the results of this study suggest that RMT may be superior to a similar dosage of SS. While the addition of repetitious exercised intervention produces an increase in the rate of recovery, the addition of the assistance or resistance from the robot and the attentional, motivational, functional component of the feedback of the movement through virtual representation of the real world produces a greater rate of recovery. The comparison of two interventions that differ by only a couple of key components is one way of helping to unpack the "black box" of physiotherapy intervention and evaluate what the key components might be.

It is recommended that, once current intervention has been accurately defined, the effect of additional treatment with RMT should be compared to additional treatment using the current practice which largely involves hands on, one on one treatments. In addition to assessing the effect on patient outcome, the cost of therapy delivered by these two methods should be considered. While the initial costs of a RMT system may be large, the benefit to the patient and to the health service in enabling people post stroke to function more independently and return to their role in society earlier through delivering additional RMT may be more cost effective than employing additional therapists to deliver the intervention. As we move into future decades where the proportion of people requiring care and assistance increases, it is important to develop and assess means of delivering rehabilitation that does not require additional time in terms of manpower.

Conclusion

The trends emerging from the results of this series of single case studies supports the literature that suggests that additional exercise based intervention involving repetition produces positive treatment effects. Treatment using the GENTLE/s RMT system may be preferable to one that simply involves repetitious exercises but further studies comparing it to additional conventional therapy are required. The differing responses of the 20 patients highlights the knowledge that patients with stroke are inherently heterogeneous and that describing patients in terms of age and time post stroke is not sufficient. Multi-centre RCTs with large numbers of well described patients and treatment and control groups with similar predictive factors for recovery are required to inform clinical practice and to increase the evidence base for RMT. The optimal duration of intervention with RMT is probably greater than that delivered in this study and research to investigate both the optimal dose and timing of intervention is required. While RMT has been developed in response to the output of both the clinical and neurophysiological literature, studies that combine treatment effects with mapping of change at brain level will most likely further knowledge of the mechanisms of recovery and guide physiotherapists in modifying treatments that optimally use this information.

Ultimately as physiotherapists the goal of rehabilitation is to optimise recovery of the upper limb post stroke to enable the patient to return to their place in society and prevent decreased well being and quality of life. It is clear that an increase the amount of intervention that the upper extremity receives is required and robotic technology is ideally placed to deliver additional exercise based intervention. The principles of robot mediated therapy are based on the output of the physiotherapy and neurophysiological research and the results of this study, and those of US researchers, provides an increasing evidence base for this novel intervention.

Appendix 1 - Outcome measures used in research of upper extremity post stroke

The range of outcome measures used in the research detailed in chapters 2 and 3 are summarised below in terms of whether they measure at the level of impairment of body functions/structures, activity limitations or participation restrictions. In addition a brief summary of the construct of the scale is given along with the maximum/minimum scores possible for the measure. For all scales (with the exception of timed components) unless otherwise stated an increase in score indicates higher or closer to normal functioning.

Abbreviated Name	**Full Name**	**Level of Measurement**	**Minimum/Maximum score**	**Construct of measure**
AMAT	Arm Motor Ability Test	Activity limitations	Time, Ability max 87, quality max 87	Time taken to complete 13 functional tasks. Rating of functional ability and quality of movement on 0-6 scales.
ARAT	Action research arm test	Impairment of body functions	0-56	19 items in four subscales: grasp, grip, pinch, gross movement rated on 4 point scale
AUT	Actual amount of use test	Activity limitations	Amount of use max 42, Quality of use max 105	21 items completed and rated as 0= nonuse of affected to 2=2 normal use for amount of use and 0=nonuse to 5=normal for quality of movement
BI	Barthel index	Activity limitations	0-100	Global measure of function rating ability to perform 10 activities of daily living
Box & Block	Box and Block test	Activity limitations	Number of blocks, usually max 16	Number of blocks transferred from one tray to another in a given time
CMM	Chedoke McMaster scale	Impairment of body functions	0-100	Impairments section has 6 dimensions measured on a 7 point scale, 10 items of gross motor function and 5 of walking
FAI	Frenchay activity index	Activity limitations	0-30 plus 0-15	Part 1 – frequency of performance of 10 activities in the last 3 months. Part 2 – 5 activities in past 6 months. Rated 0=never to 3=most days

FAT	Frenchay arm test	Activity limitations	0-5	Ability to perform 5 tasks, stabilising ruler, picking up cylinder, drinking from glass, placing clothes peg on dowel, combing hair
FIM	Functional Independence measure	Activity limitations	18-126	18 items (13 physical, 5 cognitive) rated on 1-7 scale
FM	Fugl-Meyer motor assessment (also Brunnstrom FM test)	Impairment of body functions	0-100 for motor component, (0-66 for UE)	UE, LE, balance, sections. Scored on 3 point scale 0=no function 3=full function
GHQ	General Health Questionnaire	Participation restrictions	Depends on variation used	Varying forms containing 28, 30 or 60 items scored on a Likert scale of 0,1,2,3,
M Ash	Modified Ashworth scale	Impairment of body functions	1-5	5 categories for grading abnormal tone
MAL	Motor activity log	Activity limitations	Depends on number of items included	Patient reported scale of "how well" (QOM) and "how much" (AOU) they use affected UE to perform 14, 16 or 20 ADLs rated 0 to 6 for both sections
MAS	Motor Assessment scale	Activity limitations	0-48 (0-18 for UE sections)	Rating of abilities in 8 categories on scale of 1-6, supine to side lying, supine to sitting, balanced sitting, sit to stand, walking, upper arm function, hand movements, advanced hand activities)
MCA	Motor club assessment	Impairment of body functions	0-50 (1-32 for UE) motor section. 0-54 for functional movement section	25 movements rated 0-2, 18 functional movements rated 0-3
MI	Motricity index	Impairment of body functions	Arm score 0-100, Leg score 0-100	Based on Oxford grading of muscle power rates pinch, elbow flexion, shoulder abduction, ankle dorsiflexion, knee extension, hip flexion.
MP	Motor Power	Impairment of body functions	0-20	Summed scores of power of 4 UE muscles graded on 0-5 Oxford scale for muscle power
MSS	Motor Status Scale	Impairment of body functions	Shoulder/elbow 0-40, wrist/hand 0-42	Grades motor activities in UE on 6 point scales in shoulder/elbow and wrist/finger sections

NHP	Nottingham Health profile	Participation restrictions	High scores indicate poorer functioning	Yes/no questions describing health related behaviour in 6 domains of daily life
NHPT	Nine hole peg test	Activity limitations	Time taken to transfer nine pegs from a well to a peg board	Time taken to place 9 pegs
RAP	Rehabilitation activities profile	Activity limitations	Low score = better function 0-63	21 items in 5 domains. Score 0=performs without difficulty, 3=does not perform
RMA	Rivermead motor assessment	Impairment of body functions	0-15 for arm section	Arm section scored 0 or 1 (1=completed action) for 15 tasks
SF-36	Short Form 36	Participation restrictions	Scoring system yields scores out of 100 for each subsection and total score	36 item scale with 8 subsections a mental health score and a physical health score
SMES	Sødring Motor Evaluation Scale	Impairment of body function		32 items divided into arm, leg and body section
SSS	Scandinavian Stroke Scale	Impairment of body function	0-9 total for UE	UE has sections for arm (graded out of 5) and hand (graded out of 4)
STREAM	Stroke rehabilitation assessment of movement	Impairment of body function	Expressed out of 100	5 point ordinal scale assessing quality of movement of UE for 10 items
TEMPA	Test Evaluant les Membres superieurs des Personnes Agees	Activity limitation	Functional rating maximum 27 high score = low functioning	9 unilateral and bilateral tasks measured in terms of length of execution, functional rating and task analysis
TMS	Transcranial magnetic stimulation	Impairments of body structures and functions	Amplitude of signal distally or location of stimulus on cortex	Measures threshold of stimulus to cortex required to evoke an EMG response distally, the location and size of the cortical area responsible and its centre.
WMFT	Wolf motor function test	Impairments of body function	Time/Power	14 time measured tasks, 2 strength tests

Appendix 2 – Subject information sheet

Name:__________________________

MRN:______________________

Address:__________________________

Phone:______________________

____

Trial Number:________________

____

Group: ABC / ACB, 8 / 9 / 10

Sex: Male/Female

Dominance: Right/Left

Hemiplegia: Right/Left

Consultant:__________________

Date of Birth:_________________

GP:________________________

Date of Stroke:_________________

Address:____________________

Date of 1st measurement:_________________

____

CT result: ____

____

____

Past Medical History:____

____

Medications:____

Current Therapies:____

____

Events:
(e.g. D/C home, change in med status, change in location/staffing, fall, change in medication etc)

Date: **Event:**

Appendix 3 – Nottingham Sensory Assessment

Touch/Pressure/Bilateral Simultaneous Touch:

"Say yes (*or* lift your good hand) every time I touch you".

