THE ASSOCIATION BETWEEN ANKLE JOINT FUNCTION AND KNEE HYPEREXTENSION DURING THE STANCE PHASE OF GAIT IN HEMIPARETIC STROKE PATIENTS: A PILOT STUDY

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A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Physiotherapy

Johannesburg, (2021)

Declaration

I, Catherine Cawood, declare that this research report is my own, unaided work. It is being submitted for the Master of Science in Physiotherapy at University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

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20th day of June 2022 in Johannesburg

Publications arising from this Study

Cawood C & Mashola M.K. 2022. The association between ankle joint function and knee hyperextension during the stance phase of gait in hemiparetic stroke patients: a pilot study. Manuscript in development.

Abstract

Knee hyperextension is common following stroke which clinicians hypothesise could be due to changes in muscle strength, muscle tone, and joint range of motion on the hemiparetic side. There is no clear consensus as to the cause of knee hyperextension during stance phase of gait. This pilot study's aim is to determine the feasibility of the methods in order to investigate the association between ankle joint function and hyperextension of the knee in hemiparetic stroke patients during stance phase of gait in a larger study.

This was a pilot study of a cross-sectional observational study design and assessed bilateral ankle muscle strength using a handheld dynamometer, joint range of motion (ROM) using a digital inclinometer, and muscle tone using the Modified Tardieu Scale. The knee angles of the hemiparetic leg during the three sub-phases of stance phase of gait (initial contact, loading response, and midstance) were assessed using the Kinovea movement analysis software. The data was analysed using the Statistical Package for the Social Sciences v27 with significance level set at $p < 0.05$.

The researcher included 12 participants and found positive associations between the tibialis anterior muscle tone and the hemiparetic knee angles during heel strike, terminal stance and pre-swing phases ($p < 0.05$, $p < 0.01$ and $p < 0.01$ respectively).

The results of the data analysis showed that there was no association between muscle strength and range of motion of the ankle, and knee hyperextension during stance phase of gait. Decreased tibialis muscle tone was seen in participants who presented with increased knee flexion during stance phase and does not seem to not play a role in knee hyperextension. But conclusions cannot be drawn from these results based on the small sample size and the heterogeneity of the participants. The researcher has shown feasibility of the methods described in this study for a larger study to be conducted with the recommendations considered.

Acknowledgements

I would like to thank the following people and organisations for their continued assistance and support during this study. Without their time and expertise this study would not have been possible. I truly appreciate all that you have done for me:

Ms Kholofelo Mashola, my supervisor, for her willingness to dedicate so much time to guiding my research and for her unending support and enthusiasm which made the journey of masters so enjoyable.

Jeanine Blumenau for her assistance with the statistical analysis of this research report.

The South African Society of Physiotherapy for funding the research.

The Physiotherapy Department at the University of the Witwatersrand for the loan of the equipment needed for my research.

All the staff members at the study sites for allowing me to conduct the research at their facilities, and for their willingness to assist me.

All the participants, for being so enthusiastic and willing to be part of my research study.

My family and friends for believing in me and providing support and encouragement throughout this process.

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List of Abbreviations

- **ACE2** Angiotensin-converting enzyme II
- **ADLs** Activities of daily living
- **DF** Dorsiflexion
- **MAS** Modified Ashworth Scale
- **MTS** Modified Tardieu Scale
- **PF** Plantarflexion
- **ROM** Range of motion
- **WHO** World Health Organisation

Chapter 1 Introduction

1.1 Background

Restoration of walking is one of the main physiotherapy goals for many patients following a stroke, in order to be more functional in daily life and to allow for greater community participation (Cooper et al., 2012). Sixty to 80% of stroke survivors can walk independently by six months following a stroke (Veerbeek et al., 2011). However, stroke survivors are often left with impairments such as changes in motor control, joint range of motion (ROM), muscle tone, sensation, and muscle strength (Lucareli and Greve, 2008). These functional limitations result in reduced standing balance, increased energy expenditure, joint deformity, pain, and muscle wasting (Cooper et al., 2012), which all then impact on the individual's gait.

Gait comprises of a full cycle which starts as one foot strikes the ground and ends when it strikes the ground again and is subdivided into stance and swing phases (Silva and Stergiou, 2020; Kharb et al., 2011). The stance phase of gait can be described as the moment when the foot lands on the ground and includes the 'weight acceptance' phase and the 'single limb support' phase (Richardson et al., 2012). These two phases can be further classified into 'initial contact' and 'loading response' in the weight acceptance phase, and 'midstance', 'terminal stance' and 'pre-swing' in the single limb support phase. Individuals with stroke usually present with a shorter stance phase and increased swing phase on the hemiparetic side due to changes in muscle strength and coordination, muscle tone, joint range of motion, altered sensation, and poor balance control (Li et al., 2018). These changes such as decreased muscle strength lead to decreased weight bearing through the affected leg, which means they spend a shorter time in stance phase on the affected side, but it often takes longer for the leg to swing through in swing phase (Li et al., 2018).

Knee hyperextension can be described as extension of the hemiparetic knee past 'anatomical zero' (Cooper et al., 2012). Forty to 60% of the stroke population present with hyperextension of the knee while walking (Cooper et al., 2012). In normal gait, throughout the single limb support phase, the knee remains extended, although there is a small amount of knee flexion that occurs early in the stance phase (Balaban and Tok, 2014). In hemiparetic gait, knee hyperextension can occur during the heel strike/initial contact phase, loading response phase, and midstance phase (Richardson et al., 2012). Although there is no clear consensus as to the cause of hyperextension of the knee, there is evidence that the ankle joint plays a role in knee hyperextension in patients post stroke (An and Won, 2016). Increased muscle tone in the ankle plantarflexor muscles causes early contraction of the ankle plantarflexors at ‘initial contact’, pulling the tibia posteriorly while the femur travels forward, causing knee hyperextension (Sheffler and Chae, 2015). Spasticity in the ankle plantarflexors (and even shortening of the Achilles tendon) may result in changes in ankle ROM, causing knee hyperextension at initial contact due to a lack of an antagonist muscle force (Higginson et al., 2006). Reduced ankle ROM during stance phase of gait leads to the reduced ability to shift one’s centre of mass, leading to instability and balance deficits during gait. Decreased ankle ROM also leads to soft tissue changes of the connective tissue and muscles of the ankle causing biomechanical changes in gait (An and Won, 2016). In normal gait, maximal ankle dorsiflexion of ten degrees is achieved at midstance phase of gait, and terminal stance phase (Ota et al., 2014). However, decreased dorsiflexion ROM, due to poor tibialis anterior muscle strength, or increased plantarflexion muscle tone, hinders the forward translation of the tibia over the foot, which leads to compensation at the knee and altered spatiotemporal parameters such as decreased stride length, step length, cadence, and walking speed (Ota et al., 2014). Cooper et al (2012) suggested that tibialis anterior muscle weakness may also contribute to knee hyperextension during stance phase of gait, as the ankle dorsiflexor muscles are active in loading response and midstance phases of gait to control foot descent to the floor and the movement of the tibia over the foot. Less than eight degrees of ankle dorsiflexion during stance phase leads to changes in knee biomechanics and gait parameters such as “toe walking” in stance phase and reduced step length (Ota et al., 2014).

