

Does Mental Practice Promote Cortical Excitability and Improved Hand Function in Stroke?

By

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ABSTRACT

The upper extremity is often left with permanent disability following stroke and therapeutic techniques used at present have had limited success. This prospective clinical trial evaluated the effectiveness of mental practice (MP) through motor imagery (MI) a therapy technique to enhance upper extremity motor recovery after stroke. MI ability, upper extremity hand function, finger strength, and motor cortical output were examined in 18 stroke subjects (mean 67.5 years). Subjects were randomly allocated to the MP treatment group or the control group which received cognitive therapy. Both groups received their respective treatment daily for 30 minutes for a 3 week period. Assessments were performed prior to treatment, post treatment and at 3 months post treatment. Imagery ability was measured using the Kinesthetic and Visual Imagery Questionnaire (KVIQ) and mental chronometric testing. Hand function was assessed with the box and block test (BBT) and finger strength with maximum voluntary contraction (MVC). To determine the effect of MI on neural excitability, focal transcranial magnetic stimulation was applied over the primary motor cortex while participants were at rest and while they imagined themselves performing abduction of the index finger. Motor evoked potentials were recorded from the contralateral first dorsal interosseous (FDI), abductor digiti minimi (ADM) and abductor pollicis brevis (APB) muscles. Data were analyzed using multifactor and repeated measures ANOVAs with the significance level set to $p < 0.05$. Results showed no significant difference between groups on any of the outcome measures ($p > 0.05$) although all subjects improved their hand function over the study period ($p < 0.05$). In addition, motor threshold was found to decrease over time ($p <$

0.001) in all subjects demonstrating improvement in cortical motor excitability and output. Motor evoked potentials (MEPs) elicited during MI were significantly larger compared to those evoked at rest ($p \leq 0.022$). MEP amplitudes from FDI, the muscle targeted with MP, showed a significant interaction effect between time and group ($p = 0.021$) which reflected an increase in MEPs in the MP group over time whereas a decline occurred in the cognitive group. These findings indicate that MI enhances motor cortical output in stroke and that MP using MI appears to increase corticospinal output to the target FDI muscle. No differential effects of MP and cognitive therapy interventions were evident in terms of hand function and finger muscle strength.

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LIST OF ABBREVIATIONS

ARA = Action Research Arm Test

ADLs = activities of daily living

ADM = abductor digiti minimi

APB = abductor pollicis brevis

au = arbitrary unit

BBT = Box and Block Test

CIT = constraint-induced therapy

cm = centimetre

CT = cognitive therapy

EDC = extensor digitorum communis

EMG = electromyography

FDI = first dorsal interosseous

fMRI = functional magnetic resonance imaging

Fugl-Meyer = Fugl-Meyer Assessment of Motor Recovery

ICC = intraclass correlations coefficient

KVIQ = Kinesthetic and Visual Imagery Questionnaire

m = metre

MEP = motor evoked potential

MI = motor imagery

MIQ = Movement Imagery Questionnaire

mm = millimetre

MP = mental practice

ms = millisecond

MT = motor threshold

mV = millivolt

μ V = microvolt

MVC = maximum voluntary isometric contraction

OFC = orbitofrontal cortex

PET = positron emission tomography

RCT = randomized control trial

rCBF = regional cerebral blood flow

SD = standard deviation

Ag-AgCl = silver-silver chloride

TES = transcranial electrical stimulation

TMS = transcranial magnetic stimulation

VMIQ = Vividness of Movement Imagery Questionnaire

VVIQ = Vividness of Visual Imagery Questionnaire

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Chapter 1.0 Introduction

Motor imagery (MI) is the ability to reproduce a specific action solely in the mind's eye, without any corresponding motor output⁵⁸. When this cognitive operation is repeated with the goal of improving motor performance it is known as mental practice (MP). MI through MP has been widely used to enhance motor skill performance^{22, 44, 104} in sport and has recently been proposed for use in rehabilitation for people with motor impairment, such as stroke^{59, 89}. The reason MP has been determined to be beneficial to motor skill performance is because of similarities in the responses of heart rate, breathing frequency^{19, 36} and the pattern of activation of neural structures^{14, 36} between executed and imagined movements. As such MP may yield positive training effects.

There is a need to develop adequate rehabilitation techniques for people with motor impairment following stroke. According to the Heart and Stroke Foundation of Canada⁵², 10% of people completely recover from a stroke and 15% die, leaving approximately 75% of stroke survivors with functional impairment. Motor impairment following stroke is a significant cause of permanent disability, particularly when impairment involves the hand¹¹⁸. The hand is critical for performing activities of daily living (ADLs) but recovery often remains incomplete²⁹. Presently rehabilitation techniques for people with little to no motor recovery in their hand are limited. Many of the therapy methods used (i.e. physiotherapy, constraint-induced therapy (CIT)) require some movement to begin and progress treatment. MP is a technique that does not require voluntary movement of the hand to be utilized in

rehabilitation and therefore may afford some benefit to those with severe impairments.

The amount of physical practice a person can manage early after stroke is limited because of muscle weakness, lack of endurance, poor coordination and balance deficits. Given these challenges MP provides a means of increasing the practice time without the physical constraints and fatigue associated with physical rehabilitation^{55, 79}. If stroke survivors are able to promote upper limb recovery through the use of MP, they may acquire the amount of motor control necessary to participate in intensive physical interventions that will further enhance their recovery and obtain the best possible level of function.

Research has demonstrated that following a stroke, people are able to use MI^{62, 63} and some have reported that MP improves function^{76, 91}. No studies to date have examined whether MP increases motor cortical output to those muscles involved in the imaged tasks in people with stroke. The therapeutic potential of MP needs to be explored and an understanding of the mechanisms of action is essential for MP to be used effectively as a means of enhancing recovery following stroke. This study addresses these issues.

Chapter 2.0 Literature Review

2.1 Stroke

Over 300 000 Canadians are presently living with neurological deficits acquired from stroke ⁵⁰. Following a stroke, neurological damage can impact sensorimotor integration, movement programming and execution, walking, language, balance, mood and sensory perception ¹⁰¹. The seriousness of these deficits have made stroke the leading cause of chronic disability and the third most frequent cause of death in Canada ⁵¹. About 50 000 new cases of stroke are reported every year and 1/3 of these Canadians are under the age of 65 ⁴⁹. High economic costs make stroke the most expensive disease category in Canada, and the magnitude of this problem has been predicted to increase based on the growing elderly population ^{52, 81}.

Stroke is different from many other disabling conditions in that the onset is sudden, leaving the individual and the family unprepared to cope with the lasting effects ⁸¹. It dramatically impacts quality of life, associated with chronic pain or discomfort, activity restriction, disability, and often unemployment ⁵¹. Reports indicate that 36-75% of stroke survivors are disabled resulting in dependency in one or more of their activities of daily living ^{52, 82}. Four main problem areas have been identified: the inability to perform household tasks, travel/ transportation, basic ADLs and the lack of having a meaningful activity to participate in throughout the day ⁸². This is significant considering that less than 5% of their healthy peers were found to have any limitation in their daily activities ⁸².

A stroke occurs when the supply of oxygen to the brain is interrupted resulting in cell death or damage. A stroke is categorized as ischemic or hemorrhagic. An

ischemic stroke occurs when a cerebral artery is blocked by a blood clot (thrombosis) or a wandering blood clot (embolus) is carried into the bloodstream. A hemorrhagic stroke occurs when a diseased artery in the brain bursts and floods the surrounding delicate tissue with blood which displaces brain tissue⁵³. Ischemic strokes account for approximately 80% of strokes, whereas hemorrhagic strokes account for the remaining 20%⁴. The amount and type of functional loss is dependent on the location and size of the lesion and the extent of neuronal death. Immediate treatment following a stroke is critical to minimize cascading damage and decrease edema in the cerebral area⁴.

Despite advances in acute stroke care, there is still a lack of effective interventions to minimize or reverse the effects of stroke²⁸. For this reason the majority of stroke survivors need rehabilitation services to enhance their recovery and to minimize disability. The need to determine appropriate and effective rehabilitation plans to optimize stroke recovery is a priority.

2.2 Motor Cortical Reorganization

Motor cortical reorganization or neuroplasticity refers to the brain's ability to reorganize, both sensory and motor areas, following an injury⁹⁸. When a damaged area of the brain is no longer able to perform its function, new areas may assume the function previously performed by the damaged or lesioned area. The new area might be immediately adjacent or it could be remote from the lesion⁷¹.

It has been proposed that the process of motor cortical reorganization can lead to functional recovery or improved performance following stroke¹¹⁸. To demonstrate

that neuroplastic and organizational changes have functional implications, research using imaging (i.e. positron emission tomography (PET)) and neurophysiological techniques (i.e. transcranial magnetic stimulation (TMS)), has been important. Weiller, Chollet, Friston, et al.¹²² used PET with 10 subjects recovering from striatocapsular motor lesions. They found widespread decreased blood flow to structures immediately surrounding the lesion as well as to distant structures which demonstrates the large distribution of reduced oxygenation caused by the lesion. During finger opposition, PET revealed abnormal bilateral activation of the premotor cortices only in those subjects who exhibited good or complete motor recovery of the hand. Similar activation patterns were never observed in healthy, control subjects suggesting a close association between cortical reorganization and recovery of function. Another study used TMS to assess changes in motor cortical excitability and cortical reorganization following monohemispheric stroke¹¹⁷. The motor cortical area associated with the abductor digiti minimi (ADM) was determined in 15 subjects at 1 and 8 weeks post stroke and compared to 15 healthy, age-matched control subjects. At the beginning of the study period (1 week post-stroke) the number of scalp sites from which a motor evoked potential (MEP) was elicited averaged 2.4 ± 1.5 sites (1 SD) but by week 8 the area had enlarged significantly (3.2 ± 1.8 sites). It was noted that although the representation areas remained smaller than that of the non-lesioned hemisphere and the area measured in control subjects, the increase in the cortical representation area of ADM correlated with improvements in hand function, as measured by the Canadian Neurological Scale ($r = 0.61$) and was evident in 13 of 15

subjects. These findings suggest that reorganization of the motor cortex is linked to functional improvement.

The extent of motor cortical reorganization has been used as a measure of recovery in the field of rehabilitation to assess the effectiveness of specific rehabilitation therapy techniques. For example, researchers have used CIT in isolation or together with traditional physiotherapy to promote enhanced cortical representation of the trained muscles as demonstrated using TMS mapping techniques^{73, 74}. CIT involves restraining the unaffected hand/arm thereby forcing the individual to intensively use his or her affected arm. Without a control group though, it is not possible to attribute gains to the specific features of the intervention.

Liepert and colleagues⁷³ used a combination of physiotherapy and CIT to compare changes in cortical projections to abductor pollicis brevis (APB) in 9 stroke patients who were 4 to 8 weeks post stroke. Treatment involved 2 weeks of daily physiotherapy treatment. In the second week, CIT was applied during the day in addition to regular physiotherapy. The authors measured the cortical map size of APB at 3 time periods: prior to treatment, after 1 week of physiotherapy treatment, and after 1 week of combined treatment (physiotherapy and CIT). Prior to treatment the cortical map area of the affected APB muscle was significantly smaller compared to the unaffected side. There was no change to the cortical map area or finger dexterity following 1 week of physiotherapy treatment. With the addition of CIT to physiotherapy, findings showed a 50% increase in the cortical map area of APB along with a significant improvement in finger dexterity (as measured by the Nine-Hole Peg Test). This study demonstrated that an increase in motor cortical excitability is

associated with improved hand function following specific therapy training. However, it has been suggested that reorganization measured as an increase in size of the cortical map may be due to an increase in cortical neurons' firing potential (i.e. reduced threshold), rather than true, anatomical reorganization ¹¹¹.

Although changes in motor function may be evident following CIT, the main limitation is that a minimum of 15 to 20 degrees of wrist flexion and extension as well as finger movement are required ^{73, 123} to be able to engage in this type of intense therapy. Alternative approaches are required for the large group of people who do not meet these criteria and have been left with severe paresis of the hand.

2.3 Motor Imagery

MI is an internal process that involves mental reproduction of a specific action within working memory and without activating any muscles to generate movement ⁵⁸. Reproducing a skill using MI can be performed in two ways: visual or kinesthetic. Visual imagery refers to visualizing the performance of a movement in the mind's eye, whereas kinesthetic imagery involves concentrating on the feeling and sensation that the physical performance of the task creates (i.e. tension, stretch, proprioception) ¹¹⁵. It has been suggested that visual imagery is more appropriate for tasks that emphasize form (e.g. drawing) while kinesthetic imagery should be used for tasks that emphasize timing or coordination (e.g. walking) ³⁴. MP is the act of repeating, through MI, an imagined movement several times with the intention of improving motor performance ⁷⁹. In contrast to the process of MI (a technique), MP is a training method used to enhance performance and learning of a motor skill ⁵⁹.

It is well established that when MP is combined with physical practice, motor skill performance^{22, 44}, acquisition and learning⁷⁹ are accelerated over physical practice alone. Roure and colleagues¹⁰⁴ used the skill of the volleyball pass and serve receive to assess advantages of the combination of MP with physical practice on motor skill performance. Twenty-four players were randomized into either an imagery or control group. In addition to regular season practices, both groups received 20 additional practice sessions which took place for 30 minutes, 3 times each week for 2 months. If placed in the imagery group, the players performed guided MI by listening to the sound of a volleyball serve provided through audiotape. Each subject in the imagery group was instructed to imagine passing the ball to the setter following serve receive. For the same amount of practice time, the control group worked at tasks which included improving social relationships and conversation skills. To determine change in motor performance the authors compared each athlete's skilled performance before and after the additional practice sessions. A scale of 0-3 was used to assess performance of passing the ball to the setter, where each number represented a score based on the amount of movement the setter made from the target position to reach and set the pass (i.e. 0 steps, 1 step, 3 steps, run). Results indicated significant improvement in passing accuracy for the imagery group, whereas the control group showed no change over the practice period.

The combination of physical practice and MP was found to enhance motor skill acquisition and learning of limb loading strategies for people with chronic stroke⁷⁹. Twelve subjects (mean = 1.7 years post stroke) were assessed for MI ability using the Kinesthetic and Visual Imagery Questionnaire (KVIQ), and tested on their ability

to transfer from sit to stand and stand to sit without using their arms for assistance. Each subjects' ability to equally distribute their weight through each transfer, as measured by a force plate, was assessed before and after a training procedure. The training procedure involved a series of 7 sets, where each set consisted of 1 physical repetition and 5 mental repetitions. Results demonstrated that following a single training session significant improvement of weight loading on the affected leg was evident. Furthermore, this improvement was retained 1 day later, which indicates a learned effect. The effectiveness of the physical practice relative to the MP however could not be disentangled.

The combination of MP and physical practice has also led to improved postural control ³³, speed and accuracy of upper extremity visuomotor tasks ¹²⁴ and equilibrium reactions ⁷⁵. Fairweather & Sidaway ³³ showed that a 3-week MP training program combined with physical practice for 15 minutes, 3 times per week improved postural control and reduced low back pain among individuals with lordosis and kyphosis. Another study ⁷⁵ examined the effect of an 8 day training program that combined mental and physical practice to improve walking balance in elderly women (67- 90 years). The balance and equilibrium assessment took place on a 32 foot carpeted walkway that included a narrow walking strip, steps and a ramp. Subjects were randomly allocated into the experimental group (MP and physical practice) or the control group (physical practice and cognitive training). The combined MP and physical practice resulted in better walking equilibrium reactions as measured through observation of body movements (i.e. flexion or abduction of the arms or hips, hopping, lateral flexion of head). The literature suggests that when MP is used in

conjunction with physical practice, motor performance is enhanced as compared to physical practice alone.

Studies have also suggested that MP alone yields better results as compared to no practice at all ^{44, 106}. Directly comparing MP, physical practice, and no practice in healthy people, Yue & Cole ¹²⁵ assessed muscle strength in the left hypothenar muscles. The physical practice group produced repeated maximal isometric contractions of the left hypothenar muscles; the imagery group was instructed to produce effortful isometric contractions in their mind's eye; and the control group was instructed not to strength train their upper extremities throughout the course of this study. The physical practice and imagery group performed 15 maximal contractions (either physical or imagined), 5 times per week, for 4 weeks. Results indicated that the average abduction force of the left fifth finger increased 22% in the imagery group, 30% in the physical practice group, and almost 4% in the control group. Flexor force of the same digit was also tested. Increases in strength were found in both the imagery and physical practice groups but the control group actually showed a decrease in strength. Although this shows that muscle strength can improve with mental practice alone as compared to no practice at all, different combinations of physical and mental practice have superior results than either form of practice alone ⁴⁴.

A recent study ⁹⁶ reproduced Yue and Cole's ¹²⁵ findings using a similar protocol of imagery, physical practice and no intervention. Training occurred over 12 weeks (15 minutes per day, 5 days per week) resulting in a 35% increase in finger abductor strength in the imagery group, 53% in the physical practice group and no

change in strength in the control group. The finding that MP alone has the ability to improve strength, has led to speculation that MP could be useful in neurological rehabilitation to enhance motor recovery^{88, 120}.

2.4 Mechanisms of Motor Imagery

While it is clear that MP using MI can enhance physical performance the mechanisms are not understood. It has been proposed that imagined and executed movements share much of the same neural circuitry^{14, 41}. TMS has provided evidence of imaging-induced modulation of motor cortical output⁹, and chronometric and physiological responses suggest “movement” equivalence between imagined and executed movements^{18, 19}.

2.4.1 *Neural Substrates of MI*

Current understanding of MI on motor learning and performance is that MI incorporates both preparatory and executive motor processes. Experiments using PET and functional magnetic resonance imaging (fMRI) have enabled anatomic localization of the cerebral structures involved in performing imagined and executed movements. An early study by Roland, Skinhoj, Lassen et al.¹⁰⁰ used PET to compare the cortical location of imagined and executed complex finger movements. During the imagined task both the premotor and supplementary motor area were shown to be activated, which was similar to what was observed during the actual execution of the same sequence of finger movements. The only difference between the two conditions was that the primary motor cortex was activated only if the

movement was actually executed. Other PET studies have supported the finding that the primary motor cortex was not involved in MI ^{21, 65}; however, this has been challenged ⁹⁵.

Using fMRI Porro et al. ⁹⁵ found a significant change in signal intensity in the primary motor cortex during both motor execution and imaging of a sequential finger-to-thumb task, but no significant change was found during the control condition (mental visualization of a scene). This pattern was present in 8/12 subjects. Dechent, Merboldt, & Frahm ²⁰ observed that 4/6 subjects showed initial activation in the motor cortex while imaging a finger-thumb opposition task repeated for 12 seconds however, the activation was not sustained throughout the duration of the imagined task. The investigators felt that the lack of sustained activation in the primary motor cortex might explain some of the controversial results regarding the role of the primary motor cortex in imagery ²⁰.