0= absent, fails to identify the test sensation on three occasions

1= identifies the test sensation but not on three occasions

2= correctly identifies the test sensation on three occasions

Kinaesthesia:

"Copy this position with your good arm"

0= absent, no appreciation of movement taking place

1= subject indicates on each occasion that movement takes place but the direction is incorrect

2= subject is able to appreciate and mirror the direction of the test movement taking place each time but is inaccurate in its new position

3= accurately mirrors the test movement to within 10 degrees of the new test position

	Light touch	Pressure	Bilateral Simultaneous	Kinaesthesia
Hand – Dorsum				
Wrist – Distal 1/3 radius				
Elbow – Dorsum elbow joint				
Shoulder - Deltoid				

8 Appendix 4 – Star Cancellation test

Appendix 5 – Modified Ashworth Scale

0= no increase in muscle tone

1= slight increase in tone manifested by a catch and release or by minimal resistance at the end of the range of motion when the affected part is moved in flexion or extension

2= slight increase in muscle tone manifested by a catch followed by minimal resistance throughout the remainder (<half) of the range if movement

3= more marked increase in tone but limb easily flexed

4= considerable increase in tone, passive movement difficult

5= limb rigid in flexion or extension

	Score
Wrist:	
Elbow:	

Appendix 6 – Visual analogue scale

No Pain ____ Worst Imaginable Pain

Appendix 7 – Short Orientation Memory Concentration Test

	Max score	Subtract per error	Score
What year is it now?	4	4	
What month is it now?	3	3	
Repeat this phrase:	X	X	X
About what time is it (within one hour)	3	3	
Count backwards 20 to 1	4	2/2	
Say months in reverse order	4	2/2	
Repeat the name and address: John/Brown/42/ West Street/Gateshead	10	2/5	

Total Score (/28): ____

Appendix 8 – Fugl Meyer Motor Assessment

Section	Instructions	Scoring	Component	Score
A 1 – Reflexes		0=none 2=reflex activity	Biceps or Finger Flexors	
			Triceps	
A 2a	"Bring your hand up to your ear with the palm facing backwards" Demonstrate intact side first	0=cannot 1=partly 2=faultlessly	S Retraction	
			S Elevation	
			S Abduction	
			S Ext rotation	
			E Flexion	
			F Supination	
A 2b	Start in position for 2a. (Can place in this position). "Bring back of hand to inside of opposite knee" Palpate add and triceps for activity.	0=cannot 1=partly 2=faultlessly	Add + int rot	
			E Extension	
			Pronation	
A 3	"Put your hand into the small of your back"	0=none 1= past ASIS 2= done	To lumbar spine	
	"Straighten your elbow, then keeping your elbow straight and thumb to the ceiling, lift your arm to shoulder height"	0=init s abd, e flex 1= later s abd, e flex 2=done	Shoulder flexion 0-90	
	"Bend your elbow to here, and turn your palm up and down"	0=none, can't hold position 1=movement with position sustained, limited ROM 2= done	Pronation/Supination	
A 4	"Keeping your elbow straight and palm down to the floor, lift your arm out to the side"	0=init el flex, forearm sup 1=partial ROM, later el flex, forearm sup 2=done	Shoulder abduction 0-90	
	"Straighten your elbow, then keeping your elbow straight and thumb to the ceiling, lift your arm over your head"	0=init s abd, e flex 1= later s abd, e flex 2=done	Shoulder flexion 90-180	
	"Keeping your elbow straight, turn your palm up and down". Shoulder between 30-90 flexion	0=none, can't hold position 1=movement with position sustained, limited ROM 2= done	Pronation/Supination	
A 5	Only test if >6 in section A 4	0=2/3 hyper reflexic 1=1 hyper, 2 lively 2=<1 lively, none hyper	Biceps Triceps Finger flexors	

B 1	Elbow at 90 deg flexion. Place wrist in 15 degrees extension. May support elbow position. "Hold your knuckles up" "Don't let me push your hand down"	0=cant 1=maintain without resist 2=maintain with resist	Wrist stability	
B 2	"Drop your wrist all the way down, then bring it all the way back up". Can support elbow position	0= no movement 1= not FROM 2= done	Wrist flex/ext	
B 3	Elbow at 0 deg extension. Place wrist in 15 degrees extension. May support elbow position. "Hold your knuckles up" "Don't let me push your hand down"	0=cant 1=maintain without resist 2=maintain with resist	Wrist stab	
B 4	"Drop your wrist all the way down, then bring it all the way back up". Can support elbow position	0= no movement 1= not FROM 2= done	Wrist flex/ext	
B 5	Elbow at 90, demonsrate on good hand	0= cant 1=jerky 2=done	Circumduction	
C 1	Support to maintain elbow at 90. "Curl your fingers all the way in"	0=none 1= not FROM 2= FROM	Gross flexion	
	Support to maintain elbow at 90. "straighten fingers all the way out"	As for C1	Gross extension	
	"Take my finger as if it's a suitcase handle" "Don't let me pull it out"	0=unable 1=weak 2= against resistance	Suitcase grip	
	"Take this piece of paper between your thumb and index finger like this"	0=cant 1=hold 2= hold with tug	Key grip	
	"Take this pencil as if to sign your name"	0=cant 1=hold 2= hold with tug	Pencil	
	"Take this can"	0=cant 1=hold 2= hold with tug	Can	
	"Take this tennis ball"	0=cant 1=hold 2= hold with tug	Tennis ball	
D	Do intact side first. "Straighten your arm then touch your nose with your index finger. Do this 5 times as fast as you can. I'll time you on the stopwatch"	0=marked 1=slight 2=none	Tremor	
	"	0=marked 1=slight 2=none	Dysmetria	
	"	0= 6 seconds slower 1= 2-5 secs slower 2= < 2 secs slower	Speed	

Appendix 9 – Ethical Approval

THIS NOTEPAPER MUST NOT BE USED FOR PRESCRIPTIONS OR INVOICING PURPOSES

Dan Lynch, Joint Research Ethics Committee Secretariat.
Telephone : 4142860. Fax : 4142371. Email: **dan.lynch@amnch.ie**

THE ADELAIDE & MEATH HOSPITAL, DUBLIN
INCORPORATING
THE NATIONAL CHILDREN'S HOSPITAL

TALLAGHT, DUBLIN 24, IRELAND
TELEPHONE +353 1 4142000

Dr. Desmond O'Neill,
Consultant Geriatrician,
Adelaide and Meath Hospital, Dublin
incorporating The National Children's Hospital,
Tallaght,
Dublin 24.

3rd September, 2001.

RE : The effect of Robot mediated therapy on upper extremity function following stroke.

Please quote this reference in all communications regarding this study : 010805/13201

Dear Dr. O Neill,

The Joint Research Ethics Committee at its meeting on 28th August 2001 agreed to give ethical approval to the above study.

Yours sincerely,

Daniel R. Lynch,
Senior Executive Officer.

cc ✓Ms. Emma Stokes,
Ms Susan Coote.

335703001

Appendix 10 – Consent Form

The effects of Robot Mediated Therapy on arm function following stroke

This research project has been explained to me in detail and I have read and understand the patient information leaflet. I freely and voluntarily agree to be part of this research project. I understand that this does not affect my legal and ethical rights.

I understand that I may withdraw from this project at any time and that this will not affect my normal physiotherapy treatment in any way.

Participants Name:_______________________

Participants Signature:_______________________

Date:____________

Witness' Name:_______________________

Witness' Signature:_______________________

Date:____________________

Appendix 11 – Subject information leaflet

GENTLE/s Project

Subject Information Leaflet

School of Physiotherapy
Trinity College Dublin

Title of Study: The effects of Robot Mediated Therapy on arm function following stroke

Introduction:
Following stroke many people lose some or all of the ability to move their affected arm. This affects their independence and ability to perform everyday activities.

Physiotherapists have several different treatment methods they can use to re-train movement in the arm and to increase strength in the arm, one of the newest methods is called "Robot Mediated Therapy".

Normally physiotherapy is carried out by the physiotherapist helping you to move your arm. Robot Mediated therapy uses a robot to help you move your arm. The Robot we are using is not like the robots you see on Dr Who it is simply a piece of equipment that is controlled by a computer.

This study is being funded by the European Union. It is the first time such a treatment will be available in Ireland. Because it is a new treatment this project will look at whether and how much Robot Mediated Therapy can improve strength, movement and use of your arm.

Procedures:
If you are currently being treated, or have previously received physiotherapy in Tallaght or St James' Hospital you may be asked if you would like to participate in this study.