Muscle weakness of the quadricep, hamstring, and both ankle dorsiflexor and plantarflexor muscles of the hemiparetic lower limb has been shown to have an impact on the position of the knee during stance phase (Sheffler and Chae, 2015; An and Won, 2016; Cooper et al., 2012). Weakness of the quadricep muscles leads to reduced weight bearing ability (Cooper et al., 2012) while weakness of the hamstring muscle has an influence on knee hyperextension, especially if there is spasticity in the quadricep muscle of the hemiparetic lower limb (Springer et al., 2013). The gastrocnemius and hamstring muscles are thought to work in tandem, during the stance phase of walking, to limit rapid hyperextension of the knee, but the exact action of the gastrocnemius and hamstring muscles in stance phase of gait is not well demonstrated in literature (Springer et al., 2013; and Sheffler and Chae, 2015).

During stance phase of gait, knee hyperextension can allow individuals with stroke a certain amount of stability and provide a mechanism to control their affected lower limb, as it allows the knee to lock into a stable position using the form closure of the joint (bony, capsular, and ligamentous structures) and provide a more stable lower limb to weight bear through during stance phase. However, there is a potential for injury to the posterior capsular and ligamentous structures which may lead to pain, ligament laxity, and bony deformity (Richardson et al., 2012; Cooper et al., 2012).

1.2 Problem Statement

During the stance phase of gait, knee hyperextension is common, both in acute and chronic patients with stroke. There is a current lack of consensus as to the cause of hyperextension of the knee in stroke patients during gait (stance phase) (Cooper et al., 2012), despite the high rate of ambulating stroke patients presenting with knee hyperextension during gait. Literature has reported a variety of possible factors that may cause knee hyperextension – changes in muscle strength, muscle tone, and joint range of motion of the lower limb on the hemiparetic side, however, it is not clear which of these factors affecting ankle joint function has the greatest impact on knee hyperextension. The knee plays a big role during stance phase of gait including deceleration of the limb and supporting one’s body weight (Shamaei and Dollar, 2011). The goal for physiotherapy is to restore an efficient gait, where the patient is able to ambulate independently and safely. To do this, the physiotherapist must establish the causes of the patient’s altered gait pattern in order to deliver the most effective and appropriate therapy. Hyperextension of the knee needs to be addressed during gait therapy as the repeated abnormal hyperextension of the knee may cause injury to the posterior structures of the knee causing pain, ligamentous damage, and bony changes (Richardson et al., 2012; Cooper et al., 2012). Although there is no clear consensus in literature currently, there is evidence to suggest that the ankle joint plays a role in knee hyperextension in ambulating stroke patients. It is for this reason that is essential to determine how the ankle joint plays a role in knee hyperextension in people with stroke.

1.3 Aims and Objectives

1.3.1 Aim of the Study

This pilot study's aim is to determine the feasibility of the methods for a larger study to investigate the association between ankle joint function and hyperextension of the knee in hemiparetic stroke patients during stance phase of gait.

1.3.2 Objectives of the Study

- To confirm the recruitment and consent procedures
- To confirm sample size calculation
- To confirm inclusion and exclusion criteria
- To test appropriateness of instruments
- To determine the feasibility of the study by:
    - Analysing the knee joint angles during the first three stance phases of gait (initial contact/heel strike, loading response, and midstance).
    - Analysing the association between tibialis anterior and gastrocnemius muscle strength for ankle dorsiflexion and plantarflexion, respectively; muscle tone of the muscles of the ankle joint (tibialis anterior for ankle dorsiflexion, and gastrocnemius for ankle plantarflexion); and joint range of motion of ankle dorsiflexion and plantarflexion assessed and hyperextension of the knee in the stance phase of gait.

1.4 Significance

Results from this study will determine the feasibility of conducting a larger study and those results may add to the existing body of research and may be used in further research into developing and modifying existing treatment approaches. A treatment protocol for knee hyperextension, in relation to ankle joint function, for patients with stroke can be designed to effectively reduce knee hyperextension. Prevention and management of knee hyperextension in the stroke population will help prevent and minimise the development of knee pain as well as risk of injury to the posterior capsular and ligamentous structures of the knee. By so doing, the need for expensive orthoses, aids and surgery may be reduced. Better understanding of the association of the factors affecting the ankle joint and knee hyperextension during gait in patients with stroke may lead to an improvement in targeted therapy techniques. Thus, leading to improvement in stroke survivors' outcomes in terms of walking speed, stride length, step length, and amount of support through hands needed. There is currently a dearth of literature on the association between ankle joint function and hyperextension of the knee in stroke patients during stance phase of gait, particularly in the South African population. This study will therefore provide research in a local population, as well as adding to existing research. The outline of this research report is seen in the figure below (figure 1.1).