To further examine the neural substrates involved with MI Jackson, Lafleur, Malouin et al. ⁵⁸ used PET to study motor learning through MP. Nine healthy subjects used MP to learn a foot sequence. Blood flow changes were measured and compared before and after motor learning took place. Results suggested that MP improves performance by acting on the unconscious preparation and anticipation of movements rather than on the execution of skilled performance. This rationale was based on 2 findings: increased blood flow occurred in the medial orbitofrontal cortex (OFC) and not in the striatum as is the case during physical execution. These results were compared to an earlier study conducted by the same research group ⁶⁹ where both the medial OFC and striatum were activated when physical practice was used to learn a

foot motor sequence. Since the medial OFC was activated during both imagery and physical execution the authors concluded that this region is associated with motor sequence learning in both MP and physical practice. When compared to the findings of the activation pattern during physical practice ⁶⁹, it appears that the striatum is associated with motor sequence learning only with physical execution of a motor sequence ⁵⁸. Together these results suggested that MP acts on the anticipatory and preparatory neural mechanisms; for physical execution, additional structures are activated.

The results from neuroimaging studies demonstrate common neurological substrates associated with imagery and execution of motor tasks. Some researchers believe that effective rehabilitation training after stroke should involve the primary motor cortex ¹¹⁰. However, MI can be effective by acting on premotor cortical structures that can modulate motor cortical output ⁵⁹.

If the motor cortex or the circuits projecting to it are activated with MI then it follows that the excitability of the motor cortex should be increased by imagery. Studies using TMS, a non-invasive and painless method of examining motor cortical output, have shown that the size of the MEP is greater during motor imagery compared to a resting condition and is comparable to MEPs evoked during actual execution of a movement ^{32, 48, 102, 114}. This suggests that the output from the motor cortex is modulated in a similar way during both imagined and executed movements.

In contrast, the MEP amplitude evoked from transcranial electrical stimulation (TES), which activates motor cortical cells at the axon hillock ⁶⁶ is not influenced by MI ¹. The differential response to TES and TMS suggests excitability of the motor

cortex is altered pre-synaptically during imagery (TMS activates primary motor cortex cells via cortical afferents). Both TES and TMS produce short latency motor responses, but electrically induced currents flow perpendicular to the surface of the skull, whereas magnetic stimulation produces currents oriented parallel to the surface of the skull and the stimulating coil⁶ thus preferentially activating pyramidal tract neurons and horizontally oriented cortico-cortical fibers, respectively¹³. MI therefore, likely increases the excitability of cortical motor neurons through activation of the afferent projections originating from the premotor regions⁶⁶. In actual movement execution, the primary motor cortex receives input from premotor regions, which modulate temporal and spatial motoneuron firing characteristics⁹⁹.

2.4.2 Motor Equivalence of Imagined and Executed Motor Tasks

The time required to mentally simulate an action has been found to be similar to the time required to actually perform that same action. Behavioural studies have measured temporal congruencies between mentally and physically performed movements to examine the relationship between neural and cognitive mechanisms associated with MI¹⁴. Decety, Jeannerod, & Prablanc¹⁸ blindfolded their subjects and instructed them to either actually walk or to imagine themselves walking to designated targets placed at varied distances. In both trials, subjects were instructed to start a timer on departure and stop the timer when they thought they had reached the designated target. The times recorded for actual and imagined walking were similar and increased linearly with target distance. Similar findings were observed when

comparing imagined to actual movement times associated with writing and drawing tasks¹⁹.

The temporal relationship between imagined and executed movements is dependent on the nature of the task. In tasks that are highly automatic such as reaching and grasping¹⁹, writing a signature⁹², walking^{18,92}, running¹⁷, or skating⁸⁵, healthy subjects took the same amount of time to imagine and actually perform the activity. In competition or situations that involved high stress and concentration, such as putting in golf⁸⁶, gymnastics⁴¹, or swimming⁵ athletes used more time to imagine the task than to perform it physically. The temporal relationship of imagined and physically executed actions, appear then to be influenced by factors including the nature of the task, competitive state, and skill complexity.

Chronometric studies have indicated that executed and imagined movements demonstrate a speed and accuracy trade-off as described by Fitt's Law¹⁶. Fitt's law describes an inverse relationship between the difficulty of a physical task and the speed with which it can be performed, for example, more difficult movements take more time to produce than easier movements. This law has been found to be true for both imagined and virtually executed movements¹⁶. Using a virtual reality computer program, a comparison was made between virtually walking through a target (illustrated as a gate) and closing one's eyes and using MI to walk through the same target. Gates were presented at varying geometric distances (3, 6, 9 m) and widths (45, 90, 135 cm). The response time for each task, either virtual walking or imagery, was measured as the duration between an auditory signal to begin and a motor signal produced by the subject upon completion of the task. All 15 subjects had walking

times that were linearly proportional to the distance and walking speed decreased in proportion to reduction in gate width. In accordance with Fitt's law, this study shows that the length of time to complete a task is directly proportional to the level of difficulty of the given task, for instance, the narrower the gate the more difficult it is to walk through thus the more time it takes.

From the studies described above, imagined movements appear to follow the same rules that are known to govern overt motor behaviour. The temporal relationship between MI and the actual execution of tasks has also been studied in people with brain lesions and the findings are similar^{15, 107, 112}.

2.4.3 Autonomic Responses

While engaging in MI subjects experience increases in heart and respiration rates when mentally performing strenuous actions^{23, 17, 85, 116}. Deschaumes-Molinaro et al.²³ studied national athletes who took part in an archery competition then mentally rehearsed the competition using motor imagery a few days later. Changes in skin resistance (electrodermal response), blood flow, and temperature, as well as instantaneous heart rate were comparable during the actual and imagined competitions. Only respiratory frequency was significantly higher during actual competition than during imagery. Overall, the physiologic responses indicate that physical execution and imagery of the same task are associated with autonomic changes that are very similar²³.

Decety et al.¹⁷ reported abrupt increases in blood pressure, heart rate and respiration rate when healthy subjects imaged themselves running on a treadmill.

Subjects listened to a recording of the treadmill with belt speeds of 5, 8, and 12 km/h. Both heart rate and respiratory rate increased during MI and in proportion to speed. Heart rate increased by 50% during actual running at 12 km/h from rest and by 32% during MI corresponding to 12 km/h.

2.5 Factors that Influence the Effectiveness of Motor Imagery

One of the challenges of studying MI is not being able to control when or how the subject imagines the execution of a motor task. Working memory^{43, 77}, the amount of MP using MI²⁷, and an individual's capacity to image⁴⁴ can affect MI outcomes.

2.5.1 Working Memory and Imagery Ability

Working memory or short-term memory is essential to engage in MI because it enables the temporary storage of information^{14, 77}. To engage in MI one must acquire, retain, and manipulate the information within working memory⁷⁷, which in turn allows the information to be retrieved during the process of motor imagery³. Dolman, Roy, Dimeck, et al.²⁶ have suggested that three domains of working memory exist: visuospatial, kinesthetic, and verbal. All of these domains are implicated in the performance of mental imagery.

Hall et al.⁴³ compared imagery ability and memory by asking subjects to remember movement patterns presented on a monitor, then imagine the movement, and reproduce the movement twice using a pantograph. There were 12 movement patterns in total and the subjects were asked to recall as many of the patterns as

possible. These authors found that good and poor imagers, classified by the Movement Imagery Questionnaire (MIQ), demonstrated no difference in performance on immediate recall, but good imagers performed better on the delayed recall memory tasks. The good imagers also demonstrated more accurate reproduction of the patterned movements, which led the authors to conclude that the quality of the imagery depends on the accuracy of the representation of the image in one's working memory.

The importance of working memory has also been evaluated in relation to motor improvement in people recovering from stroke⁷⁷. In a single training session of physical practice and MP, subjects were taught to increase loading through the affected leg while standing and sitting. The outcomes measured were change in loading on the affected limb and working memory (all domains). The authors clearly demonstrated that all domains of working memory were significantly correlated with improved limb loading (visuospatial: $r=.83$; verbal: $r=.62$; kinesthetic: $r=.59$). It follows that assessing working memory may be important when determining if MP could be useful as a treatment regime. Impairments in working memory can compromise the retention of a motor task in the minds' eye and the clarity of the image established through verbal, kinesthetic, and visuospatial rehearsal.

2.5.2 Amount of Mental Practice Required to Enhance Performance

Little research has been done on the amount of MP training required to maximize its effectiveness. A meta-analysis of studies involving healthy adults suggests that to maximize performance MP sessions should be about 20 minutes in

length²⁷. Longer practice sessions did not offer any advantage, but rather long sessions could result in a loss of concentration and decreased motivation due to a lack of sensory feedback providing knowledge of one's performance²⁷.

There is no recommendation made specifically for the number of MP sessions that should occur per day or per week to maximize performance, however the total number of trials ranged from 1 to 4 410 in the 35 studies reviewed²⁷. No relationship was found between the number of MP trials and performance²⁷.

Driskell et al.²⁷ found that the more time that lapsed between MP and physical performance, the weaker the effects of MP on performance. The strongest effect of MP was obtained when performance was tested immediately after MP. Through regression analysis it was found that the positive effect of MP declines after approximately 2 weeks, and after 3 weeks any performance benefit from MP was gone. From this analysis Driskell et al.²⁷ estimated that to gain the maximum benefit from MP, "refresher training" (p. 489) should be implemented every 1-2 weeks. The authors do not specify whether refresher training refers to physical practice or if it refers to re-education from an instructor to ensure that MP is being implemented appropriately.

2.5.3 An Individual's Capacity to Image

The effectiveness of MI in improving motor performance can be influenced by an individual's capacity to image⁴⁶ which can vary widely^{34, 45}. Imagery ability is typically evaluated by subjective tests or self-evaluation assessments that ask subjects to report on the quality of their images. For example, the Vividness of Movement

Imagery Questionnaire (VMIQ) ⁵⁷ and the MIQ ⁴⁶ require subjects to perform a specific physical action once and then imagine themselves performing the same action. Subjects rate the vividness of the image on an ordinal scale. Imagery ability can also be evaluated by objective or performance-based tests such as mental rotation tests which require subjects to mentally manipulate specific objects then report the spatial position of the object ⁴².

More vivid imagers tend to demonstrate greater improvement in performance and motor skill acquisition in response to MP with MI ⁵⁶. Neurophysiologic measures have provided insight into imagery ability ^{10, 37, 67}. For example, Goldenberg et al. ³⁷ reported a positive correlation between the amount of regional cerebral blood flow (rCBF) in the inferior occipital cortex and the vividness of the imagined tasks as determined from the Vividness of Visual Imagery Questionnaire (VVIQ).

Several studies have investigated the association between imagery ability and the effectiveness of using motor imagery in learning motor skills ^{39, 43, 56, 106}. Ryan and Simmons ¹⁰⁶ demonstrated a positive relationship between imagery ability and improvement of balance skill following motor imagery training. Imagery ability was assessed using a questionnaire developed by the authors. Subjects learned a balance skill with motor imagery or through physical practice. While those who trained physically performed better on the stabilometer than those using motor imagery, in the latter group subjects reporting strong visual and kinesthetic images showed greater improvement in the balance skill than those with weaker images. Goss et al. ³⁹ reported similar findings as subjects who scored higher on the MIQ (more vivid images) demonstrated faster acquisition and greater retention of motor skills. On the

other hand, Start and Richardson¹¹³ found no relationship between vividness of imagery as evaluated by the MIQ and learning a gymnastics skill. Epstein³⁰ was also unable to demonstrate a relationship between imagery ability and performance accuracy on a dart throwing task following training using motor imagery. However, it has been argued that failure to demonstrate a relationship between imagery and motor learning was likely due to the measurement tool used⁴⁵. In both studies only visual imagery was assessed however it has been suggested that kinesthetic imagery may also be important to motor learning⁴⁴.

2.6 Stroke and Motor Imagery

The use of MP with MI is gaining acceptance as a therapeutic strategy to promote motor recovery following stroke. Participation in MP has been found to yield better results than no practice at all⁹⁹. If this is true then MP may benefit people unable to engage in physical practice due to lack of motor ability.

Evidence shows that many people retain the ability to imagine movements in the acute⁶² and chronic⁶³ stages following stroke. In a study of subjects 3 weeks post stroke, Johnson⁶² had them visualize and verbally describe the spatial orientation of their hand in order to “grasp” a dowel displayed on a screen; no actual movements were allowed. Subjects were able to adjust their imagined movement strategy in accordance with changes in the visual display. The extent of hand function for each subject varied from flaccid to slight hand movement (Brunnstrom Stage I and II), but none were capable of grasping with the affected hand. All lesions were monohemispheric however the specific location varied within the cortical and

subcortical structures. These findings suggest that imagery ability can be exhibited in stroke even when physical impairments are severe. These results were replicated in a group of chronic stroke survivors ⁶³.

In combination these studies support that imagery ability can be preserved following stroke in subacute and chronic stages. Other authors have documented that MI ability may be compromised in subjects with right posterior parietal ¹¹², putamen ⁷², or cerebellar lesions ³⁸. To be certain an individual is able to produce vivid images following a stroke it would be important to screen imagery capability to ensure MP would be an appropriate treatment regime to assist with motor recovery.

Studies that have examined the possible benefit of MP for upper limb motor rehabilitation following stroke are limited. Page ⁸⁸ conducted a randomized control trial (RCT) involving 16 male subjects with left hemispheric stroke to determine if MP provided 3 times a week for 4 weeks in addition to regular therapy improved upper extremity function over regular therapy alone (control group). The MP group showed significantly greater improvement in the Fugl-Meyer Assessment of Motor Recovery (Fugl-Meyer) and the Action Research Arm Test (ARA) over the control group. Page and colleagues ^{90, 91} also performed two small RCTs, with different MP regimes in each study. In the 2001 study ⁹⁰, 16 subjects (6.5 months post stroke) performed imagery at home 3 times per week and in the clinic 2 times per week in 10 minute sessions, for a 6-week period. In the 2005 study ⁹¹, the authors implemented 30 minute sessions, 2 days per week for 6 weeks for 9 subjects with chronic stroke (greater than 1 year post stroke). In both studies the control groups listened to information on stroke and were given instructions on relaxation by tape for the same

amount of time that the MP group was receiving treatment. These studies found that MP improved subjects' scores on the Fugl-Meyer^{88, 90} and the ARA^{90, 91}. Imagery ability was either assessed with the MIQ⁹⁰ or not at all⁹¹. All of Page et al.'s studies^{88, 90, 91} used a listening activity (provided by audiotape) as the control intervention. This type of control has been critiqued because of the likelihood that boredom and inattention would occur within the session¹¹⁰. Ideally, the control intervention should be equally engaging as the experimental one.

Liu et al.⁷⁶ conducted a RCT to assess the efficacy of MI on improving motor function in acute stroke subjects (1-4 weeks post stroke). Forty-six subjects, all of whom were independent in ADLs, were placed into an imagery group or an occupational therapy group (control). Imagery ability was not assessed. Both groups participated in their respective therapy regimes for 15 sessions (1 hour per day over 3 weeks). Subjects in the imagery group were trained in the technique of MI and were taught to use it for analyzing task sequences, problem solving, and the motor planning of various tasks (i.e. cooking, cleaning, shopping). The third week of treatment focused on using both imagery and physical practice together to improve functional performance. The control group physically practiced the same functional tasks as the imagery group for the same time period. Performance on trained and untrained ADL tasks were used as functional outcome measures scored on a scale from 1 to 7 developed by the authors where 1 = complete dependence and 7 = complete independence. Results showed a significant benefit of the intervention for the MI group for both the trained and untrained ADL tasks assessed post treatment and 1 month later. This suggests imagery may have generalized effects in improving

functional tasks. There was no difference in performance between groups on the Fugl-Meyer (measures upper and lower extremity motor function) or the Color Trails Test (measures visual attention and scanning) after treatment. Without neural imaging or TMS evaluations, it remains unclear if MP using MI induced changes in the neural substrates and/or motor cortical excitability.

In summary, this review indicates a potential benefit of using MP through MI as a rehabilitation training technique to enhance motor performance following stroke. There is a need to determine if MP training is associated with better upper extremity motor recovery following stroke compared to some alternative non-motor intervention to ensure subjects receive equivalent amount of therapy. It is also important to determine if MP can increase motor cortical output to the muscles associated with the imagined task as this may facilitate the introduction of physical practice. The purpose of this study was to examine the relative effectiveness of MP verses a non-motor intervention in enhancing hand function and motor cortical output following stroke.

Chapter 3.0 Methods

A two group randomized, prospective clinical trial was designed to determine the relative effectiveness of MP using MI and cognitive training as interventions to improve contralesional hand function and control in individuals with hemiparesis due to stroke. The main objectives of this study were:

- 1) To determine if MP was associated with better upper extremity motor recovery than cognition training post intervention and three months later;
- 2) To determine if MP was associated with enhanced motor cortical output as compared to cognition training post intervention and three months later.

Secondary objectives were:

- 1) To determine if MI alters motor cortical output;
- 2) To determine whether the effects of MI was specific to muscles targeted by the training.

3.1 Subjects

Participants for this study were recruited from the inpatient stroke rehabilitation unit of a local hospital, from the community through newspaper advertisements and from stroke support groups. Individuals were considered for participation the study if they had:

- experienced a unilateral hemispheric stroke;
- residual upper extremity impairment as defined by a score of 2 to 6 on the Chedoke-McMaster Stroke Assessment (Appendix D) ⁴⁰, where stage two

indicates the individual demonstrates a positive Hoffman's reflex, resistance to passive wrist or finger extension, or facilitated finger flexion, and in stage six the individual demonstrates isolated tapping of the index finger, a pistol grip, or pronation of the wrist with finger extension and finger abduction;

Candidates were subsequently excluded if they had any of the following:

- cerebellar or brainstem stroke (determined from chart records);
- previous stroke in the opposite hemisphere;
- severe apraxia (defined as the inability to tap a non-paretic finger on a table, and pick up a peg and place it in a jar);
- receptive aphasia;
- severe body or visuospatial hemi-neglect or hemi-inattention;
- contraindications to TMS (intracranial metal implant, history of epileptic seizures, cardiac pacemaker, or cochlear implant(s) (Cadwell Laboratories Inc., 1987, Kennewick, WA, USA);
- other self reported relevant medical condition(s) (e.g. depression, cancer).

