

THE EFFECT OF MUSCLE FATIGUE OF THE NON-PARETIC LIMB ON
POSTURAL CONTROL OF STROKE PATIENTS.

by

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A thesis submitted in partial fulfillment
of the requirements for the Master of Science
in Human Kinetics at the University of Ottawa

April 2011

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Abstract

Since a significantly greater percentage of body weight is supported by the non-paretic limb following stroke, a greater amount of fatigue may be present during daily activities. This may affect the ability of these individuals to maintain a stable upright posture. The presence of falls following a stroke has been attributed in part to this asymmetrical stance post-stroke. Therefore the purpose of this study was to assess the effect of quadriceps muscle fatigue on bi-pedal posture in individuals who had a stroke and an age-matched control group. Although individuals after stroke displayed greater postural sway under the paretic limb than the non-paretic limb or control subjects, results of this study show that sustaining an isometric knee extension of the non-paretic limb induces changes in postural control for individuals after stroke, but that these changes do not markedly differ from those of healthy age-matched controls.

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CHAPTER I
INTRODUCTION

Background

According to the Heart and Stroke Foundation of Canada, there are over 50,000 cases of stroke in Canada per year. Statistics Canada puts the total cost associated with stroke at approximately 3.6 billion dollars per year in physician services, hospital costs, lost wages, and decreased productivity (Statistics Canada, 2000). The understanding of the underlying mechanisms explaining a decrease in functional abilities post-stroke, which may lead to better, more effective interventions for this population, is thus important and timely.

The specific consequences of a stroke may vary depending on the location and severity of the stroke, and can involve difficulties in the ability to move, see, remember, speak, reason, read, write, etc. It has been shown in previous research that approximately 40% of people fall within the first year of a stroke (Langhorne et al. 2000, Nyberg et al. 1995). Hip fractures also occur at a higher rate among stroke patients creating a high level of disability following stroke and hip fracture from falls. The cause of falls has been attributed in part to the asymmetrical stance post-stroke (Geurts et al, 2004). The location of a stroke is often uni-lateral, creating impairments mostly on the contralateral side of the body, including paresis or paralysis.

A paretic limb does not provide the stability required for a symmetrical and stable bipedal stance (Genthon et al. 2008). Following a stroke, the paretic limb has abnormal muscle activation patterns, reduced force generation capacity (muscle weakness), increased passive tone, impaired processing of afferent signals and sensory deficits (Arene, N, et al 2009). As a consequence, there is an asymmetry in favour of the non-paretic limb, which becomes the preferred bi-pedal posture of stroke patients. The asymmetrical posture may be, in severe cases, up to 90% of total body weight on the non-

paretic limb (Genthoon et al. 2008). Since a significantly greater percentage of body weight is supported by the non-paretic limb, a greater amount of fatigue may be present during daily activities, which could affect the ability to maintain a stable upright posture.

Muscle fatigue is considered to be the ‘transient decrease in the capacity to perform physical actions’ (Enoka & Duchateau, 2008). Muscle fatigue combined with postural control has been studied in a variety of populations. This ranges from young healthy adults to elderly (Lin et al, 2009), as well as patient populations of chronic low back pain (Janssens, et al, 2010) and chronic ankle instability (Monaghan, et al 2006). The site of induced muscle fatigue also ranges from cervical neck muscles, lumbar muscle groups to the more dominant ankle, knee and hip muscle groups. However, the effect of peripheral muscle fatigue on posture has yet to be studied in the stroke population.

Maintaining a stable upright posture is a task that is dependent on numerous physiological systems. Postural control is reliant on input from the visual, vestibular and somatosensory systems (Lord, et al. pg 70) It is theorized that a disruption of the somatosensory system due to muscle fatigue will induce impairments in proprioception and kinesthesia at the joint in question (Toledo et al, 2010). These physiological impairments will have an adverse effect on function at the joint. Muscle fatigue has also been shown to impair force production around the joint (Lorist et al. 2002). Impaired force production reduces the ability to respond to internal or external perturbations to posture during quiet standing. If a patient is unable to respond to these perturbations efficiently, or is unable to detect postural instability, a reduction in postural control may occur.

A reduction in postural control can be quantified with centre of pressure (COP) movements during quiet standing trials. The centre of pressure has been defined as “the magnitude of the vertical supportive force and the position of the action line of this force at its point of intersection with the supporting surface” (Murray, et al 1967). Increased movements of the COP demonstrate an inability to maintain a stable posture. Following fatigue, the COP has been shown to move faster (increased velocity) and further (increased area) (Bizid et al, 2009). If the COP variability caused by fatigue becomes too great, this could lead to an increased fall risk (Piirtola, M. et al 2006). A fall or step response is unavoidable if the centre of pressure travels outside of the base of support and therefore the ability to maintain static COP locations is important for stability.

The extent to which peripheral muscle fatigue affects postural control of individuals who had a stroke has yet to be assessed in scientific research. The motor impairments evident in the affected paretic side leading to the unique bi-pedal posture following stroke make this an area of research requiring further analysis.

Purpose of the Study

The purpose of this study was to assess the effect of quadriceps muscle fatigue on bi-pedal posture in individuals who had a stroke and an age-matched control group. The study consisted of one experimental session within which clinical (BERG) and laboratory measures of balance were performed, before and after an isometric fatigue protocol of the non-paretic/dominant quadriceps muscle. The interest in fatiguing the non-paretic leg stems from two issues: first, this leg supports a greater proportion of body weight in individuals who had a stroke, which would likely lead to a greater effect of fatigue than if fatigue was induced in the leg that supports less weight (the non-paretic leg is also the leg

that is more likely to experience fatigue with everyday activities, and thus the external validity of the present results is likely greater); second, it may be difficult to fatigue the paretic limb, as individuals with a stroke may not be able to sustain a sufficient neural drive to their muscles to lead to significant fatigue, which phenomenon would not occur in the non-paretic leg (Riley and Bilodeau, 2002).

CHAPTER II
REVIEW OF LITERATURE

Introduction

This chapter reviews the literature that forms the foundation for this thesis. Key topics include 1) changes following stroke, 2) posture after stroke, 3) falls and fall prevention and 4) how muscle fatigue induces changes in posture.

Stroke

Stroke is defined as a sudden loss in brain functioning due to a disruption in the blood flow to the affected area of the brain. This disruption can either be a block of passage in a vessel (ischemic stroke) or a leaking of blood to surrounding tissue (hemorrhagic stroke). Although the chance of having a stroke more than doubles for each decade of life after 55, (Heart & Stroke Foundation Canada, 2009) stroke may occur at any age. If the stroke is severe enough, it will damage or even destroy the surrounding brain tissue at the affected site. The resultant cell-death can cause potentially irreversible damage which may lead to various health complications. These may include the possibility of recurrent stroke, infections, thromboembolism, pain, psychological and mobility complications (Langhorne et al, 2000).

Following a stroke, multiple changes occur in the side of the body that is contralateral to the stroke location. Changes are opposite of the stroke location due to the fact that the motor pathways from the cortex cross and descend to the contralateral side of the spinal cord. Main motor impairments in the paretic limbs consequent from a stroke include increased tone (Hufschmidt et al, 1988), loss of motor units (McComas et al, 1973), and of importance to this project, loss of capacity to generate normal muscle force levels due to disturbed motor control (Lamontagne et al, 2002). For example, a decrease in the capacity to maximally activate elbow flexor muscles voluntarily has been shown in

the paretic compared with the non-paretic arm of individuals post-stroke (Riley & Bilodeau, 2002). Newham and Hsiao (2001) also found a significant decrease in the ability to maximally activate muscles around the knee. This decrease in force production ability may reduce the ability to maintain balance and posture (Lee et al, 1988).

Stroke and Posture

Of all the motor impairments consequent of stroke, postural control deficiencies have the greatest impact on activities of daily living (Fong, et al. 2001). Postural control has been defined as the control of the body's position in space for the purposes of balance and orientation (Shumway-Cook et al, 2007, page 158). Postural sway is a term used to describe the body's movements during quiet stance. Minimizing postural sway allows for a stable balance to prevent a potential fall (Fernie, et al. 1982).

Following a stroke, the ability to maintain a stable upright posture becomes a more challenging task when compared to a healthy, age-matched population. Dickstein & Abulaffio (2000) showed greater sway amplitude in both anterior-posterior and medio-lateral axes in individuals post-stroke compared with age-matched control subjects. Using a method of two force platforms underfoot, Genthon et al. 2008 showed that sway parameters are also greater under the paretic limb when compared to the non-paretic limb and also greater than that found under the loaded limb of control subjects that adopted a similar asymmetrical posture. In another study using only one platform to discuss overall sway, the patient population exhibited severe postural instability with increases in both sway amplitude and velocity (de Haart et al. 2004). Overall, impaired postural control is a major problem for stroke patients as seen during posturography.

Since the simple task of standing quietly on two feet becomes a challenging task for stroke patients, the risk of falls increases. The upright stance is usually characterized by weight bearing asymmetry in favour of the non-paretic limb and by larger postural sway (Geurts et al. 2004). There is usually a shift in static posture towards the non-paretic limb which was found to be on average 62% of total body weight, with extremes as high as 90% of total body weight (Genthon et al, 2008). However, postural asymmetry in favour of the paretic limb has also been observed and has been termed Pusher Syndrome (Davies, P. 1985). While standing or sitting, patients tend to use their non-paretic limb to push towards the paretic side. In both situations, lateral stability is compromised.

The asymmetrical posture becomes the preferred stance for a majority of stroke patients. Engardt et al (1993) proposed that the asymmetrical posture is adopted by stroke patients for reasons of safety and speed during movements. Although they may feel safer, there is increased postural sway during quiet stance due to this shift (Genthon et al. 2008), which was found to be a predictor of falls during recovery from stroke (Sackley, 1991). The increased postural sway may cause the centre of pressure to exceed the limits of the base of support which results in severe postural instability and potentially a fall (Shumway-Cook & Wollacott, 2007, page 217).

Neglect

The asymmetrical posture can also be attributed to numerous changes including asymmetrical muscle tone (Pérennou, D. 2005), motor weakness (Bourbonnais et al 1989) and alterations in spatial cognition with regards to the body schema (Parton et al. 2004). The alteration in body schema is termed hemi-neglect in stroke patients. Hemin neglect can be defined as “a failure to report, respond or orient to novel or

meaningful stimuli presented contralaterally to a brain lesion and is not attributable to primary sensory or motor deficits.” (Heilman, et al. 1993). It is more common following right brain damage and more severe and longer lasting (Halligan et al, 1994) due to the dominance of the right hemisphere during attentional tasks (McGlone et al. 1997).

Patients with neglect can have severe disabilities and may behave as if whole areas of space no longer exist. Activities of daily living are impacted and safety becomes a concern. Hemineglect also distorts the coordinates for body weight distribution. (Gentson et al, 2008.) van Nes et al (2009) showed that hemineglect independently contributes to impaired postural control in the acute phase of stroke. This was confirmed by Gentson et al (2008) in that spatial neglect was the best predictor for postural instability. Therefore, it is important to assess hemineglect for use as a correlated factor to postural reweighting following muscle fatigue.

Hemineglect may be present in a variety of ways and may be missed if inappropriate assessment scales are used. Therefore, multi-item test batteries (Wilson et al, 1987) have been developed to attempt to cover all possible types of neglect. Visuo-spatial neglect, personal and extra-personal neglect, motor neglect and directional hypokinesia all present with various deficiencies and therefore cannot be detected by the same measure. A modified test battery was used for this thesis by finding assessments with good validity and reliability in each type of neglect while considering time, resources and energy of the patient (see methodology).

Falls

A fall has been defined in numerous ways but is primarily considered as ‘unintentionally coming to the ground or some lower level and other than as a

consequence of sustaining a violent blow, loss of consciousness, sudden onset of paralysis as in stroke or an epileptic seizure.’ (Gibson, et al, 1987).

Balance impairments ultimately lead to a high prevalence of falls among stroke patients even after completion of rehabilitation (Nyberg et al, 1995). Lamb et al (2003) approximate the prevalence of falls among stroke survivors at 40%. The debilitating effect of falls has been cited in numerous studies concerning older adults (Tinetti, 2003). However, stroke patients are at an increased risk of complications after a fall due to hemi-osteoporosis (Ramnemark et al 1999). The bone mineral density loss was found to be primarily on the paretic side around the neck of the femur (Jørgensen et al, 2000). The reduction in bone mineral density increases the possibility of hip fracture from a fall (Poole et al. 2001). Therefore, stroke patients are at, not only an increased risk of falls, but also an increased chance of disability after a fall. With the high number of stroke cases per year, in combination with the prevalence of falls, the reduction of falls among stroke patients must become a priority in the rehabilitation setting (MacKintosh, 2005).