1.5 Outline of this Research Report

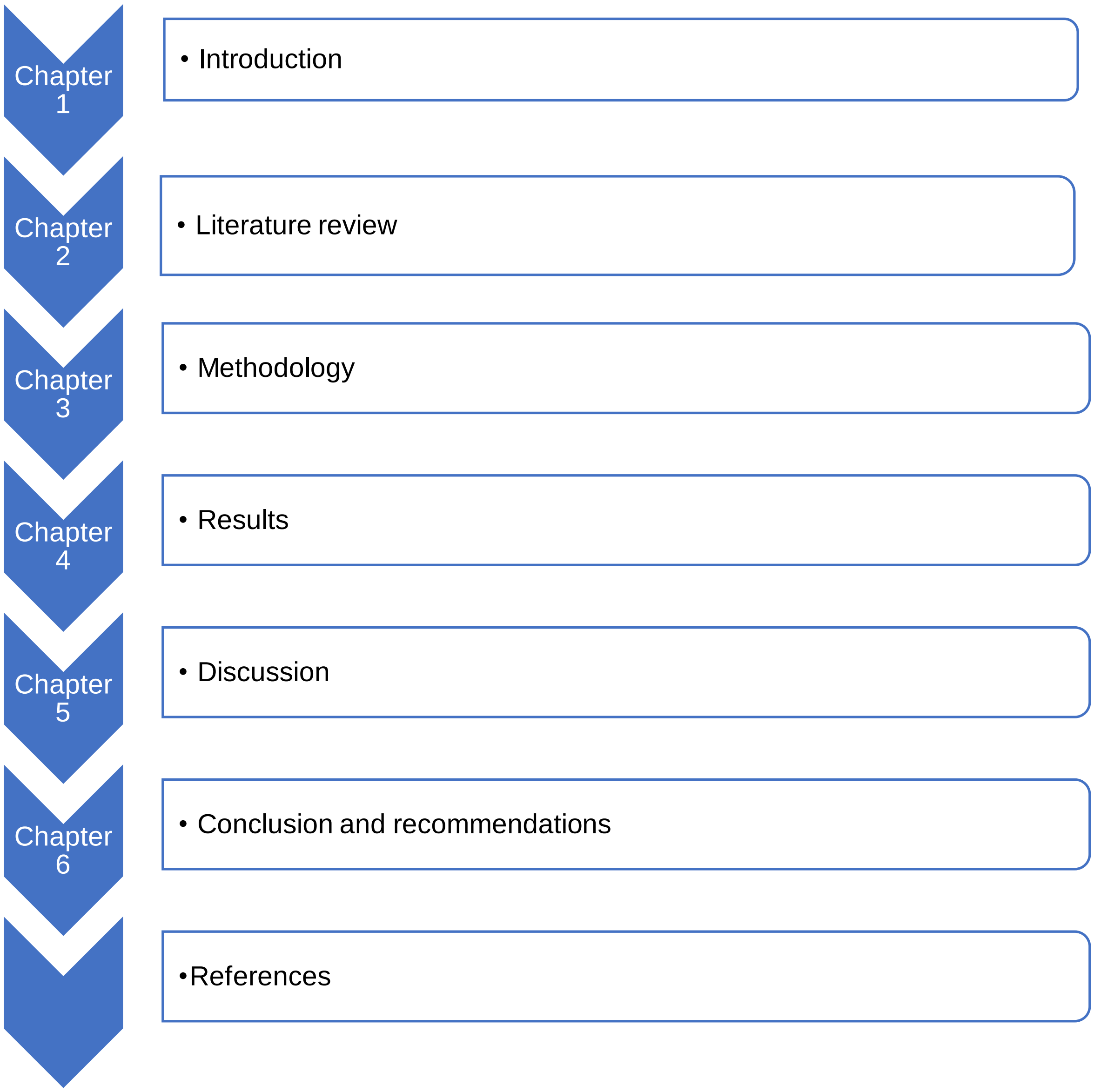

Figure 1.1. Outline of the research report

Chapter 2 Literature Review

2.1 Introduction

This chapter reviews the current available literature of knee hyperextension in hemiparetic people with stroke, and the contributing factors which may cause knee hyperextension in these patients. The chapter will be discussed in the following manner: background and epidemiology of stroke, gait dysfunction post stroke, and knee hyperextension during hemiparetic gait. Evidence was sourced from online literature databases including Google Scholar, PubMed, Science Direct and CINAHL. The search included English articles published between 2010 and February 2022. Keywords used in the search were stroke, knee hyperextension, gait, muscle strength, ankle, range of motion, muscle tone, and covid-19.

2.2 Stroke

2.2.1 Background and epidemiology

A stroke or cerebrovascular accident (CVA) is defined as “the damaging of, or death to brain cells that are starved of oxygen due to the sudden disruption of blood supply to certain areas of the brain” (Schellack et al., 2020: 26). African countries are suggested to be experiencing a change in the epidemiology of stroke as a result of lifestyle and socioeconomic changes, and an increase in non-communicable diseases is thus being seen (Matizirofa and Ranganai, 2020). Stroke results in permanent neurological damage, and, in South Africa, it is one of ten leading reasons for disability (Taylor and Ntusi, 2019) and the third highest cause of disability worldwide (Matizirofa and Ranganai, 2020).

Stroke is divided into two types, the first is ischaemic, which is when a blood vessel in the brain is blocked by an atherosclerotic plaque or blood clot and interrupts the blood flow. An ischaemic stroke can either be thrombotic (obstruction in a blood vessel locally in the brain) or embolic (a blood clot breaks off and travels from another area of the body and blocks blood flow in a blood vessel in the brain) and results in the cerebral parenchyma receiving inadequate blood flow (Stroke Center, 2021). Acute ischaemic strokes are most commonly caused by atherosclerosis, thrombosis, embolism, or systemic hypoperfusion (Taylor and Ntusi, 2019).

The second type is haemorrhagic stroke, caused by a weakened blood vessel, which ruptures in the brain. Haemorrhagic strokes cause haematoma formation and the build-up of pressure due to the rupture causes compression of the surrounding tissue and blood vessels. This results in decreased blood supply to the downstream tissue and can lead to infarction (Stroke Forum, 2021). Stroke severity and age influences functional outcome predictors in both stroke types, and, while on admission haemorrhagic stroke patients may present with a poor clinical and functional status compared to ischaemic stroke patients, the two stroke types have the same trajectory of functional recovery and outcomes (Salvadori et al., 2021).

Underlying conditions of the blood vessels or heart such as hypertension and atherosclerosis are the primary causes of stroke (Stroke Center, 2021). These lead to dyslipidaemia/hyperlipidaemia, coronary artery disease, and heart disease (Stroke Center, 2021). Secondary causes of stroke include one or more underlying diseases, and non-modifiable and modifiable risk factors. Non-modifiable risk factors include age, history of stroke, gender, and heredity. With regards to age, the risk of stroke doubles for every decade over 55 years of age; a previous TIA is seen in 60% of individuals who suffer a stroke; and family history of stroke or TIA increases one's risk of a stroke (Taylor and Ntusi, 2019; Stroke Center, 2021). Modifiable risk factors include hypertension, cigarette smoking, diabetes, physical inactivity and obesity (Taylor and Ntusi, 2019). The most common risk factor in both ischaemic and haemorrhagic strokes is hypertension, and can be controlled through pharmacological intervention, exercise, and diet; cardiac conditions; uncontrolled diabetes mellitus causes increased risk of ischaemic stroke in a younger population (Schellack et al., 2020). Dyslipidaemia increases one's risk of stroke and is associated strongly with atherosclerosis (Schellack et al., 2020). Increased abdominal fat with a body mass index of more than $25kg/m^2$ increases the risk of a stroke, as well as heavy alcohol consumption. Compared to physically active individuals, individuals who exercise less than four times per week have a 20% increased risk of stroke after 5.7 years (Schellack et al., 2020).