3.2 Screening

Individuals were screened by an experienced physiotherapist to ensure subjects were able to engage in MI and that they had preserved working memory (Screening Form, Appendix C). Imagery ability was determined by chronometric testing which compares actual and imagined movement times to provide a crude indication of whether subjects were capable of motor imagery⁷⁷. Subjects were seated directly in front of two circular targets (2 cm diameter), 30 cm apart (centre to centre)

marked on a box and placed on a table. Individuals were instructed to point to each target in an alternating fashion with the unaffected hand and think about how it felt. They were then asked to close their eyes and imagine themselves performing the task in their mind's eye. They were asked to begin at the word "go" and to say "now" every time they 'touched' a target. The number of targets 'hit' in a period of 15, 25, or 35 seconds was recorded. The duration of each trial was determined randomly and was not known by the subject. If the number of targets they imagined they had reached increased with longer durations the subject was included. If this was not the case, the subject was excluded.

Working memory was assessed using immediate serial recall. This is a well-established, valid indicator of short term memory function in brain injured clients¹¹⁹. Three domains of working memory were assessed: verbal, visuospatial, and kinesthetic. A series of items were presented and the individual asked to reproduce the series in the same order. For each domain, subjects initially completed five trials of two-item lists and if they successfully reproduced at least three out of five trials then the list length was increased by one and another five trials performed. The pattern of increasing list length continued until the subject was no longer successful in at least three of five trials.

The verbal lists were derived from a set of nine common monosyllabic words; there were no repeats in any given list. To assess the visuospatial domain, the assessor tapped on two or more (depending on list length) blocks located in front of the subject in a standard configuration. The subject was instructed to tap on the same blocks in the correct order. To test kinesthetic working memory, the subject was blindfolded

while the examiner passively moved the individual's limb through a series of single movement gestures always beginning and ending with the subject sitting on a chair with their feet flat and hands on their lap. The subject was asked to reproduce the series of movements with the unaffected limb; the number depending on the list length. Subjects unable to reproduce a minimum list of three items in either the verbal or visuospatial domain were excluded. Kinesthetic working memory was assessed as part of a larger study to determine its validity and therefore was not considered as a criterion for exclusion. Details of the items included in the lists are provided in Appendix E.

Subjects who successfully completed the screening were invited to participate in the study and asked to provide their signed consent. The protocol for this study was approved by both the Queen's University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board and the Providence Care Research Review Committee. The ethics approval form is included in Appendix A. The study was described to each subject prior to obtaining written informed consent (Appendix B). All testing took place at St. Mary's of the Lake Hospital in Kingston, Ontario in a quiet room designated for research studies. Each test session lasted approximately 1.5 hours and was conducted by the same trained research assistants throughout this study period. They were blind to group allocation.

3.3 Protocol

At the baseline test session only demographic information including age, contact information, date and type of stroke were obtained from each subject. Tests of

imagery ability, muscle strength, and hand function were performed. These were followed by electrophysiological testing and evaluation of motor cortical excitability and output.

3.4 Outcome Measures

3.4.1 Imagery Ability

Tests used to assess motor imagery ability included the Kinesthetic and Visual Imagery Questionnaire (KVIQ) and a chronometric test. The KVIQ is an imagery assessment tool for people with acquired disability⁶⁹ and is derived from the MIQ⁴⁶. It is comprised of 10 items, each scored for visual and kinesthetic dimensions (see⁷⁷ for details). Briefly, each item describes a distinct action: flexion-extension of the head, shoulder elevation, trunk flexion, shoulder flexion, elbow flexion-extension, finger opposition, knee extension, hip abduction, and hip external rotation, and foot tapping. Subjects physically execute each movement only once physically and immediately afterwards imagine performing the same movement as if they were “seeing” and “feeling” themselves perform the movements from within. In the visual dimension subjects rated their ability to elicit a mental image on a 5-point scale, where 1 is “no image” and 5 is “image as clear as seeing”. In the kinesthetic domain, the scale measures the intensity with which each subject ‘felt’ the imagined movement; where 1 is “no sensation” and 5 is “as intense as executing the action” (Appendix F).

The KVIQ has been validated (Cronbach $\alpha = .92$) and its concurrent validity determined with the MIQ ($r = .61$) in a group of healthy subjects¹⁰⁵. The KVIQ is the

only motor imagery assessment tool that has been designed to determine imagery ability in individuals with stroke ⁶⁹. The structure of the test emulates that used in MP treatment sessions, i.e. one physical performance followed by MI.

Chronometric testing used the same paradigm described for the screening. In this case, the time required to reach 5 targets using simulated pointing (imagery) and physically executed (actual) pointing was recorded for each upper limb. Subjects were seated and testing always began with the imagery condition for the unaffected hand. After a single physical practice trial, subjects were asked to imagine themselves pointing to each target and in turn verbally say 'now' each time they reached a target. Two trials were performed and the average time for completion recorded. Following the imagery trials of the unaffected hand, the subject performed 2 trials physically pointing to each target. The same sequence was repeated for the affected arm. During physical execution subjects could support their affected arm at the elbow. A motor imagery index was calculated (imagery time/executed time) for each subject as an indicator of temporal congruence of imaged and physically executed tasks ⁸⁰. When the same amount of time is taken to imagine performing a task as executing the same task, the motor imagery index has a value of one ¹⁹.

3.4.2 Hand Function

Gross manual dexterity is a good indicator of global upper limb performance ²⁴ and was determined using the box and block test (BBT) ¹². Subjects moved blocks (2.5 cm x 2.5 cm x 2.5 cm) from one side of a box (53.7 cm long by 17.2 cm wide) to the other by picking up 1 block at a time, crossing a 15.2 cm high barrier in the centre and dropping it on the other side before grasping the next block ⁸⁴. The number of

blocks moved in 60 seconds was recorded. Test-retest reliability of the BBT is excellent in older (> 60 years), healthy people (intraclass correlations coefficient (ICC) = 0.90 (right hand) and 0.89 (left hand)) and for individuals with an upper extremity impairment (ICC = 0.97 (right hand affected) and 0.96 (left hand affected))²⁴. In the current study, both the affected and unaffected extremities were tested and the order of testing was determined by coin toss.

3.4.3 Intrinsic Hand Muscle Strength

The force generated during maximum voluntary isometric contractions (MVC) of the abductor pollicis brevis (APB), abductor digiti minimi (ADM), and first dorsal interosseous (FDI) muscles provided a measure of strength. Three MVCs were recorded for each muscle and the average force calculated. Coin toss determined which hand was tested first and the order of testing (APB, ADM, FDI) was determined by card draw. Rest was provided between trials as needed.

Subjects were seated with their forearm of the test limb resting on the table in front of them. The wrist was secured with Velcro straps to minimize movement. A load cell (model MLP-100, Transducer Technologies, Temecula, CA, USA) was positioned perpendicular to the middle phalangeal joint of the index or 5th digit to test FDI and ADM strength, respectively. To test APB strength, the forearm was supinated and the load cell was positioned perpendicular to the phalangeal joint of the thumb. Subjects were instructed to push as hard as possible against the load cell and to hold it. A digital read out of the force applied was recorded in arbitrary units (volts). Since the interest was to examine changes over time, data were not converted.

3.4.4 Cortical Excitability and Output

Motor cortical excitability and output was assessed using TMS (Cadwell Magneto-Electric Stimulator (MES-10), Cadwell Laboratories Inc., Kennewick, WA, USA) and recording the stimulus induced motor evoked potential from the muscles of interest. Single pulse TMS was applied through a figure-of-eight coil (external wing diameter 90 mm). The stimulus intensity discharged through the coil was set according to a linear scale ranging from 0% to 100%, where maximum output corresponds to a peak magnetic flux of 2 Tesla as per manufacturer's specifications.

Surface electromyographic (EMG) activity was recorded using disposable silver-silver chloride (Ag-AgCl) electrodes placed in a bipolar configuration over the FDI, ADM, and APB muscles bilaterally. One electrode was placed over the muscle belly and the other near the insertion point. A common ground electrode was placed on the dorsum of the hand. EMG signals were bandpass filtered (20 Hz to 1 kHz), amplified 1000 times, and digitized at a rate of 2 kHz (National Instruments A/D model, Austin, TX) using custom software developed in LabView (National Instruments, Austin, TX).

Subjects were seated comfortably with elbows slightly flexed, arms and hands pronated in a relaxed position resting on a pillow placed on their lap. The junction of the TMS coil was placed 3 cm lateral to the vertex, contralateral to the non-paretic target muscles with the stimulus intensity initially set to 60% of maximum output⁸. The coil was moved systematically in medial-lateral and anterior-posterior directions until the stimulus site evoking the largest MEP was found. This site was marked on the scalp. Motor threshold (MT) was then determined as the lowest stimulus intensity

that produced at least 5 MEPs (minimum amplitude of 50 μ V) in the relaxed FDI in response to 10 stimuli applied to the optimal scalp site^{11, 103}. The same process was repeated for the affected hemisphere although a higher initial stimulus intensity was often required.

TMS was applied to the optimal scalp site at intensities ranging from 90% to 130% of MT increasing in increments of 10% of MT. Three stimuli at each of the 5 stimulus intensity levels were applied; the order determined randomly. EMG data were acquired in response to each stimulus; traces included a 50 ms pre-stimulus portion and a 200 ms post-stimulus portion. The three EMG traces obtained at each intensity level were averaged off line.

The hemisphere stimulated first was determined by coin toss. Two conditions: imagery and relaxation were then tested in random sequence. During imagery subjects imagined sliding a bead along a string using only their index finger (abduction). The task was first demonstrated and described verbally by the investigator. Subjects were then instructed to physically perform the task once and then encouraged to concentrate on how the action felt and to visualize it in their mind. While they were imagining the task, the EMG was monitored on an oscilloscope to ensure electrical silence and TMS was applied while subjects were verbally encouraged to 'focus on sliding the bead now'. For the relaxation condition, subjects were simply instructed to relax and clear their mind. A total of 4 data sets were acquired from each subject; 2 from each side under each of the 2 conditions.

Supramaximal electric stimulation of the ulnar (FDI, ADM) and median (APB) nerves was performed to determine the maximal EMG output from the target

muscles. Electrical stimulation (Grass S44, Grass Instruments Medical, Quincy, MA) was delivered (1 ms, square wave pulse) to the ulnar and median nerves at the wrist via a bipolar stimulating electrode. The stimulus intensity was slowly increased until there was a visible contraction of the target muscle(s). The magnitude of the muscle response was monitored on an oscilloscope and the stimulus intensity increased until the amplitude plateaued. A further 10% increase in stimulus intensity was introduced and 10 supramaximal muscle responses recorded (M-waves). The M-waves were used to provide an indication of consistency in electrode placement across test sessions.

3.5 Treatment

After completion of baseline testing subjects were randomly allocated into either the MP or cognitive therapy group using block randomization (blocks of four). The treating therapist was notified of the subject's group placement and then arrangements were made for treatment sessions. The therapist conducting the treatment was blind to all test results.

Treatment occurred over a three week period (30 minutes per day, 5 days per week). If a treatment session was missed for any reason, treatment was rescheduled on day 6 if possible such that each subject had a total of fifteen treatment sessions. The therapist kept a daily log noting the activities performed throughout each subjects daily schedule (e.g. physiotherapy, occupational therapy) and a description of each treatment session (e.g. amount of time spent on each task, number of repetitions completed, speed to complete the task).

3.5.1 Mental Practice Intervention

Subjects were asked to mentally rehearse a series of tasks which involved index finger movements such as pinch (tripod and tip) and grasping activities. MP therapy was graded by increasing the number of repetitions of each task, the number of tasks, and the complexity of the tasks. To standardize the treatment process, each task was first demonstrated and explained by the therapist. Subjects were asked to physically execute the task once with the unaffected limb and encouraged to concentrate on how the muscles and the fingers felt as they moved, this action was then attempted physically with the affected limb. Performing the task with the unaffected hand helped to ensure that motor images were formed based on normal muscular and sensory sequences. Subjects were then instructed to mentally rehearse the same task 5 times using the affected hand. This was progressed to 10 repetitions per set. One physical practice was performed before each set to reinforce the strength of the kinesthetic and visual image, i.e. the quality of the MI ⁴⁴. Subjects were instructed to verbally signal when each MP set was complete. In this way the subject remained focused on completing the designated task and allowed the therapist the opportunity to monitor the time to completion of each set to the duration of performing the relative physical movement.

In conformity with standard treatment practice, the tasks were progressed in difficulty to present additional challenge and to avoid boredom. Examples of how this was achieved follow:

- Abduction/ adduction of index finger: progression was achieved by increasing the surface friction (e.g. smooth to rough), increasing the distance moved, slide/ push objects of increasing sizes and weights (e.g. coin, block).
- Using tripod and tip pinch to pick up or hold an object: used objects of various shapes and sizes with differing weights to increase the task difficulty as required (e.g. sheet of paper, pad of paper; block, bead, pin; loonie, quarter, dime).
- Grasp and release: the difficulty adjusted by varying the shape, size, weight (e.g. mug, mug filled with water; paper cup, glass, glass with water).
- Functional use: incorporated tasks requiring varying levels of fine motor dexterity (e.g. pick up a pencil and write name; shuffle cards, hold a hand of cards, pick a card up from the table).

3.5.2 Cognitive Intervention

Subjects were instructed in non-motor cognitive tasks such as focusing on visual spatial tasks, concentrating on arithmetic calculations, recalling a short series of numbers, shapes, or letters; or problem solving activities. As with MP, for each cognitive activity 5 repetitions constituted one set which was progressed to 10 per set. Prior to each set of cognitive activities, subjects were asked to perform a physical task with the unaffected then affected arm, similar to the physical actions performed in the MP. In this way the amount of actual physical practice was the same for both groups.

Once subjects completed the 3 week intervention they were asked to return within 1 to 5 days for post intervention testing and again 3 months later for a follow-

up assessment. All outcomes were measured as described previously, except for the KVIQ which was conducted only at baseline. All participants were reimbursed for their travel costs associated with their involvement in the study.

3.6 Data Analysis

3.6.1 *Data Processing*

The EMG traces (3 per intensity level) were averaged and the MEP amplitude measured from the average trace. Recruitment curves were generated by plotting the MEP amplitudes (normalized as a % of supramaximal M wave) as a function of the stimulus intensity. This illustrated if excitability of corticospinal neurons were altered with imagery^{47, 111}. These curves reflect differences in the effects of imagery in the FDI (prime mover) and in ADM and APB.

3.6.2 *Statistical Approach*

Data were first examined for normalcy using descriptive statistics. To equate the groups at baseline either t-tests or ANOVAs were used appropriately. Multifactor ANOVAs were used to test whether dependent variables relating to cortical excitability and output (threshold stimulus intensity and MEP amplitude, respectively) and hand function differed as a function of hemisphere (affected versus unaffected) or group (MP versus cognitive). A mixed model repeated measures analysis of variance was used with three within subject factors: side (affected and unaffected), muscle (FDI, ADM and APB), and time (baseline, post intervention and follow-up assessment periods). Group (MP or cognitive) was the between subject

factor. Dependent measures included MI index determined from the chronometric testing, results from the box and block test, MVC, MT and MEP amplitude. MEP latency data were not analyzed, but were inspected to ensure that the responses analyzed were exclusively the short-latency, (approximately 25 ms) fastest conducted motor response.

The Statistical Package for the Social sciences (SPSS version 15.0), a commercially available software package, was used for all statistical analyses. The level of significance was set at $p < 0.05$. Post-hoc Tukey tests were performed as appropriate to determine where differences occurred.

Chapter 4.0 Results

A chart audit revealed that a total of 112 people were admitted to Saint Mary's of the Lake hospital with a stroke between August 2005 and April 2007. Of these, 27 met the study criteria and 13 agreed to participate in the study and 14 refused. Twelve people answered newspaper advertisements, 6 met study criteria and 4 agreed to participate in the study. From the stroke support group, 2 people showed interest in study participation and 1 person met the study criteria. Eighty-five people from Saint Mary's of the Lake hospital, 6 people from newspaper advertisements and 1 individual from the stroke support group were not considered for the study for one or more of the following reasons: their stroke was not hemispheric, upper limb rehabilitation was not required (Brunstrom Stage 7), upper limb was completely flaccid (Brunstrom Stage 1), they had a history of seizures, cardiac pacemaker, severe aphasia and/ or apraxia or other medical complications (i.e. cancer, depression).

Eighteen subjects were admitted to the study and completed baseline testing, however 4 people did not complete the post intervention and follow-up testing for reasons including illness (1), personal choice (2), and withdrawal due to non-compliance (1). Of the 14 people who completed the study period 8 were allocated to the MP group and 6 to the cognitive group.

Subjects in both groups were similar in age ($p = 0.126$), weeks post stroke ($p = 0.537$), height ($p = 0.958$), and weight ($p = 0.919$). Subject demographics are presented in Table 4.1.

Table 4.1. Demographic information for all subjects by group allocation (top = mental practice group; bottom = cognitive training group).

Subject	Age (years)	Gender	Weight (Kg)	Height (cm)	Weeks Post Stroke	Paretic Side	Stroke Type
1	80	F	64	168	6	L	I
2	79	F	66	153	9	R	I
3	73	F	72	163	10	L	H
4	64	F	75	163	40	R	H
5	71	M	68	168	183	R	I
6	62	F	77	163	176	R	I
7	72	F	57	161	16	R	I
8	73	M	75	180	10	L	I
9	62	M	74	178	62	R	I
Group Mean	71 (range 62-80)	6 F 3 M	70	166	57 (range 6-176)	3 L 6 R	7 I 2 H
10	76	F	73	166	6	L	I
11	61	M	87	174	7	L	I
12	53	F	73	163	82	R	I
13	78	F	55	160	8	L	I
14	47	F	62	170	8	L	I
15	65	M	68	178	728	R	I
16	58	F	54	152	5	R	I
17	72	M	100	183	132	L	H
18	66	F	50	152	5	R	I
Group Mean	64 (range 47-78)	6 F 3 M	69	167	109 (range 5-728)	5 L 4 R	8 I 1 H

F= female; M= male; L = left; R = right; I= ischemic; H= hemorrhagic
 Shading = subject's data excluded from further analysis because they did not complete the study.

4.1 Group Comparison at Baseline

There was no difference between groups at baseline in terms of hand function measured using the Box and Block Test (BBT) ($p \geq 0.512$) and muscle strength in any of the muscles of interest ($p \geq 0.431$) for either the affected or non-affected side. Clinically, groups were comparable in the ability to use the paretic hand ($p = 0.498$) and arm ($p = 0.136$) as measured by the Chedoke McMaster Stroke Assessment.

Subjects in both groups demonstrated similar imagery abilities as determined from the KVIQ ($p = 0.991$) and chronometric testing ($p \geq 0.183$).