Fall Prevention

Postural stability is modulated through the interaction of three major sensory systems. These systems are the visual, vestibular and somatosensory systems. Studies have been done to assess the contribution of each system on postural control by altering visual input (Marigold, 2006), proprioception (Toledo et al, 2010) and vestibular stimulation (St. George et al, 2010). Reliance on these systems may be altered depending on age and diagnosis. Each system is therefore assessed in various populations and over age. For the purpose of this thesis, the somatosensory system will be perturbed through inducing muscle fatigue.

Numerous studies have attempted to provide evidence on various rehabilitation methods to correct postural impairments including transcutaneous nerve stimulation (Johansson et al. 2001), electromyographic feedback (Schleenbaker et al 1993), as well as body weight supported treadmill training (Moseley et al 2003). However, no definitive conclusions on the facilitation of balance recovery in quiet stance following a stroke have been made (Geurts et al, 2004). It is very important that the underlying compensatory mechanisms and causes of postural instability be understood prior to development of rehabilitation strategies.

Postural Sway

Variations in postural sway during quiet stance have been studied extensively, including changes with aging (Maki et al, 1990), effects of attentional demand on posture (Teasdale et al, 2001) as well as the effects of muscle fatigue on posture (Gribble et al. 2004). Typically, the centre of pressure (COP) characteristics obtained from a force platform are used to document postural sway. This allows the dissection of postural sway into both the anterior-posterior as well as the medio-lateral planes. The velocity, total area of sway and the amplitude of the movement of the COP are used to describe the changes under various conditions, including during a fatigued state.

As mentioned by Rougier (2007) the use of one force platform only allows for the resultant COP displacements to be documented, which may result from an infinite number of combinations involving movements under each foot. Genthon et al (2008) states that this may lead to a loss of a great deal of information, particularly in subjects that have an asymmetrical stance as with stroke patients. Therefore, the use of two force

platforms would be advantageous to assess postural sway changes with fatigue for stroke patients.

An upright quiet posture is stabilized by corrective torques generated around the joints, primarily the ankle (Winter, D., 1995). Internal or external perturbations will create unwanted movements to which the body must respond. The central nervous system will perceive the changes in posture through feedback from visual, vestibular, proprioceptive/somatosensory systems. Based on this feedback, an afferent signal will be generated that will result in a muscle contraction and a corrective torque. (van Asseldonk et al. 2006). If there is a disruption in the feedback to the CNS, the body will be forced to make more corrections which it may not be able to do successfully. If the body is unable to make a correction, the amplitude in either plane will be increased and may reach the stability limit, resulting in a fall (Shumway-Cook & Wollacott, 2007, page 217). However, if the body is forced to make more corrections, the velocity will be increased as to limit the amplitude of movements. Fatigue is a factor that will limit the body's ability to make these corrections successfully (Mademli, et al, 2008).

Muscle Fatigue

A great deal of research has been dedicated to the field of fatigue post-stroke. It is frequently noted as a common symptom following a stroke with complaints of emotional fluctuations, poor memory and difficulty with concentration (Staub et al, 2001; Ingels et al. 1999). Falconer et al, (1996) found that up to 72% of patients at approximately 8 months post stroke complained of fatigue in assessments. However, these fatigue states are primarily overall feelings of tiredness. Mark Davis (1995) states these to be factors

that reside in the brain (central mechanisms), such as brain serotonin levels leading to a lack of motivation to continue a proposed task.

This is in contrast to neuromuscular fatigue which Davis states as changes occurring in the muscles themselves (peripheral neuromuscular fatigue). This could be resultant of increase in metabolites following a prolonged bout of muscle contractions (Merletti et al, 1991). Neuromuscular fatigue may also result in a failure of the central processes to drive the muscle activity (central neuromuscular fatigue). Since it can include both central and peripheral mechanisms, neuromuscular fatigue can be characterized by a reduction in the capacity of the total neuromuscular system to produce a maximum force following a bout of prolonged/sustained muscle activity (Semmler et al. 1999).

Muscular stimulation techniques help categorize fatigue. A ratio of reduction in the 'at rest doublet' twitches provided information about peripheral muscle fatigue while the VA (voluntary activation) equation indicates the presence or absence of central fatigue.

Fatigue can be induced with a wide range of muscular activity (isometric, isokinetic, etc.), which are all included in activities of daily living. Prolonged standing posture during certain daily activities for a stroke patient population will induce states of muscle fatigue due to the unique bipedal posture following stroke. The difficulty of maintaining a bipedal posture in a fatigue state may therefore become greater. As noted by Riley & Bilodeau (2002), only a few studies have documented fatigue characteristics in persons with hemiparesis. In general, results have shown that fatigue induces impairments that limit the ability to maximally activate a muscle (Newham et al, 2001), produce abnormal activation patterns (Ballantyne et al, 2010) and reduce muscle

conductivity (Horstman, A. et al, 2010). To our knowledge, no studies to date have assessed the effects of muscle fatigue on posture in persons following stroke.

The effects of neuromuscular fatigue on quiet stance have been described in articles including fatigue of the ankle and hip (Gribble, Hertel, 2004), fatigue of the cervical musculature (Vuillerme et al 2005), as well as the lumbar musculature (Davidson et al. 2004). These articles generally found increased sway parameters of COP movements from pre- to post-fatigue trials. While some report an increase in velocity of COP movements (Gribble et al, 2004), others found increases in amplitude following fatigue (Salavati et al, 2007).

However, some articles have found that fatigue of certain muscle groups may have greater effects on postural stability than others. For example, Gribble & Hertel (2004) have shown that fatigue of the ankle does not have an effect on posture for young adults while fatigue of the hip and knee increase postural sway. This was confirmed by finding no fatigue effect on posture after isokinetic ankle fatigue of young adults (Bisson et al. 2011).

Research Hypothesis

The research hypotheses for this project are based on the body weight distribution and hemineglect aspects of post-stroke posture. The effect of muscle fatigue of the non-paretic limb may result in a shift of body weight distribution (increase in Fz component from pre- to post-fatigue) towards the paretic limb. Since there have been numerous physiological changes in the paretic limb, it will not be able to support the body weight put upon it during post-fatigue trials. The increased load and inability to support this load, will lead to greater postural sway, as documented through greater amplitude and velocity

measures of the COP in individuals post-stroke. In contrast, fatigue of the dominant leg in healthy controls will not have any effect on COP measures.

The research hypotheses suggest an increase in postural instability (which may lead to falls) when the non-paretic limb of individuals post-stroke is fatigued. Although falls per se are not a measured outcome in the present study, the information generated may be useful for rehabilitation professionals aiming at preventing falls post-stroke. For example, following a rehabilitation session, if the non-paretic limb is fatigued, the patient may need to rest to facilitate recovery of the musculature and shift the weight bearing back to the non-paretic limb.

CHAPTER III
METHODS

Subjects

Through convenience sampling, two groups (n=8 per group, Table I) were recruited from the Élisabeth Bruyère outpatient rehabilitation service (stroke group) and from local community centres (control group). Subjects were either persons following a single unilateral stroke (hereafter called stroke group), or age-matched healthy older adults (control group). Ages for both groups ranged from 57-80 years old.

Both groups answered a health questionnaire (appendix A) to ensure no confounding health concerns. Both groups performed the BERG balance scale (Appendix B). This scale has been shown to be a valid and reliable measure of balance impairment for use in post-stroke assessment (Blum, et al. 2008). The stroke group also completed various clinical measures to assess hemi-neglect. All participants were screened for contraindications for participations in exercise studies (Geig, C. 1994; Appendix A) Written informed consent (Appendix B) was obtained from all subjects prior to participating in the study, which was approved by the Research Ethics Board at the University of Ottawa and the Élisabeth Bruyère Research Institute (Appendix C).

Materials

Postural Data

The primary outcome measures are related to the centre of pressure (COP) movements during the postural tasks. It has been shown that, due to hemiparesis post stroke, patients have an asymmetrical preferred stance in favour of the non-paretic limb (Gentho et al, 2008). Due to this asymmetrical stance, two AMTI force platforms (AMTI AccuGait, Watertown, MA) were used to assess the contribution of each limb to postural control before and after the fatigue task. The use of two force platforms allows

for the analysis of sway under each foot, which is necessary due to the unique posture of stroke patients or else a great deal of information may be lost (Genthon et al. 2008). Of importance to this thesis is the postural reweighting (Fz) component for each platform while resultant sway parameters provide a better estimate of overall postural control. The platforms were set up adjacent to each other, 2.5m from a visual fixation point on a wall. The platform location was standardized between subjects with floor markings to allow the use of the safety harness.

Dynamometer

The fatigue protocol was performed on a dynamometer (BIODEX System 3, Shirley, NY), which allowed the isolation of muscle fatigue to a specific muscle group in the non-paretic limb. The torque output measurements were used as the criteria to quantify fatigue. Once torque output is consistently below a pre-determined threshold, it can be assumed that the neuromuscular system can no longer produce the required torque due to fatigue. The use of 50% of a maximum voluntary contraction (MVC) as a criteria to end a fatigue task has been used in prior research (Bilodeau et al. 2003), and was deemed sufficient to induce a fatigued state in the present study.

Electrical Stimulation

To characterize the extent of peripheral and central fatigue, single and doublet pulses of brief electrical stimulation from a constant-current electrical stimulator (Model DS7A, Digitimer LTD, Welwyn Garden City, England) were used. Individual pulses were square wave with 0.5ms duration and 100-mA amplitude, and were delivered to the quadriceps muscle group. Two electrode pads were located on the quadriceps muscle; one proximally across the upper portion of the muscle (anode) and the other distally just above the knee (cathode). We aimed to increase stimulation intensity until no further

increase in torque output was noticeable so as to obtain a supramaximal intensity which is ideal when using the interpolated twitch technique. This technique is commonly used to assess the degree to which skeletal muscle is activated during voluntary contractions (Sheild & Zhou, 2004) although this method has revealed potential sources of error (Amundsen, 1990). One of which is the discomfort associated with this technique (Hales & Gandevia, 1988). Since all participants were volunteers, wishes to stop further increase in stimulation were respected. All but three subjects reached a stimulation level of 25% of MVC. This is well accepted as sufficient for ITT (Bulow et al, 1993).

Procedure

Each subject participated in one experimental session. The session lasted about 2 hours and participants were compensated for their time. Participation was completely voluntary with written informed consent being obtained prior to the session.

The session began with one clinical measure of balance abilities (BERG balance scale), as well as multiple neuropsychological assessments for the stroke group assessing hemi-neglect (baking tray task, line bisection test, bells test and the comb and razor test). Multiple tests were done due to the nature of hemi-neglect, which is often task-specific and may go undetected if assessment is limited to one measure. All tests have been used in prior stroke research with validity and reliability being substantiated (see below).

The BERG balance scale (Appendix D) is a well known, valid clinical measure of posture and stability including static and dynamic tasks. Participants were instructed to safely perform 14 tasks ranging from standing unaided for 2 minutes to standing on one foot for 10 seconds. Both groups performed the BERG balance scale. Comparison of mean group scores can be found in the demographics chart (Chart I).

Simple ‘paper and pencil’ assessments for hemi-neglect were only done with the stroke group. This is due to the nature of hemi-neglect as presenting only following a brain injury. It also allowed for full recovery of the musculature following the BERG assessment. Subjects were asked to do four different assessments for hemi-neglect.

The Line Bisection Test (Appendix E) is possibly the most widely known and accepted test in neuropsychology for testing unilateral spatial neglect (USN) (Ferber & Karnath, 2001). Participants are presented with a sheet of paper presented at their midline and asked to draw a mark at the perceived mid points of multiple horizontal lines. If the markings are in favour of one side of the paper (usually the same side as the brain lesion), with possibility of complete omission of lines, there may be signs of hemi-neglect.

The Bells Test (Gauthier et al. 1989) (Appendix F) is a cancellation test that can assess visual neglect in the near extra personal space. The participant is asked to circle 35 bell shaped images on an 8.5 x 11-inch paper which also contained 280 distracters (houses, apples etc.). Omission of 6 or more bells on the right or left half of the page indicates USN. Judging by distribution of the omissions, severity of neglect can also be determined.

To assess for spatial neglect, the Baking Tray Task (Tham, et al. 1996) was administered. It has been shown to be one of the most sensitive single tasks to detect hemi-neglect (Appelros, et al 2004). In this task, a baking tray (28cm x 42cm) is presented along with 16 blocks (3cm x 3cm). The participant is instructed to spread the blocks out over the baking tray as if they were ‘baking cookies’. If the blocks were to favour one side of the tray, presence of hemi-neglect is possible. If the participants were to group the blocks together or create a design, a cognitive impairment could be present.