Stroke is also the second leading cause of death, and worldwide, it is estimated that there will be 70 million survivors of stroke and 20 million deaths due to stroke annually by 2030 (Taylor and Ntusi, 2019). Annually, in South Africa, there are approximately 25 000 deaths due to stroke (Taylor and Ntusi, 2019). There is an increasing trend due to the South African population having a greater exposure to and developing stroke risk factors (Taylor and Ntusi, 2019; Owolabi et al., 2018; Matizirofa and Ranganai, 2020). Hypertension is the leading cause of stroke in Africa and South Africa is not exempt, with hypertension closely followed by tobacco use, obesity, hypercholesterolemia, low vegetable and fruit intake, physical inactivity, diabetes, and alcohol consumption (Taylor and Ntusi, 2019). Urbanisation can be blamed for the lifestyle changes linked to increased stroke risk and the risk of non-communicable diseases in general, and the rapid growth of our urban population has put pressure on our urban healthcare infrastructure (Matizirofa and Ranganai, 2020). Along with the rapid urbanisation and increasing incidence of non-communicable diseases, there is a trend of increasing stroke incidence in younger people from low- and middle-income countries as compared to the increasing trend of stroke in an aging population in high-income countries (Katan and Luft, 2018). Studies by Duff, Ntsiea and Mudzi (2014) and Statistics South Africa (2004), described the mean age of stroke survivors as 51 and 52.95 years, respectively, in South Africa. This is thought to be due to the exponential increase in non-communicable diseases in developing countries, with the existing burden of communicable diseases (HIV, malaria etc.), as well as multiple factors across one's lifespan such as early-life malnutrition, migration from rural to urban areas, air pollution, obesity, stress, and population growth (Akinyemi et al., 2021). Younger stroke survivors are severely impacted physically, mentally and emotionally, but also socially and economically. They are often breadwinners for their families and are not able to fulfil their previous social roles poststroke (Duff, Ntsiea and Mudzi, 2014).

HIV/AIDS affects individuals worldwide, but South Africa has a high prevalence of HIV/AIDS (19.0% [16.1 - 20.9]) (UNAIDS, 2021) which complicates stroke management, especially in younger South Africans. HIV/AIDS leads to an increase in the risk of both ischaemic and haemorrhagic stroke (Gutierrez et al., 2015). The mechanism is uncertain, however it is thought that the HI-virus may injure the arterial wall directly (Gutierrez et al., 2015), while Boehme et al., (2017) suggest that adverse metabolic effects from the antiretroviral medications may cause an increase in cardiovascular and cerebrovascular risk factors. The risk of stroke is higher in individuals who are more immunosuppressed with a low CD4+ T-cell count (<200 cells/mm^3) and a high viral load (Boehme et al., 2017).

In the absence of HIV/AIDS, men have shown to have a greater stroke incidence rate that is approximately 33% higher and stroke prevalence is 41% higher than in women (Appelros et al., 2009). Furthermore, below the age of 75 years, men have a higher incidence of stroke compared to women, and the reverse is seen over the age of 75 (Taylor and Ntusi, 2019). This is thought to be due to the following: 1) women tend to live for longer and are older at the time of stroke onset; 2) women with acute stroke are less likely to have lipid testing done and to receive intravenous alteplase treatment; 3) and post-stroke, women present with decreased functional outcomes, a lower quality of life, and higher rates of depression than men (Taylor and Ntusi, 2019; Reeves et al., 2008). However, some studies also suggest that younger women (≤ 55 years) have equal or higher risk of stroke than men, which is reversed at an older age with men having a higher risk up to the age of 75 years old (Boehme et al., 2017). This is thought to be because of the risks related to pregnancy and other hormonal factors, such as hormonal contraceptive use (Boehme et al., 2017; Thomas et al., 2021).

With regards to the stroke subtypes, ischaemic stroke occurs at a higher rate than haemorrhagic stroke (68% vs 32-38%) (Taylor and Ntusi, 2019; Salvadori et al., 2021). Studies have shown that haemorrhagic strokes have a higher incidence in lower socioeconomic countries, as there is a burden of disorders related to hypertension, which is a major cause of haemorrhagic stroke (Taylor and Ntusi, 2019; Boehme et al., 2017). As countries such as China (Beijing) move towards improved socioeconomic development, the incidence of haemorrhagic stroke decreases, while the incidence of ischaemic stroke increases (Boehme et al., 2017). The emergence of the global pandemic Sars-CoV-2 (also known as the coronavirus/covid-19), which has resulted in 404 million infections and over 5.7 million deaths (World Health Organisation (WHO), 2022), has also had an effect on people affected by stroke.

Primarily, the virus causes respiratory and cardiovascular complications, however, it has also shown to cause neurological complications such as stroke, seizures, anosmia, and hypogeusia (loss of taste and smell) adding to the mortality and morbidity (Bridwell et al., 2020; Hess et al., 2020). There are multiple factors which cause a stroke in covid-19 patients. These factors are mainly cardiovascular in nature, such as high blood pressure, dyslipidaemia, diabetes, congestive heart failure, and atrial fibrillation. The virus causes a widespread inflammatory response in the body and the coagulability of the blood increases (Yokota et al., 2021).

Stroke can have a negative influence on a person's daily life such as their mobility, are often left unable to return to work, and face social isolation due to physical and social barriers in their communities (Rhoda et al., 2011). With decreasing mortality among stroke survivors, there is a greater number of stroke survivors with residual activity limitations (Srivastava et al., 2010), with the prevalence of disability among stroke survivors between 36-71% (Yang, 2016). Functional impairments include physical (mobility, limb function, balance, pain, speech, sensation), cognitive (executive function, attention, perception, memory), and psychological (fatigue, depression) impairments, which all contribute to one's ability to perform activities of daily living (ADLs), mobility in homes and community, and participation including social roles and ability to return to work (Saunders et al., 2014). Mobility impairments such as gait is the focus of this research and will be discussed in more detail below.

2.3 Gait dysfunction poststroke

Gait, also known as walking, is a fundamental human movement and forms an integral part of our life, it allows us to perform ADLs, move through the world, and interact with others. Gait involves both the musculoskeletal and nervous systems, with the basic motor pattern for walking being generated at spinal cord level, with supraspinal input from various areas of the brain including the motor cortex, brainstem, and cerebellum (Verma et al., 2012). It is influenced by age, sociocultural factors such as whether an individual lives in an urban versus rural area, mood, and personality (Pirker and Katzenschlager, 2017). Restoration of walking is one of the main physiotherapy goals for many patients following a stroke, in order to be more functional in daily life and allow for greater community participation (Cooper et al., 2012).