If you agree to take part you will attend the physiotherapy department in Tallaght Hospital three times a week (on Monday, Wednesday and Friday) for nine weeks. Each session should take approximately one hour.
For the first three weeks we will test whether and how much your arm is improving without any additional treatment. This will be done using standard physiotherapy tests, which look at the movement and strength in your arm.
For the second and third three week phases you will receive 30 minutes of Robot treatment or sling therapy while we continue to test the improvement of your arm. This will be in addition to your regular treatment.

The Robot therapy will involve you sitting in a chair in front of a computer screen. Your arm will be supported in a splint, suspended from an overhead frame, to make it easier to move. The robot will guide your arm through exercises set by the Physiotherapist and give as much assistance or resistance as you require. You will see the movement you are to do on the computer screen.

Sling therapy will involve you sitting and lying with your arm in a series of slings suspended from a frame above you. Your arm will feel lighter and you will perform exercises set by the physiotherapist.

Benefits:
The additional therapy may help you to gain some additional movement in your arm, however we are unsure as to how beneficial the treatment will be.

Risks:
There are no risks involved in participating in this study. The treatment and testing should not be uncomfortable and will be stopped if it causes you any pain.

Exclusion from Participation:
If you have a pacemaker installed you will not be able to participate in this study. If you have had more than one stroke you will also not be able to take part.

Alternative treatment:
This treatment will be in addition to any other treatment you are currently receiving. If you take part in this study it will not prevent you from receiving any other forms of treatment.

Confidentiality:
Your identity will remain confidential. Your name will not be published and will not be disclosed to anyone outside the hospital.

Compensation:
The investigators carrying out this study are all Chartered Physiotherapists. They work under the supervision of a lecturer from Trinity College. All investigators are covered by insurance.

Voluntary Participation:
If you volunteer to take part in this study, you may quit at any time. If you decide not to participate you will not be penalised in any way.

Stopping the study:
Your doctor or physiotherapist may stop your participation in the study at any time without your consent if any unforeseen problems arise.

Permission:
This study has been approved by the Research Ethics Committee. Your hospital consultant has also given permission for your participation in this study.

Further Information:
You can get more information or answers to your questions about the study and your participation in the study from Susan Coote who can be telephoned at 608 3613.

Appendix 12 – Data sheet for SPSS

Group 1, Fugl Meyer

Subject	FMA	FMB	FMC	FMD	FMT	Time A	Time B	Time C
1	12	2	7	1	22	1	0	0
1	13	6	7	1	27	2	0	0
1	16	7	8	1	32	3	0	0
1	17	6	7	1	31	4	0	0
1	19	6	7	1	33	5	0	0
1	19	4	8	1	32	6	0	0
1	19	5	8	2	34	7	0	0
1	19	6	8	1	34	8	0	0
1	19	4	7	1	31	8	1	0
1	18	4	7	1	30	8	2	0
1	19	3	7	1	30	8	3	0
1	21	3	8	1	33	8	4	0
1	20	5	8	1	34	8	5	0
1	21	6	8	2	37	8	6	0
1	22	9	10	1	42	8	7	0
1	22	8	8	2	40	8	8	0
1	23	9	10	3	45	8	9	0
1	21	8	9	3	41	8	9	1
1	23	9	10	3	45	8	9	2
1	25	9	10	3	47	8	9	3
1	23	9	10	5	47	8	9	4
1	23	9	8	3	43	8	9	5
1	23	9	9	4	45	8	9	6
1	23	9	10	3	45	8	9	7
1	24	9	10	3	46	8	9	8
1	25	9	11	3	48	8	9	9
4	24	8	6	2	40	1	0	0
4	25	9	9	3	46	2	0	0
4	27	9	11	3	50	3	0	0
4	22	9	7	2	40	4	0	0
4	25	9	7	3	44	5	0	0
4	24	9	9	2	44	6	0	0
4	26	9	8	3	46	7	0	0
4	24	9	9	2	44	8	0	0
4	24	9	9	2	44	9	0	0
4	24	9	9	3	45	9	1	0
4	26	9	9	3	47	9	2	0
4	27	9	9	3	48	9	3	0
4	27	9	9	2	47	9	4	0
4	28	9	9	3	49	9	5	0
4	27	9	9	2	47	9	6	0

4	28	9	9	3	49	9	7	0
4	.	.	.	.	.	9	8	0
4	27	9	10	3	49	9	9	0
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9 References

Aisen ML, Krebs HI, Hogan N, McDowell F, Volpe BT (1997) The effect of robot-assisted therapy and rehabilitative training on motor recovery following stroke. *Archives Neurology* 54:443-6

Alderson P, Green S, Higgins JPT (2004) *Cochrane reviewers handbook 4.2.2Ed The* Cochrane library, Issue 1 2004, Chichester, Wiley and Sons.

American Heart Association (2003) *2004 Heart and stroke statistical update*. Dallas, Texas: American Heart Association.

Anastasi A, Urbina S (1997) *Psychological Testing, 7th Ed.* Prentice Hall Inc, New Jersey.

Anderson C, Laubscher S, Burns R (1996) Validation of Short Form 36 (SF-36) health survey questionnaire among stroke patients. *Stroke* 27:1812-6

Appelros P; Karlsson GM; Seiger Å; Nydevik I (2002) Neglect and anosognosia after first-ever stroke: incidence and relationship to disability. *Journal of Rehabilitation Medicine* 34(5): 215-20

Ashburn A. (1993) Physiotherapy in the rehabilitation of stroke: a review *Clinical Rehabilitation*. 7:337-45

Bach-y-Rita P (1992) Applications of principles of brain plasticity and training to restore function. *In Principles and Practice of Restorative Neurology* Ed Young PR, Delawaide PJ, Butterworth Heinemann

Backman CL, Harris SR (1999) Case studies, single subject research, and N of 1 randomized trials, comparisons and contrasts. *American Journal Physical Medicine and Rehabilitation* 78:170-6

Backman CL, Harris SR, Chisholm J-AM, Monette AD (1997) Single-subject research in rehabilitation: a review of studies using AB, withdrawal, multiple baseline and alternating treatment designs. *Archives Physical Medicine Rehabilitation* 78:1145-53

Bailey MJ, Riddoch MJ, Crome P (2000). Evaluation of a test battery for hemi neglect in elderly stroke patients for use by therapists in clinical practice. *Neurorehabilitation;* 14(3):139-50

Ballinger C, Ashburn a, Low J, Roderick P (1999) Unpacking the black box of therapy – a pilot study to describe occupational therapy and physiotherapy interventions for people with stroke. *Clinical Rehabilitation* 13:301-9

Bamford J, Sandercock P, Dennis M, Burn J, Warlow C (1991) Classification and natural history of clinically identifiable subtypes of cerebral infarction. *Lancet* 337:1521-26

Barlow DH, Hersen M, (1984) *Single Case Experimental Designs*, 2nd Ed. Pergamon Press, Oxford.

Beaton DE, Bombardier C, Katz JN, Wright JG, Wells G, Boers M, Strand V, Shea B (2001) Looking for important change/differences in studies of responsiveness. *Journal Rheumatology* 28:400-5

Beckerman H, Roebroeck ME, Lankhorst GJ, Becher JG, Bezemer PD, Verbeek ALM (2001) Smallest real difference, a link between reproducibility and responsiveness. *Quality of Life Research* 10:571-8

Berglund K, Fugl-Meyer AR (1986) Upper extremity function in hemiplegia. A cross validation of two assessment methods. *Scandinavian Journal of Rehabilitation Medicine* 18:155-7

Bithell C (1994) Single subject experimental design: a case for concern? *Physiotherapy* 80(2):85-7

Blanton S, Wolf SL. (1999) An application of upper extremity constraint-induced movement therapy in a patient with sub acute stroke. *Physical Therapy* 79(9):847-53

Bobath B (1978) *Hemiplegia: evaluation and treatment*. London, Heinemann.