The Comb and Razor test (McIntosh et al. 2000) assesses for unilateral spatial neglect in the personal space by assessing the performance of individuals with functional activities. A razor is substituted with a powder brush for female participants. Participants are given the comb and asked “show me how you would use this item”. Scoring is done using the Beschin and Robertson (1997) scoring method. The number of strokes with the razor, comb, or powder compact that are performed on the left, right, or ambiguously is recorded to calculate a mean percentage score for the three categories.

$$\% \text{ left} = (\text{left strokes}) / (\text{left} + \text{ambiguous} + \text{right strokes})$$

The % left is calculated for the comb and razor/powder compact case, and the scores are combined in the formula below as the index for left personal neglect:

$$((\text{razor/compact case \% left}) + (\text{comb \% left})) / 2$$

A score < 0.35 indicates the presence of left personal neglect. A score > 0.35 indicates the absence of left personal neglect.

Following the clinical and neuropsychological measures, pretest-posttest laboratory-based measures of balance were carried out using the AMTI force platforms. The trials were separated by an isometric fatigue protocol using the BIODEX dynamometer. Before posturography measures on the platforms, all participants were securely fitted with a climbing harness and hooked to a safety chain from a structural beam above to negate the possibility of a fall. Participants were instructed to find a comfortable stance with one foot on each platform. Tracing of the feet was done prior to the postural tasks to ensure within-subject standardization of foot position between pre and post fatigue trials. The subjects were instructed to fixate on a target on the wall and to “stay as still as possible”. Trials lasted 45 s each and forceplate data was collected at 100 Hz.

To induce muscle fatigue in the non-paretic (or dominant limb for control subjects) quadriceps, an isometric fatigue protocol was performed. With the subjects seated comfortably in the BIODEX chair, the leg was strapped into the attachment at 70° of knee flexion (0 = full knee extension). The lateral epicondyle of the femur was aligned with the axis of rotation of the BIODEX. Straps were fastened around the shank as well as the waist to eliminate the possibility of involvement of other musculature during the fatigue task. The system was set to isometric mode and did not move throughout the session. Torque scaling was set to 256 ft-lbs for all subjects.

After a brief warm up, to assess the level of voluntary activation, electrical stimulation intensity was increased until no further increase in torque output was noticeable or at the participants request. The level remained at the same intensity for the entirety of the protocol for single and doublet pulses.

Three maximum voluntary contractions (MVCs) were performed with a 1-min recovery time separating them. Only the second two MVCs contained stimulation during as well as a single and doublet following the contraction (see figure 1). This allowed assessment of voluntary activation of the musculature.

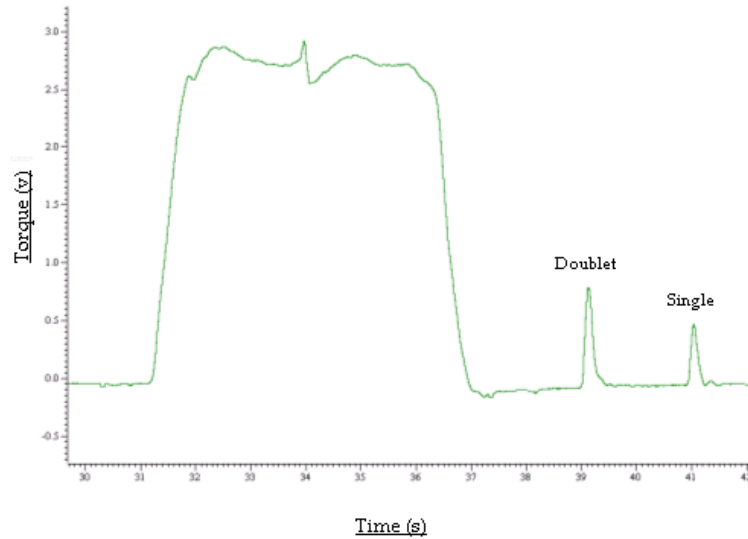


Figure 1: Sample of MVC with the doublet pulse during followed by a doublet at rest and finally a single impulse.

The highest torque output that was obtained from the 3 MVCs was used to set the target for the fatigue task. This target was pre-defined as 50% of the maximum torque. The torque output and a target line were presented on a computer screen in front of the subjects. They were instructed to keep the lines together (ie. force output at 50% of MVCs) for as long as they possibly could. Strong verbal encouragement was provided throughout the fatigue task.

Once the participants were unable to maintain 50% of MVC for longer than 3 s, the fatigue task ended following a doublet stimulation during the sustained contraction followed by a doublet and a single at rest (see figure 2). Once the single pulse was delivered, the participant was quickly unstrapped and safely transported back to the AMTI platforms. After safe transport to the platforms, the post-fatigue trials were performed (same as pre-fatigue).

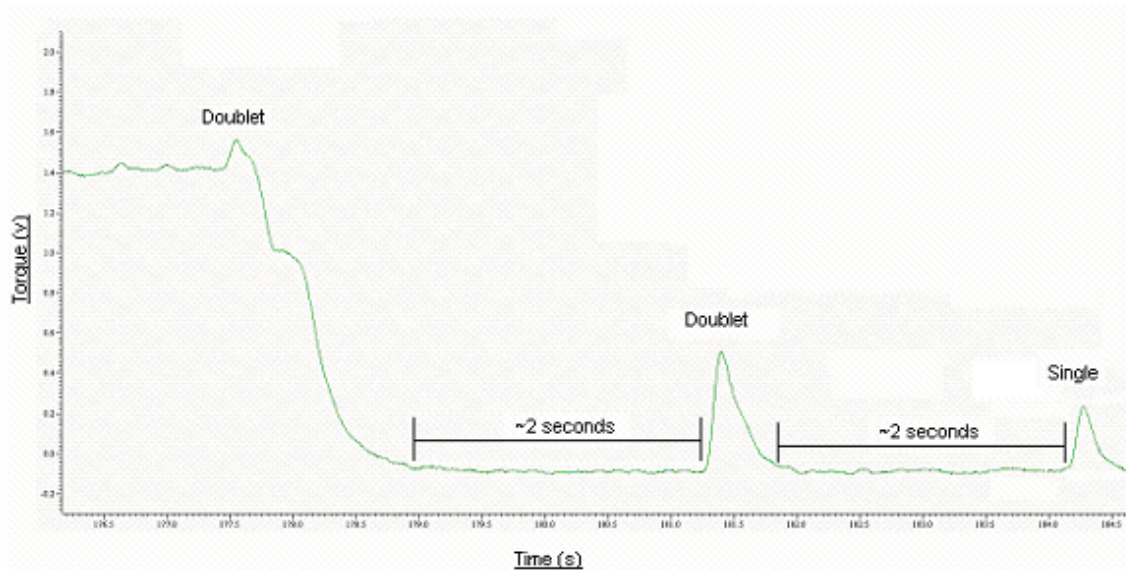


Figure 2: End of the fatigue protocol with doublet during the isometric contraction followed by a doublet and a single impulse at rest.

Participants remained in the lab for at least 10 minutes following the cessation of the exercise and were escorted back down to their transportation to ensure safety.

Data Processing

All BIODEX data were collected at 250 Hz through an A/D converter and stored on a personal computer for future analysis using specialized computer software (Spike 2, Cambridge Electronic Design, Cambridge UK.) All AMTI platform data were collected at 100 Hz directly into NETFORCE and were processed with BioAnalysis (Advanced Mechanical Technology Inc., Watertown MA.).

The calculated variables of interest during posturography focused on the movements of the centre of pressure (COP). The COP position in both the X (medio-lateral) and Y (anterior-posterior) axis as well as forces and moments produced under each foot were available for every data point (4500 in total) for each trial. With

importance for weight-shifting, the Fz or 'upwards (z-axis)' force placed on each platform, was also extracted for analysis. Since two individual platforms were used for data collection, velocity in both the X and Y axis as well as the area (95% ellipse) of the COP movements could be calculated using computer software for each platform separately. Velocity (cm/s) is simply calculated by the total length of the COP path divided by the number of frames by time: $V_{avg} = L/n * \Delta t$. Area (cm²) is calculated with an ellipse in which lies 95% of the data.

In addition, using simple formulas, a resultant COP position in both X and Y was calculated by combining data from both platforms. For the X values:

$X_{res} = ((X_1 + 25) * Fz_1 + (X_2 - 25) * Fz_2) / 2$ where X_{res} is the resultant position of COP, X_1 is the position in the X axis under the non fatigued leg while X_2 represents the fatigued leg. Addition and subtraction of 25 is to offset the centre of each platform towards the centre of both platforms. For the left platform (X_1) the X moved 25 cm positively towards the centre while the right (X_2) the X had to move 25cm in the negative direction along the axis. For the Y values: $Y_{res} = ((Y_1 * Fz_1) + (Y_2 * Fz_2)) / 2$ where Y_1 represents location of the COP in the Y axis under the non fatigued leg while Y_2 represents the fatigued leg.

The resultant COP provides information pertaining to overall stability during quiet standing regardless of the asymmetry. Velocity in each axis was calculated from the absolute values between the adjacent resultant X values. This represents the distance travelled between each data point. The total distance travelled was averaged for each trial and divided by 45 seconds.

A script was written to assist with analysis of the stimulation data. Values of increased torque during contraction due to doublet stimulation and torque elicited during doublet at rest were obtained. These variables were used to assess the voluntary

activation of the quadriceps for each participant. The following formula was used to assess level of voluntary activation (L.O.V.A.):

$$\text{L.O.V.A.} = [1 - (\text{Extra Torque(mV)}/\text{Control Torque(mV)})] \times 100$$

Extra torque was the increase in torque elicited by the doublet stimulation superimposed on the voluntary contraction. The control torque is the torque elicited by the same doublet stimulation but while the participants were at rest following the contraction. If the subject is maximally driving their quadriceps, the electrical stimulation during a contraction would fail to elicit extra torque resulting in a L.O.V.A. value close to 100.

In order to assess the extent of peripheral fatigue, the control doublet torque elicited after the fatigue task was expressed as a percent of that elicited pre-fatigue.

Statistical Analysis

All statistical analyses were done using PASW version 18 for Windows (Predictive Analysis SoftWare, Somers NY). All demographic, BERG scores, time to achieve fatigue state, time to transfer from BIODEX to the platform, individual platform COP variables as well as resultant COP variables were entered into a PASW spreadsheet for analysis. All data points were checked for outliers using Z-scores and were assessed for skewness and kurtosis. Independent sample t-tests were run to assess differences between groups on demographic and muscle contraction variables while a mixed model two-way ANOVA was run for all postural variables followed by post-hoc tests on significant main effects or interactions using a Bonferroni correction of the alpha level. Difference between groups (SG and CG) and time point (pre-fatigue, post-fatigue) as

well as any interactions were analyzed. The level of significance for all statistical tests was set at 0.05.

CHAPTER IV

RESULTS

Introduction

In this chapter, the results of the study are presented. All tables and figures are shown in the corresponding appendices. The values following the means in the text and error bars in the figures are standard deviation for the values. The results are presented using a p value of 0.05.

Participants

The stroke group consisted of 7 male and 1 female participants with an age range from 47-81 yrs, with a mean of 68 ± 11 . The means of the height and weight were 175.13 ± 7.8 cm and 78.3 ± 10.5 kg respectively. Average time post-stroke was 22 months ± 21 . Information concerning the type and location of stroke is available in Table 2. The average score on the BERG assessment was 45 ± 6 (out of 56). The amount of time to reach a fatigued state was 143.9 ± 64.3 s while the transfer time from the end of the fatigue protocol to the commencement of post-fatigue postural trials was 68.6 ± 42.7 s.

The control group consisted of 3 male and 5 female participants with an age range of 58-79 with a mean age of 68 yrs ± 8 . The means of the height and weight were 168.67 ± 12.1 cm and 71.47 ± 19.1 kg respectively. The average score on the BERG assessment was 55 ± 1 (out of 56). The amount of time to reach a fatigued state was 126.9 ± 48.7 s while the transfer time was 36.4 ± 12.4 s.

Independent sample t-tests and chi-squared tests were performed on all demographic variables (Table I) to check for group differences and found that only two variables of interest resulted in p values < 0.05 . The groups were confirmed to be statistically different for gender ($F=5.744$, $p=0.034$) and BERG balance scale ($F=9.462$, $p=0.0008$) (Figure 3).