Gait is described as a cyclic pattern and is defined as the sequence from when one foot reaches the ground and ends when that same foot reaches the ground again (Watkins, 2020). Gait is subdivided into two phases, swing and stance phase, where swing phase is the time in which the foot does not touch the ground and the weight of the body is carried through the contralateral leg. Swing phase is broken down into three phases: initial swing, mid-swing and terminal swing phase. Swing phase constitutes forty percent of the gait cycle, while stance phase is the remaining sixty percent (Watkins, 2020). The stance phase of gait can be described as the moment when the foot hits the ground and includes the 'weight acceptance' phase and the 'single limb support' phase (Richardson et al., 2012). These two sub-phases of stance can be further classified into ‘initial contact’ and ‘loading response’ in the weight acceptance phase, and ‘midstance’, ‘terminal stance’ and ‘pre-swing’ in the single limb support phase. A more descriptive breakdown of each phase of the gait cycle can be read at Appendix A.

Individuals with stroke usually present with a shorter stance phase and increased swing phase on the hemiparetic side and this is thought to be due to poor muscle coordination of the affected limb, mass flexor/extensor patterns, decreased muscle strength, reduced weight bearing on affected limb, and poor balance control (Li et al., 2018). During normal gait, throughout the single limb support phase, the knee remains extended, although there is a small amount of knee flexion that occurs early in the stance phase (Balaban and Tok, 2014). In hemiparetic gait, knee hyperextension can occur during the heel strike/initial contact phase, loading response phase, and midstance phase thus affecting gait symmetry together (Richardson et al., 2012).

2.4 Knee hyperextension during hemiparetic gait

Knee hyperextension can be described as extension of the hemiparetic knee past ‘anatomical zero’ and 40 to 60% of the stroke population present with knee hyperextension while walking, although there is no clear consensus as to the cause of hyperextension of the knee. (Cooper et al., 2012). Some causes of knee hyperextension poststroke may be related to the knee joint itself, alignment or control of joints and muscles above and below the knee, e.g., the hip and ankle joints. Other causes include quadriceps muscle weakness (Sheffler and Chae, 2015; Lucareli and Greve, 2008; Morris et al., 1992; and Moore, 1993), spasticity of the quadriceps muscles (Sheffler and Chae, 2015; Springer et al., 2013; Lucareli and Greve, 2008; Moore, 1993; Morris et al., 1992), and hamstring muscle weakness (Sheffler and Chae, 2015; Springer et al., 2013; Moore, 1993). Weakness of the quadricep muscles leads to reduced weight bearing ability (Cooper et al., 2012) while weakness of the hamstring muscle has an influence on knee hyperextension, especially if there is spasticity in the quadricep muscle of the hemiparetic lower limb as it would cause the tibia to be pulled posteriorly and the femur anteriorly causing hyperextension of the knee (Springer et al., 2013). Spasticity is an increase in the tonic stretch reflexes with changes in velocity and is a common symptom seen in stroke patients (Abolhasani et al., 2012). The prevalence of spasticity post-stroke is suggested to be between 18 and 50%, and excessive spasticity can impact on a patient’s functional ability and may lead to secondary compilations such as pain and joint contracture (Abolhasani et al., 2012; Singh et al., 2011). Decreased selective motor control have also been identified as possible causes of knee hyperextension poststroke, and the disrupted interplay between the pyramidal and extrapyramidal tracts may result in mass flexor/extensor patterns during gait (Sheffler and Chae, 2015; Verma et al., 2012). During stance phase, a mass extensor pattern of spasticity causing gluteus maximus and quadriceps activation may lead to knee hyperextension too (Sheffler and Chae, 2015; Verma et al., 2012).

Apart from the abovementioned knee involvement that may cause knee hyperextension, there are a number of factors causing altered ankle joint functioning that have an impact on the knee joint in stroke patients during gait (An and Won, 2016). Increased muscle tone in the ankle plantarflexor muscles causes early contraction of the ankle plantarflexors at 'initial contact', pulling the tibia posteriorly while the femur travels forward, causing decreased ankle dorsiflexion, the foot to slap the ground and knee hyperextension (Balaban and Tok, 2014; Sheffler and Chae, 2015). Spasticity in the ankle plantarflexors (and even shortening of the Achilles tendon) may result in changes in ankle ROM, causing knee hyperextension at initial contact due to a lack of an antagonist muscle force (eccentric tibialis anterior activity) (Higginson et al., 2006). Reduced ankle ROM during stance phase of gait leads to the reduced ability to shift one's centre of mass, leading to instability and balance deficits during gait. Soft tissue changes of the connective tissue and muscles of the ankle lead to biomechanical changes in gait with regards to both kinematics or spatiotemporal parameters (An and Won, 2016). Normally, maximal ankle dorsiflexion of 10 degrees is achieved at midstance phase of gait, and terminal stance phase (Ota et al., 2014). However, reduced dorsiflexion ROM hinders the forward translation of the tibia over the foot, which leads to compensation at the knee and altered spatiotemporal parameters such as decreased step length, stride length, cadence, and walking speed (Ota et al., 2014). Less than eight degrees of ankle dorsiflexion during stance phase leads to changes in knee biomechanics and gait parameters such as "toe walking" in stance phase and reduced step length (Ota et al., 2014).

Muscle weakness of the ankle dorsiflexor and plantarflexor muscles of the hemiparetic lower limb has been shown to have an impact on hyperextension of the knee during stance phase of gait (Sheffler and Chae, 2015; An and Won, 2016; Cooper et al., 2012). The gastrocnemius and hamstring muscles are thought to work in tandem, during the stance phase of walking, to prevent rapid hyperextension of the knee, but the exact action of the gastrocnemius and hamstring muscles in stance phase of gait is not well demonstrated in literature (Springer et al., 2013; Sheffler and Chae, 2015). Cooper et al (2012) suggest that tibialis anterior muscle weakness may also contribute to knee hyperextension during stance phase of gait, as the ankle dorsiflexor muscles are active in early stance phase of gait to control foot descent to the floor and control the loading response. If there is not enough eccentric control of tibialis anterior, the forward translation of the tibia over the foot will be hindered, causing compensation in the knee (Ota et al., 2014).