Bohannon RW (1986) Test-retest reliability of hand-held dynamometry during a single session for strength assessment. *Physical Therapy*. 66(2):206-9

Bohannon RW (1987) Relationship between static strength and various other measures in hemiparetic stroke patients. *International Rehabilitation Medicine* 8:125-8

Bohannon RW (1989) Is the measurement of muscle strength appropriate in patients with brain lesions? A special communication. *Physical Therapy.* 69(3):225-36

Bohannon RW (1995) Consistency of upper extremity motor performance soon after stroke. *Journal of Physical Therapy Science.* 7:49-51

Bohannon RW, Larkin PA, Smith MB, Horton MG (1986) Shoulder pain in hemiplegia: Statistical relationship with five variables. *Archives Physical Medicine Rehabilitation* 6;67:514-6

Bohannon RW, Smith MB (1987) Interrater reliability of a modified Ashworth scale of muscle spasticity. *Physical therapy.* 67:206-7

Bohannon RW, Smith MB (1987a) Assessment of strength deficits in eight paretic upper extremity muscle groups of stroke patients with hemiplegia. *Physical Therapy.* 67(4):522-5

Boissy P, Bourbonnais D, Carlotti MM, Gravel D, Arsenault BA (1999) Maximal grip force in chronic stroke subjects and its relationship to global upper extremity function. *Clinical Rehabilitation.* 13(4):354-62

Bonifer N, Anderson KM (2003) Application of constraint-induced movement therapy for an individual with severe chronic upper-extremity hemiplegia. *Physical Therapy* 83(4):384-98

Boone DC, Azen SP, Lin CM, Spence C, Baron C, Lee L (1978) Reliability of goniometric measurements. *Physical Therapy.* 58:1355-60

Brasil-Neto JP, Valls-Sole J, Pascual-Leone A, Cammarota A, Amassian VE, Cracco R, Maccabee P, Cracco J, Hallet M, Cohen LG (1993) Rapid reversible modulation of human motor outputs after transient de-afferentation of the forearm: A study with transcranial magnetic stimulation. *Brain* 116:511-25

Brobovitz CD, Ottenbacher KJ (1998) Comparison of visual inspection and statistical analysis of single-subject data in rehabilitation research. *Archives Physical Medicine Rehabilitation* 77:94-102

Broeks JG, Lankhorst GJ, Rumping K, Prevo AJ (1999) The long-term outcome of arm function after stroke: results of a follow up study. *Disability & Rehabilitation.* 21(8):357-64

Brunnstrom S (1966) Motor testing procedures in hemiplegia. *Journal American Physical Therapy Association* 46:357

Brunnstrom S (1970) *Movement therapy in hemiplegia: a neurophysiological approach.* Hagerstown. Harper and Row.

Burgar CG, Lum PS, Shor PC, van der Loos HFM (2000) Development of robots for rehabilitation therapy: The Palo Alto VA/Stanford experience. *Journal Rehabilitation Research and Development* 37(6):663-73

Bütefisch C, Hummelsheim H, Denzler P, Mauritz K-H (1995) Repetitive training of isolated movements improves the outcome of motor rehabilitation of the centrally paretic hand. *Journal Neurological Sciences* 130:59-68

Cao Y, D'Olhaberriague L, Vikingstad EM, Levine SR, Welch KMA (1998) Pilot study of functional MRI to assess cerebral activation of motor function after post stroke hemiparesis. *Stroke* 29(112-22

Carr JH, Shepherd RB (1982) *A motor relearning programme for stroke.* London, Heinemann.

Carr JH, Shepherd RB, Nordholm L, Lynne D (1985) Investigation of a new motor assessment scale for stroke patients. *Physical Therapy.* 65:175-80

Cauraugh J, Light K, Sangbum K, Thigpen M, Behrman A (2000) Chronic motor dysfunction after stroke. Recovering wrist and finger extension by electromyography-triggered neuromuscular stimulation. *Stroke* 31:1360-4

Chae J, Yu D (1999) Neuromuscular stimulation for motor relearning in hemiplegia. *Critical Reviews in Physical Rehabilitation Medicine* 11:279-97

Chen C-L, Tang F-T, Chen H-C, Chung C-Y, Wong M-K (2000) Brain lesion size and location: effects on motor recovery and functional outcome in stroke patients. *Archives Physical Medicine Rehabilitation* 81:447-52

Cherney LR, Halper AS, Kwasnica CM, Harvey RL, Zhang M (2001) Recovery of functional status after right hemisphere stroke: relationship with unilateral neglect. *Archives Physical Medicine and Rehabilitation* 82(3):322-8

Chollet F, diPeiro V, Wise RJS, Brooks DJ, Dolan RJ, Frackowiak RSJ (1991) the functional anatomy of motor recovery after stroke in humans: a study with positron emission tomography. *Annals Neurology* 29:63-71

Cohen LG, Bandinelli S, Findley TW, Hallet M (1991) Motor reorganisation after upper limb amputation in man. *Brain* 114:615-27

Coote S, Stokes EK (2001) Physiotherapy for upper extremity dysfunction following stroke. *Physical Therapy Reviews* 6:63-69

Coote S, Stokes EK (2003) Physiotherapy treatments for the upper extremity post stroke: a survey in Ireland. *Physiotherapy Ireland* 24(2):11-18

Coote S, Stokes EK (2003a) Robot mediated therapy: attitudes of patients and therapists towards the first prototype of the GENTLE/s system. *Technology and Disability* 15:27-34

Cotton E, Kinsman R (1983) *Conductive Education for Adult Hemiplegia.* Edinburgh, Churchill Livingstone.

Cramer SC, Bastings E (2000) Mapping clinically relevant plasticity after stroke. *Neuropharmacology* 39:842:51

Crosbie JH, McDonough SM, Gilmore DH, Wiggam MI (2004) The adjunctive role of mental practice in the rehabilitation of the upper limb after hemiplegic stroke: a pilot study. *Clinical Rehabilitation* 18:60-8

Davidson I, Waters K (2000) Physiotherapists working with stroke patients. *Physiotherapy* 86(2):69-80

De Weerdt W, Feys H (2002) Assessment of physiotherapy for patients with stroke. *Lancet* 359(Jan 19):182-3

De Weerdt W, Lincoln NB, Harrison MA, (1987). Prediction of arm and hand recovery in stroke patients. *International Journal Rehabilitation Research;* 10(4 Sup5):110-2

Decety J (1996) The neurophysiological basis of motor imagery. *Behaviour and Brain Research* 77(1-2) 45-2

DeSouza LH, Langton Hewer R, Lynn PA, Miller S, Reed GAL (1980) Assessment of recovery of arm control in hemiplegic stroke patients. Arm function test. *International Rehabilitation Medicine* 2:10

Deutsch JE, Merians AS, Burdea GC, Boian R, Adamovic SV, Poizner H (2002) Haptics and virtual reality used to increase strength and improve function in chronic individuals post –stroke: two case reports. *Neurology Report* 26(2):79-86

Dixon JK, Keating JL (2000) Variability in straight leg raise measurements. *Physiotherapy* 86(7):361-70

Dobkin BH (1998) Activity-dependent learning contributes to motor recovery *Annals of Neurology* 44(2):158-60

Dobson AJ (2001) *An introduction to generalized linear models.* Chapman & Hall Inc, Boca Raton, Florida.

Dohrman GJ, Norwak WJ (1974) Relationship between various clinical signs in lesions of the motor system. *Diseases of the Nervous System.* 35:375-77

Domholt E (2000) *Physical Therapy research. Principles and Applications*, 2nd Ed. WB Saunders,

Dorman P, Slattery J, Farrell B, Dennis M, Sandercock P, (1998) Qualitative comparison of the reliability of health status assessment with the EuroQol and SF-36 questionnaires after stroke. *Stroke.* 29:63-8

Dromerick AW, Edward DF, Hahn M (2000) Does the application of constraint-induced therapy during acute rehabilitation reduce arm impairment after ischemic stroke. *Stroke* 31:2984-8

Duncan PW, Goldstein LB, Horner RD, Landsman PB, Samsa GP, Matchar DB (1994) Similar motor recovery of upper and lower extremities after stroke. *Stroke*. 25(6):1181-8

Duncan PW, Propst M, Nelson SG (1983) Reliability of the Fugl-Meyer assessment of sensorimotor recovery following cerebrovascular accident. *Physical Therapy* 63(10):1606-10

Edmans JA, Towle D, Lincoln NB (1991) The recovery of perceptual problems after stroke and the impact on daily life. *Clinical Rehabilitation;* 5:301-9

Edwards S (1996) Abnormal tone and movement as a result of neurological impairment: considerations for treatment. In Edwards S (Ed) *Neurological Physiotherapy. A problem solving approach.* Churchill Livingstone, Edinburgh 63-86

Edwards S, Partridge C, Mee R (1990) Treatment schedules for research: A model for physiotherapy. *Physiotherapy* 76:605-7

Eliasziw M, Young SL, Woodbury MG, Fryday-Field K (1994) Statistical methodology for the concurrent assessment of interrater and intrarater reliability: using goniometric measurements as an example. *Physical Therapy* 74(8):777-88

Ernst E (1990) A review of stroke rehabilitation and physiotherapy. *Stroke* 21:1081-85

Evans J (1994) Physiotherapy as a clinical science: the role of single case research designs. *Physiotherapy Theory and Practice*10:65-8

Everitt BS (1995) The analysis of repeated measures: a practical review with examples. *The Statistician* 44(1):113-35

Faghri PD, Rodgers MM (1997) The effects of functional neuromuscular stimulation-augmented physical therapy program in the functional recovery of hemiplegic arm in stroke patients. *Clinical Kinesiology* 51(1):9-15