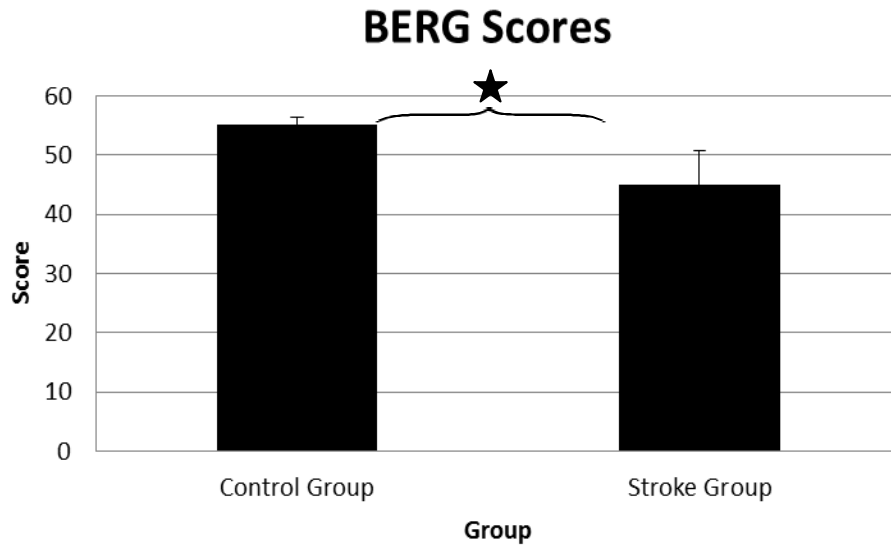


Figure 3: Scores on the BERG Balance Assessment Scale. (Maximum score of 56.) ★ Illustrates group difference (p=0.0008)

All hemi-neglect tests were negative for neglect but may have revealed a potential cognitive deficit in two subjects (Appendix G). The time to achieve a fatigued state (figure 4), transfer time (figure 5) and all other demographic statistics (height, weight etc.) were not statistically significant ($p > 0.05$). Therefore, the two groups can be considered independent age-matched groups.

Isometric Contraction Time

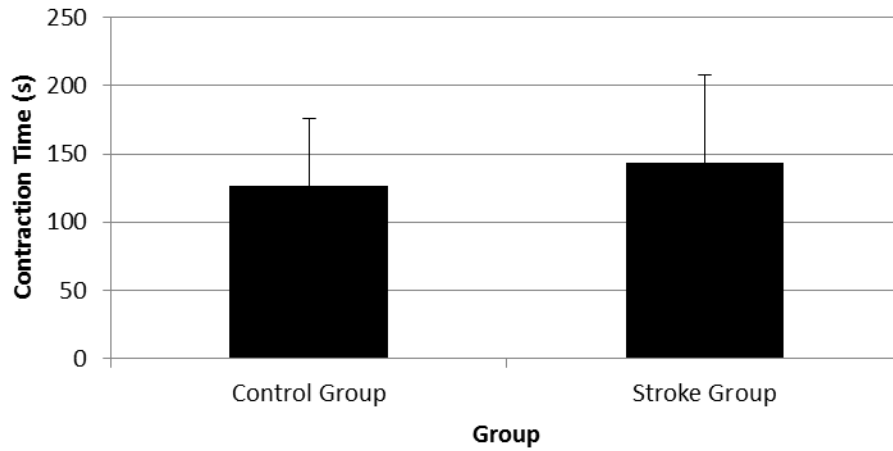


Figure 4: Length of fatigue protocol for both groups.

Transfer Time

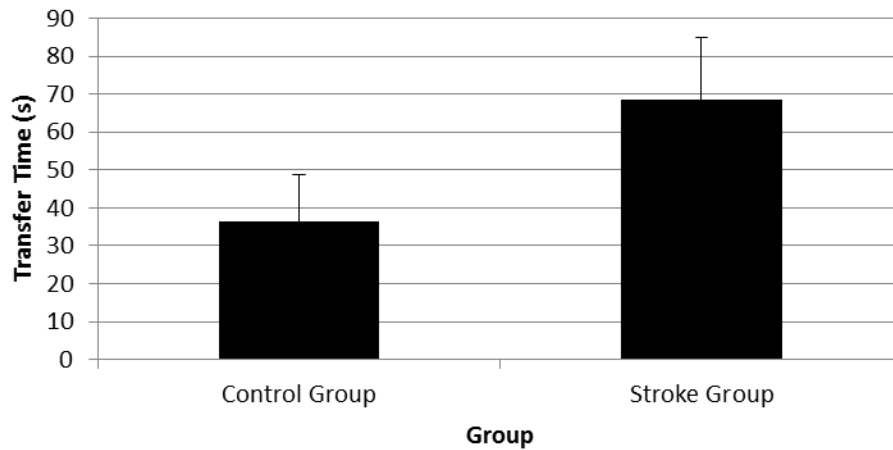


Figure 5: Transfer time or time from the end of the isometric contraction to the commencement of post fatigue posture trials.

Voluntary Activation

Stimulation data revealed a decrease in voluntary activation (figure 6) following fatigue ($F=12.91$, $p=0.004$) with no group effect or interaction. Percent reduction in at rest doublet torque (figure 7) revealed no significant evidence of peripheral fatigue (no decrease in torque post-fatigue).

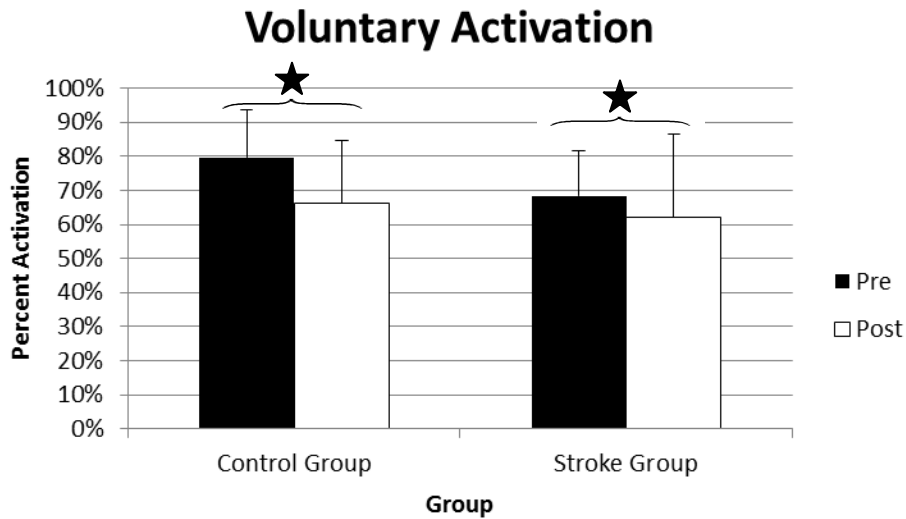


Figure 6: Voluntary activation for both groups comparing pre-fatigue to the end of the fatigue protocol. ★ shows fatigue effect ($p=0.004$)

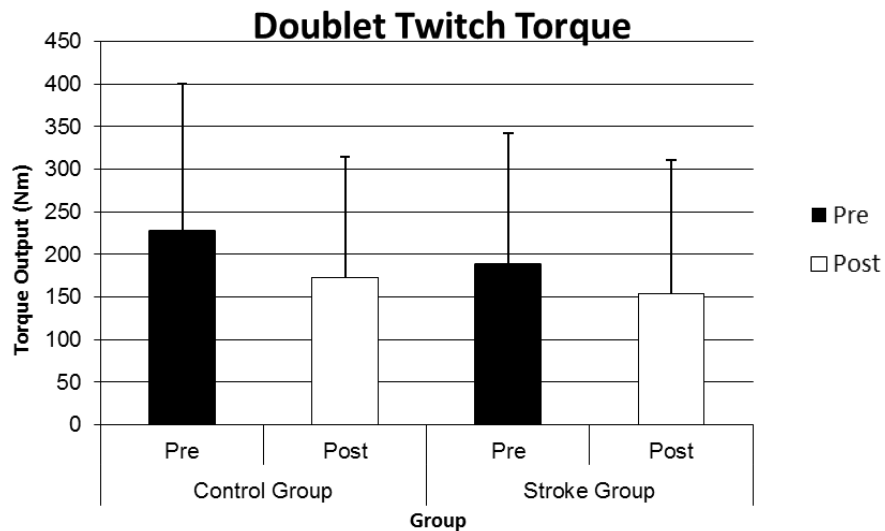


Figure 7: No evidence of peripheral fatigue with doublet-doublet torque reduction from fatigue.

Posturography

Postural data were analyzed with SPSS through a mixed model ANOVA. Factors of interest included time (pre and post), foot (left and right) and group (stroke group and control group). When no group differences were found, data were pooled together to form one group.

Posturography is split into two methods of analysis. Individual platform analysis considers postural COP movements under each foot (paretic and non-paretic for the stroke group and non-dominant and dominant for the control group). Resultant platform analysis considers the average COP movements for both feet to provide overall performance measures on postural tasks. Both methods provide a detailed description of performance and adaptation to postural instability.

Individual Platform Analysis

COP parameters under each foot revealed no group main or interaction effects for velocity, but when both groups were combined, a time by foot effect was shown ($F=7.23$, $p=0.017$; Figure 8). Pairwise comparisons with Bonferroni adjustments showed significance was found to be an increase in velocity under the paretic and non-dominant leg. In contrast, the weight bearing component F_z increased for the fatigued leg ($F=4.87$, $p=0.048$; F_z on Figure 9) following the fatigue protocol, indicating that both groups placed more weight on the fatigued leg than pre-fatigue trials.

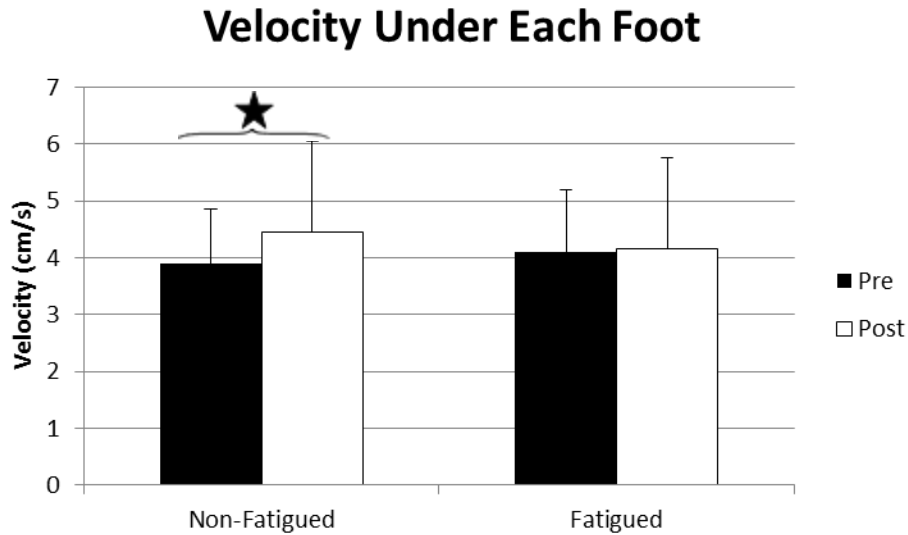


Figure 8: Resultant COP velocity showing a time by foot effect ($p=0.021$). Both groups included in this graph ($n=16$).

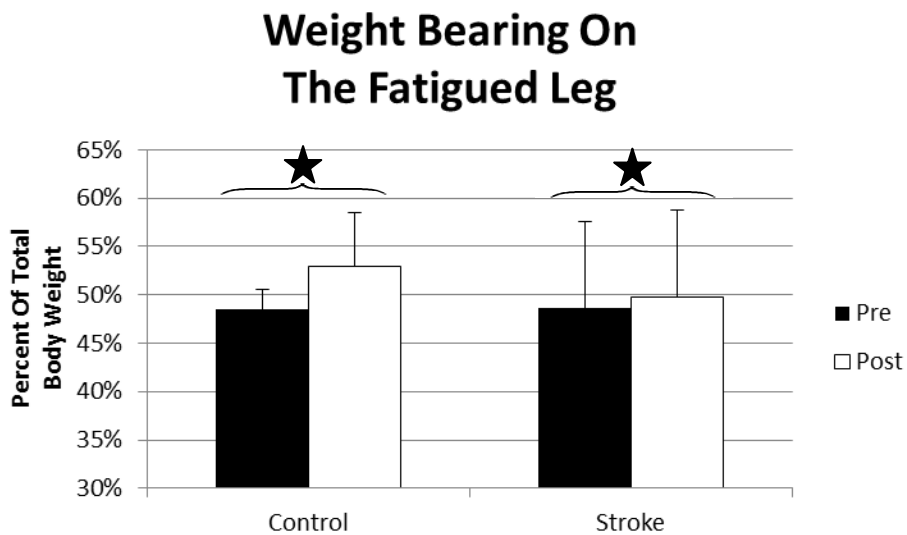


Figure 9: Fz2 or vertical force. Pre (black bars) and post (white bars) under the fatigued leg (non-paretic for SG and dominant for CG) standard deviation shown. Fatigue effect ($p=0.048$)

Analysis of the area that was covered under each foot revealed no significant effect of fatigue but a significant foot by group effect ($F=7.12$, $p=0.018$) as well as a group effect ($F=5.233$, $p=0.038$). (figure 10). Pairwise comparisons demonstrated significance to be due to the greater postural sway under the paretic limb of stroke

patients when compared to the non-paretic as well as when compared to the dominant limb for control group participants.