During stance phase of gait, knee hyperextension can allow individuals with stroke a certain amount of stability and provide a mechanism to control their affected lower limb by acting as a rigid pillar for direct weightbearing, especially in the midstance subphase of gait. However, there is a potential for injury to the posterior capsular and ligamentous structures which may lead to pain, ligament laxity, and bony deformity and potentially cause more damage to the knee (Richardson et al., 2012; Cooper et al., 2012). Knee hyperextension can also aggravate existing osteoarthritis of the hemiparetic knee (Kong et al., 2004). This study focused on the how ankle function may influence knee hyperextension in hemiparetic stroke patients during the stance phase of gait.

2.5 Summary

Literature has reported a variety of possible factors that may cause knee hyperextension as mentioned above, however, it is not clear which of these factors affecting ankle joint function has the greatest impact on knee hyperextension. The goal for physiotherapy is to restore an efficient gait, where the patient is able to ambulate independently and safely. To do this, the physiotherapist needs to establish the causes of the patient’s altered gait pattern in order to deliver the most effective and appropriate therapy. Hyperextension of the knee has the potential to negatively impact gait therapy, and this study therefore aimed to investigate, during stance phase of gait, the association between ankle joint function and hyperextension of the knee in hemiparetic stroke patients.

Chapter 3 Methods

3.1 Study Design

This pilot study used a cross-sectional observational study design, which would be used by a larger study.

3.2 Setting

Five private healthcare rehabilitation facilities were approached, and participants of this pilot study were sourced from two consenting private healthcare rehabilitation units in Durban, South Africa. *Rehab Matters Durban* is an outpatient therapy unit providing physiotherapy, occupational therapy, and speech therapy neurorehabilitation services in the Durban central, Durban North, Pinetown, and Umhlanga areas. *Nurture iLembe* is a facility in the Ballito area, which provides acute and sub-acute inpatient and outpatient rehabilitation services (50 bed capacity) to patients from Ballito and surrounding inland areas.

3.3 Sample

3.3.1 Sample Size

For a larger study, Von Hoorhis & Morgan (2007) suggests that for regression equations with at least six predictors, a sample of a minimum of 10 participants per variable is appropriate. For a larger study, determining ankle involvement in knee hyperextension would include six predictors namely: ankle muscle strength, muscle tone and ankle ROM, which were subdivided into ankle dorsiflexion and ankle plantarflexion components. Therefore, the sample size was calculated to be 6 x10 participants per predictor variable that equates to 60 participants. For this pilot study, the rule of thumb is ten percent of the sample size calculated for the larger study. However, when there is no previous information to base the sample size on, 12 participants is the recommended size (Julious, 2005).

3.3.2 Sampling

Consecutive sampling was used in this study where all patients at the facilities specified in 3.2.1, who fit the inclusion criteria, were approached to take part in the study. Participants were assessed at the facility where they were currently receiving inpatient or outpatient therapy.

3.3.2.1 Inclusion Criteria

- Unilateral hemiplegia from a single clinical stroke, irrespective of the cause of stroke (including covid-19 related causes),
- Ability to walk independently (minimum of ten metres) either with or without an assistive device,
- No pathologies of the lower limb joints such as joint arthroplasty, fractures, osteoarthritis, or rheumatoid arthritis,
- Consenting adults (18 years and above)

3.3.2.2 Exclusion Criteria

- Unable to follow verbal instructions and demonstration (as determined by basic questions of orientation and reasoning to establish mental status as well as speaking)

3.4 Instrumentation and Outcome Measures

<u>3.4.1 Demographic information:</u>

A demographic information capture sheet (Appendix B) was used to document data on the participant's age, sex, months since stroke, affected side, type of assistive device used when walking, dominant side, height, weight and Covid-19 related questions (such as previous exposure and/or associated symptoms).

The participant data capture sheet (Appendix C) was used to document the information related to ankle and knee joint outcome measures the below.

<u>3.4.2 Dynamometry to assess muscle strength of the ankle:</u>

Manual muscle testing is commonly used by healthcare professionals to test the muscle strength of their patients affected by musculoskeletal or neurological conditions. It is both an objective measure to assess weakness in an individual, but also an essential method of measuring a patient's progress over time (Beaudart et al., 2019). In stroke patients, muscle strength correlates to functional independence in gait, stair climbing, ADLs, and transfers, and can be used as an indicator for length of inpatient stay, mortality, and long-term functional outcomes (Andrews and Bohannon, 2003).

The isokinetic dynamometer is the most reliable and reproducible instrument for measuring muscle strength but is difficult to use in persons with mobility problems, is expensive, and not easy to use (Andrews and Bohannon, 2003). Handheld dynamometers on the other hand are cost effective, portable, and can be used in nearly every clinical setting. In a clinical setting, handheld dynamometers are a convenient and appropriate method to test muscle strength with a high test-retest and inter-rater reliability in normal adult and in frail older population (Scott et al., 2004; Mentiplay et al., 2015). Isometric strength testing with the handheld dynamometer has also been established in the stroke population and it is for this reason that the researcher used the handheld dynamometer in this study (Mentiplay et al., 2018). Andrews and Bohannon (2003) found that the tester's muscle strength affected the reliability and validity of all the measurements using the handheld dynamometer if their strength was less than the participant's muscle they were testing. Thus, the tester must ensure that the strength of the participant's affected and unaffected lower limbs does not exceed their own upper limb strength (Andrews and Bohannon, 2003). Ankle dorsiflexion and ankle plantarflexion muscle strength were recorded using a handheld dynamometer and the procedure in terms of positioning, support and exact testing location are outlined in Appendix D.

3.4.3 Modified Tardieu Scale to assess muscle tone of the muscles of the ankle:

The researcher used the Modified Tardieu Scale (MTS) as the outcome measure to test spasticity in this study due to its ability to determine dynamic muscle tone (Abolhasani et al., 2012) and to differentiate between the peripheral (soft tissue changes) and the neural contributions (overactive stretch reflex) of spasticity (Singh et al., 2011). Furthermore, the MTS is more effective than the Modified Ashworth Scale (MAS) in identifying spasticity and differentiating it from contracture (Glinsky, 2016). The MTS takes three measurements: R2, R1 and R2−R1 to measure spasticity. The R2 is measured at a slow velocity with the passive range of motion measured, while the R1 is measured at a fast velocity with the angle of muscle reaction. A larger R2-R1 value indicates spasticity, while a smaller R2-R1 value indicates muscle contracture (Abolhasani et al., 2012). Lastly, the quality of muscle reaction is graded based on 0–4 score.