Faghri PD, Rodgers MM, Glaser RM, Bors JG, Ho C, Akuthota P (1994) The effects of functional electrical stimulation on shoulder subluxation, arm functional recovery, and shoulder pain in hemiplegic stroke patients. *Archives Physical Medicine and Rehabilitation* 75(1):73-9

Fasoli S, Krebs HI, Stein J, Frontera WR, Hogan N (2003) Effects of robotic therapy on motor impairment and recovery in chronic stroke. *Archives Physical Medicine and Rehabilitation* 84(4):477-82

Feys H, de Weerdt W, Nuyens G, van de Winckel A, Selz B, Kiekens C (2000) Predicting motor recovery of the upper limb after stroke: value of a clinical examination. *Physiotherapy Research International* 5(1):1-18

Feys H, deWeerdt W, Verbeke G, Cox Steck G, Capiau C, Kiekens C, Dejaeger E, van Hoydonk G, Vermeersch G, Cras P (2004) Early and repetitive stimulation of the arm can substantially improve the long-term outcome after stroke: a 5-year follow up study of a randomised trial. *Stroke* 35:924-9

Feys HM, de Weerdt W, Selz BE, Cox Steck GA, Spichiger R, Vereeck LE, Putman KD, van Hoydonk GA (1998) Effect of a therapeutic intervention for the hemiplegic upper limb in the acute phase after stroke: a single-blind, randomised, controlled multicentre trial. *Stroke*. 29(4):785-92

Finch E, Brooks D, Stratford P, Mayo N (2002) *Physical Rehabilitation Outcome Measures. 2nd Ed* Canadian Physical Therapy Association, BC Decker Inc

Fleiss JL (1981) *Statistical methods for rates and proportions.* Wiley, New York

Friedman PJ (1990) Gait recovery after hemiplegic stroke. *International Disability Studies* 12:119-22

Friedman PJ (1992) The star cancellation test in acute stroke. *Clinical Rehabilitation* 6:23-30

Fugl Meyer AR, Jaasko L, Leyman I, Olsson S, Steglind S (1975) The post stroke hemiplegic patient. 1. A Method for evaluation of physical performance. *Scand J Rehab Med.* 7:13-31

Fuller G (1993) *Neurological Examination mad easy.* Churchill Livingstone, Edinburgh.

Fullerton KJ, Mackenzie G, Stout RW (1988) Prognostic indices of stroke. *Quarterly Journal of Medicine.* 66:147-62

Glanz M, Klawansky S, Stason W, Berkey C, Chalmers TC (1996) Functional electro stimulation in post stroke rehabilitation: a meta-analysis of the randomised controlled trials. *Archives Physical Medicine Rehabilitation* 77:549-53

Gregson J, Leathley A, Moore P, Smith T, Sharma A, Watkins C (2000) Reliability of measurements of muscle tone and muscle power in stroke patients. *Age and Ageing.* 2:223-8

Griffin JW. (1986) Hemiplegic shoulder pain. *Physical Therapy* 66(12):1884-93

Guyatt G, Walter S, Norman G (1987) Measuring change over time: assessing the usefulness of evaluative instruments. *Journal of Chronic Disease* 40(2):171-8

Hackett ML, Duncan JR, Anderson CS, Broad JB, Bonita R (2000) Health related quality of life among long-term survivors of stroke. *Stroke.* 31:440-7

Hallett M (2001) Plasticity of the human motor cortex and recovery from stroke. *Brain Research Reviews.* 36:169-74

Halligan PW, Marshall JC, Wade DT (1989). Visuospatial neglect: underlying factors and test sensitivity. *Lancet;* Oct 14.

Hanlon RE (1996) Motor learning following unilateral stroke. *Archives Physical Medicine Rehabilitation* 77:811-5

Hayes K, Walton J, Szomor ZL, Murrell GAC (2001) Reliability of five methods for assessing shoulder range of motion. *Australian Journal of Physiotherapy* 47:289-94

Held JM, Pay T (1999) Recovery of function after brain damage. *In Neuroscience for Rehabilitation* Ed Cohen H. Lipincott Williams & Wilkins, Philadelphia

Heller A, Wade DT, Wood VA, Sunderland A, Hewer RL, Ward E (1987) Arm function after stroke: measurement and recovery over the first three months. *Journal Neurology Neurosurgery and Psychiatry.* 50(6):714-9

Hendricks HT, van Limbeek J, Guerts A, Zwarts MJ (2002) Motor recovery after stroke: a systematic review of the literature. *Archives Physical Medicine and Rehabilitation* 83:1629-37

Hesse S, Bertelt C, Jahnke MT, Schafrin A, Baake P, Malezic M, Mauritz KH (1994) Restoration of gait in nonambulatory hemiplegic patients by treadmill training with partial body weight support. *Archives Physical Medicine Rehabilitation* 75(10):1087-93

Hesse S, Schulte-Tigges G, Knorad M, Bardeleben A, Werner C (2003) Robot-assisted arm trainer for the passive and active practice of bilateral forearm and wrist movements in hemiparetic subjects. *Archives Physical Medicine Rehabilitation* 84:915-20

Hollis M, Fletcher-Cook P (1999) *Practical exercise therapy*. Blackwell Science, Oxford.

Hopwood V, Lewith G (1997) The effect of acupuncture on the motor recovery of the upper limb after stroke. *Physiotherapy* 83(12):614-9

Humm JL, Kozlowski DA, James DC, Grotts JE, Schallert T (1998) Use-dependent exacerbation of brain damage occurs during an early post-lesion vulnerable period. *Brain Research* 783:286-92

Irish Heart Foundation, Council for Stroke (2000) Towards excellence in stroke care in Ireland. Dublin, Eireann Healthcare Publications,

Johnstone M (1983) *Restoration of motor Function in the Stroke patient: A Physiotherapists approach*. Edinburgh, Churchill Livingstone.

Kahn LE, Averbuch M, Rymer WZ, Reinkensmeyer D (2001) Comparison of robot-assisted reaching to free reaching in promoting recovery from chronic stroke. *Integration of Assistive Technology in the Information Age.* Ed Mokhtari *M.* IOS Press, p39-44

Katz N, Hartman-Maeir a, Ring H, Soroker N (1999) Functional disability and rehabilitation outcome in right hemisphere damaged patients with and without unilateral spatial neglect. *Archives Physical Medicine and Rehabilitation* 80:379-84

Katzman R, Brown T, Fuld P, Peck A, Schechter R, Schimmel H (1983) Validation of a short orientation-memory-concentration test of cognitive impairment. *American Journal Psychiatry* 140:734-9

Kazdin AE (1982) *Single case research designs*. Oxford University Press. Oxford

Keith RA, Granger CV, Hamilton BB, Sherwin FS (1987) The Functional Independence Measure: a new tool for rehabilitation. In: Eisenberg MC, Grzesiak RC (Eds) *Advances in Clinical Rehabilitation.* New York, Springer Publishing Company, p6-18

Kelly JL, Baker MP, Wolf SL (1979) Procedures for EMG biofeedback training in involved upper extremities of hemiplegic patients. *Physical Therapy* 59(12):1500-7

Kilmer DD, McCrory MA, Wright NC, Rosko RA, Kim H-R, Aitkens SG (1997). Hand-held dynamometry reliability in persons with neuropathic weakness. *Archives Physical Medicine and Rehabilitation.* 78:1364-8

Knott M, Voss DE (1968) *Proprioceptive Neuromuscular Stimulation.* New York, Harper & Row.

Kralj A, Acimovic R, Stanic U (1993) Enhancement of hemiplegic patient rehabilitation by means of functional electrical stimulation. *Prosthetics and Orthotics International* 17(2):107-14

Krebs HI, Hogan N, Aisen M, Volpe BT (1998) Robot-aided neuro rehabilitation. *IEEE Transactions on Rehabilitation Engineering* 6(1):75-87

Krebs HI, Volpe BT, Aisen ML, Hogan N (2000) Increasing productivity and quality of care: robot-aided neuro-rehabilitation. *Journal Rehabilitation Research Development* 37(6)

Kunkel A, Kopp B, Muller G, Villiringer K, Villiringer A, Taub E, Flor H (1999) Constraint-induced movement therapy for motor recovery in chronic stroke patients. *Archives Physical Medicine Rehabilitation* 80(6):624-8

Kwakkel G, Kollen BJ, Wagenaar RC (2002) Long term effects of upper and lower limb training after stroke: a randomised trial. *Journal Neurology Neurosurgery and Psychiatry* 72:473-9

Kwakkel G, Wagenaar RC, Koelman TW, Lankhorst GJ, Koetsier JC (1997) Effects of Intensity of Rehabilitation after Stroke. A research synthesis. *Stroke* 28:1550-6

Kwakkel G, Wagenaar RC, Kollen B, Lankhorst G (1996) Predicting disability in stroke – a critical review of the literature. *Age and Ageing* 25:479-89

Kwakkel G, Wagenaar RC, Twisk JW, Lankhorst GJ, Koetsier JC (1999) Intensity of leg and arm training after primary middle-cerebral-artery stroke: a randomised trial. *Lancet* 354(9174):191-6

Langhammer B, Stanghell JK (2000) Bobath or motor relearning programme? A comparison of two different approaches to physiotherapy in stroke rehabilitation: a randomised controlled trial. *Clinical Rehabilitation* 14:361-9

Langhammer B, Stanghell JK (2003) Physiotherapy in the rehabilitation of stroke patients. *Proceedings 14th International Congress of World Confederation Physical therapy, Barcelona, 7th-12th June.*

Langhorne P, Legg L, Pollock A, Sellars C (2002) Evidence based stroke rehabilitation. *Age and Ageing* 31-S3:17-20

Langhorne P, Wagenaar R, Partridge C (1996) Physiotherapy after stroke: more is better? *Physiotherapy Research International* 1(2):75-83.