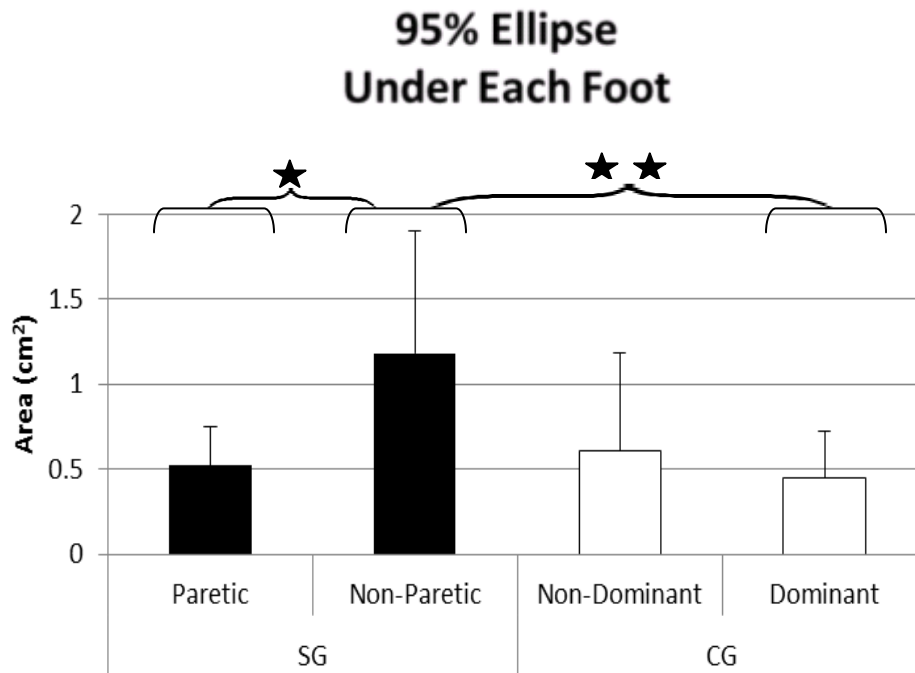


Figure 10: 95% Ellipse area under each foot showing pairwise comparison significance between the paretic and non-paretic as well as between the non-paretic and dominant. Data from pre and post trials were pooled due to no significant effect of time. ★ Shows foot effect (p=0.018) ★★ Shows foot by group effect (p=0.038)

Although not significant, interesting trends were observed. Both a time by group (p=0.063) and foot by group (p=0.079) interaction failed to reach significance for velocity, as well as a main effect of time (p=0.069).

Resultant Platform Analysis

For all postural variables in resultant COP parameters, neither group nor time by group effects were found to be significant. Therefore, all further results concerning resultant postural variables will be presented as one group (n=16) in the text, but are kept separate in the figures. A significant effect of fatigue was found as velocity increased in

the Y axis ($F=6.98$, $p=0.021$; Figure 11). Neither velocity in the x-axis ($p=0.178$) nor mean change in position ($p=0.185$) were found to be significant. Total resultant area was not available.

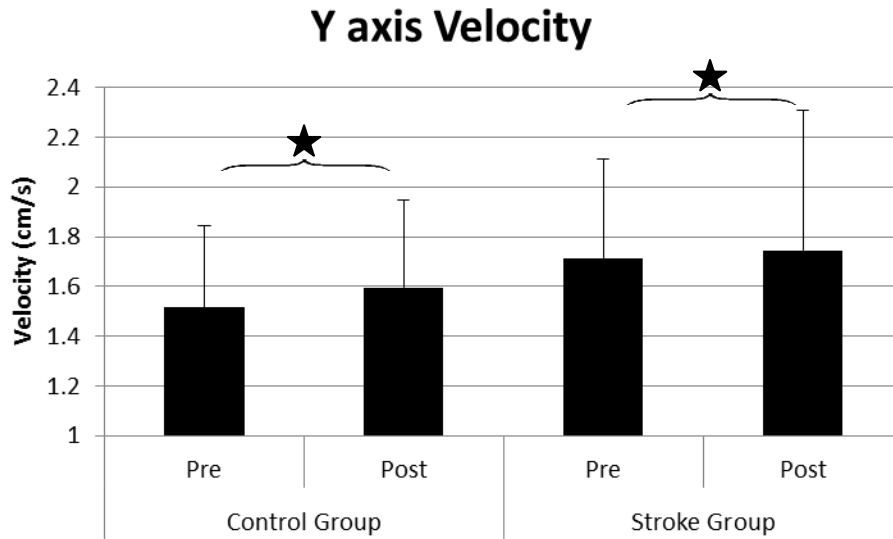


Figure 11: Velocity in the Y axis (anterior-posterior movement) with standard deviation shown.
★ shows fatigue effect (0.021)

CHAPTER V
DISCUSSION

Introduction

The discussion is organized in the order of: demographic and clinical assessments, fatigue characterization (stimulation and contraction variables), posturography and finally clinical relevance. At the end of the chapter, limitations and suggestions for future studies are included.

To summarize the results section, the groups are considered matched on age, height and weight but not on gender as there were more female participants in the control group. The clinical measures revealed no hemi-neglect in the stroke group but demonstrated balance impairments in the stroke group with significantly lower BERG scores than the control group. The isometric fatigue protocol induced central fatigue but failed to fatigue the peripheral muscle to statistically significant levels in both groups. Posturography demonstrated the stroke group had greater sway under the paretic compared to the non-paretic and compared to the non-fatigued leg of control subjects. A fatigue effect with increased velocity under the non-fatigued leg, an increase in weight bearing under the fatigued leg and increased sway in the Y axis (A/P direction) was evident for both groups.

Demographics & Clinical Assessments

All demographic variables were found to be similar between the two groups, except for gender. This confirms that the groups were generally matched. There is potential for gender to influence group differences. Gender related differences in fiber size for the quadriceps muscle group have been reported (Miller et al, 1993) which could affect MVCs between the groups. However, gender differences should not affect any postural stability measure (Hageman et al, 1995). Furthermore, Bilodeau et al (2003)

found no gender differences in EMG signals of the quadriceps with fatigue. Therefore, any difference between the groups is more likely attributed to changes following stroke, and not gender.

Hemi-neglect assessments indicated that participants in the stroke group did not present with hemi-neglect. This is not surprising as it is noted that hemineglect is a transient disorder that dissipates as time post-stroke progresses. Paolucci et al (1996) and Sunderland et al (1987) have reported that significant neglect was rarely observed 6 months post-stroke. Individuals in our stroke group were on average 22 months post stroke. Halligan (1989) gives credibility to assessments of neglect in chronic patients in that signs of neglect may persist for several months or even several years. Assessments in this study were therefore justified, but our results ultimately supported the research by Paolucci et al and Sunderland et al.

Although no signs of neglect were found in any assessment, results of two tests warrant further comments. Two participants failed to complete the Baking Tray Task as instructed. The results of their attempts did not show signs of neglect (they attended to the entire tray), they did however make designs with the blocks. As noticed in appendix G, the designs of the blocks do not match the instructions of “spread the blocks out as evenly as possible as if you were baking cookies on the tray.” Although it appears the blocks in both figures in Appendix G are favouring one side, the sides do not correspond to the side of the stroke for these individuals and therefore cannot correspond to neglect.

Appelros et al (2004) found several patients (out of 270) who made similar designs with the blocks. They credited this to forgetting or misunderstanding the instructions. They also found that these patients had signs of low cognition and scored low on psychological assessments like the Mini-Mental State Examination (MMSE)

(<24). The presence of cognitive deficits is possible in the two patients depicted in appendix G, but this cannot be confirmed; and as with Appeleros, these patients did not show any other signs of neglect. Neither of these participants had data that was removed due to being an outlier. Therefore, the potential cognitive deficit did not influence postural variables as compared to the rest of the stroke group.

Both groups were evaluated with a well documented balance assessment, the BERG Balance scale. The control group was able to obtain a near perfect mean score (55 out of 56) due to the relatively low mean age and good physical condition for individuals in this age group. This mean score puts them above the average reported by Lusardi M. (2004) of 54 for participants 60-69 years of age that do not depend on a gait-aid for safe ambulation. The stroke group had difficulty with certain items on the scale. The mean score of 45 represents a potential fall risk, and actually represents the score which some authors consider a cut-off for independent safe ambulation (Riddle & Stratford, 1999). The fact that the majority of participants in the stroke group used an assistive device for ambulation is consistent with this. Overall, it is apparent that while the control group obtained good clinical balance, the stroke group had significantly worse scores indicating postural instability.

Stimulation & Muscle Contractions

The interpolated twitch technique (ITT) provided multiple levels of information concerning the ‘quality’ of the fatigued state each participant reached and the source of fatigue that caused the cessation of the isometric contraction. A ratio of reduction in the at rest doublet twitches provided information about peripheral muscle fatigue while the L.O.V.A. equation indicated the presence or absence of central fatigue.

Both groups performed the same fatigue protocol. The control group used the dominant leg while the stroke group used the non-paretic leg. Both groups lasted about the same amount of time during their isometric fatigue protocol with the stroke group taking slightly longer to fatigue by 40 s. This could be attributed to the criteria adopted to end the fatigue task, i.e., a relative target of 50% MVC. The control group had a higher mean torque output (+180.9N) and therefore had a higher absolute target torque associated with their 50% MVC. Bilodeau et al (2003) found that a higher absolute torque during an isometric contraction is associated with a shorter endurance time in the quadriceps muscle group. Therefore, since the control group was able to achieve a higher absolute MVC, the fatigue task was shorter than the stroke group.

Although strong positive verbal encouragement was provided throughout the entirety of the fatigue protocol, 5/16 total participants stated they were not able to maintain the isometric contraction and ended the fatigue task before the experimenter instructed them to stop. Therefore, the fatigue time was cut short before 50% MVC was achieved in a few participants. This meant that on average, at the end of the fatigue task, control group participants reached 51% of MVC while the stroke group reached 65% of MVC. If the participants did not reach 50% MVC, the fatigue effect will be less than expected and therefore may limit the influence on postural control.

As seen in chapter IV, although there was a reduction in at rest doublet torque post-fatigue (CG = 42.8% or 55.7N, SG = 45.7% or 34.9N), this did not reach significance, as there was large inter-individual variability. Such a non-significant reduction suggests that peripheral fatigue was not the main cause for ending the protocol in a number of subjects. However, although non-significant, there is obvious reduction in doublet torque showing that there was peripheral muscle fatigue being induced.

As stated in chapter I, neuromuscular fatigue may also result in a failure of the central processes to drive muscle activity (central neuromuscular fatigue). Using the ITT, voluntary activation is calculated and any decrease is representative of central fatigue. An increase in the interpolated twitch amplitude (decrease in the VA as seen in chapter IV) reflects that the inability to maintain the isometric contraction and can be attributed, at least partly, to mechanisms upstream of the muscle in the central nervous system (CNS).

The reduction in VA was slightly greater for the control group (21% decrease) over the stroke group (12% reduction) but was not statistically significant. This magnitude of reduction is comparable to other studies (eg Riley et al 2002). The lack of a group difference may be due to the fact that the non-paretic limb was used for the fatigue protocol. Riley et al (2002) found that the paretic limb produces much lower voluntary activation producing only 50% of the MVC produced by the non-paretic limb. Greater fatigue related changes in the CNS were observed when induced in the paretic compared to the non-paretic side. Individuals after stroke have reduced capacity to maximally drive the paretic limb but maintain the ability to activate the non-paretic limb to a greater extent. Therefore, since the non-paretic limb was used for fatigue, no significant difference between the groups should be expected.

Central fatigue has been attributed to two categories of mechanisms (Taylor et al, 2006). The first are mechanisms that reduce descending output from the motor cortex. This includes changes to the membrane properties of neurons caused by repetitive activation (Taylor et al 2006). The second category credits mechanisms that reduce the efficacy of output from the motor cortex in generating force. This includes changes in motoneurons that make them less responsive to descending motor commands (Butler et al. 2003).