Banky et al. (2019) found that there is a large degree of variability of intra- and inter-tester values. The inter-rater variability was almost double the intra-rater variability with the largest variability existing at the ankle joint when it came to testing velocity when using the MTS to assess for lower limb spasticity (Banky et al., 2019). Singh et al. (2011) found that the intra-rater reliability of the MTS was very good when measuring values for R1, R2, and R2-R1 of the ankle plantarflexors. The final MTS score (intraclass correlation coefficient > 0.85, P<0.0001) was very good for ankle plantarflexor muscle tone assessment over two different sessions. The MTS was therefore selected as the preferred reliable clinical tool to measure spasticity in ankle plantarflexors and dorsiflexors in this study and the procedure in terms of positioning, velocity, and measurement of quality of reaction are outlined in Appendix E.

3.4.4 Digital inclinometer to measure ankle joint passive range of motion:

Accurate measuring of joint range of motion is often required in both clinical practice and in research, and is usually measured with a digital inclinometer, goniometer, or using a video-based system (Vohralik et al., 2015). Digital inclinometers can be expensive, and with the advances in smartphone technology, there is a move towards using smartphone application to measure joint range of motion (Konor et al., 2012). A digital inclinometer on a smartphone has been found to be a valid and reliable tool to measure joint ROM and both easily accessible and inexpensive (Konor et al., 2012). When comparing standard goniometer, digital inclinometer, and a tape measure in a weight-bearing lunge position to obtain ankle dorsiflexion ROM, Konor et al. (2012) found that the digital inclinometer resulted in higher reliability coefficients (intraclass correlation coefficient = 0.96-0.99), while the goniometer had an intraclass correlation coefficient =0.85-0.96. These findings indicated that the digital inclinometer was more sensitive to ROM changes (minimal detectable change = 3.8°) compared to the goniometer (minimal detectable change = 7.7°). Vohralik et al. (2015) compared an inclinometer application installed on a phone (*iHandy Level*) and an inclinometer on ankle dorsiflexion ROM of 20 participants using a weight-bearing lunge test. Intraclass correlation coefficients of the digital inclinometer on a smartphone demonstrated excellent intra-rater (0.97) and inter-rater reliability (0.76). Both studies show excellent reliability of the test. These aforementioned studies as well as studies by Banwell et al. (2019) and Cox et al. (2018) all suggest that there is good to excellent intra and inter-rater reliability when using a smartphone inclinometer application to measuring ankle joint ranges of motion using the weight bearing lunge test for ankle dorsiflexion and a non-weightbearing position to measure ankle plantarflexion. The weight-bearing lunge test is thought to be more accurate when measuring ankle dorsiflexion range of motion and may be more reliable (ICC=0.93- 0.96) than a non-weight-bearing position (ICC 0.32-0.72) (Venturini et al., 2006; Bennell et al., 1998). A weight-bearing position also reflects the available range of motion during functional activities such as walking ambulation (Venturini et al., 2006). The researcher therefore used the smartphone inclinometer as the preferred reliable clinical tool to measure ankle joint passive ROM in this study (Appendix F). Ankle dorsiflexion was measured with an inclinometer while the participant performed a weightbearing lunge test against a wall, while ankle plantarflexion ROM was measured in a supine position (Appendix F).

3.4.5 Video analysis of gait:

Analysis of movement is an important clinical and research tool to assess joint kinematics and changes in ROM, and muscle activity during activities such as walking. Gait analysis has been historically performed in motion laboratories with expensive equipment which requires extensive training (Tan et al., 2015). Kinovea movement analysis software (Appendix G) was used to analyse knee joint angles during gait in this study.

Puig-Diví et al. (2017) assessed the validity and reliability of angular and distance data measured using Kinovea movement analysis software. Kinovea is an open-access, 2D motion analysis software, which has been used in sports, research work, and in clinical settings (Puig-Diví et al., 2017). Angles of the joints of the lower limb were simulated during walking and captured and analysed at four different perspectives – 45, 60, 75, and 90 degrees. The results (ICC = 1) indicate that Kinovea software is an accurate and reliable instrument when measuring angular and distance data up to five metres from the object and at an angle of 90 degrees (Puig-Diví et al., 2017).

3.5 Procedure

3.5.1 Pre-testing of procedures and outcome measures

The researcher conducted a pre-test in order to familiarise herself with the different outcome measures and testing procedures, and the time taken to perform the tests. This was conducted at one of the facilities who granted permission for the pilot study and included two participants. There were no key features that needed to be altered and therefore the results were included into the pilot study.

3.5.2 The pilot study

3.5.2.1 Participant Recruitment:

Physiotherapists working at both rehabilitation units were asked to screen their patients for potential study participants, which included determining if their patients fit the inclusion criteria for the study (patients had to be adults and have had only a single clinical stroke with hemiplegia, be able to walk independently (minimum of ten metres) either with or without an assistive device, have no pathologies of the lower limb joints such as joint arthroplasty, fractures, osteoarthritis, or rheumatoid arthritis, and be able to sign informed consent). Phone calls to the two study settings were done biweekly to attain the names and contact details of the patients who fit the inclusion criteria and appointments were made for the data collection. On the day of the appointment, the researcher explained the study and gave all potential participants a study information sheet (see Appendix H) in the presence of a witness (their treating therapist, nurse, or unit manager). The potential participants were allowed to have time to read through the information sheet and the study was explained to potential participants in a language that they understood. The researcher is fluent in English and Afrikaans and a translator did not have to be made available as all the participants were able to fully understand English. Potential participants were allowed to also ask any questions and the researcher clarified all queries regarding the study. All potential participants who agreed to participate in this study signed a consent form before the researcher recorded all their data (Appendix I). Only one facility was visited each day to limit travelling between multiple hospitals during the Covid-19 level three and four national lockdowns.

3.5.2.2 Data collection procedure:

3.5.2.2.1 Muscle strength testing of the ankle:

Each participant was asked to do three isometric contractions (maximal) for both muscle groups on both the affected and unaffected sides being tested. The isometric contractions were held for three seconds, and the average of the maximal isometric contractions was used for data analysis.

3.5.2.2.2 Muscle tone testing of the ankle:

The MTS identifies the point in the muscle's range where velocity-dependent spasticity occurs (Cerebral Palsy Alliance, 2018). The dynamic spasticity of a muscle is the relationship between R1 and R2 and is calculated by subtracting R1 from R2. Three measurements were taken on the affected side, and the average of these measurements was used for data analysis. The quality of muscle reaction was measured using a grading system (Fayazi et al., 2014) specified in Appendix E.