Baseline differences between groups were found only in the kinesthetic domain of working memory ($p = 0.005$). Other domains were comparable between groups ($p \geq 0.309$). These data are summarized in Table 4.2.

4.2 Effectiveness of Interventions and Changes over Time

4.2.1 *Hand Function*

Overall, subjects increased hand function as measured by the box and block test and muscle strength (FDI, ADM and APB) on the affected side over the study period ($p \leq 0.044$). There was no main effect of group or interaction effect of time and group for any of the measures of hand function ($p > 0.100$) indicating that subjects in both groups improved to a similar extent. This finding addresses primary objective 1. As expected, however, measures associated with the unaffected hand in all cases showed better performance than measures recorded from the paretic side ($p \leq 0.002$). These findings are summarized in Table 4.3.

Table 4.2: Comparison of baseline measures between mental practice and cognitive groups.

Units		Mental Practice	Cognitive	p value
Chedoke McMaster (/7)	Hand	3 ± 2	3 ± 1	0.498
	Arm	3 ± 1	5 ± 2	0.136
BBT (# blocks / 60 seconds)	Affected	15 ± 12	11 ± 13	0.512
	Not Affected	41 ± 14	40 ± 8	0.930
MVC FDI (au)	Affected	1.34 ± 1.31	1.20 ± 1.34	0.847
	Not Affected	2.95 ± 1.06	3.41 ± 1.02	0.423
MVC APB (au)	Affected	1.63 ± 1.88	0.91 ± 1.20	0.431
	Not Affected	3.46 ± 1.63	4.08 ± 1.46	0.475
MVC ADM (au)	Affected	0.72 ± 0.77	0.46 ± 0.63	0.512
	Not Affected	1.50 ± 0.82	1.83 ± 0.73	0.445
KVIQ (/100) (/35) (/35) (/50) (/35) (/35) (/50)	Total KVIQ	76.75 ± 11.44	76.83 ± 15.51	0.991
	Kinesthetic Affected	22.63 ± 7.69	23.33 ± 6.53	0.859
	Kinesthetic NA	21.13 ± 6.85	24.67 ± 12.39	0.506
	Kinesthetic Total	33.25 ± 7.54	33.17 ± 13.01	0.988
	Visual Affected	29.88 ± 4.70	31.00 ± 2.28	0.601
	Visual NA	30.25 ± 3.96	32.00 ± 2.76	0.374
	Visual Total	43.50 ± 5.48	43.67 ± 4.48	0.948
Chronometric (imagery/ executed time) *	MI Index Affected	0.74 ± 0.45	1.02 ± 0.13	0.183
	MI Index NA	1.51 ± 0.77	1.22 ± 0.35	0.429
Working (/8) Memory (/6) Span (/8)	Visuospatial	4.13 ± 0.99	4.17 ± 0.75	0.933
	Kinesthetic	2.50 ± 0.54	3.50 ± 0.55	0.005
	Verbal	4.75 ± 0.89	5.17 ± 0.41	0.309

BBT=Box and Block Test; MVC=Maximum Voluntary Contraction; FDI= First Dorsal Interosseous; APB= Abductor Pollicis Brevis; ADM= Abductor Digiti Minimi; au=arbitrary units; KVIQ=Kinesthetic and Visual Imagery Questionnaire; NA= not affected; MIND= motor imagery index (imagined time/executed time).

* data were missing from 2 subjects in the mental practice group.

Table 4.3: Mean \pm 1 standard deviation associated with measures of hand function over time.

		<i>BBT</i> (# blocks/ 60 sec)			<i>FDI</i> (au)			<i>APB</i> (au)			<i>ADM</i> (au)		
		Base	Post	F/u	Base	Post	F/u	Base	Post	F/u	Base	Post	F/u
MP													
A	M (SD)	15 (12)	16 (10)	17 (13)	1.34 (1.31)	1.64 (1.63)	1.87 (1.77)	1.63 (1.88)	2.08 (1.93)	2.19 (2.02)	0.72 (0.77)	0.80 (0.91)	1.00 (1.16)
NA	M (SD)	41 (14)	40 (11)	37 (11)	2.95 (1.06)	3.05 (1.04)	2.74 (1.91)	3.46 (1.62)	3.84 (2.28)	3.64 (2.47)	1.50 (0.82)	1.93 (0.97)	1.55 (1.29)
COG													
A	M (SD)	11 (13)	15 (14)	18 (13)	1.20 (1.34)	1.32 (1.44)	1.45 (1.28)	0.91 (1.20)	1.38 (1.36)	1.55 (1.89)	0.46 (0.63)	0.48 (0.60)	0.66 (0.75)
NA	M (SD)	40 (8)	42 (8)	45 (8)	3.42 (1.02)	3.93 (1.14)	3.98 (1.03)	4.08 (1.46)	4.45 (2.17)	4.40 (1.69)	1.83 (0.73)	1.95 (0.75)	2.18 (0.75)

BBT=Box and Block Test; FDI= First Dorsal Interosseous; APB= Abductor Pollicis Brevis; ADM= Abductor Digiti Minimi; sec=seconds; au=arbitrary units; Base=Baseline test; Post=Post intervention test; F/u=Follow up test; MP= mental practice group; COG=cognitive group; A=affected side; NA= non-affected side; M=mean; SD=standard deviation.

4.2.2 Motor Imagery

Chronometric Testing

Chronometric testing demonstrated consistent imagery ability over time ($p \geq 0.217$) and between groups ($p \geq 0.224$). There was however much better temporal congruency between imagined and executed movements on the affected side than on the unaffected side. Subjects tended to mentally overestimate the time to perform a task when using the unaffected arm *i.e.* subjects took longer to imagine the task compared to performing the action. The opposite was true for the affected side; subjects underestimated the time to perform the task when using imagery (Table 4.4). This disparity between sides was significant ($p = 0.016$). The lack of difference in imagery ability between groups over time is important to consider when interpreting the data associated with TMS.

Table 4.4. Mean (± 1 SD) chronometric motor imagery index (imagined time/ executed time) throughout the study period.

	Assessment Period	MP Group	Cognitive Group	p value
Affected Hand	Baseline	0.74 \pm 0.45	1.02 \pm 0.13	0.183
	Post	0.60 \pm 0.34	0.82 \pm 0.17	0.190
	Follow up	0.85 \pm 0.26	0.82 \pm 0.27	0.831
Unaffected Hand	Baseline	1.51 \pm 0.77	1.22 \pm 0.35	0.429
	Post	2.35 \pm 1.97	1.26 \pm 0.26	0.209
	Follow up	1.38 \pm 0.29	1.28 \pm 0.51	0.710

*p value reflects the difference between groups at each assessment period.

4.2.3 Motor Cortical Excitability and Output

Short latency MEPs were obtained from all subjects. The mean latency of the MEPs generated in response to stimulation of the lesioned hemisphere was 27.5 ± 4.7 ms and 24.1 ± 2.6 ms for the unaffected hemisphere. Latencies were consistent across both conditions (imagery and rest) and reflective of short latency responses transmitted via the fast conducting corticospinal tract^{13,17}.

Motor Threshold

Motor thresholds (MT) provides an indication of the excitability of corticospinal projections. Over the study period MT decreased over time ($p < 0.001$) with a significant reduction occurring between baseline and post-intervention assessments ($p < 0.001$) and a less marked decline in the period between week 3 (post-intervention) and follow-up ($p = 0.207$). There was a main effect of side ($p < 0.001$) reflecting a much higher threshold associated with the lesioned hemisphere (mean: 65% stimulator output) than the intact hemisphere (mean: 45% stimulator output). There was no main effect of group ($p = 0.085$), but there was an interaction between time and side ($p = 0.006$) indicating that the MT of the intact hemisphere remained stable while the MT on the lesioned hemisphere decreased as time progressed. Results are displayed in Figure 4.1.

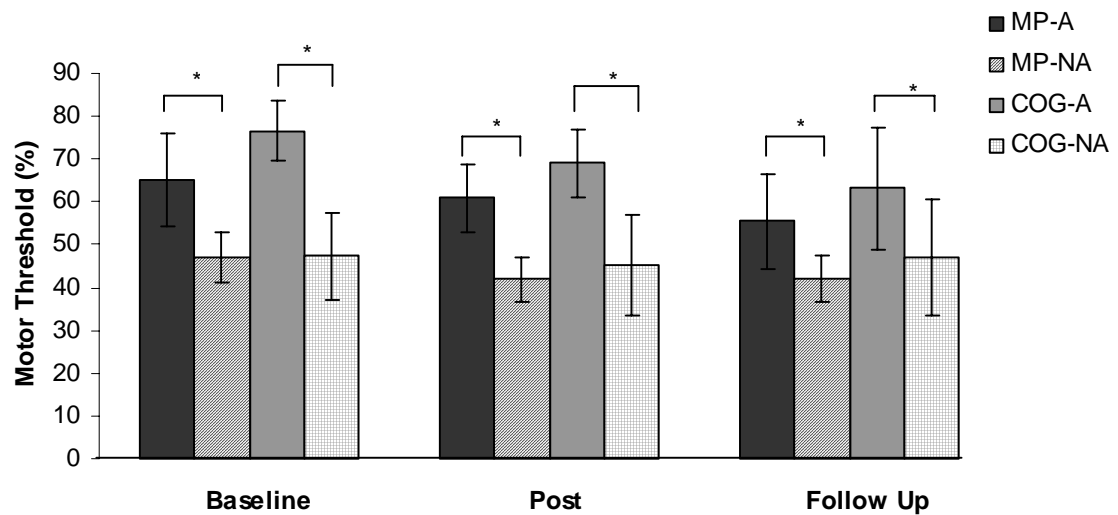


Figure 4.1. Change in value of mean (± 1 SD) motor thresholds over time as a function of group and hemisphere stimulated.

MP-A= mental practice group, affected side; MP-NA= mental practice group not affected side; COG-A= cognitive group, affected side; COG-NA= cognitive group, not affected side.

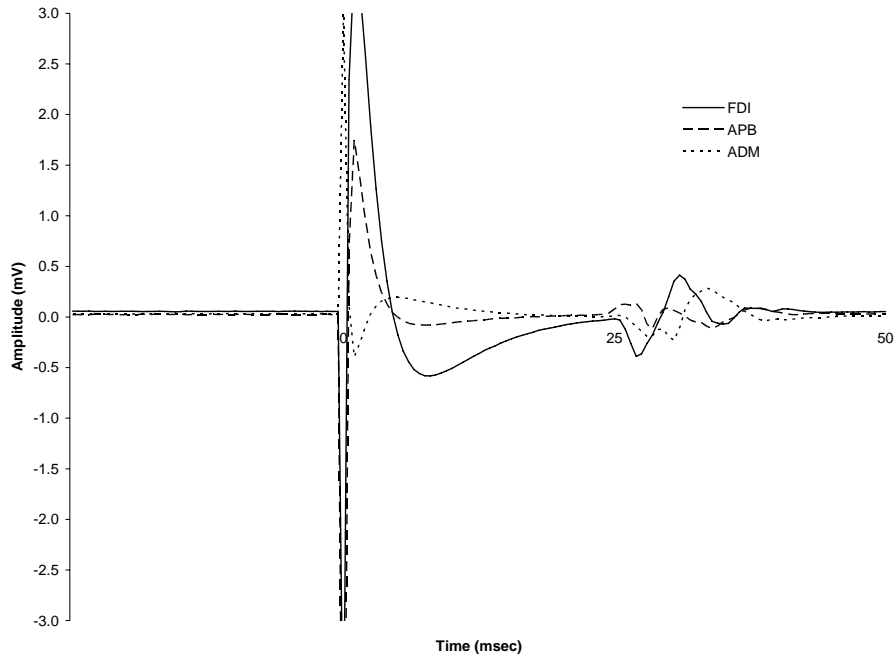
TMS Amplitude

Repeated measures ANOVAs were performed to determine the effects of time, condition (rest, imagery), side (affected, non-affected) and stimulus intensity (0.9 MT to 1.3MT) on MEP amplitude for each muscle of interest as a function of intervention group. For each muscle, the MEP amplitude increased as stimulus intensity increased ($p \leq 0.001$) and the amplitudes were in all cases higher during imagery than at rest ($p \leq 0.022$) even though the imagery task focused on index finger abduction (see Figure 4.2 for an example). There was no effect of time on the MEP generated in any muscle ($p \geq 0.056$). Only the MEP amplitudes associated with the FDI muscle showed a main effect of side ($p = 0.006$) and an interaction effect of any kind. The interaction effect between time and group ($p = 0.021$) is notable because it reflects that the FDI MEPs from subjects

in the mental practice group increased in amplitude over baseline, whereas in the cognitive group, they declined. The changes in MEP amplitude relative to baseline could not be explained by different recording characteristics since maximal M waves were consistent across test sessions ($p = 0.494$). Data associated with FDI, APB, and ADM muscles are summarized in Table 4.5.

A consequence of the higher MT of the lesioned hemisphere was an inability to generate recruitment curves for one subject (cognitive group) because the maximum stimulator output was reached. This reduced the number of datasets considered in the analysis described above, which is particularly problematic because of the fewer number of subjects in the cognitive group compared to the MP group. To maximize the data yield, recruitment curves were generated for each subject for the FDI muscle on the affected side (see Figure 4.3). Since all subjects produced data up to 1.2 MT, the slope for each curve was calculated using data points associated with TMS intensities of 1.0 and 1.2 MT. Analysis of the slopes revealed a significant difference between the resting and imagery conditions ($p = 0.042$). The slope associated with the imagery condition was about twice as steep compared to that generated from the resting condition. There was no difference between groups ($p = 0.247$).

(a) Resting MEP



(b) Imagery MEP

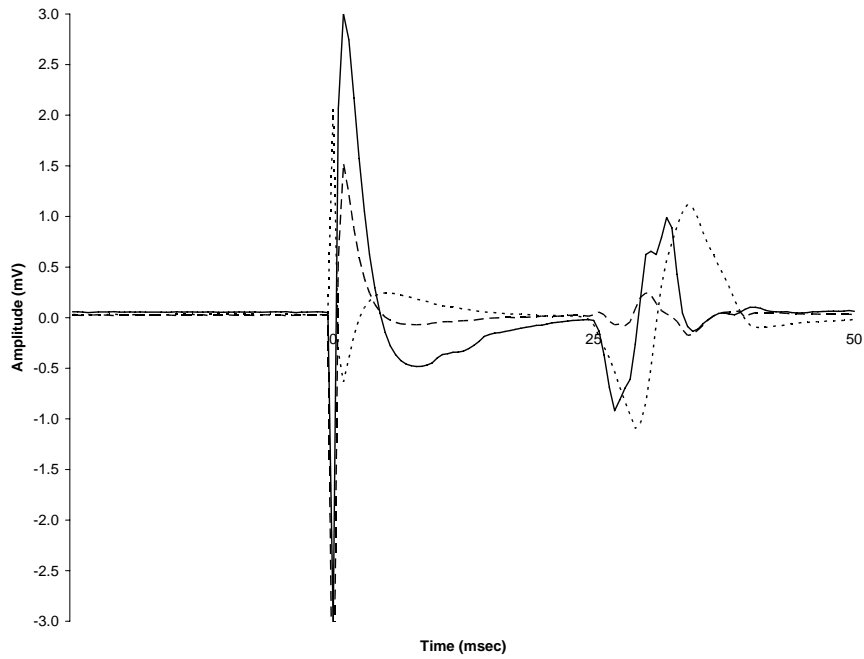


Figure 4.2. MEPs elicited in response to stimuli at 110% of motor threshold on the affected hemisphere for one subject. The large stimulus artifact is evident at time 0.

Table 4.5. Mean (± 1 SD) MEP amplitudes (mV) pooled across stimulus intensities for each muscle of interest over time as a function of condition assessed and intervention group.

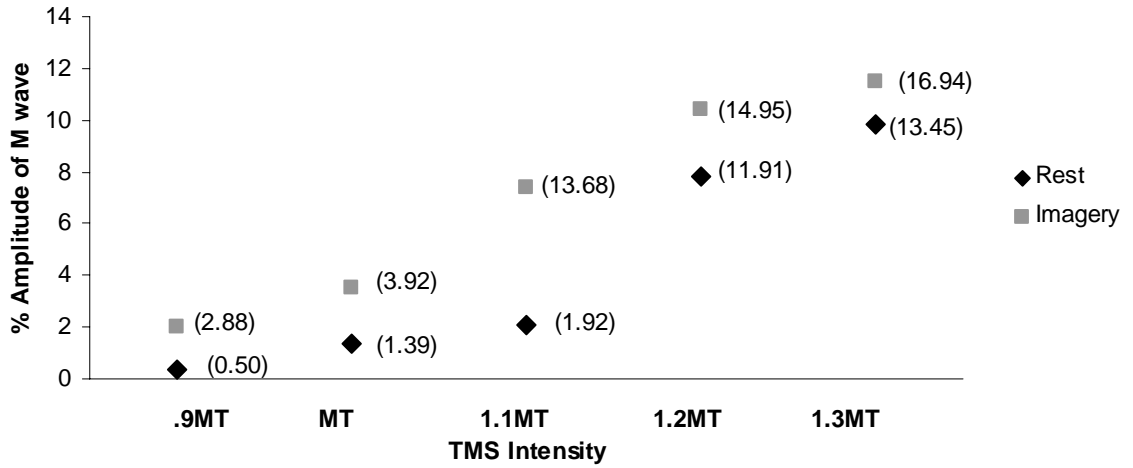
			Baseline (mV)			Post (mV)			Follow up (mV)		
			<i>A</i>	<i>NA</i>	<i>Both</i>	<i>A</i>	<i>NA</i>	<i>Both</i>	<i>A</i>	<i>NA</i>	<i>Both</i>
FDI	MP	Rest	0.22 (0.30)	0.28 (0.34)	0.25 (0.32)	0.25 (0.34)	0.47 (0.42)	0.36 (0.38)	0.22 (0.34)	0.40 (0.40)	0.31 (0.37)
		Image	0.49 (0.75)	0.51 (0.51)	0.50 (0.63)	0.40 (0.61)	0.76 (0.52)	0.58 (0.56)	0.42 (0.54)	0.63 (0.65)	0.52 (0.59)
	COG	Rest	0.17 (0.35)	0.93 (0.94)	0.55 (0.65)	0.15 (0.31)	0.17 (0.14)	0.16 (0.23)	0.03 (0.04)	0.15 (0.20)	0.09 (0.12)
		Image	0.30 (0.63)	1.42 (1.44)	0.86 (1.04)	0.47 (1.07)	0.65 (0.82)	0.56 (0.95)	0.05 (0.10)	0.40 (0.57)	0.23 (0.33)
	ALL	Rest	0.20 (0.33)	0.60 (0.64)	0.40 (0.48)	0.20 (0.33)	0.32 (0.28)	0.26 (0.30)	0.12 (0.19)	0.28 (0.30)	0.20 (0.24)
		Image	0.39 (0.69)	0.97 (0.98)	0.68 (0.83)	0.43 (0.84)	0.71 (0.67)	0.57 (0.76)	0.24 (0.32)	0.52 (0.61)	0.38 (0.46)
APB	MP	Rest	0.33 (0.47)	0.32 (0.36)	0.33 (0.41)	0.38 (0.55)	0.49 (0.57)	0.44 (0.56)	0.15 (0.19)	0.32 (0.42)	0.24 (0.30)
		Image	0.61 (0.71)	0.41 (0.51)	0.51 (0.61)	0.66 (0.92)	0.62 (0.70)	0.64 (0.81)	0.29 (0.40)	0.38 (0.49)	0.34 (0.45)
	COG	Rest	0.06 (0.13)	0.34 (0.19)	0.20 (0.16)	0.06 (0.10)	0.14 (0.14)	0.10 (0.12)	0.05 (0.11)	0.23 (0.23)	0.14 (0.17)
		Image	0.07 (0.13)	0.41 (0.23)	0.24 (0.18)	0.32 (0.70)	0.41 (0.51)	0.36 (0.60)	0.25 (0.52)	0.43 (0.63)	0.34 (0.57)
	ALL	Rest	0.19 (0.30)	0.33 (0.27)	0.26 (0.29)	0.22 (0.33)	0.31 (0.36)	0.27 (0.34)	0.10 (0.15)	0.28 (0.33)	0.19 (0.24)
		Image	0.34 (0.42)	0.41 (0.37)	0.37 (0.40)	0.49 (0.81)	0.51 (0.60)	0.50 (0.71)	0.27 (0.46)	0.40 (0.56)	0.34 (0.51)