A likely factor related to the inability of the CNS to drive the muscle to maintain an isometric contraction could involve discomfort or motivation. A prolonged isometric contraction is not comfortable for any participant to maintain when maximal force output has to be sustained (such as required towards the end of the fatigue task). This was likely reflected in participant's statements of "I don't think I can continue", which when met with strong positive verbal encouragement, the torque output was consequently increased back above the 50% MVC line and the contraction lasted longer than the participant thought possible. This is in line with the results that doublet reduction did not show (statistically) peripheral fatigue, while voluntary activation suggested the presence of central fatigue.

Although peripheral fatigue can occur immediately at the start of a fatigue protocol, if no (statistically significant) peripheral fatigue is present, such as was found here, the body should have the ability to contract the musculature to respond to postural instability. It is possible that greater changes in posture control would have occurred had there been a significant level of peripheral fatigue induced. However, posture control was still found to be impaired by the fatigue protocol, which could be associated with the presence of central fatigue. Full understanding of the mechanisms of central fatigue remain uncertain (Rasmussen et al, 2007), and its potential effect on posture control has not been studied previously. Central fatigue could have an effect on posture control through, for example, the delay in appropriate motor responses even in states of no significant peripheral muscle fatigue.

Posturography

The use of two platforms for analysis of posture allows for a deeper analysis than one platform protocols. COP movements can be assessed under both feet with the individual platforms, or a resultant COP can be calculated using formulas to find the mean position from both platforms. This method is essential for assessments in posture for a clinical population like stroke where the posture may not be symmetrical and due to physiological changes in the paretic limb, the response to postural instability may differ between legs and from healthy control group responses.

When both platforms are assessed individually, group differences were found for the area (cm²) of COP movements but no group differences were found for velocity (cm/s). Group differences in area show that the stroke patient population exhibit more sway overall than a control group.

The total area of the COP movements is calculated by a 95% ellipse which is defined as “an ellipse that encloses ninety five percent of the centre of pressure data.” (AMTI, pg. BA22). This reduces the effect of extreme perturbations in both AP and ML directions. Pairwise comparisons demonstrated that the stroke group exhibited greater area under the non-paretic limb than under the paretic limb. This large area is much greater than the postural sway exhibited by the control group under the dominant leg.

Following a stroke, the paretic limb undergoes physiological changes that reduce the stability and reliability of feedback on that leg. (Horstman et al. 2010). Since the paretic limb is unable to maintain motor function as well as the non-paretic limb, compensation occurs. van Asseldonk et al (2006) found that patients begin to use the paretic limb as a ‘crutch’ to bear minimal weight on while they perform balance tasks with their non-paretic limb. This is confirmed in the article by Genthon (2008) in that the

COP dispersion under the non-paretic limb was greater than that measured under the paretic limb in a non-fatigued state. The area under the non-paretic limb in participants for this study was over double the value under the paretic limb. The motor impairments in the paretic limb are therefore compensated for by increasing movements in the non-paretic limb. Future research could confirm this by assessing postural stability under each foot during external perturbations to confirm that the non-paretic limb is the primary performer during balance tasks.

Although it remains only statistically a trend, the control group demonstrated similar area during pre-fatigue trials for both limbs but responded to fatigue in a way not demonstrated by the stroke group. Following fatigue, the control group increased postural sway under both feet but much more noticeably under the non-fatigued leg (non-dominant). If the power is increased to provide statistical significance on this trend, a potential reason for falls in stroke patients may be suggested. This postural behaviour has been defined by Vuillerme et al (2009) as an adaptive process to cope with the impaired ability of the fatigued leg to efficiently control posture. Multiple authors have discussed this adaptation and defined it as exploratory 'testing of the ground' movements under the non-fatigued leg. (Riley, et al, 1997). As the non-fatigued leg increases movements, increased supplementary somatosensory feedback is provided to the central nervous system in order to maintain a stable posture.

This adaptation was only found in the control group. The stroke group did not increase area under the non-fatigued leg. This confirms earlier comments concerning the paretic limb (non-fatigue leg) acting solely as a crutch while the non-paretic limb performs postural stability tasks. Even under a state of muscle fatigue, the non-paretic limb will not assist in postural control. Dependence on the non-paretic limb for postural

control during states of postural instability and (internal) perturbations does not create a safe environment for postural control for stroke patients.

Although group differences were found during individual platform analysis, resultant COP data demonstrated no group differences. This could be attributed to the ability of the non-paretic limb to compensate for the paretic limb and therefore will limit resultant COP movements. Since there were no group differences on resultant COP data, results were pooled (n=16) to assess the effect of fatigue on postural control.

Fatigue was found to influence two parameters of interest. Velocity in the Y axis, as well as the Fz component which were significantly different during post-fatigue compared with pre-fatigue trials. As the COP moves, postural adjustments must be made to prevent the COP from extending past the base of support. Both variables demonstrate adjustments made to compensate for the increased difficulty in maintaining “as stable a posture as possible” after fatigue.

Fatigue-related changes in the force generating capacity of muscles (eg. the reduction in contraction time (Almeida, et al, 2008), strength (Enoka et al, 2008) and joint awareness (Ju et al. 2010)) can affect an individual’s ability to keep the COP stable. For example, the increase in metabolites following a sustained contraction will decrease the contribution of proprioception in maintaining stability (Hiemstra et al, 2001). The COP would therefore travel closer towards stability limits before the participant recognizes this. Once movement is detected, the corrective torque will take longer to influence the joint and require a higher level of force output to control the COP, leading to the need for increased corrective actions (velocity of COP).

Fatigue of the lower limb musculature has been shown to induce changes in COP parameters as the participant attempts to maintain a stable posture. Bizid et al (2009)

found that fatigue of the quadriceps induced increased mean COP velocity in a group of young healthy individuals to a greater extent than fatigue of the ankle muscle (triceps surae). This is in agreement with Gribble & Hertel (2004) who found that fatigue of the knee flexor and extensors produced an increase in ML COP velocity.

The postural stance in these two studies (Bizid & Gribble) was a unipedal (dominant) limb stance. The results indicated increase in velocity of the COP in the ML direction. This is in contrast to the results of this thesis. The bipedal stance used in this thesis provided the participants with a very wide base of support compared to the unipedal stance used in the Bizid et al article. Since the base of support is wider in the ML direction than in the AP direction, there is a greater possibility for increased AP (Y axis) postural sway.

Fatigue also induced a significant change in the Fz component. Although there are two Fz components (one for each platform) analysis and discussion considers only one due to the nature of the variable. Since the Fz is the vertical component for the platforms, it considers how much weight the participant places on each. Therefore if Fz1 increases, Fz2 must decrease. Since there was a significant fatigue effect on Fz, it can be said that there is postural reweighting following fatigue. Our data showed that the reweighting was in favour of the fatigued leg. Participants placed on average 3 kg or 4 % more of their total body weight on the fatigued leg compared to pre-fatigue. Although this is contrary to our initial hypothesis, it can be explained for both groups.

Any stroke patient with significant paresis will not depend on the affected side of the body for movement, task completion or in the case of this thesis, postural stability. As noted in the literature review, the physiological changes following a stroke reduce the ability of the body to respond to perturbations (internal or external). Therefore, in a case

of postural instability, reliance on the paretic limb (unfatigued limb) will be minimal. Rather than increasing the Fz1 component (paretic/unfatigued limb) as was hypothesized, participants in the stroke group increased the Fz2 component.

For the control group, since there are no physiological changes (ie paresis due to stroke, injury or arthritis (appendix A)) to either lower limb, postural reweighting towards the fatigued limb must be explained in a different light. This may also be applicable to the stroke group. It has been well documented that exhausting activities deteriorate sensory proprioception and decrease the muscular system efficiency. (Lepers et al. 1997; Nagy et al, 2004). The reduction in proprioception alters the sensation of what participants feel is a “50-50(percentage)” weight distribution in favour of the fatigued leg (Fz1). Reweighting onto the fatigued leg may occur to compensate for the decrease in proprioception following fatigue. This could be done to increase sensory information from the fatigued leg such as seen with active joint repositioning which is more accurate than passive joint repositioning (Friemert, et al 2006). This attempt to increase sensory information from the fatigue leg is done in combination with exploratory movements of the non-fatigued leg to regain postural stability.

Therefore, postural stability was significantly altered in that the participants began to sway faster in the AP direction and began to place a higher percentage of body weight on the fatigued leg. However, this was not different between the two groups.

Clinical Relevance

During postural instability during day to day activities, whether it be due to internal factors (ie. Fatigue) or external perturbations (ie movements of the ground surface as on a bus) (Horak et al, 1997), a neuromuscular response must occur to prevent

falls. Numerous clinical populations have difficulty initiating (Grimbergen et al, 2004) or difficulty exhibiting an appropriate response to the instability. Without adequate responses, falls become inevitable.

Although falls are also experienced in 'healthy' control group populations, overall, a healthy older adult exhibits less falls than clinical populations. Gillespie et al (2003) found through a systematic review that approximately 30% of older persons experience a fall per year while Forster & Young (1995) found that 73% of elderly stroke patients fell within six months of hospital discharge. Therefore, we can consider the postural responses of a control group more adequate to maintain balance while clearly noting that a stroke patient population has postural control deficiencies.

If the control group portrays adequate postural responses, then with regards to this current thesis, to maintain stable bi-pedal posture during quadriceps muscle fatigue, the neuromuscular response should entail an increase in weight bearing on the fatigued leg, increase in speed of movements in the AP direction and potentially an increase in movement area under the non-fatigued leg. All these adaptations can be considered an appropriate response necessary to prevent a fall.

Since there were no significant group differences, it can be stated that the stroke group responded to fatigue in the same way as control subjects. This lack of significance can be viewed in two distinct ways. First, the lack of significance could illustrate the ability of individuals after stroke to compensate using the non-paretic limb and that they retain the ability to respond to a fatigued state appropriately. However, the lack of significance could also be viewed as hazardous due to the impaired ability to control posture (lower BERG scores) after a stroke, and therefore adaptations should be made to compensate for such.

The stroke group failed to make certain adaptations to the quadriceps fatigue. Although there is an increase in weight bearing on the fatigued leg as well as an increase in velocity for AP movements, the failure to use the paretic limb as an active agent in postural control induces overall postural instability. This is noted in group differences for area indicating that stroke patients cover a greater area following muscle fatigue. This greater area can be considered a precursor to a fall as the COP has greater chance of exceeding the base of support.

Therefore due to the paretic nature of the affected limb, stroke patients are unable to elicit a 'normal' postural strategy to maintain balance as efficiently as a healthy age matched control group. This inability to control posture during a state of muscle fatigue may be a factor in falls following stroke.

Limitations & Recommendations

This study can be considered to have several limitations that could be addressed with further research within this protocol and within similar consequent studies.

The limited fatigue effect may be due to the transfer time for both groups. Due to increased blood flow to a fatigued muscle, recovery happens very quickly. Therefore, the longer transfer time will reduce potential postural instability due to fatigue. Since there was still a significant fatigue effect, lowering the transfer time and therefore reducing recovery may create greater postural instability with COP parameters.

Multiple values in the ANOVA approached significant values illustrating a trend. For example, group differences were noted in Fz ($p=0.172$) and ML velocity ($p=.187$). These values could have been significant if more participants were recruited. Power calculations suggested $n=12$ for each group to find group differences. Therefore, limited

power can explain the lack of certain group differences. However, recruitment of outpatients that met appendix A criteria and were willing to participate, proved to be difficult and explain why we decided to end data collection with the number of subjects included in this thesis.

Conclusions

In conclusion, we must reject some of the hypotheses presented in chapter II. It was hypothesized that muscle fatigue of the non-paretic limb would result in a shift of body weight distribution (increase in Fz component from pre- to post-fatigue) towards the paretic limb. Although postural reweighting was significant, it was in favour of the non-paretic or fatigued limb. It was also hypothesized that there would be greater postural sway for individuals post-stroke. This hypothesis can be accepted in that postural sway was greater under the non-paretic limb as well as when compared to the dominant limb of healthy control participants. However, following fatigue, participants in both groups had a higher velocity in the AP direction. This leads us to reject our final hypothesis that fatigue of the dominant leg of healthy controls will not have any effect on COP measures due to the increased velocity in the AP direction as well as the Fz shift towards the fatigued leg.