Lee RG, van Donkelaar P (1995) Mechanisms underlying functional recovery following stroke. *Canadian Journal Neurological Sciences* 22(4):257-63

Lennon S, Baxter D, Ashburn A (2001) Physiotherapy based on the Bobath concept in stroke rehabilitation: a survey within the UK. *Disability and Rehabilitation* 23(6):254-62

Levy CE, Nichols DS, Schmalbrock PM, Keller P, Chakeres DW (2001) Functional MRI evidence of cortical reorganisation in upper-limb stroke hemiplegia treated with constraint induced movement therapy. *American Journal Physical Medicine Rehabilitation.* 80(1):4-12

Liepert J, Bauder H, Miltner W, Taub E, Weiller C (2000) Treatment-induced cortical reorganisation after stroke in humans. *Stroke* 31:1210-6

Liepert J, Miltner WHR, Bauder H, Sommer M, Dettmers C, Taub E, Weiller C (1998) Motor cortex plasticity during constraint-induced movement therapy in stroke patients. *Neuroscience Letters* 250:5-8

Liepert J, Uhde I, Graf S, Leidner O, Weiller C (2001) Motor cortex plasticity during forced-use therapy in stroke patients: a preliminary study. *Journal Neurology* 248:315-21

Lincoln NB, Crow JL, Jackson JM, Waters GR, Adams SA, Hodgson P (1991) The unreliability of sensory assessments. *Clinical Rehabilitation* 5:273-82

Lincoln NB, Jackson JM, Adams SA (1998) Reliability and revision of the Nottingham sensory assessment for stroke patients. *Physiotherapy;* 84(8):358-65

Lincoln NB, Parry RH (1999) Randomised, controlled trial to evaluate increased intensity of physiotherapy treatment of arm function after stroke. *Stroke* 30(10):2242-3

Livesay JR, Samaras MR (1998) Covert neuromuscular activity of the dominant forearm during visualisation of a motor task. *Perceptual Motor Skills* 86(2) 371-4

Loewen SC, Anderson BA (1988) Reliability of the modified motor assessment scale and the barthel index. *Physical Therapy* 68(7):1077-81

Loewen SC, Anderson BA (1990) Predictors of stroke outcome using objective measurement scales. *Stroke* 21(1):78-81

Lum P, Reinkensmeyer D, Mahoney R, Rymer Z, Burgar C (2002a) Robotic devices for movement therapy after stroke: current status and challenges to clinical acceptance. *Topics Stroke Rehabilitation* 8(4):40-53

Lum PS, Burgar CG, Shor P, Majmundar M, van der Loos M (2002) Robot-assisted movement training compared with conventional therapy techniques for the rehabilitation of upper-limb motor function after stroke. *Archives Physical Medicine Rehabilitation* 83:952-9

Mahoney FI, Barthel DW (1965) Functional evaluation: the Barthel Index. *Maryland State Medical Journal* 14: 61-5

Mahoney RM (1996) Introduction to special edition on Robotics. *Tech and Dis.* 5:121-3

Malouin F, Pichard L, Bonneau C, Durand A, Corriveau D (1994) Evaluating motor recovery early after stroke: comparison of the Fugl-Meyer assessment and the Motor Assessment Scale. *Archives Physical Medicine Rehabilitation.* 75(11):1206-12

Mathiowetz V, Weber K, Volland G, Kashman N (1984) Reliability and validity of grip and pinch strength evaluations. *Journal of Hand Surgery.* 9A:22-6

Mayerson NH, Milano RA (1984) Goniometric measurement reliability in physical medicine. *Archives of Physical Medicine and Rehabilitation.* 65(2):92-4

McDowell I, Newell C (1996) *Measuring Health, a guide to rating scales and questionnaires*, 2nd Ed. Oxford University Press, Oxford

McEwen S, Mayo N, Wood-Dauphinee S (2000) Inferring quality of life from performance based assessments. *Disability and Rehabilitation* 22(10):456-63

McHorney CA, Ware JE Jr, Lu JFR (1994) The MOS 36-item Short-Form Health Survey (SF-36): 3. Tests of data quality, scaling assumptions, and reliability across diverse patient groups. *Med care*;32:40-66

Merians AS, Jack D, Boian R, Tremaine M, Burdea G, Adamovich SV, Recce M, Poizner H (2002) Virtual reality – augmented rehabilitation for patients following stroke. *Physical Therapy* 82(9):898-915

Miltner WH, Bauder H, Sommer M, Dettmers C, Taub E (1999) Effects of constraint induced movement therapy on patients with chronic motor deficits after stroke: a replication. *Stroke* 30(3):586-92

Moher D, Jadad A, Nichol G, Penman M, tugwell T, Walsh S (1995) Assessing the quality of randomised controlled trials: an annotated bibliography of scales and checklists. *Controlled Clinical Trials 16:62-73*

Moreland J, Thompson MA (1994) Efficacy of electromyographic biofeedback compared with conventional physical therapy for upper-extremity function in patients following stroke: a research overview and meta-analysis. *Physical Therapy* 74(6):534-43

Mudie MH, Matyas TA (1996) Upper extremity retraining following stroke: Effects of bilateral practice *Journal Neurological Rehabilitation* 10(3):167-84

Mudie MH, Matyas TA (2000) Can simultaneous bilateral movement involve the undamaged hemisphere in reconstruction of neural networks damaged by stroke? *Disability and Rehabilitation* 22(1/2):23-37

Myers RH, Montgomery DC, Vining GG (2002) *Generalized Linear Models, with applications in engineering and the sciences.* John Wiley & Sons Inc, New York.

Nakayama H, Jorgensen HS, Raaschou HO, Olsen TS (1994) Recovery of upper extremity function in stroke patients: the Copenhagen stroke study. *Archives Physical Medicine Rehabilitation* 75(4):394-8

Nakayama H, Jorgensen HS, Raaschou HO, Olsen TS (1994a) Compensation in recovery of upper extremity function after stroke: the Copenhagen Stroke Study. *Archives Physical Medicine Rehabilitation* 75(8):852-7

Nelles G, Jentzen W, Jueptner M, Muller S, Diener HC (2001) Arm training induced brain plasticity in stroke studied with positron emission tomography. *Neuroimage* 13(6,1):1146-54

Nelles G, Spiekermann G, Jueptner M, Leonhardt G, Muller S, Gerhard H, Diener HC (1999) Reorganisation of sensory and motor systems in hemiplegic stroke patients. A positron emission tomography study. *Stroke* 30(8):1510-6

Nelles G, Spiekermann G, Jueptner M, Leonhardt G, Muller S, Gerhard H, Diener HC (1999a) Evolution of functional reorganisation in hemiplegic stroke: a serial positron emission tomographic activation study. *Annals Neurology* 46:901-09

Norkin C, White DJ (1995) *Measurement of joint motion, a guide to goniometry*. FA Davis Company, Philadelphia.

Nudo RJ, Barbary S, Kleim J (2000) Role of neuroplasticity in functional recovery after stroke. *In Cerebral Reorganisation of Function after Brain Damage.* Ed Levin H, Grafman J. Oxford University Press, New York.