			A	NA	Both	A	NA	Both	A	NA	Both
ADM	MP	Rest	0.16 (0.16)	0.41 (0.50)	0.28 (0.33)	0.21 (0.24)	0.58 (0.71)	0.40 (0.47)	0.17 (0.26)	0.39 (0.46)	0.28 (0.36)
		Image	0.37 (0.63)	0.69 (0.82)	0.53 (0.72)	0.53 (0.87)	0.97 (1.21)	0.75 (1.04)	0.53 (0.82)	0.85 (0.84)	0.69 (0.83)
	COG	Rest	0.25 (0.55)	0.33 (0.26)	0.29 (0.41)	0.21 (0.46)	0.32 (0.34)	0.26 (0.40)	0.25 (0.50)	0.34 (0.31)	0.29 (0.40)
		Image	0.48 (0.95)	0.70 (0.62)	0.59 (0.79)	0.46 (1.02)	1.53 (2.80)	0.99 (1.91)	0.60 (1.17)	0.77 (0.75)	0.69 (0.96)
	ALL	Rest	0.20 (0.36)	0.37 (0.38)	0.29 (0.37)	0.21 (0.35)	0.45 (0.52)	0.33 (0.44)	0.21 (0.38)	0.36 (0.38)	0.29 (0.38)
		Image	0.43 (0.79)	0.69 (0.72)	0.56 (0.76)	0.50 (0.95)	1.25 (2.01)	0.87 (1.48)	0.56 (0.99)	0.81 (0.79)	0.69 (0.89)

Rest= resting condition; Imagery=imagery condition; A=affected side; NA=unaffected side; MP= mental practice group; COG= cognitive group; FDI= First Dorsal Interosseous; APB= Abductor Pollicis Brevis; ADM= Abductor Digiti Minimi.

Standard Deviation displayed in brackets.

a) MP group



b) cognitive group

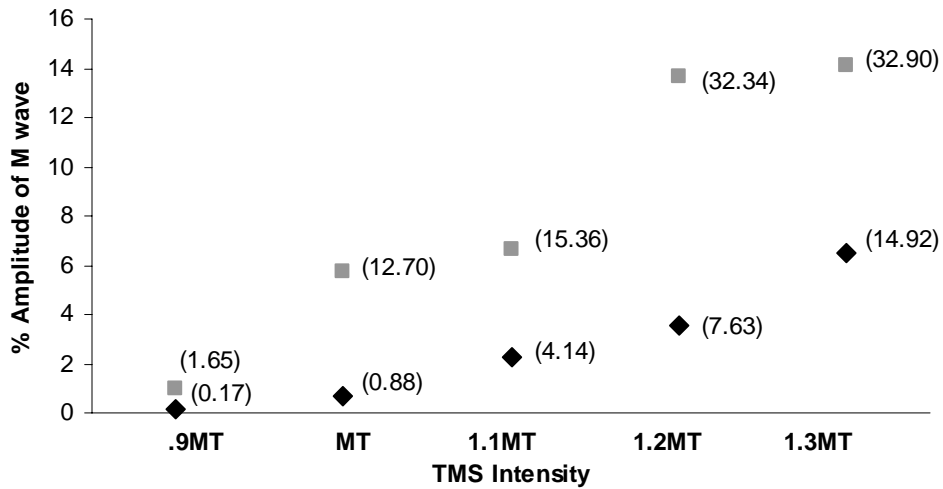


Figure 4.3. Recruitment curve for FDI affected at post assessment comparing the rest and imagery conditions in the MP (a) and cognitive (b) groups.

Standard deviation displayed in brackets.

To summarize the statistical findings in relation to the study objectives; there was no group effect on measures of cortical excitability (MT) or cortical output (MEP amplitude and slope). However there was an interaction effect of time and group for FDI MEP amplitude showing an increase in the MP group and decline in the cognitive group. In terms of secondary objectives, MI increases both cortical excitability and motor cortical output, but it is not specific to the target muscle involved in the imagery task.

Chapter 5.0 Discussion

Motor imagery is known to influence motor performance and modulate motor cortical excitability and output. This study examined the effectiveness of MP using MI relative to a non-motor cognitive intervention in terms of improving hand function and motor cortical excitability in people with stroke. The main findings were that while motor imagery enhances motor cortical output, MP using MI does not enhance the recovery of hand function over a cognitive therapy intervention. There was limited evidence to suggest that MP augmented projection strength to the FDI muscle, but because functional gains were comparable between groups over time this improvement could not be linked with better FDI strength or function.

Researchers have debated whether imagery can be used effectively following stroke⁵⁸. In the present study MI was found to increase motor cortical output. The MEPs elicited when the participants were engaged in MI were significantly larger compared to the resting condition. This demonstrates that MI has the capacity to facilitate the excitability of the motor cortex in stroke survivors. These results support findings from a recent TMS study performed by Cicinelli et al.⁹, in which imagery of the fifth digit (ADM) performing an abduction task was shown to enhance the size of the descending volley compared to the resting condition. If motor cortical excitability and output is elevated when performing MI, it follows that MI could be used through MP to strengthen stored motor programs or neural connections involved in planning specific motor actions^{19, 60, 61}.

To evaluate the strength of the neural connections involved in motor planning, it is important to establish how these MI induced changes in motor cortical excitability affect the target muscle (i.e. muscle implicated in performing the imagined action) relative to the non-involved muscles. TMS studies often assess the muscles of the hand because they have large representations in the motor cortex that allow their cortical neurons to be more easily accessible to TMS than others¹²¹. Previous TMS studies have found that the motor cortical excitability changes that are evident during MI are specific to the target muscle^{9, 31, 48, 114}. In contrast, one of the main findings from this study was that motor cortical output was enhanced in all of the hand muscles assessed even though FDI was the target muscle implicated in the imagery task. This discrepancy with other studies may be due to the fact that many studies to date have involved healthy subjects^{31, 48, 114}.

Following a stroke, individuals have difficulty with performing isolated finger movements and often activate surrounding muscles to produce a grasp rather than a pincer grip. This occurs due to the co-activation between synergists and agonist-antagonist muscles⁹⁴ and the inability to selectively activate muscles in isolation. In such instances, it is possible that these same neural circuits that lead to co-activation during physical task performance may be active during imagery. Cicinelli et al.⁹ assessed motor cortical excitability in stroke to find increased motor cortical output to ADM (target muscle) without a corresponding increase in extensor digitorum communis (EDC). However, these two muscles do not typically work in a flexor or extensor synergy⁹⁴ and therefore would not likely show evidence of co-activation. In contrast, the intrinsic hand muscles of interest in the current study do typically work

in concert as part of a synergy after stroke and the synergy often manifests when effort is elevated⁹⁴. Therefore the globally enhanced motor cortical output that was evident during MI in the present study may have reflected the disordered movement control that would ultimately trigger descending signals to these muscles during actual physical task performance. With prolonged practice with using MI, the MP group did show target specific improvement in the projection strength to FDI. This was not attributable to improved imagery ability over time as chronometric testing results were stable for all subjects.

Another consideration which might explain the non-target specific increase in MEP amplitudes may be the task itself. During physical performance of index finger abduction the FDI muscle is the prime mover and APB and ADM may act synergistically to stabilize the hand. It is possible that when using motor imagery, subjects may visualize the entire hand and not solely focus on the index finger. In the absence of knowing what subjects are actually imaging during MI, this is speculative. Imagined movements are greatly influenced by the perception and understanding each person has of the motor task⁷⁷. It is possible that the internal representation of the movement could influence the outcomes in response to TMS.

TMS indirectly activates motor cortical neurons and therefore reveals the extent to which motor cortical output is modulated¹¹⁴ after stroke or in response to some condition. With the use of TMS, the current study found that motor cortical excitability and output improved in all subjects over time as demonstrated by a significant decrease in MT^{111, 114}. The decrease in threshold demonstrates improvement in the integrity and function of the motor cortex and the corticospinal

tract. This corresponds with the motor improvement found in all stroke subjects over the assessment period shown by the BBT (hand function) and MVC testing (finger strength). Chronic and subacute stroke subjects in the current study performed similarly on all outcome measures; this is compatible with findings reported by Brouwer and Schryburt-Brown⁸. Brouwer and Schryburt-Brown⁸ found no difference between chronic and subacute stroke groups on index finger tapping, peg-placing and FDI strength measures. In a cross sectional study it cannot be determined whether one group or another may have exhibited greater changes in function in the period post-stroke, but it does suggest that time alone may not necessarily lead to functional change. These authors also noted moderate correlations between motor cortical excitability and output with hand function and strength indicating these variables are linked. In this regard it is curious that the improvement in cortical projection strength to the FDI muscle in the MP group only was not uniquely associated with better recovery in general or in FDI strength specifically. It may be that the gain in cortical output was subthreshold for any improvement in function to be observed.

The absence of any additional benefit in terms of motor recovery of hand function of MP using MI over cognitive therapy intervention was unexpected in view of other studies^{25, 76, 88, 90, 91}. Dijkerman et al.²⁵ reported that MP enhances motor performance following stroke. They allocated 20 people with chronic stroke into 3 groups: a MI group (10 subjects), a visual imagery group (5 subjects), and a control group (5 subjects). All subjects practiced the same grasp and release task with blocks (trained task) once daily for 4 weeks to ensure that all participants received an equal

amount of physical practice. To augment the trained task, the MP group used MI training of the block task at home 3 times per day under the direction of an audiotape (unsupervised). The visual imagery group also practiced 3 times per day but the focus was on visualization of non-task related pictures and the control group was not engaged in any form of imagery. The outcome measures included the trained block task, pegboard task, grip strength, somatosensory function (position sense and 2-point discrimination), attention, and ADL independence. At the end of the 4 week training period there were no differences between the visual imagery and control groups for any outcome measure. The subjects in the MP group however, outperformed those in the other groups on tests of hand function (blocks and pegboard task) but not on measures of grip strength or ADL. The authors concluded that MP was effective. This conclusion though may be over stated since the data from 2 subjects in the MP group had been excluded on the basis of poor baseline performance and limited motor function. The superiority of the MP group was not evident when the data from these subjects were included. Since it is subjects with low function who are unable or have a limited ability to engage in active therapy may derive the most benefit from MP the rationale for their exclusion is questionable.

Page et al.⁹⁰ also concluded that MP promotes motor recovery following stroke after comparing upper limb function in ADL in a randomized control trial. Thirteen stroke survivors (mean of 6.5 months post stroke) were randomly allocated to a control group receiving educational material on stroke or a MP group that engaged in MI of ADL tasks (e.g. reaching for a cup, turning a page) for 10 minutes, 5 days a week for 6 weeks. At the end of 6 weeks the MP group outperformed the

control group on all measures of physical function including the Fugl-Meyer and ARA. The MP protocol used by Page et al.⁹⁰ was less intensive than the training regimen used in the current study in terms of total practice time (3 hours verses 7.5 hours, respectively), although it was delivered over a longer time period which may have been a critical difference.

A meta-analysis²⁷ suggested that to maximize performance MP should last approximately 20 minutes per session over at least 2 weeks to demonstrate improvements in healthy people. The 46.8 % and 64.2 % improvement in Fugl-Meyer and ARA scores, respectively seen by Page et al.⁹⁰ following 10 minute daily sessions for 6 weeks suggests that alternative regimens are also effective. In the current study increases of 39% and 13% were seen in group mean values for FDI strength (MVC) and the BBT scores respectively, underscoring the fact that benefits can be associated with MP regimens that vary dramatically in terms of intensity, frequency and program duration.

In the current study there was no differential benefit of MP over the control condition which involved cognitive training. The control group in the Page et al.⁹⁰ study listened to information about stroke by audiotape which would not have emulated a comparable amount of engagement as those in the MP group received through interaction with a therapist⁴⁴. In the present study cognitive training was used as the control condition, which involved active participation of the subjects in tasks relating to short term recall and spatial recognition. Since both interventions were associated with similar gains in hand function the question of whether or not MP and cognitive therapy interventions are equally effective in promoting improved

motor function or are both equally ineffective and gains were reflective of natural recovery must be addressed. The latter will be addressed first.

During the first 6 months following a stroke the rate of motor recovery is greatest⁶⁴. This is due in part to natural recovery including the resorption of edema and necrotic tissue, the opening of collateral vessels to improve blood flow to the lesioned area⁸³ and substitution as areas of the brain take on new functions which were previously performed by the lesioned area⁷¹. In the present study most subjects were within 4 months of their stroke suggesting that natural recovery may have contributed to the improvements in hand function and cortical output over time. It is unlikely though that natural recovery alone could account for the magnitude of improvements seen on the affected side over the 12 week study period. Inspection of the data indicated that the 6 subjects who were beyond 1 year post stroke shared similar improvement as those in the sub-acute stage. In the absence of therapeutic intervention chronic stroke survivors rarely demonstrate strength gains or improvement in function² and often show physical decline⁸². The subjects in the Page et al.⁹⁰ study were mostly less than 6 months post stroke and without an effective intervention (i.e. the control group) no gains were observed. In the present study the majority of subjects were discharged from regular physical and occupational therapy therefore no or minimal change was expected without further intervention to facilitate motor improvement. It follows that the subjects in the current study likely derived benefit from both interventions.

It has been well established that there is a relationship between cognition and motor performance, but the nature of the association is not well understood⁹³. Stroke

survivors who demonstrate better cognition as measured using the Mini Mental State Examination (MMSE) have higher motor function as scored by the Nottingham Extended ADL Index and Timed Get Up and Go test compared to those with cognitive impairment⁵⁴. This could be simply an illustration of greater deficits and multi-system involvement with increasing stroke severity^{4, 68} or that the cognitive ability to understand and plan motor tasks is associated with the ability to perform motor function^{54, 97}.

Linden et al.⁷⁵ assessed whether MP (provided by audiotape) would be effective at enhancing balance and equilibrium reactions in elderly women when compared to a control group that received a cognitive intervention (i.e. remembering the contents of a jar, word games, twenty questions). Each group received their respective treatments in 6 minute sessions for 8 days over a 2 week period. After the treatment period, there was no significant difference between groups in terms of walking balance, although the MP group had significantly fewer equilibrium reactions (i.e. flexion and/or abduction of the shoulders, lateral flexion of the head or trunk, use of spotters) when carrying objects. There were no changes in performance reported for the control group. In the current study the control (cognitive) group received similar training but did show improvement in function. It may be that the more interactive approach adopted in the current study and the longer duration may have contributed to the positive effect.

Evidence has shown that stroke survivors who score higher on cognitive tests have greater functional gains over the course of the rehabilitation period^{54, 87}. Ozdemir et al.⁸⁷ compared cognition and functional improvement scores in 43 stroke

survivors (mean 33.4 ± 18.3 days post stroke). All subjects received only physical therapy (no cognitive intervention). A significant correlation, though low ($r = 0.31$) was found between the baseline cognitive scores (measured with MMSE) and the discharge motor improvement scores (measured with Functional Independence Measure). In traditional rehabilitation programs, as with MI, it is necessary to understand the command, remember the instructions, and maintain focus on the task at hand to have a successful treatment session. Recognition of the importance of cognition has lead some to suggest that therapy should be directed at improving cognitive function rather than poor motor function ⁹⁷. It may be that in the current study the group receiving the cognitive intervention acquired skills that were equally useful in augmenting task performance as those who mentally rehearsed physical actions.

The TMS findings demonstrated that motor cortical output was enhanced during imagery in all subjects, but only those in the MP group showed an increase in cortical output to the target FDI muscle over time. Jackson et al. ⁵⁹ said MP using MI trains neural circuits therefore one would expect MP to lead to more effective connections which would be reflected as increased response amplitude to TMS. That subjects in the MP group showed larger FDI MEPs elicited at rest while those in the cognitive group showed a slight decrease in the corresponding measure supports this view. The corticospinal projections may have been strengthened secondary to MP using MI. That this did not translate into greater gains in function over that observed in the cognitive group may reflect that these changes in neural projection strength were inadequate. That is, they may bring motor cortical cells closer to threshold, but

not sufficiently so to facilitate a descending volley voluntarily or result in appropriate motor unit recruitment.

5.1 Limitations

The main limitations of this study are the small sample size and an inadequate control group. In stroke research, subject groups are often quite heterogeneous such that the variability for a given outcome is high. As a result, the power to detect differences in groups in response to different interventions can be low. In the current study, 36 subjects per group would be required to detect a difference of 6 blocks between groups at follow up for the box and block test as determined using Frison and Pocock's³⁵ sample size equation.

In hindsight, the cognitive intervention may not have been an appropriate control group. Even though all subjects involved in the study scored high on clinical measures of cognitive ability, the training may have improved cognitive skills such that it had impact on their attention, planning and focus on motor tasks. Since cognitive ability was not tested after the intervention, the effectiveness of the training cannot be determined. The significant gains in motor performance for the cognitive group however provide a compelling argument that subjects did benefit.