Therefore, it can be stated that sustaining an isometric knee extension of the non-paretic limb induces changes in postural control for individuals after stroke, but that these changes do not markedly differ from those of healthy aged matched controls. Further research and analysis is warranted to fully understand the complexity of the interaction of muscle fatigue and posture control for individuals after stroke.

APPENDICES

ID	Age	Gender	BBS (/56)	BMI
CG01	70	F	56	19.8
CG02	71	F	56	31.2
CG03	77	F	52	21.8
CG04	62	F	55	32.7
CG05	59	F	55	19.2
CG06	58	M	55	24.9
CG07	71	M	56	30.5
CG08	79	M	56	25.1
MEAN	68 ± 8	3M/5F	55/56 ±1	24.9 ± 5.3

Table 1: Demographics for the healthy control group.

BBS=BERG Balance Score, BMI=Body Mass Index.

ID	Age (years)	Gender	BBS (/56)	TPS (months)	BMI (kg/cm ²)	Type of Stroke
SG01	82	M	45	22	30.8	Right ACA/MCA frontal lobe ischemia
SG02	69	M	52	3	23.2	Right MCA ischemia
SG03	68	F	39	39	24.6	Right ACA/MCA
SG04	73	M	41	60	31.4	Right Lacunar infarct
SG05	59	M	38	11	23.0	Left MCA ischemia
SG06	73	M	47	5	27.6	Right MCA ischemia
SG07	47	M	53	36	22.9	Left temporal lobe ischemia
SG08	75	M	46	3	21.3	Left watershed ACA/MCA ischemia
MEAN	68 ± 11	7M/1F	45/56 ±6	22 ± 21	25.6 ±3.8	

Table 2: Demographics for the stroke group.

BBS=BERG Balance Score, BMI=Body Mass Index, TPS=Time Post Stroke (months), ACA = Anterior Cerebral Artery, MCA=Middle Cerebral Artery.

Appendix A:

List of Exclusion Criteria (Greig, C. 1994)

Have you had a fall in the past year?	Yes	No
Do you have any of the following medical conditions?:		
Any cardiovascular problems (eg. Infarct, aneurysm, angina) or pulmonary problems (eg. embolus).	Yes	No
If yes, is it one of the following:		
A myocardial infarction within the previous 2 years?		
A thrombophlebitis within the previous 2 years?		
A pulmonary embolus within the previous 2 years?		
A cardiac illness such as symptoms of aortic stenosis, acute pericarditis, acute myocarditis, aneurysm, severe agina, clinically significant valvular disease, uncontrolled dysrhythmia, claudication within the previous 10 years?	Yes	No
History of cerebrovascular disease.	Yes	No
Neurological disease (eg. Alzheimer, Parkinson's, Huntington's)	Yes	No
Acute feverish illness within the previous 3 months	Yes	No
Severe airflow obstruction	Yes	No
Uncontrolled metabolic disease (eg. diabetes, thyroid disease)	Yes	No
Major systemic active disease such as cancer, severe rheumatoid arthritis within the previous 2 years	Yes	No
Significant emotional distress, psychotic illness or depression within the previous 2 years	Yes	No
Lower limb problems (eg. arthritis, injuries)	Yes	No
If yes, is it one of the following:		
Lower limb arthritis, classified by inability to perform maximal contractions	Yes	No
Fracture sustained within the previous 2 years		
Non-arthroscopic lower limb joint surgery within the previous 2 years		
Any reason for a loss of mobility for greater than 1 week in the previous 2 months or greater than 2 weeks in the previous 6 months?	Yes	No
High resting blood pressure (systolic > 200 or diastolic > 100)	Yes	No
Taking medications affecting heart rate (beta-blockers or digoxin).	Yes	No
On daily analgesia.	Yes	No
Loss of sensation (peripheral neuropathy).	Yes	No
Severe back pain	Yes	No

Notes:

Appendix B:

INFORMATION LETTER AND CONSENT FORM

THE EFFECT OF MUSCLE FATIGUE OF THE NON-PARETIC LIMB ON POSTURAL CONTROL OF STROKE PATIENTS.

INVESTIGATORS:

Dan McEwen (BSc. Hon HK)

[REDACTED]

Martin Bilodeau, Ph. D., PT,

[REDACTED]

Invitation to participate: I am invited to participate in the study cited above conducted by the researchers cited in the section *investigators*. I am a) stroke patient at least 3 months post-stroke or b) healthy age and gender matched adult.

Purpose of this study: The purpose of this research is to assess and compare the effects of muscular fatigue of the non-paretic limb on balance.

Participation: If I agree to participate, my involvement will consist of 1 experimental visit to the Movement and Aging Research Laboratory at the Élisabeth Bruyère Research Institute. The visit will last approximately one hour in duration. The experimental session will proceed as follows:

- 1) First, my balance will be assessed by using the clinical tool of the BERG Balance Scale. For stroke patients only, my level of hemineglect will be assessed using various clinical activities.
- 2) Secondly, my balance in a comfortable two legged stance will be tested. I will be asked to stand as still as possible for 4 bouts of 30 seconds.
- 3) After this, my maximal force will be evaluated using a device designed to measure muscular strength and for rehabilitation exercises. I will be asked to sit with my non-paretic limb strapped to avoid unwanted movements. Two surface electrodes used for stimulation will be placed at the top and bottom of my quadriceps. I will then have the opportunity to do a warm up for the quadriceps.
- 4) After sufficient warm up, my leg will then be held constant at 70 degrees of knee flexion. Then my maximal strength of that leg will be evaluated. I will be asked to perform 3 maximal contractions. To assess my ability to completely contract my muscle, supra-maximal electrical stimulation will be delivered once during and once immediately after only the 2nd and 3rd maximal contractions.

- 5) In the same position as my maximal contractions, my quadriceps will be fatigued by keeping a contraction at 50% of my maximum by matching a line on a small screen. The fatigue task will end when my force drops below the line for 3 consecutive seconds. Electrical stimulation will be given at the start of the fatigue task, immediately before the task ends as well as immediately after.
- 6) Once a fatigued state is reached, I will be unstrapped and safely transported to the force platforms and will be asked to execute task 2.

Risks: I understand that the possible risks are associated with participation in this research project include:

1) Minor irritation of the skin at the site of the surface electrodes is possible but rare due to the use of non-irritating, non-abrasive nature of the pad. If present, the irritation should disappear in a few hours. Also, some discomfort may happen while removing the surface electrodes (like removing a band-aid).

2) Muscle Soreness associated with performing maximal contractions with my leg may be experienced after the experimental sessions. However, a warm-up period before testing begins will reduce muscle soreness. Also, muscle stimulation during contractions and at rest may be uncomfortable for some participants and request to stop the study will be respected at any time.

3) The loss of balance during standing trials is possible but any fall will be prevented with the use of a climbing harness and rope system anchored to structural beams above. A research assistant will always be in close proximity to provide additional support when necessary.

Benefits: I understand that I may not benefit directly from participation in this study. However, we hope that through this project, others may benefit from the increased knowledge of factors affecting balance, postural control and falls.

Cost: I will not have any costs for participating in this research study.

Confidentiality and anonymity: I understand that the investigators will keep my participation in this research study confidential to the extent permitted by law. My identity will be kept confidential and protected by using a subject code instead of personal information. Any documents with my personal information will be stored in a locked cabinet in Dr. Bilodeau's office at the Élisabeth Bruyère Research Institute.

Data Conservation: I understand that the results from this study (including mine), may be presented at scientific conferences and submitted for publication in a scientific journal. When a report is written about a study, the results will be described in a summary format as to not reveal individual participant information. I understand that the data will be destroyed after 5 years. I also understand that a debriefing session will be offered to me once the results will be accepted for publication.

Voluntary participation: I understand that taking part in this research study is completely voluntary. I may choose not to take part at all. If I decide to be in this study, I may stop participation at any time without question.

Acceptance: I _____ (*name of participant*) accept to participate in this research conducted by _____

Questions: I am encouraged to ask questions at any time during the process. If I have any questions, I can contact Dan McEwen at _____

If I have any questions concerning the rights of participants or I have ethical concerns about this study, I understand that I can contact _____ or I can contact the Protocol Officer for Ethics in Research, University of Ottawa, _____

Signature of participant

____ / ____ / ____
yyyy mm dd

Signature of witness

____ / ____ / ____
yyyy mm dd

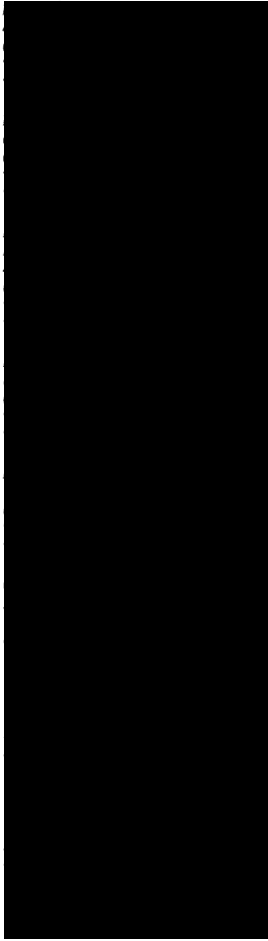
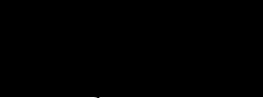
Appendix C: Ethics Approval

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Bruyère Is Continuing Care.*

March 1, 2010



RE: The effect of muscle fatigue of the non-paretic limb on postural control of stroke patients.
(Bruyère REB Protocol # M16-10-003)

Final Approval

Dear Mr. McEwen,

Thank you for your response to our conditional approval, dated February 4, 2010. The revised documents were received on February 23, 2010 and have been found to satisfy all of the ethical requirements.

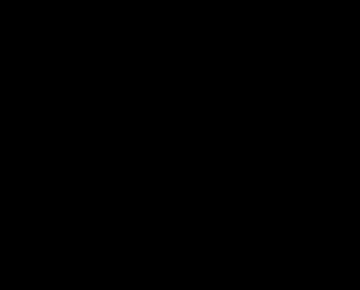
We are pleased to give ethical approval for one year (March 1, 2010 to March 1, 2011) to proceed with the above titled study.

Please be advised that any changes to the study must be reported to the REB and any complaints from the participants must be reported to the REB.

Written notification of the termination of the study is required by the end of the approved year, as stated above.

We wish you the best of luck with this study.

Sincerely,



Affilié à / Affiliated with



uOttawa

Appendix D:

BERG Balance Scale

ID: _____ Date: _____

ITEM DESCRIPTION SCORE (0-4)

- Sitting to standing _____
- Standing unsupported _____
- Sitting unsupported _____
- Standing to sitting _____
- Transfers _____
- Standing with eyes closed _____
- Standing with feet together _____
- Reaching forward with outstretched arm _____
- Retrieving object from floor _____
- Turning to look behind _____
- Turning 360 degrees _____
- Placing alternate foot on stool _____
- Standing with one foot in front _____
- Standing on one foot _____
- Total _____

BERG Balance Scale

SITTING TO STANDING

INSTRUCTIONS: Please stand up. Try not to use your hand for support.

- () 4 able to stand without using hands and stabilize independently
- () 3 able to stand independently using hands
- () 2 able to stand using hands after several tries
- () 1 needs minimal aid to stand or stabilize
- () 0 needs moderate or maximal assist to stand

STANDING UNSUPPORTED

INSTRUCTIONS: Please stand for two minutes without holding on.

- () 4 able to stand safely for 2 minutes
- () 3 able to stand 2 minutes with supervision
- () 2 able to stand 30 seconds unsupported
- () 1 needs several tries to stand 30 seconds unsupported
- () 0 unable to stand 30 seconds unsupported

If a subject is able to stand 2 minutes unsupported, score full points for sitting unsupported. Proceed to item #4.

SITTING WITH BACK UNSUPPORTED BUT FEET SUPPORTED ON FLOOR OR ON A STOOL

INSTRUCTIONS: Please sit with arms folded for 2 minutes.

- () 4 able to sit safely and securely for 2 minutes
- () 3 able to sit 2 minutes under supervision

- () 2 able to sit 30 seconds
- () 1 able to sit 10 seconds
- () 0 unable to sit without support 10 seconds

STANDING TO SITTING

INSTRUCTIONS: Please sit down.

- () 4 sits safely with minimal use of hands
- () 3 controls descent by using hands
- () 2 uses back of legs against chair to control descent
- () 1 sits independently but has uncontrolled descent
- () 0 needs assist to sit

TRANSFERS

INSTRUCTIONS: Arrange chair(s) for pivot transfer. Ask subject to transfer one way toward a seat with armrests and one way toward a seat without armrests. You may use two chairs (one with and one without armrests) or a bed and a chair.