Nudo RJ, Miliken GW (1996) Reorganisation of movement representations on primary motor cortex following focal ischemic infarcts in adult squirrel monkeys. *Journal Neurophysiology* 75:2144-49

Nudo RJ, Wise BM, SiFuentes F, Miliken GW (1996) Neural substrates for the effects of rehabilitative training on motor recovery after ischemic infract. *Science* 272:1791-4

Ohlsson A-L, Johansson BB (1995) Environment influences functional outcome of cerebral infarction in rats. *Stroke* 26:644-9

Ottenbacher KJ, Jannell S. (1993) The results of clinical trials in stroke rehabilitation research. *Archives of Neurology* 50(1):37-44

Ottenbacher KJ (1986) *Evaluating clinical change: strategies for occupational and physical therapists.* Williams and Wilkins, Philadelphia

Ottenbacher KJ, Hinderer SR (2001) Evidence-based practice. Methods to evaluate individual patient improvement. *American Journal Physical Medicine and Rehabilitation* 80(10):786-96

Ottenbacher KJ, Johnson MB, Hojem M (1988) The significance of clinical change and clinical change of significance: issues and methods. *American Journal Occupational Therapy* 42(3):156-63

Page S, Sisto SA, Levine P (2002a) Modified constraint-induced therapy in chronic stroke. *American Journal Physical Medicine Rehabilitation* 81(11):870-5

Page SJ, Levine P, Sisto SA, Johnston MV (2001a) A randomised efficacy and feasibility study of imagery in acute stroke. *Clinical Rehabilitation* 15: 233-40

Page SJ, Levine P, Sisto SA, Johnston MV (2001b) Mental practice combined with physical practice for upper limb motor deficit in subacute stroke. *Physical Therapy* 81(8) 1455-62

Page SJ, Sisto SA, Johnston MV, Levine P, Hughes M (2002) Modified constraint-induced therapy in subacute stroke: a case report. *Archives Physical Medicine Rehabilitation* 83:286-90

Page SJ, Sisto SA, Levine P, Johnston MV, Hughes M (2001) Modified constraint induced therapy: a randomised feasibility and efficacy study. *Journal Rehabilitation Research Development* 38(5):385-90

Pandya S, Florence JM, King WM, Robison JD, Oxman M, Province MA (1985) Reliability of goniometric measurement in patients with Duchenne muscular dystrophy. *Physical Therapy.* 65(9) , p. 1339-42.

Pandyan AD, Johnson GR, Price CIM, Curless RH, Barnes MP, Rodgers H (1999) A review of the properties and limitations of the Ashworth and modified Ashworth scales as measures of spasticity. *Clinical Rehabilitation* 13:373-83

Parker VM, Wade DT, Langton-Hewer R. (1986) Loss of arm function after stroke: measurement, frequency and recovery. *International Rehabilitation Medicine;* 8:69-73

Parry RH, Lincoln NB, Vaas CD (1999) Effect of severity of arm impairment on response to additional physiotherapy early after stroke. *Clinical Rehabilitation* 13(3):187-98

Pascual-Leone A, Dang N, Cohen LG, Brasil-Neto JP, Cammarota A, Hallet M (1995) Modulation of muscle responses evoked by transcranial magnetic stimulation during the acquisition of new fine motor skills. *Journal Neurophysiology* 74(3):1037-45

Platz T, Winter T, Muller N, Pinkowski C, Eickhof C, Mauritz K-H (2001) Arm ability training for stroke and traumatic brain injury patients with mild arm paresis: a single blind, randomised, controlled trial. *Archives Physical Medicine Rehabilitation* 82:961-8

Plautz EJ, Miliken GW, Nudo RJ (2000) Effects of repetitive motor training on movement representations in adult squirrel monkeys: role of use versus learning. *Neurobiology of Learning and Memory* 74:27-55

Ploughman M (2002) A review of brain neuroplasticity and implications for the physiotherapeutic management of stroke. *Physiotherapy Canada* Summer:164-76

Pomeroy V, Tallis R (2002a) Neurological rehabilitation: a science struggling to come of age. *Physiotherapy Research International* 7(2):76-89

Pomeroy VM, Dean D, Sykes L, Faragher EB, Yates M, Tyrell P, Moss S, Tallis RC (2000) The unreliability of clinical measures of muscle tone: implications for stroke therapy. *Age and Ageing* 29:229-33

Pomeroy VM, Tallis RC (2000) Physical therapy to improve movement performance and functional ability post stroke. Part 1. Existing evidence. *Reviews Clinical Gerontology* 10:261-90.

Pomeroy VM, Tallis RC (2002) Restoring movement and functional ability after stroke, now and the future. *Physiotherapy* 88(1):3-17

Poole JL, Whitney SL (1988) Motor assessment scale for stroke patients: concurrent validity and interrater reliability. *Archives Physical Medicine and Rehabilitation* 69:195-7

Price CIM, Curless RH, Rodgers H (1999) Can stroke patients use visual analogue scales? *Stroke* 30:1357-61

Rand D, Weiss PL, Gottlieb D (1999) Does proprioceptive loss influence recovery of the upper extremity after stroke? *Neurorehabilitation and Neural Repair* 13:15-21

Rankin G, Stokes M (1998) Reliability of assessment tools in rehabilitation: an illustration of appropriate statistical analyses. *Clinical Rehabilitation* 12:187-99

Reinkensmeyer DJ, Dewald JPA, Rymer WZ (1996) Robotic devices for physical rehabilitation of stroke patients: fundamental requirements, target therapeutic techniques and preliminary designs. *Technology and Disability* 5:205-15

Riddle DL, Finucane SD, Rothstein JM, Walker ML (1989) Intrasession and intersession reliability of hand-held dynamometer measurements taken on brain-damaged patients. *Physical Therapy* 69(3):182-94

Riddoch J, Lennon S (1991) Evaluation of practice: the single case study approach. *Physiotherapy Theory and Practice* 7:3-11

Riddoch J, Lennon S (1994) Single subject experimental design: one way forward? *Physiotherapy* 80(4):215-8

Robertson IH (1994) Methodology in neuropsychological rehabilitation research. *Neuropsychological Rehabilitation* 4(1):1-6

Robertson IH, Murre JMJ (1999) Rehabilitation of Brain Damage: Brain plasticity and principles of guided recovery. *Psychological Bulletin* 125(5):544-75

Robertson IH, Ridgeway V, Greenfield E, Parr A (1997) Motor recovery after stroke depends on intact sustained attention: a 2-year follow up study. *Neuropsychology* 11(2):290-5

Rodgers H, Mackintosh J, Price C, Wood R, McNamee P, Fearon T, Marritt A, Curless R (2004) Does and early increased-intensity interdisciplinary upper limb therapy programme following acute stroke improve outcome? *Clinical Rehabilitation* 17:579-89

Rood M (1954) Neurophysiological reactions as a basis for physical therapy. *Physical Therapy* Rev. 34:444-9

Rothstein JM, Miller PJ, Roettger RF (1983) Goniometric reliability in a clinical setting. *Physical Therapy* 63(10):1611-5

Roy CW, Sands MR, Hill LD, Harrison A, Marshall S (1995) The effect of shoulder pain on outcome of acute hemiplegia. *Clinical Rehabilitation* 9:21-7

Sabari JS, Kane L, Flanagan S, Steinberg A (2001) Constraint-induced motor relearning after stroke: a naturalistic case report. *Archives Physical Medicine Rehabilitation* 82:524-8

Sabari JS, Maltzev I, Lubarsky D, Liszkay E, Homel P (1998) Goniometric assessment of shoulder range of motion: comparison of testing in supine and sitting positions. *Archives Physical Medicine and Rehabilitation* 79:647-51

Sackley CM, Lincoln NB (1996) Physiotherapy for stroke patients: A survey of current practice. *Physiotherapy Theory & Practice* 12:87-96

Salmoni AW, Schmidt R, Water C (1984) Knowledge of results and motor learning: a review and critical appraisal. *Psychological Bulletin* 95(3):355-86

Sanford J, Moreland J, Swanson LJ, Stratford PW, Gowland C (1993) Reliability of the Fugl-Meyer assessment for testing motor performance in patients following stroke. *Physical Therapy* 73(7):447-54

Schleenbaker RE, Mainous AG III (1993) Electro-myographic feedback for neuromuscular re-education in the hemiplegic stroke patient. A meta-analysis. *Archives Physical Medicine Rehabilitation* 74:1301-4

Shelton F de NAP, Reding MJ (2001). Effect of lesion location on upper limb motor recovery after stroke. *Stroke;* 32:107-12

Shelton F de NAP, Volpe BT, Reding M (2001) Motor impairment as a predictor of functional recovery and guide to rehabilitation treatment after stroke. *Neurorehabilitation Neural Repair* 15:229-37

Shumway-Cook A, Woolacott MH (2001) *Motor Control, Theory and Practical Applications 2nd Ed.* Lippincott Williams and Wilkins, Philadelphia.