One of the challenges in MI research is the uncertainty about the clarity and vividness of the image and sensation the individual is actually imaging. The investigator is unable to control or monitor this aspect of the research. The strength and clarity of the image and the accuracy of reproducing a motor task in the mind's eye is important if appropriate neural circuits are to be "trained." Functional MRI has

demonstrated that individuals with strong imagery ability activate the same brain regions as those activated when the action is physically performed except for the motor cortex ⁹⁵. In the current study, there is no way of knowing how well subjects performed MI only that subjects in both groups scored equally well on the KVIQ and on the chronometric test. The total KVIQ score was 76.8 ± 13.4 out of 100 points for subjects in the current study which is higher than scores reported in the literature for other stroke subjects (mean = 69.4 ± 8.4) ⁷⁷. This was not significantly different from scores obtained from healthy subjects in the same study. Chronometric testing, considered a reliable measure of imagery ability ¹⁴, also supports that subjects in the present study were well able to engage in MI.

Chapter 6.0 Conclusions and Recommendations for Further Study

This study examined whether MP using MI enhances motor function of the hand and cortical output following stroke over cognitive training, a non-motor intervention. TMS was used to evaluate motor cortical excitability and output to muscles in the paretic hand and motor ability was assessed from measures of strength (MVC) and function (BBT). The findings of the study lead to the following conclusions:

- Motor imagery enhances motor cortical output to muscles in the hand in a non-specific manner.
- Mental practice using motor imagery appears to increase corticospinal projection strength in the target FDI muscle.
- There is no differential benefit of mental practice and cognitive therapy in terms of hand function and finger strength.

It is apparent from this study that MI enhances motor cortical output. The MEPs elicited in hand muscles when subjects were engaged in MI of index finger abduction were significantly larger compared to the resting condition. This shows motor cortical excitability in stroke survivors with the use of MI. Furthermore, activation was seen in all muscles assessed (FDI, APB, ADM) suggesting that stroke survivors may be unable to image isolated movements or that because in practice they often exhibit co-activation of hand muscles that during imagery the same circuits are activated. With MP however, corticospinal projections to the target muscle were enhanced.

No additional benefit was found as a function of the treatment intervention received. Both treatment techniques resulted in functional gains in hand function and finger strength. A significant decrease in motor threshold on the affected hemisphere was found over time demonstrating increased motor cortical excitability and output which accompanied gains in function. Both MP and cognitive therapy interventions were effective in promoting motor improvement of the hand following stroke.

6.1 Recommendation for Future Research

Based on the findings and limitations of the present study the next logical step would be to introduce a true non-motor contact control group. Reminiscence activities may serve as an adequate control group to determine the unique benefits of MP through MI for rehabilitation following stroke. Reminiscence activities would be catered to the age of the participant and examples might include discussion of past politicians, significant societal events, housing or food prices, family vacations.

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APPENDIX A



**Providence
Continuing Care
Centre**

Sisters of Providence
of St. Vincent de Paul

*A leading regional
provider of compassionate,
non-acute healthcare and
a major centre for related
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Providence Manor site

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**St. Vincent de Paul
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Complex Continuing Care
Palliative Care • Rehabilitation
42 Garden Street
Brockville, Ontario
K6V 2C3
613-342-4461
Fax 613-342-5592

**St. Mary's of the Lake
Hospital site**

Complex Continuing Care
Geriatric Medicine • Palliative Care
Rehabilitation
340 Union Street
Kingston, Ontario
K7L 5A2
613-544-5220
Fax 613-544-8558

Mental Health Services site

752 King Street West
Postal Bag 603
Kingston, Ontario
K7L 4X3
613-546-1101
Fax 613-548-5588

40024 (04/03) SITE 1.0E2
www.pcccncch.on.ca

**AUTHORIZATION AND NOTIFICATION
OF APPROVED RESEARCH ACTIVITY**

TITLE OF RESEARCH PROJECT:

Does mental practice (MP) promote cortical reorganization and improved hand function in acute stroke? A prospective intervention study?

Provide a brief description of the Research Project, outlining the information required from the Record:

The proposed clinical trial represents the first major exploration of the effectiveness of MP as a method of priming neural circuits associated with voluntary movement to promote hand recovery following acute stroke. To explain intersubject differences and identify confounds the following information will be sought from patient records and charts: site, severity and type of stroke; cognitive function (mini-mental score); amount and nature of upper extremity rehabilitation received as an inpatient.

Externally funded? Yes No If yes, provide Source.

Heart and Stroke Foundation of Ontario

Principal Investigator: Brenda Brouwer, Ph.D.; Queen's University

Name(s) of Co-Investigators:

Stephen Bagg, MD PCCC; Francine Malouin, Ph.D University of Laval.

DATA SECURITY Identify methods of maintaining security of the data during and at the end of the study period, such as destruction of raw data.

Patient information and data will be identified by an alphanumeric code and the key linking name to code will be kept in the possession of the principal investigator in a locked office. Under no circumstances will patient identity be revealed; all reference to data in presentations, publications and the like will be by code only. The key will be shredded upon completion of the study and publication of the findings.

Estimated number of records required (Total number): ~50

Time period for record review FROM: (Y/M/D) 2004/07/01 TO: (Y/M/D) 2007/06/30

AUTHORIZATION

DATE: (Y/M/D) 2004/04/13

[Signature]
Signature of PCCC Research Committee Chair or Designate

DATE: (Y/M/D) 2004/04/20

[Signature]
Signature of Director of Patient Records & Registration Services (PRRS) or Designate

COMPLETED ORIGINAL TO Chief of Staff, PCCC (c/o Mental Health Services site) with attachments as required

AUTHORIZED COPIES TO Patient Records & Registration Services; Human Resources; Principal Investigator

QUEEN'S UNIVERSITY HEALTH SCIENCES & AFFILIATED TEACHING
HOSPITALS RESEARCH ETHICS BOARD



Queen's University, in accordance with the "Tri-Council Policy Statement, 1998" prepared by the Medical Research Council, Natural Sciences and Engineering Research Council of Canada and Social Sciences and Humanities Research Council of Canada requires that research projects involving human subjects be reviewed annually to determine their acceptability on ethical grounds.

A Research Ethics Board composed of:

- | | |
|-----------------|--|
| Dr. A.F. Clark | Emeritus Professor, Department of Biochemistry, Faculty of Health Sciences, Queen's University (Chair) |
| Dr. S. Burke | Professor, School of Nursing, Queen's University |
| Rev. T. Deline | Community Member |
| Dr. M. Green | Assistant Professor, Department of Family Medicine, Queen's University |
| Mr. C. Kenny | Community Member |
| Ms. T.C. Knott | Research & Evaluation, Southeastern Regional Geriatric Program, Providence Continuing Care Centre – St. Mary's of the Lake Hospital Site |
| Dr. J. Low | Professor, Department of Obstetrics and Gynaecology, Queen's University and Kingston General Hospital |
| Dr. H. Murray | Assistant Professor, Department of Emergency Medicine, Queen's University |
| Dr. W. Racz | Professor, Department of Pharmacology & Toxicology, Queen's University |
| Dr. A.N. Singh | WHO Professor in Psychosomatic Medicine and Psychopharmacology
Professor of Psychiatry and Pharmacology
Chair and Head, Division of Psychopharmacology, Queen's University |
| Dr. S. Taylor | Director, Office of Bioethics, Queen's University and Kingston General Hospital;
Associate Professor, Department of Medicine, Queen's University |
| Dr. G. Torrible | Community Member |

has examined the protocol and consent form for the project entitled "Does mental practice (MP) promote cortical reorganization and improved hand function?" as proposed by Dr. Brenda Brouwer of the School of Rehabilitation Therapy at Queen's University and considers it to be ethically acceptable. This approval is valid for one year. If there are any amendments or changes to the protocol affecting the subjects in this study, it is the responsibility of the principal investigator to notify the Research Ethics Board. Any adverse events must be reported to the Chair within 48 hours.

Albert Clark
Chair, Research Ethics Board

Feb 25, 2004
Date

REH-211-04
EX

ORIGINAL TO INVESTIGATOR - COPY TO DEPARTMENT HEAD - COPY TO HOSPITAL(S) - P&T - FILE COPY

APPENDIX B

CONSENT FORM

TITLE OF PROJECT: Does mental practice (MP) promote cortical excitability and improved hand function?

INVESTIGATORS: Dr. Brenda Brouwer, School of Rehabilitation Therapy,
Queen's University
Dr. Stephen Bagg, Department of Physical Medicine and
Rehabilitation, St. Mary's of the Lake Hospital
Dr. Francine Malouin, CIRRUS, Laval University

BACKGROUND INFORMATION

You are being invited to participate in a research study to determine whether mental practice (MP) using motor imagery of specific activities involving the affected hand increases the excitability and output of the part of the brain that controls the hand muscles (motor cortex) and whether MP improves hand function. This study is being sponsored by the Heart and Stroke Foundation of Ontario.

DETAILS OF THE STUDY

The purpose of this study is to determine the effectiveness of mental practice (MP) using mental imagery of specific activities involving the affected hand in increasing the output of the motor cortex (that part of the brain controlling muscle activation) and improving hand function. You will be considered for the study if you have had a stroke that has affected your ability to move your arm and hand on one side of your body.

Description tests to be performed as part of the study

In order to determine your capacity to use MP we will conduct chronometric testing. This requires that you imagine yourself performing a specific repetitive action and that you verbally signal the completion of each imagined movement until instructed to stop. Your ability to recall lists of items and reproduce a series of simple actions with your unaffected limb will also be tested and you will be asked to complete a questionnaire relating to your ability to visualize certain action in your mind's eye.

To test motor cortical output, we use a technique called transcranial magnetic stimulation. A coil will be placed over one side of your head and when current flows through the coil you will hear a "click" and you will feel something like a tap to your head under the coil. Your eyes might blink and your scalp muscles will contract slightly in response to the stimulus—it should not be painful. The strength of the stimulus will be adjusted as we look for a twitch in the muscles in your hand. We will measure these muscle twitches using disposable electrodes that are stuck onto your skin overlying the muscles of interest (three muscles in your hand). We will measure the muscle responses to stimulation while you are relaxed and while you imagine performing a specific action (like squeezing a ball between your thumb and index finger). The intensity of stimulation will be increased to the point where there is no

further increase in the size of the muscle response. At higher stimulus intensities your scalp muscles will contract more strongly. We will then repeat this procedure with the coil placed on the other side of your head. In order to allow us to interpret the size of the muscle responses we will electrically stimulate the nerve in your wrist. This will make your hand muscles contract very strongly.

As our interest is in hand function, we will test how strong your hand muscles are by having you push against an immovable bar that is instrumented with a force gauge. You will also be asked to retrieve and move blocks as quickly as you can and also perform specific hand actions which we will time.

All of the above described tests will be performed upon admission into the study, after the period of intervention and again three months later. The last test session may be scheduled after you have been discharged—you but will be asked to return for testing. Each test session will last about 1.5 hours.

Description of the interventions

After baseline testing (the first test session) you will be randomly allocated to receive either cognitive training or mental practice training using motor imagery. A numbers table will be used to determine what group you are assigned to. Both interventions will be introduced in addition to your regular therapy and will be provided by an occupational therapist who will direct your training for 20-25 minutes per day, 5 days per week for a total of three weeks.

If you are in the cognitive training group you will be involved in non-physical cognitive tasks requiring that you focus your attention on arithmetic tasks, recalling lists of items and problem solving. Rest periods will be provided between activities.

If you are in the mental practice group you will be engaged in mentally rehearsing physical tasks that involve hand and finger movements. A series of tasks will be presented and you will imagine the sensations and effort required to perform these tasks. Rest periods will be provided.

Risks/ Side-Effects

There are no risks associated with the interventions although because they involve some degree of physical and/ or mental effort you may find that you are tired after the training session. With respect to the testing, we have been using transcranial magnetic stimulation for over 20 years on many different patient populations. On rare occasions people report a headache after stimulation, mainly when high intensities are used repetitively. We will use high intensity stimulation, but they will be introduced singly and not in high repetition. The electrical stimulation applied to your wrist can sometimes be uncomfortable, but the stimuli are very short in duration and there are no lingering effects.

If you have any concerns, please ask the investigators immediately or contact Dr. Brouwer at 533-6087 at any time.

Benefits

It is expected that all participants will experience some benefit from their involvement in this study either in terms of improved arm and hand function or cognitive ability. The findings will contribute to our understanding of the benefits of specific interventions and help direct future stroke rehabilitation care.

Exclusions

The testing involves stimulation of the cells in your brain using transcranial magnetic stimulation. This induces electrical currents via a changing magnetic field. For this reason you will not be considered for this study if you have any of the following: a history of epilepsy, any mental implants in your head (aneurism clips, staples), metal stints, cochlear implants or a cardiac pacemaker. If you are not sure if you have any of these things we will confirm with your attending physician.

Confidentiality

All information obtained during the course of this study is strictly confidential and your anonymity will be protected at all times. You will be identified by a code based on the date of entry into the study and a project identifier. Data will be stored in locked files and will be available only to the investigators associated with this study. You will not be identified in any publication, presentation or reports.

Voluntary nature of study/ Freedom to withdraw or participate

Your participation in this study is voluntary. You may withdraw from this study at any time for any reason and your withdrawal will not affect present or future care.

Withdrawal of subject by principal investigator or co-investigators

A study investigator may decide to withdraw you from this study if you are unable to comply with the intervention or the test schedule for any reason.

Liability

In the event that you are injured as a result of the study procedures, health care will be provided to you until resolution of the problem.

By signing this consent form, you do not waive your legal rights nor release the investigators and sponsors from their legal and professional responsibilities.

Payment

We appreciate your involvement in this study and do not want you to incur any cost associated with returning for a final test session after you have been discharged from the hospital. We will compensate your travel costs to and from the laboratory, which will be sent to you by mail after the final testing session.

SUBJECT STATEMENT AND SIGNATURE SECTION:

I have read and understand the consent form for this stud. I have tad the purposes, procedures and technical language of this study explained to me. I have been given sufficient time to consider the above information and to seek advice if I chose to do so. I have had the opportunity to ask questions which have been answered to my satisfaction. I am voluntarily signing this form. I will receive a copy of this consent form for my information.

If at any time I have further questions, problems or adverse events, I can contact:

Dr. Brenda Brouwer, Principal Investigator at 533-6087.

If I have questions regarding my rights as a research subject I can contact Dr. Albert Clark, Chair, Research Ethics Board at 533-6081.

By signing this consent form, I am indicating that I agree to participate in this study

Signature of Subject

Date

Signature of Witness

Date

STATEMENT OF INVESTIGATOR

I, or one of my colleagues, have carefully explained to the subject the nature of the above research study. I certify that, to the best of my knowledge, the subject understands clearly the nature of the study and demands, benefits, and risks involved to participants in this study.

Signature of Principal Investigator

Date

DOES MENTAL PRACTICE PROMOTE CORTICAL EXCITABILITY AND IMPROVED HAND FUNCTION IN STROKE?

Dr. Brenda Brouwer (School of Rehabilitation Therapy, Queens Univaersity), Dr. Stephen Bagg (PCCC-SMOL), and Dr. Francine Malouin (Laval University).
Contact: B. Brouwer at 533-6087

APPENDIX C

FORM FOR PARTICIPANT ENROLMENT AND SCREENING DATA

Participant Name _____ Age _____

Side of Lesion: Left Right

Type of Lesion: Hemorrhagic Ischemic

Structures Involved:

Inclusion Criteria

No:

1. Unilateral hemispheric stroke (please specify if first-ever or repeat) _____

2. Upper extremity impairment (but not flaccid) _____

3. Signed consent form _____

Exclusion Criteria

1. Cerebellar or brainstem stroke _____

2. Previous stroke in opposite hemisphere _____

3. Severe apraxia or aphasia (evident from screening tests) _____

4. Severe hemi-neglect or hemi-inattention _____

5. Inability to engage in motor imagery (screening test) _____

6. Severe working memory disability (screening test) _____

7. Contraindications for TMS (metal implants, epilepsy, pacemaker) _____

8. Other relevant medical conditions (e.g. depression, cancer) _____

Specific Data

Level of hand recovery (please indicate Chedoke-McMaster score)

Hand _____ Arm _____

Cognitive ability (Folstein Mini-Mental score) _____

Working Memory Results (document highest successful span size achieved)

Verbal _____

Visuospatial _____

Kinesthetic _____

Motor Imagery Results

<i>Unaffected Arm</i>	<i># Repetitions</i>	<i>Trial #</i>
Number of targets reached in 15 sec.	_____	_____
Number of targets reached in 25 sec.	_____	_____
Number of targets reached in 35 sec.	_____	_____

PLEASE ENSURE THAT ALL RAW DATA FORMS ARE ATTACHED

Please contact B. Brouwer at 533-6087 or email: brouwerb@post.queensu.ca if you have a candidate for the study.

Thank you!

Therapist: _____ Date: _____

APPENDIX D

CHEDOKE-McMASTER INSTRUCTIONS

IMPAIRMENT INVENTORY: STAGE OF ARM

Standard starting Position: Sitting with the forearm in the lap in a neutral position, wrist at 0° and fingers slightly flexed. Sitting either unsupported over the side of the bed or plinth, or supported in a chair or wheelchair. Feet should be supported. Start the assessment at Stage 3.

STAGE 1

Unable to demonstrate at least two of the Stage 2 tasks.

STAGE 2

Task 1: Resistance to passive shoulder abduction or elbow extension

Position: Standard starting position.

Instruction: “Let me move your arm.”

Method: Choose either (a) or (b):

- (a) Abduct and adduct shoulder 5 times with sufficient speed of passive movement to elicit a stretch reflex. Feel for resistance to passive movement and watch for active contraction of pectoral muscles.
- (b) Flex and extend elbow 5 times with sufficient speed of passive movement to elicit a stretch reflex. Feel for resistance to passive movement and watch for active contraction of biceps.

Task 2: Facilitated elbow extension

Position: Standard starting position.

Instruction: “Straighten your elbow and try to touch your opposite knee.”

Method: Facilitate a contraction of the elbow extensors.

Required: Some active elbow extension.

Task 3: Facilitated elbow flexion

Position: Standard starting position.

Instruction: “Bend your elbow.”

Method: Facilitate a contraction of the elbow flexors.

STAGE 3

Task 1: Touch opposite knee

Position: Standard starting position.

Instruction: “Straighten your elbow and try to touch your opposite knee.”

Required: Active shoulder adduction and full elbow extension with palm facing down.

Task 2: Touch chin

Position: Standard starting position.