- () 4 able to transfer safely with minor use of hands
- () 3 able to transfer safely definite need of hands
- () 2 able to transfer with verbal cuing and/or supervision
- () 1 needs one person to assist
- () 0 needs two people to assist or supervise to be safe

STANDING UNSUPPORTED WITH EYES CLOSED

INSTRUCTIONS: Please close your eyes and stand still for 10 seconds.

- () 4 able to stand 10 seconds safely
- () 3 able to stand 10 seconds with supervision
- () 2 able to stand 3 seconds
- () 1 unable to keep eyes closed 3 seconds but stays safely
- () 0 needs help to keep from falling

STANDING UNSUPPORTED WITH FEET TOGETHER

INSTRUCTIONS: Place your feet together and stand without holding on.

- () 4 able to place feet together independently and stand 1 minute safely
- () 3 able to place feet together independently and stand 1 minute with supervision
- () 2 able to place feet together independently but unable to hold for 30 seconds
- () 1 needs help to attain position but able to stand 15 seconds feet together
- () 0 needs help to attain position and unable to hold for 15 seconds

REACHING FORWARD WITH OUTSTRETCHED ARM WHILE STANDING

INSTRUCTIONS: Lift arm to 90 degrees. Stretch out your fingers and reach forward as far as you can. (Examiner places a ruler at the end of fingertips when arm is at 90 degrees. Fingers should not touch the ruler while reaching forward. The recorded measure is the distance forward that the fingers reach while the subject is in the most forward lean position. When possible, ask subject to use both arms when reaching to avoid rotation of the trunk.)

- () 4 can reach forward confidently 25 cm (10 inches)
- () 3 can reach forward 12 cm (5 inches)

- 2 can reach forward 5 cm (2 inches)
- 1 reaches forward but needs supervision
- 0 loses balance while trying/requires external support

PICK UP OBJECT FROM THE FLOOR FROM A STANDING POSITION

INSTRUCTIONS: Pick up the shoe/slipper, which is place in front of your feet.

- 4 able to pick up slipper safely and easily
- 3 able to pick up slipper but needs supervision
- 2 unable to pick up but reaches 2-5 cm(1-2 inches) from slipper and keeps balance independently
- 1 unable to pick up and needs supervision while trying
- 0 unable to try/needs assist to keep from losing balance or falling

TURNING TO LOOK BEHIND OVER LEFT AND RIGHT SHOULDERS WHILE STANDING

INSTRUCTIONS: Turn to look directly behind you over toward the left shoulder. Repeat to the right. Examiner may pick an object to look at directly behind the subject to encourage a better twist turn.

- 4 looks behind from both sides and weight shifts well
- 3 looks behind one side only other side shows less weight shift
- 2 turns sideways only but maintains balance
- 1 needs supervision when turning
- 0 needs assist to keep from losing balance or falling

TURN 360 DEGREES

INSTRUCTIONS: Turn completely around in a full circle. Pause. Then turn a full circle in the other direction.

- 4 able to turn 360 degrees safely in 4 seconds or less
- 3 able to turn 360 degrees safely one side only 4 seconds or less
- 2 able to turn 360 degrees safely but slowly
- 1 needs close supervision or verbal cuing
- 0 needs assistance while turning

PLACE ALTERNATE FOOT ON STEP OR STOOL WHILE STANDING UNSUPPORTED

INSTRUCTIONS: Place each foot alternately on the step/stool. Continue until each foot has touch the step/stool four times.

- 4 able to stand independently and safely and complete 8 steps in 20 seconds
- 3 able to stand independently and complete 8 steps in > 20 seconds
- 2 able to complete 4 steps without aid with supervision
- 1 able to complete > 2 steps needs minimal assist
- 0 needs assistance to keep from falling/unable to try

STANDING UNSUPPORTED ONE FOOT IN FRONT

INSTRUCTIONS: (DEMONSTRATE TO SUBJECT) Place one foot directly in front of the other. If you feel that you cannot place your foot directly in front, try to step far

enough ahead that the heel of your forward foot is ahead of the toes of the other foot. (To score 3 points, the length of the step should exceed the length of the other foot and the width of the stance should approximate the subject's normal stride width.)

- () 4 able to place foot tandem independently and hold 30 seconds
- () 3 able to place foot ahead independently and hold 30 seconds
- () 2 able to take small step independently and hold 30 seconds
- () 1 needs help to step but can hold 15 seconds
- () 0 loses balance while stepping or standing

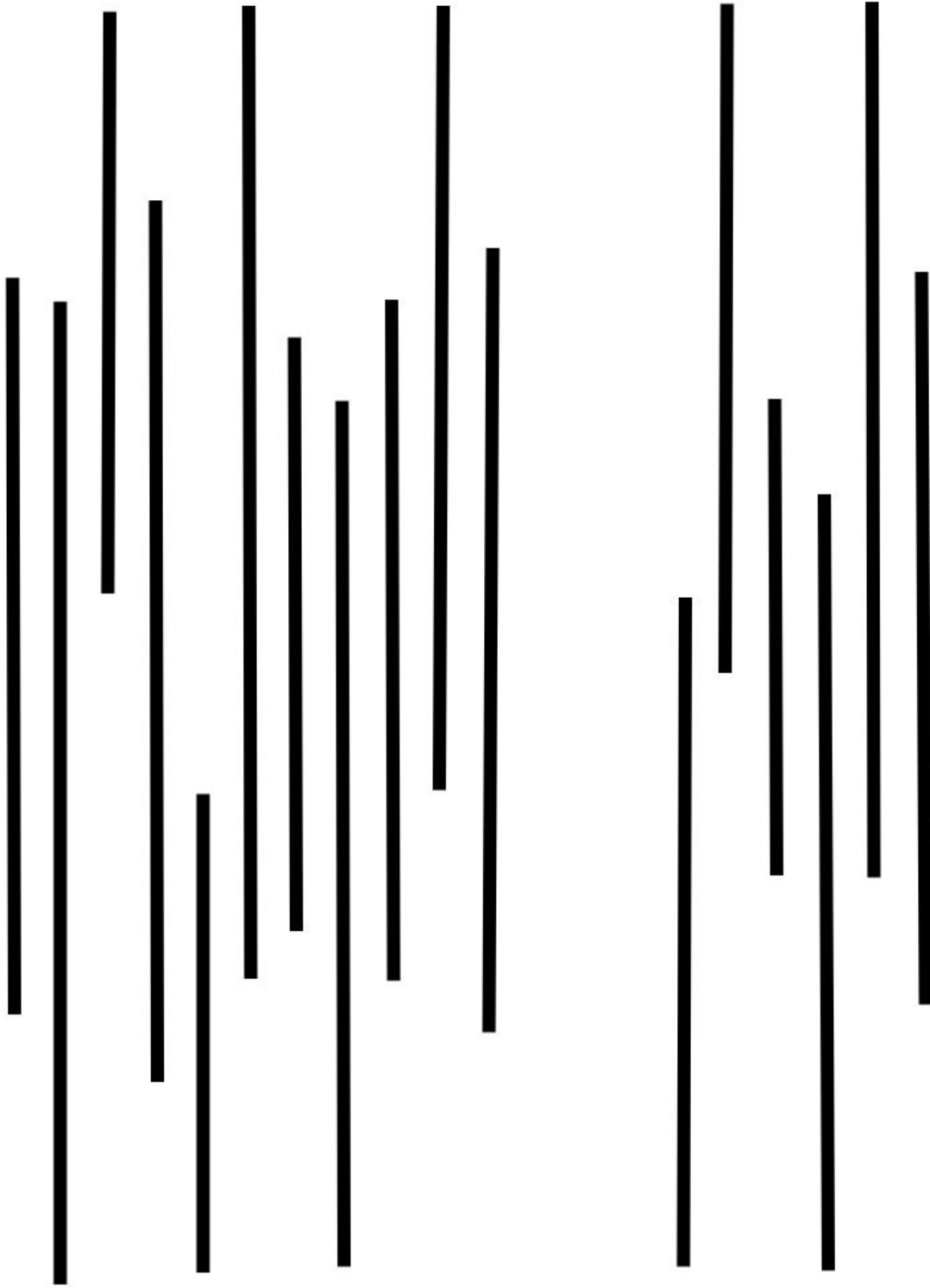
STANDING ON ONE LEG

INSTRUCTIONS: Stand on one leg as long as you can without holding on.

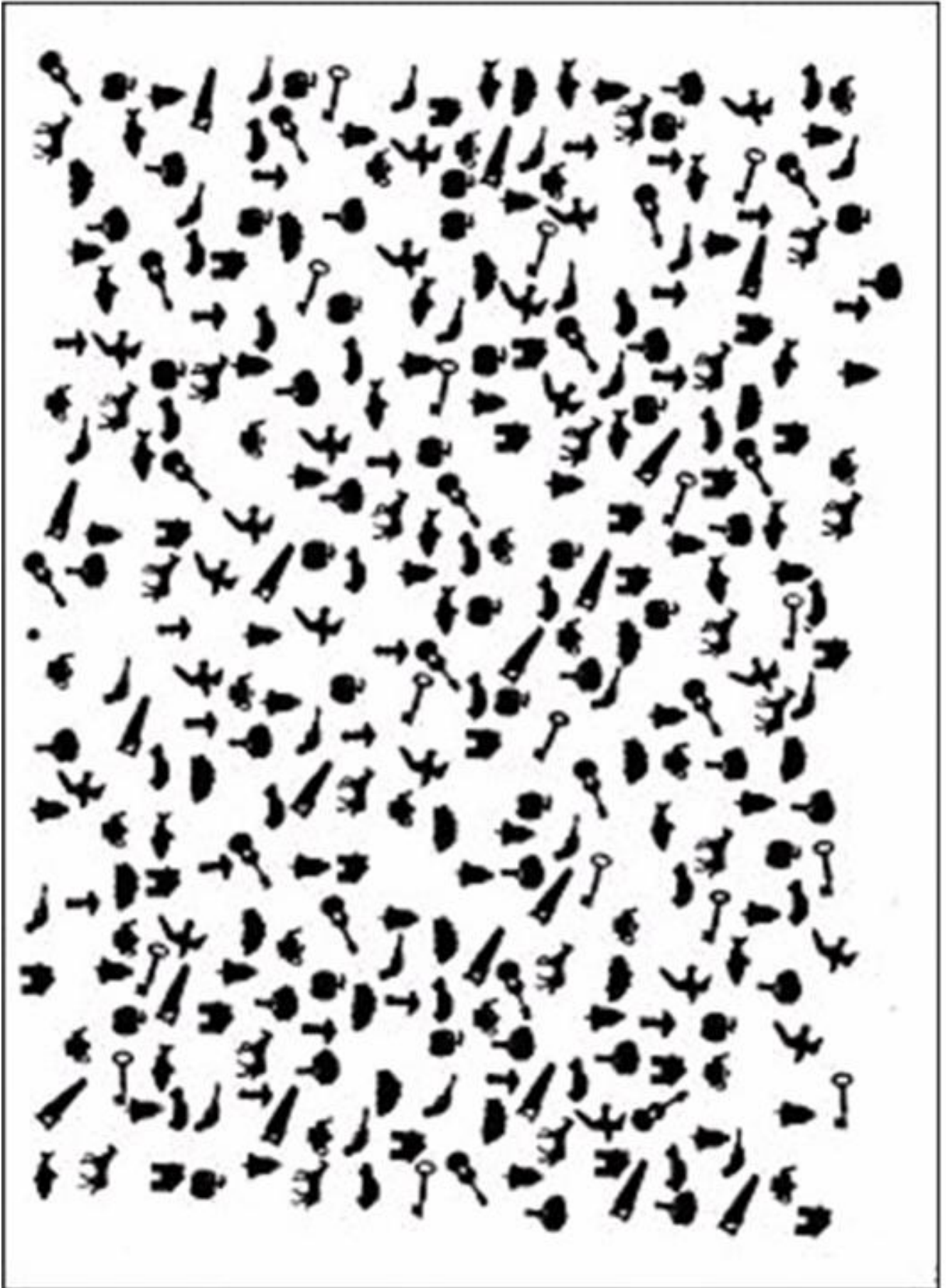
- () 4 able to lift leg independently and hold > 10 seconds
- () 3 able to lift leg independently and hold 5-10 seconds
- () 2 able to lift leg independently and hold \geq 3 seconds
- () 1 tries to lift leg unable to hold 3 seconds but remains standing independently.
- () 0 unable to try or needs assist to prevent fall

() **TOTAL SCORE (Maximum = 56)**

Appendix E



Appendix F



Appendix G



Patient: SG06

Results of the Baking Tray Task for two patients. No signs of neglect but these are potential signs of a cognitive impairment.



Patient SG08

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