Sim J (1995) The external validity of group comparative and single system studies. *Physiotherapy* 81(5):263-70

Skilbeck CE, Wade DT, Langton-Hewer R, Wood VA (1983) Recovery after stroke. *Journal Neurology Neurosurgery Psychiatry* 46:5-8

Smedley RR, Fiorino AJ, Soucar E et al (1986) Slot machines, their use in rehabilitation after stroke. *Archives Physical Medicine and Rehabilitation.* 67:546-9

Sonde L, Gip C, Fernaeus SE, Nilsson CG, Viitanen M (1998) Stimulation with low frequency (1.7 Hz) transcutaneous electric nerve stimulation (low tens) increases motor function of the post-stroke paretic arm. *Scandinavian Journal Rehabilitation Medicine* 30(2):95-9

Sterr A, Elbert T, Berthold I, Kolbel S, Rockstroh B, Taub E (2002) Longer versus shorter daily constraint-induced movement therapy of chronic hemiparesis: an exploratory study. *Archives Physical Medicine Rehabilitation* 83(10):1374-4

Stevenson T (2001) Detecting change in patients with stroke using the Berg balance scale. *Australian Journal Physiotherapy* 47:29-38

Stone SP, Halligan PW, Wilson B, Greenwood RJ, Marshall JC (1991) Performance of age-matched controls on a battery of visuo-spatial neglect tests. *Journal Neurology Neurosurgery and Pshychiatry* 54:341-44

Stratford PW, Binkley J, Solomon P, Finch E, Gill C, Moreland J (1996) Defining the minimal level of detectable change for the Roland-Morris questionnaire. *Physical Therapy* 76(4):359-65

Stroke Unit Triallists' Collaboration (1998) Organised inpatient (stroke unit) care for stroke (Cochrane Review). *Cochrane Library Issue 3, 1999.* Oxford, Update Software.

Sunderland A (1990) Single-case experiments in neurological rehabilitation. *Clinical Rehabilitation* 10:181-92

Sunderland A, Fletcher D, Bradley L, Tinson D, Hewer RL, Wade DT (1994) Enhanced physical therapy for arm function after stroke: a one year follow up study. *Journal Neurology Neurosurgery and Pshychiatry* 57(7):856-8

Sunderland A, Tinson D, Bradley L, Langton-Hewer R (1989) Arm function after stroke. An evaluation of grip strength as a measure of recovery and a prognostic indicator. *Journal of Neurology Neurosurgery and Psychiatry.* 52:1267-72

Sunderland A, Tinson DJ, Fletcher d, Langton-Hewer R, Wade DT (1992) Enhanced physical therapy improves arm function after stroke. A randomised controlled trial. *Journal of Neurology Neurosurgery and Psychiatry* 55:530-5

Sze FK-H, Wong E, Yi X, Woo J (2002) Does acupuncture have additional value to standard post stroke motor rehabilitation? *Stroke* 33:186-94

Taub E, Miller NE, Novak TA, Cook EW3rd, Fleming WC, Nepomuceno CS, Connell JS, Crago JE (1993) Technique to improve chronic motor deficit after stroke. *Archives Physical Medicine Rehabilitation* 74(4):347-54

Taub E, Uswatte G (2000) Constraint-induced movement therapy and massed practice. *Stroke* 31:986-8

Taub E, Uswatte G, Pidikiti R (1999) Constraint-Induced Movement Therapy: a new family of techniques with broad application to physical rehabilitation – a clinical review. *Journal Rehabilitation Research Development* 36(3):237-51

Taub E. (1980) Somatosensory deafferentation research in monkeys: implications for rehabilitation medicine. In: Ince L, ed, *Behavioural Psychology in Rehabilitation Medicine: Clinical Applications.* Baltimore, MD: Williams & Wilkins 371-440

Tinson DJ (1989) How stroke patients spend their days. *International Disability Studies* 11:45-9

Tremblay F, Tremblay LE (2002) Constraint-induced movement therapy: evidence for its applicability in the context of a home rehabilitation intervention for sub-acute stroke. *Physiotherapy Canada* Spring:116-22

Turton A, Pomeroy V (2002) When should upper limb function be trained after stroke? Evidence for and against early intervention. *Neurorehabilitation* 17:215-24

Turton AJ, Fraser CM (1986) A test battery to measure recovery of voluntary movement control following stroke. *International Rehabilitation Medicine.* 8:74-8

Van der Lee JH, Snels IAK, Beckerman H, Lankhorst GJ, Wagenaar RC, Bouter LM (2001) Exercise therapy for arm function in stroke patients: a systematic review of randomised controlled trials. *Clinical Rehabilitation* 15:20-31

Van der Lee JH, Wagenaar RC, Lankhorst GJ, Vogelaar TW, Deville WL, Bouter LM (1999) Forced use of the upper extremity in chronic stroke patients: results from a single blind randomised clinical trial. *Stroke* 30(11):2369-75

Volpe BT, Krebs HI, Edelstein OTR L, Diels C, Aisen M (2000) A novel approach to stroke rehabilitation: robot aided sensorimotor stimulation. *Neurology* 54(10):1938-44

Volpe BT, Krebs HI, Hogan N, Edelstein L, Diels CM, Aisen M (1999) Robot training enhanced motor outcome in patients with stroke maintained over 3 years. *Neurology* 53:1874-6

Wade DT (2000) *Measurement in Neurological Rehabilitation.* Oxford University Press, Oxford.

Wade DT, Langton-Hewer R, Wood VA, Skilbeck CE, Ismail HM (1983) The hemiplegic arm after stroke: measurement and recovery. *Journal Neurology Neurosurgery Psychiatry* 46(6):521-4

Wang RY, Yang YR, Tsai MW, Wang WTJ, Chan RC (2002) Effects of functional electrical stimulation on upper limb motor function and shoulder range of motion in hemiplegic patients. *American Journal Physical Medicine Rehabilitation* 81(4):283-90

Wanklyn P, Forster A, Young J (1996) Hemiplegic shoulder pain (HSP): natural history and investigation of associated features. *Disability and Rehabilitation* 18(10):497-501

Ware JE Jr, Snow KK, Kosinski M (1993) *SF-36 health survey: manual and interpretation guide.* The Health Institute, New England medical centre. Boston, Massachusetts.

Weiller C, Jeuptner M, Fellows S (1996) Brain representation of active and passive movements. *Neuroimage* 4:105-10

Weiller C, Ramsay S, Wise RJS, Friston KJ, Frackowiak RSJ (1993) Individual patterns of functional reorganisation in the human cerebral cortex after capsular infarction. *Annals Neurology* 33:181-9

Weiss T, Hansen E, Beyer L, Conradi ML, Merten F, Nichelmann C, Rost R, Zippel C (1994) Activation processes during mental practice in stroke patients. *International Journal of Psychophysiology* 17(1):91-100

Whitall J, McCombe Waller S, Silver KH, Macko RF (2000) Repetitive bilateral arm training with rhythmic auditory cueing improves motor function in chronic hemiparetic stroke patients *Stroke* 31(10):2390-5

Williams BK, Galea MP, Winter AT (2001) What is the functional outcome for the upper limb after stroke? *Australian Journal Physiotherapy* 47:19-27

Wilson B, Cockburn J, Halligan PW (1987) *Behavioural inattention test.* Titchfield, Thames Valley Test Company.

Winstein C, Merians A, Sullivan K (1999) Motor learning after unilateral brain damage. *Neuropsychologia* 37:975-87

Woldag H, Waldmann G, Heuschkel G, Hummelsheim H (2003) Is the repetitive training of complex hand and arm movements beneficial for motor recovery in stroke patients? *Clinical Rehabilitation* 17:723-30

Wong AM, Su TY, Tang FT, Cheng PT, Liaw MY (1999) Clinical trial of electrical acupuncture on hemiplegic stroke patients. *Am J Phys Med* 78(2):117-22

Woolfson RF, Clarke WR (2002) Least-squares regression methods: predicting one variable from another. *In: Statistical Methods for analysis of biomedical data* (2nd Ed) Wiley and Sons, New York

World Health Organisation (2001) *International Classification of Functioning, Disability and Health,* Geneva, Chapter A

World Health Organization. Stroke (1989). Recommendations on stroke prevention, diagnosis, and therapy. Report of the WHO Task Force on stroke and other cerebrovascular disorders. *Stroke* 1989, 20, 1407–31.

Wu C, Trombly C, Lin K, Tickle-Degnen L (2000) A kinematic study of contextual effects on reaching performance in persons with and without stroke: influence of object availability. *Archives Physical Medicine Rehabilitation* 81:95-101

Wyller TB, Sveen U, Sodring KM, Pettersen AM, Bautz-Holter E (1997) Subjective well-being one year after stroke. *Clinical Rehabilitation.* 11(2):139-45

Zhan S, Ottenbacher KJ (2001) Single subject research designs for disability research. *Disability and Rehabilitation* 23(1):1-8

Zorowitz RD, Hughes MB, Idank D, Ikai T, Johnston MV (1996) Shoulder pain and subluxation after stroke: correlation or coincidence? *American Journal Occupational Therapy* 50(3):194-201