Instruction: "Touch your chin with your hand."

Required: Sufficient elbow flexion for any part of the hand to touch the chin. Movement in synergy is permissible.

Task 3: Shoulder shrugging greater than half range

Position: Standard starting position

Instruction: "Shrug both shoulders up towards your ears."

Required: Active scapular elevation greater than half range. Movement in synergy is permissible.

STAGE 4

Task 1: Extension synergy, then flexion synergy

Position: Standard starting position.

Instruction: "Reach across and touch your opposite knee, then without stopping, touch the ear on your weak side."

Required: Shoulder adduction and full elbow extension to touch the top of the opposite knee with enough internal rotation and pronation so that the palm is facing the weak knee. Then without stopping the shoulder should attain at least 90° of abduction with 0° horizontal flexion and some external rotation when the hand touches the ear. The forearm may be either pronated or supinated.

DON'T ACCEPT: Stopping between synergies.

Task 2: Shoulder flexion to 90 degrees

Position: Standard starting position.

Instruction: "Keep your elbow straight, and lift your arm up to shoulder height."

Required: Shoulder flexion to 90° with full elbow extension. Forearm may be pronated.

DON'T ACCEPT: Shoulder abduction, scapular elevation or elbow flexion.

Task 3: Supination then pronation

Position: Elbow at side with 90° elbow flexion.

Instruction: "Keep your elbow at your side, and turn your palm up and then down."

Required: Full supination and pronation (compared to other arm). Elbow remains at side of trunk.

DON'T ACCEPT: Compensatory movement of trunk.

STAGE 5

Task 1: Flexion synergy, then extension synergy

Position: Standard starting position.

Instruction: "Touch your ear with your weak hand, then without stopping reach down and touch your opposite knee."

Method: Watch for 90° of shoulder abduction with 0° horizontal flexion and external rotation to touch the ear with any part of the hand. The elbow may be flexed with either pronation or supination. Touch the opposite knee while fully extending the elbow and adducting and internally rotating the shoulder with pronation so that the palm faces down.

Required: Smooth controlled reversal between synergies.

Task 2: Shoulder abduction to 90 degrees with pronation

Position: Standard starting position.

Instruction: "Keeping your elbow straight and palm down, lift your arm to the side."

Required: Shoulder abduction 90°, full elbow extension and pronation. Wrist control is not necessary.

DON'T ACCEPT: Compensatory movements: truck side flexion, scapular elevation, shoulder flexion, or elbow flexion or supination.

Task 3: Pronation then supination

Position: Shoulder flexion to 90°

Instruction: "Keep your elbow straight, and turn your palm down and then up."

Required: Full pronation, supination (with or without internal and external rotation of shoulder) and elbow extension with 90° of shoulder flexion.

DON'T ACCEPT: Compensatory trunk movements or elbow flexion.

STAGE 6

Task 1: Hand from knee to forehead 5 times in 5 seconds

Position: Standard starting position.

Instruction: "Touch your forehead and your weak knee as quickly as possible."

Method: Count the knee to forehead repetitions in 5 seconds. Note that some part of the hand or wrist touches the knee and the forehead on each repetition.

DON'T ACCEPT: To lower head or raise knee.

Task 2: Trace a figure 8

Position: Shoulder flexion to 90°

Instruction: "Draw a large "figure 8" keeping your elbow straight."

Required: The figure 8 is drawn smoothly, both above and below 90° of shoulder flexion. The elbow must be straight throughout the movement. Finish with the arm at shoulder level.

DON'T ACCEPT: A small pattern, or compensatory trunk movements to achieve the pattern. Elbow flexion through any part of the pattern, to use the wall to support the arm or a jerky pattern.

Task 3: Raise arm overhead with full supination

Position: Arm resting at side of body.

Instruction: "Raise your arm over your head keeping your elbow straight and finish with your palm facing backwards."

Required: 180° shoulder flexion, full elbow extension and supination. Elbow extended through the movement.

DON'T ACCEPT: Shoulder abduction, elbow flexion, less than full supination or any compensatory trunk movements.

STAGE 7

Task 1: Clap hands overhead, then clap hands behind back 3 times in 5 seconds

Position: Arm resting at side of body.

Instruction: "Clap your hands above your head, then behind your back as quickly as possible."

Method: One movement consists of clapping hand overhead and behind back. Time the number of movements performed in 5 seconds. Listen for clap overhead.

DON'T ACCEPT: Clapping hands in front, not overhead.

Task 2: Scissor in front 3 times in 5 seconds

Position: Shoulder flexion to 90°, elbows extended and forearms pronated.

Instruction: "Keep your elbows straight and your palms down. Cross your arms in front of you, alternating the arm that crosses on top. Repeat the movement 3 times."

Required: Shoulders remain held in 90° flexion throughout the movement with elbow extended arm forearm pronated. Equal range and speed of crossovers.

DON'T ACCEPT: Stopping between repetitions.

Task 3: Resisted shoulder external rotation

Position: Elbows at side 90° flexion.

Instruction: "Keep your elbow at your side. Tighten your muscles and don't let me push your arms in."

Methods: Place hands on client's forearms. Instruct client as above and apply resistance to external rotation.

Required: Equal strength bilaterally.

IMPAIRMENT INVENTORY: STAGE OF HAND

Standard sitting position: Sitting with the forearm in the lap in a neutral position, wrist at 0° fingers slightly flexed. The client can sit either unsupported on the side of the bed or plinth, or supported in a chair or wheelchair. Feet should be supported. Start the assessment at Stage 3.

STAGE 1

Unable to demonstrate at least two of the Stage 2 tasks.

STAGE 2

Task 1: Positive Hoffman

Position: Standard starting position.

Instruction: "Let me move your fingers."

Method: With one hand support the client's middle phalanx of the middle finger. With the other hand quickly snap the distal phalanx of the middle finger into flexion. A positive response is flexion of the fingers or thumb (or both).

Task 2: Resistance to passive wrist or finger extension

Position: Standard starting position.

Instruction: "Let me move your hand."

Method: Choose either (a) or (b):
(a) Extend and flex wrist 5 times with sufficient speed of passive movement to elicit a stretch reflex. Feel for resistance to passive movement and watch for contraction of wrist flexors.
(b) Extend and flex fingers 5 times with sufficient speed of passive movement to elicit a stretch reflex. Feel for resistance to passive movement and watch for contraction of finger flexors.

Task 3: Facilitated finger flexion

Position: Standard starting position.

Instruction: "Bend your fingers."

Method: Facilitate a contraction of the finger flexors.

Required: Some active finger flexion.

STAGE 3

Task 1: Wrist extension greater than 1/2 range

Position: Standard starting position.

Instruction: "Bend your wrist back."

Method: Forearm may be supported.

Required: Active wrist extension greater than ½ range. Movement in synergy is permissible.

Task 2: Finger or wrist flexion greater than ½ range

Position: Standard starting position.

Instruction: Choose either (a) or (b):

(a) “Make a fist.”

(b) “Bend your wrist forward as far as you can.”

Required: (a) Finger flexion greater than half range, OR,
(c) Wrist flexion greater than half range.
It is permissible to flex wrist or fingers or both.

Task 3: Thumb to index finger

Position: Supination, thumb in extension.

Instruction: “Touch your index finger with your thumb.”

Method: Place thumb in extension if client is unable to assume the position.
Watch or feel for active thumb adduction sufficient to touch the index finger. Some thumb opposition is permissible.

DON'T ACCEPT: Gravity assisting with the performance of the movement.

STAGE 4

Task 1: Finger extension then flexion

Position: Standard starting position.

Instruction: “Stretch your fingers out straight, then make a tight fist.”

Required: Greater than ½ range of extension of all fingers followed by full flexion of all fingers.

Task 2: Thumb extension greater than half range, then lateral prehension

Position: Standard starting position.

Instruction: “Straighten your thumb, then bring it down to hold onto the paper.”

Method: Place a piece of paper between the thumb and index finger. With the client holding onto the paper, try to pull it out. The client may touch the lateral border of index finger anywhere between PIP and SIP joints.

Required: thumb extension greater than ½ range. Exertion of some pressure to hold the paper.

Task 3: Finger flexion with later prehension

Position: Standard starting position.

Instruction: “Make a tight fist and bring your thumb down to your index finger.”

Method: test for active lateral prehension by trying to move the thumb away from the index finger.

Required: Sufficient finger flexion to bring tips of fingers to palm of the hand.
Active thumb flexion.

STAGE 5

Task 1: Finger flexion then extension

Position: Standard starting position.

Instruction: "Make a tight fist and then straighten your fingers out."

Required: Smooth reversal from flexion to extension. Full flexion and extension of fingers.

DON'T ACCEPT: To bend or straighten fingers unevenly.

Task 2: Finger abduction

Position: Standard starting position with forearm pronated.

Instruction: "Spread your fingers apart as far as you can."

Required: Full range finger abduction (compared to other side).

DON'T ACCEPT: wrist and finger flexion during movement.

Task 3: Opposition of thumb to little finger

Position: Hand unsupported (forearm may be supported).

Instruction: "Touch the tip of your little finger with your thumb."

Required: Some flexion of MCP, PIP, and DIP joints of the thumb and 5th finger.

DON'T ACCEPT: Wrist flexion, hand support or use of only opposition.

STAGE 6

Task 1: Tap index finger 10 times in 5 seconds

Position: Standard starting position with forearm pronated.

Instruction: "Tap your index finger as quickly as you can."

Required: Active flexion and extension at MCP joint.

DON'T ACCEPT: Movement taking place at wrist, flexion of IP joints.

Task 2: Pull trigger, then return

Position: Pistol grip, wrist in neutral position, thumb and index finger extended, 3 other fingers flexed.

Instruction: "Bend and straighten your index finger."

Required: Full range flexion and extension of index finger with no movement of thumb and other fingers.

DON'T ACCEPT: Any change in starting position.

Task 3: Wrist and finger extension with finger abduction

Position: hand resting on lap or support, forearm pronated.

Instruction: "Lift your wrist as far as you can and then stretch your fingers apart."

Required: Full range wrist and finger extension with full range of abduction (compare to the other side).

STAGE 7

Task 1: Thumb to finger tips, then reverse 3 times in 12 seconds

Position: Standard starting position with thumb touching the little finger.

Instruction: “Starting with the little finger, touch the tip of each finger with your thumb and then go back to the little finger. Make sure the index finger is touched twice. Do this 3 times.

Required: Smooth, coordinated movement repeated 3 times in 12 seconds.

Task 2: Bounce a ball 4 times in succession, then catch it

Position: Sitting on side of the bed, holding onto a ball 2 ½ inches in diameter.

Instruction: “Bounce the ball 4 times and then catch it.”

Required: The activity is controlled and the height of the ball is consistent. It is permissible to bounce ball between the knees or to the outside of weak side.

Task 3: Pour 250 ml from 1 L pitcher, then reverse

Position: Sitting at a table with measuring cup and 1 litre pitcher on table. The measuring cup is medial to the pitcher.

Instruction: “With your weak hand, pour the water from the pitcher to the cup. Pick up the cup and pour the water back into the pitcher by running the palm of your hand up. Put the pitcher back where it was.”

Required: Task accomplishment without spilling the liquid.

CHEDOKE-McMASTER STROKE ASSESSMENT SCORE FORM

IMPAIRMENT INVENTORY: STAGE OF RECOVERY OF ARM AND HAND

ARM and HAND: start at Stage 3. Starting position: sitting with forearm in lap in a neutral position, wrist at 0 degrees and fingers slightly flexed. Changes from this position are indicated by underlining. Place an X in the box of each task accomplished. Score the highest Stage in which the client achieves at least two Xs.

ARM	HAND
1 <input type="checkbox"/> not yet Stage 2	1 <input type="checkbox"/> not yet Stage 2
2 <input type="checkbox"/> resistance to passive shoulder abduction or elbow extension <input type="checkbox"/> facilitated elbow extension <input type="checkbox"/> facilitated elbow flexion	2 <input type="checkbox"/> positive Hoffman <input type="checkbox"/> resistance to passive wrist or finger extension <input type="checkbox"/> facilitated finger flexion
3 <input type="checkbox"/> touch opposite knee <input type="checkbox"/> touch chin <input type="checkbox"/> shoulder shrugging > ½ range	3 <input type="checkbox"/> wrist extension > ½ range <input type="checkbox"/> <u>finger/ wrist flexion</u> > ½ range <input type="checkbox"/> <u>supination, thumb in extension</u> : thumb to index finger
4 <input type="checkbox"/> extension synergy, then flexion synergy <input type="checkbox"/> shoulder flexion to 90° <input type="checkbox"/> <u>elbow at side, 90° flexion</u> : supination, then pronation	4 <input type="checkbox"/> finger extension, then flexion <input type="checkbox"/> thumb extension > ½ range, then lateral prehension <input type="checkbox"/> finger flexion with lateral prehension
5 <input type="checkbox"/> flexion synergy, then extension synergy <input type="checkbox"/> shoulder abduction to 90° with pronation <input type="checkbox"/> <u>shoulder flexion to 90°</u> : pronation then supination	5 <input type="checkbox"/> finger flexion, then extension <input type="checkbox"/> <u>pronation</u> : finger abduction <input type="checkbox"/> <u>hand unsupported</u> : opposition of thumb to little finger
6 <input type="checkbox"/> hand from knee to forehead 5 times in 5 sec. <input type="checkbox"/> <u>shoulder flexion to 90°</u> : trace a figure 8 <input type="checkbox"/> <u>arm resting at side of body</u> : raise arm overhead with full supination	6 <input type="checkbox"/> <u>pronation</u> : tap index finger 10 times in 5 sec. <input type="checkbox"/> <u>pistol grip</u> : pull trigger, then return <input type="checkbox"/> <u>pronation</u> : wrist and finger extension with finger abduction
7 <input type="checkbox"/> clap hands overhead, then behind back 3 times in 5 sec. <input type="checkbox"/> <u>shoulder flexion to 90°</u> : scissor in front 3 times in 5 sec. <input type="checkbox"/> <u>elbow at side, 90°</u> : resisted shoulder external rotation	7 <input type="checkbox"/> thumb to finger tips, then reverse 3 times in 12 sec. <input type="checkbox"/> bounce a ball 4 times in succession, then catch <input type="checkbox"/> pour 250 mL from 1 L pitcher, then

<input type="checkbox"/> STAGE OF ARM	<input type="checkbox"/> STAGE OF HAND
---------------------------------------	--

APPENDIX E

Working Memory Assessment (version 5)

Verbal Working Memory (words: pen, car, bank, fish door, red, tree, song, moon)

Version 5

2 item span					Check if successful	Total # of successes
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
Door, pen	Tree, car	Bank, moon	Red, song	Fish, door		
3 item span						
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
Moon, car, moon	Pen, tree, bank	Car, fish, song	Red, pen, song	Car, moon, bank		
4 item span						
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
Red, tree, bank, car	Song, tree, door, bank	Red, bank, door, fish	Song, bank, tree, pen	Fish, bank, red, door		
5 item span						
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
Moon, car, door, bank, red	Bank, fish, tree, pen, red	Moon, pen, song, car, tree	Pen, bank, fish, moon, tree	Red, tree, bank, song, door		
6 item span						
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
Tree, fish, car, pen, red, moon	Car, tree, bank, door, red, song	Pen, car, red, bank, fish, tree	Song, tree, moon, bank, fish, red	Moon, song, door, fish, tree, pen		
7 item span						
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
Bank, pen, red, moon, tree, car, song	Red, song, moon, fish, door, bank, car	Car, fish, pen, door, song, moon, bank	Song, bank, fish, moon, car, door, red	Car, pen, door, song, fish, moon, tree		
8 item span						
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
Song, fish, tree, car, door, pen, bank, red	Song, moon, door, car, bank, tree, pen, red	Door, red, song, tree, moon, car, pen, fish	Fish, pen, door, song, red, bank, car, moon	Song, red, door, bank, car, moon, tree, pen		

Working Memory Assessment (version 5)

Visuospatial Working Memory

Version 5

2 item span					Check if successful	Total # of successes
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
5, 1	7, 1	3, 9	6, 8	4, 5		
3 item span						
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
8, 2, 9	2, 7, 3	1, 4, 8	6, 1, 8	2, 9, 3		
4 item span						
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
6, 7, 3, 2	8, 7, 5, 3	6, 3, 5, 4	8, 3, 7, 1	4, 3, 6, 5		
5 item span						
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
9, 2, 5, 3, 6	3,4,7,1,6	9,1,8,2,7	1, 3, 4, 9, 7	7, 6, 3, 8, 5		
6 item span						
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
7, 4, 2, 1, 6, 9	7, 2, 3, 5, 6, 8	2, 1, 6, 3, 4, 7	7, 8, 9, 3, 4, 6	9, 8, 5, 4, 7, 1		
7 item span						
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
3, 1, 6, 9, 7, 2, 8	6, 8, 9, 4, 5, 3, 2	2, 4, 1, 5, 8, 9, 3	8, 3, 4, 9, 2, 5, 6	2, 1, 5, 8, 4, 9, 7		
8 item span						
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
8, 4, 7, 2, 5, 1, 3, 6,	8, 9, 5, 2, 3, 7, 1, 6	5, 6, 8, 7, 9, 2, 1, 4	4, 1, 5, 8, 6, 3, 2, 9	8, 6, 5, 3, 2, 9, 7, 1		

Working Memory Assessment (version 5)

Kinesthetic Working Memory (start position: feet flat on floors, hands flat on thighs)

1. Extend the unaffected wrist such that the unaffected hand is off the thigh **WE**
2. Abduct the unaffected arm out to the side. **Abd**
3. Lift the palm of the unaffected hand off the thigh. **Palm**
4. Cross both hands at the wrist and center on the lap (can use the unaffected hand to guide the affected side). **X**
5. Slide the unaffected hand forward on the thigh to touch the knee. **FWD**
6. Touch the ankle of the affected side with the unaffected hand. **Ankle**
7. Touch the opposite shoulder with the unaffected hand. **Shlder**

Version 5

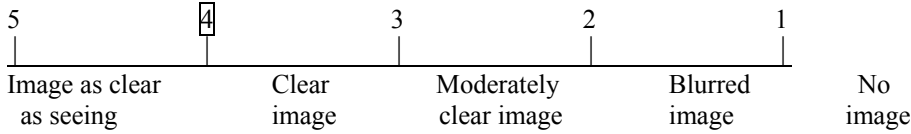
2 item span					Check if successful	Total # of successes
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
Abd, WE	WE, Fwd	X, Fwd	Abd, Palm	WE, Shlder		
3 item span						
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
Abd, Shlder, Palm	Shlder, Ankle, WE	Fwd, Palm, Ankle	Ankle, Fwd, Abd	We, Ankle, Shlder		
4 item span						
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
WE, Ankle, Shlder, X	Fwd, WE, Abd, Ankle	X, Abd, WE, Ankle	Fwd, WE, Ankle, Shlder	Shlder, Fwd, Palm, Ankle		
5 item span						
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
Fwd, WE, Abd, X, Shlder	X, Ankle, Fwd, WE, Abd	Palm, Abd, Ankle, Fwd, X	Abd, Palm, WE, Shlder, Fwd	Palm, Ankle, Fwd, X, Abd		
6 item span						
Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5	1 2 3 4 5	
Abd, Fwd, Shlder, Ankle, Palm, WE	WE, Palm, Ankle, Shlder, Fwd, Abd	Abd, Palm, Fwd, Ankle, WE, X	Palm, X, Ankle, Abd, Shlder, WE	Shlder, Palm, Fwd, Abd, WE, Ankle		

APPENDIX F

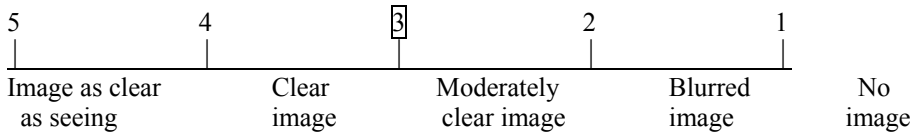
Kinesthetic and Visual Motor Imagery Questionnaire (KVIQ)

Visual Scale

1) Neck flexion/extension

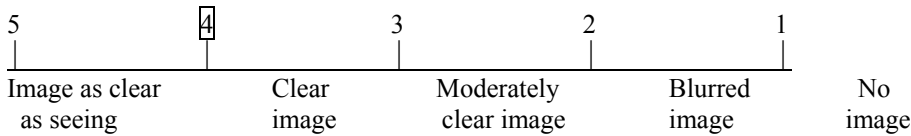


2) Shoulder elevation



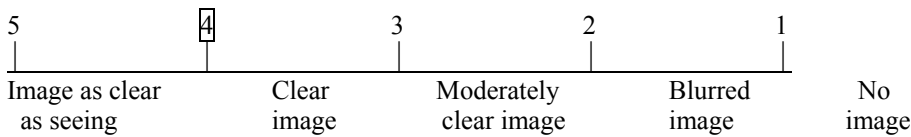
3A) Forward shoulder flexion to vertical (non dominant)

L R



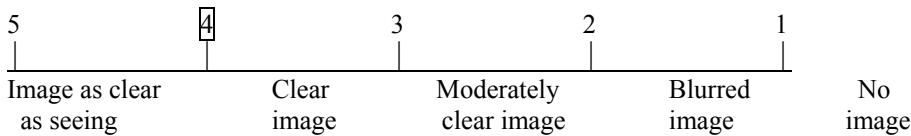
4A) Elbow flexion/supination (dominant)

L R



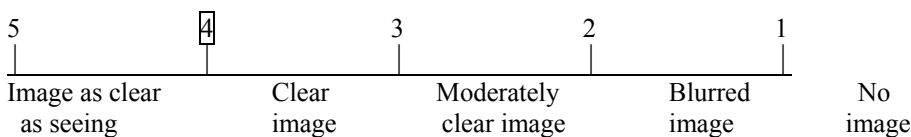
5A) Thumb/finger opposition (dominant)

L R



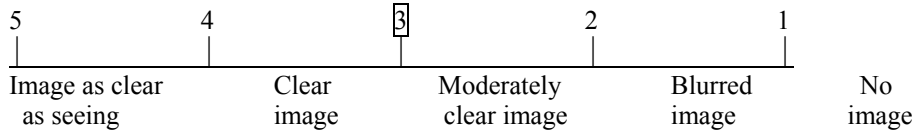
3B) Forward shoulder flexion to vertical (dominant)

L R



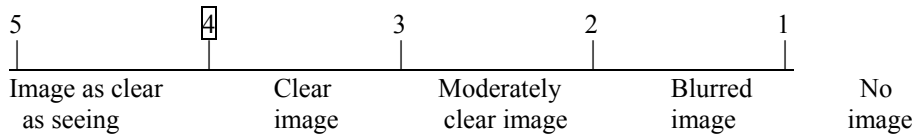
4B) Elbow flexion/supination (non dominant)

L R

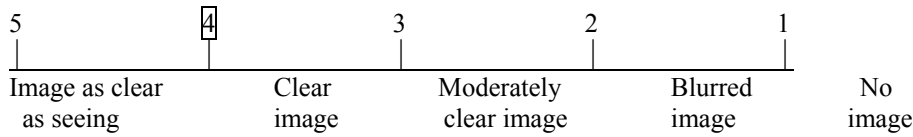


5B) Thumb/finger opposition (non dominant)

L R

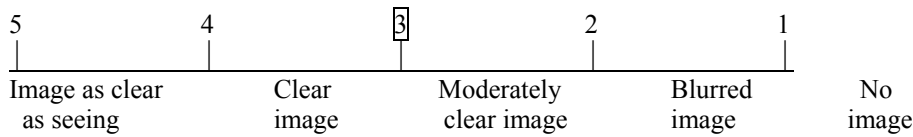


6) Forward trunk flexion



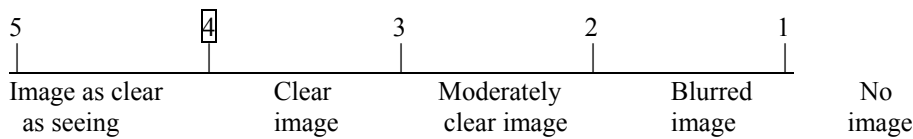
7A) Knee extension (non dominant)

L R



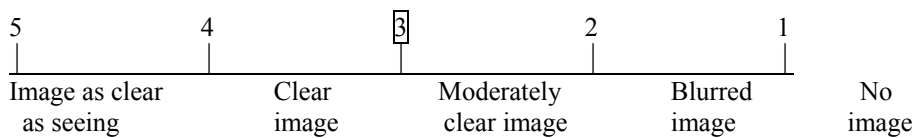
8A) Foot displacement (dominant)

L R



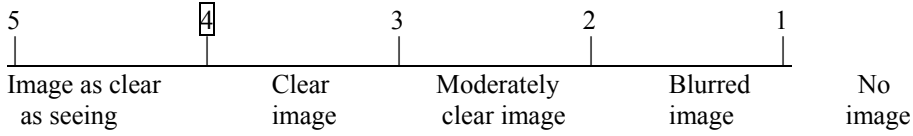
9A) Toe tapping (non dominant)

L R



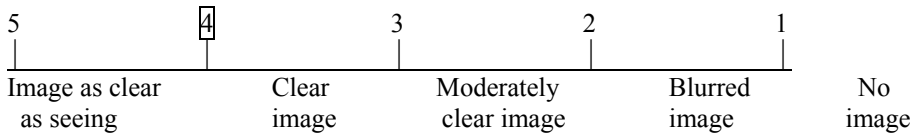
10A) Foot external rotation (dominant)

L R



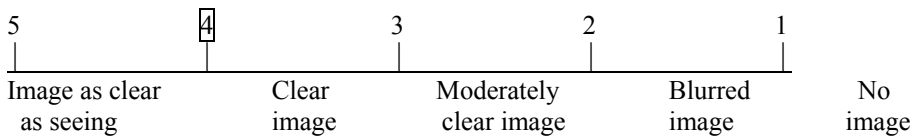
7B) Knee extension (dominant)

L R



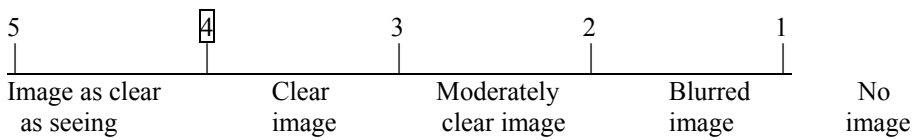
8B) Foot displacement (non dominant)

L R



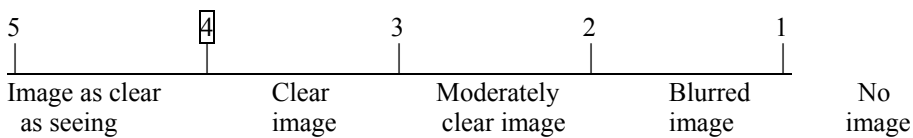
9B) Toe tapping (dominant)

L R



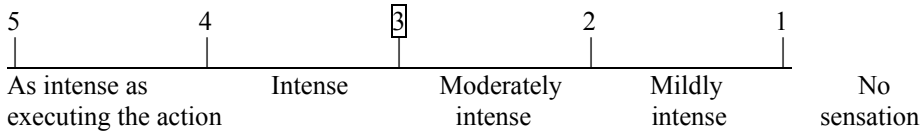
10B) Foot external rotation (non dominant)

L R

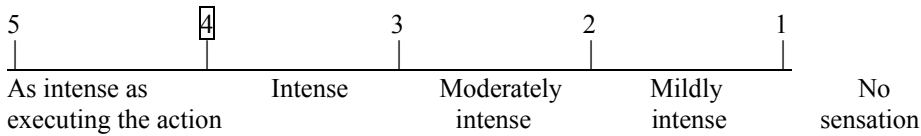


Kinesthetic Scale

1) Neck flexion/extension

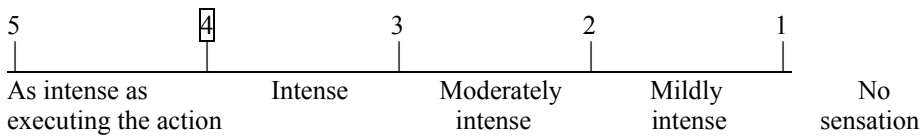


2) Shoulder elevation



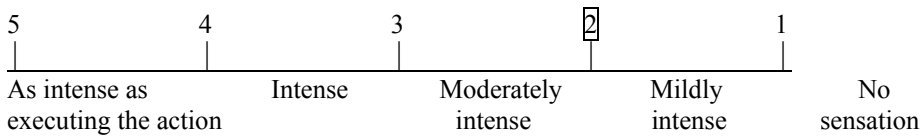
3A) Forward shoulder flexion to vertical (non dominant)

L R



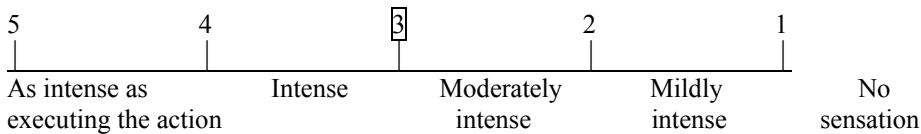
4A) Elbow flexion/supination (dominant)

L R



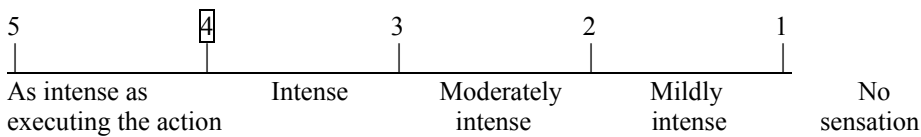
5A) Thumb/finger opposition (dominant)

L R



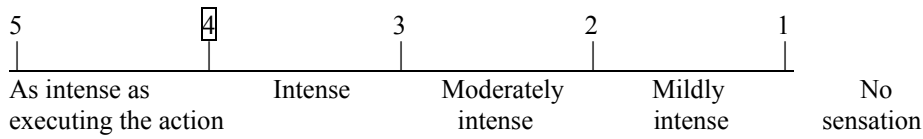
3B) Forward shoulder flexion to vertical (dominant)

L R



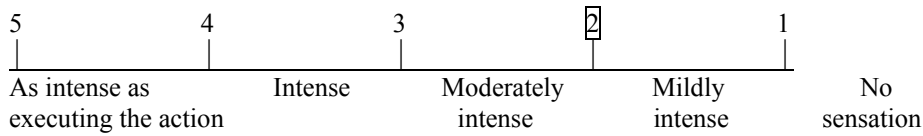
4B) Elbow flexion/supination (non dominant)

L R

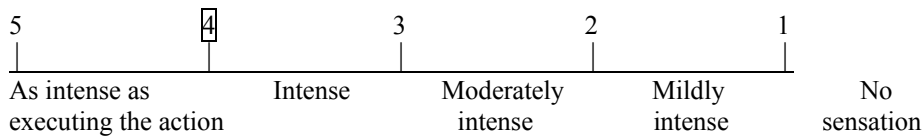


5B) Thumb/finger opposition (non dominant)

L R

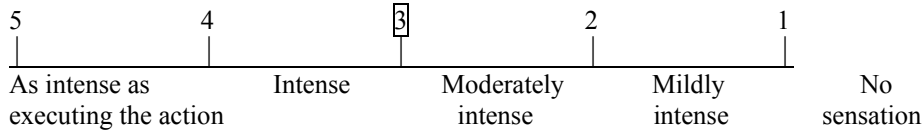


6) Forward trunk flexion



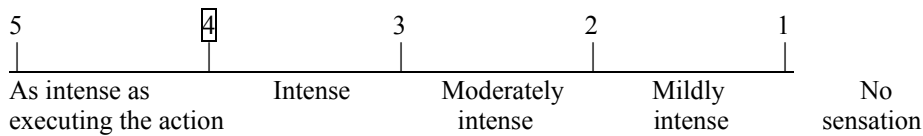
7A) Knee extension (non dominant)

L R



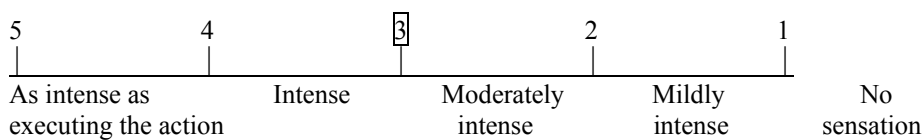
8A) Foot displacement (dominant)

L R



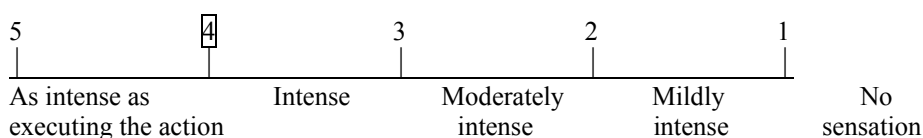
9A) Toe tapping (non dominant)

L R



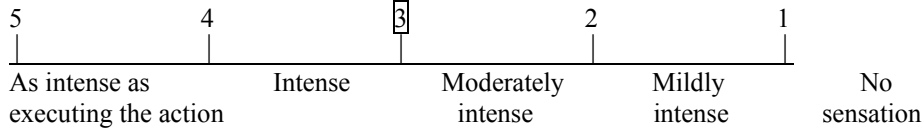
10A) Foot external rotation (dominant)

L R



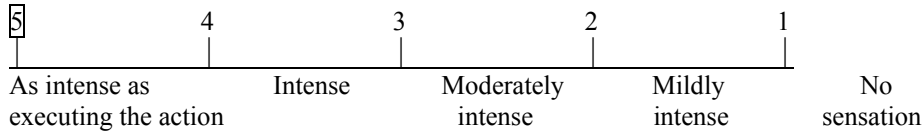
7B) Knee extension (dominant)

L R



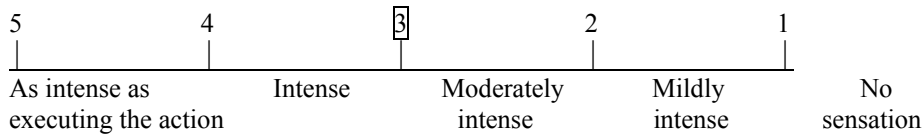
8B) Foot displacement (non dominant)

L R



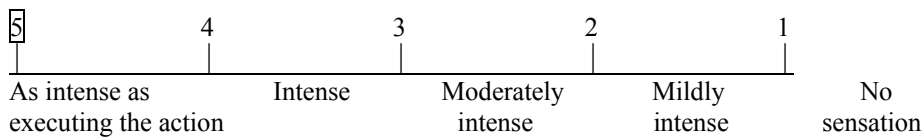
9B) Toe tapping (dominant)

L R



10B) Foot external rotation (non dominant)

L R



Data Analysis for the KVIQ: Score Sheet

KVIQ Visual Score (Qv1+ Qv2+Qv3a+Qv4a+Qv5a+Qv6+Qv7a+Qv8a+Qv9a+Qv10a)	
KVIQ Kinesthetic Score (Qv1+ Qv2+Qv3a+Qv4a+Qv5a+Qv6+Qv7a+Qv8a+Qv9a+Qv10a)	
KVIQ total score = visual score + kinesthetic score	

Variables	Affected	Not Affected
UE visual score	$Qv3a + Qv4b + Qv5b$	$Qv4a + Qv5a + Qv3b$
LE visual score	$Qv7a + Qv9a + Qv8b + Qv10b$	$Qv8a + Qv10a + Qv7b + Qv9b$
UE kinesthetic score	$Qk3a + Qk4b + Qk5b$	$Qk4a + Qk5a + Qk3b$
LE kinesthetic score	$Qk7a + Qk9a + Qk8b + Qk10b$	$Qk8a + Qk10a + Qk7b + Qk9b$
UE + LE visual score		
UE + LE kinesthetic score		

APPENDIX G

Chronometric Test

SUBJECT NAME: _____ DATE: _____

CHRONOMETRIC TESTING (MI ABILITY)

Materials: stop watch, box with two circular targets (2 cm diameter) spaced 30 cm apart drawn on the side.

Patient Position: Seated in front of a desk, with the box placed in front of the patient at arm’s length.

Instructions to patient: with your unaffected hand, touch one target with your index finger then touch the other target moving at your normal speed. “See” the movement in your mind and “feel” the sensation of moving. Now, close your eyes and when I say go I want you to imagine yourself touching each target in turn moving at your normal speed until I say stop. Say “now” or make a sound each time you have touched a target. Keep your eyes closed as you imagine performing this task.

Next, actually perform the task at your normal speed by touching each target in turn with your index finger. Begin when I say go.

Outcome: $MI\ index = \frac{\text{imaged movement time}}{\text{executed movement time}}$

Instructions to Examiner: Do not specify the duration of the trial, but record the time to complete 5 repetitions. Test both unaffected and affected limbs twice (if the patient is unable to perform the task with their affected arm, they score ‘0’). Allow rest break between trials.

Unaffected Arm

Trial 1

Trial 2

Imagined: time to complete 5 repetitions

Executed: time to complete 5 repetitions

MI Index (calculated)

Average: _____

Affected Arm

Trial 1

Trial 2

Imagined: time to complete 5 repetitions

Executed: time to complete 5 repetitions

MI Index (calculated)

Average: _____