3.5.2.2.3 Ankle joint range of motion testing:

Three measures of the dorsiflexion lunge test and ankle plantarflexion ROM on both the affected and unaffected sides were recorded, and for data analysis, the average of these measures of both tests on each lower limb was used (Cox et al., 2018).

3.5.2.2.4 Video capturing of gait over a distance of ten metres:

Three coloured stickers were placed on the participant's paretic lower limb: over the greater trochanter, over the lateral femoral epicondyle, and over the lateral malleolus (Cooper et al., 2012) (Appendix G). The participant was asked to then walk a distance of 10 meters at their own chosen speed. The walkway was demarcated with tape and the same walkway was used every time at each testing site. The participants were all asked to remove their shoes, but their chosen assistive device could be used for the walking. The camera was placed at a 90-degree angle less than five metres away from the participant, at the level of their knee as they walked (Puig-Diví et al., 2017). The video was imported into Kinovea movement analysis software and the ankle, knee, and hip angles of the affected side were measured during the three different stance sub-phases.

3.5.2.2.5 Data Management:

All data were recorded on a Microsoft Excel spreadsheet in preparation for data analysis.

3.5.2.2.6 Health safety:

Due to the prevailing Covid-19 pandemic, the researcher adhered to strict infection control protocol and wore the required personal protective equipment. All equipment and working surfaces used during data collection was sanitised before and after testing. The coloured stickers used during gait analysis were disposed of after each use.

3.6 Ethical Considerations

The University of the Witwatersrand Human Research Ethics Committee (HREC) granted ethical clearance (Appendix J). Written permission to include potential participants was obtained from the hospital manager and clinical heads of the rehabilitation units (Appendix K). Prior to commencing the study, potential participants signed written informed consent. Participants could withdraw from this study at any time, without any ramifications. The outcome measures used in this study were performed in a safe, clinical setting, and did not pose harm to the participants. Participants were made to feel comfortable, and no areas of the body were unnecessarily exposed, and areas were exposed with the participant's consent and done so in a professional and respectful manner. The video recording did not include their face in order to protect their identity. Care was taken to ensure participants' safety by remaining close to the participant during the assessment session to ensure there was reduced risk of falling and injury and ensuring that the environment in which the assessment was taking place was well lit and free of any hazardous or obstacles. There was a consideration if the participants experienced any pain at the affected knee during the assessment, the patient could be given the contact details of a general practitioner at the hospital where they were currently receiving therapy, or the nearest facility, if there was no general practitioner at that facility. The treating physiotherapist would have been notified about the participant's knee pain, if they are not aware of it already, for further management. The contact details of the general practitioners were included in the information sheet. However, no participant experienced any pain during the assessment, and therefore, no referral was needed.

Information collected during this study was only used for the intended purpose of this study and no personal information relating to the participants was divulged during data collection nor in this research report. All participants were allocated a participant code known to the researcher only.

In light of the Covid-19 pandemic, extra precaution was taken to ensure participant safety. Any potential participants who presented with signs and symptoms of Covid-19 such as fever, sore throat, shortness of breath, fatigue, loss of smell and taste, discolouration of fingers and toes (WHO, 2020) and with a travel history to high-risk areas or exposure to someone with Covid-19 were only assessed after a self-quarantine period of 10-14 days and a negative Covid-19 test. Due to the rigorous screening and testing done at the facilities, no participants presented with signs and symptoms of Covid-19 on the day of assessment.

3.7 Statistical Analyses

Using the Statistical Package for the Social Sciences (SPSS), statistical analysis was performed. The significant level was set at $p < 0.05$. Table 3.1 shows the statistical tests that were used in data analysis.

Table 3.1 - Statistical tests that were used to analyse the collected data

Objective	Outcome Measure	Scale	Statistic Test
Demographics	Demographic capture sheet	Age – nominal	Descriptive statistics - mean, standard deviation, ranges
		Sex – categorical	Percentages and frequencies
		Months since stroke – nominal	Descriptive statistics - mean, standard deviation, ranges
		Affected – categorical	Percentages and frequencies
		Dominant side – categorical	Percentages and frequencies
		Assistive device used when walking (Y/N) – categorical	Percentages and frequencies
		Covid-19 – related information	Percentages and frequencies
		Height – ratio	Descriptive statistics - mean, standard deviation, ranges
		Weight – ratio	Descriptive statistics - mean, standard deviation, ranges
Muscle strength of the muscles of the ankle joint.	Handheld dynamometer (lb)	Nominal	- Pearson's chi-squared test - correlation between ankle muscle strength and hyperextension of the knee. - Fisher's Exact test - if the conditions for the Pearson's chi-squared test were not met. - Pearson product-moment correlation coefficient
Muscle tone in the muscles of the ankle joint.	MTS	Interval, nominal	- R2-R1 ankle plantarflexion and R2-R1 ankle dorsiflexion. - Kolmogorov-Smirnov test (K-S test) - normal distribution of R2-R1. - Pearson's chi-squared test - correlation between the R2-R1 measurement and knee hyperextension. - Pearson product-moment correlation coefficient
Ankle joint range of motion.	Inclinometer (degrees)	Interval	- Pearson's chi-squared test - assess the correlation between ankle ROM and knee hyperextension. - Fisher's Exact test - if the conditions for the Pearson's chi-squared test were not met.

To analyse knee joint angles during stance phase of gait.	Kinovea movement analysis software	Ratio data	- Mean, standard deviation and ranges using descriptive statistics
To determine the association between the ankle components assessed and knee hyperextension during stance phase.			- Pearson's correlation coefficient test - assess the correlation between the independent variables - muscle strength and muscle tone, or muscle tone and altered ankle joint ROM etc. - Multiple regression - to assess how the factors affecting the ankle predict hyperextension of the knee in the stance phase.

3.8 Summary

This chapter outlined the instrumentation, outcome measures, and methods used to for this study. All the participants' anonymity was maintained, and the data used to perform quantitative research as described in this study.

Chapter 4 Results

4.1 Introduction

This section reports the demographics of the participants as well as the participants' ankle muscle strength, muscle tone, and joint range of motion, and the knee angles during the stance phases of gait (initial contact, loading response and midstance). The association between the ankle components assessed and knee hyperextension during walking (stance phase) are also reported.

4.2 Description of sample

The pilot study included 12 participants (figure 4.1) where 10 were male (83.30%) and 2 were female (16.70%). The majority of participants had left hemiplegia compared to right hemiplegia (n=8, 66.7% vs n=4, 33.3%) and all participants were right side dominant. Half of the participants did not require an assistive device (50%), while two participants required a crutch for longer distances community/outdoor mobility (16.7%), and four participants required a quadrupod (33.3%).

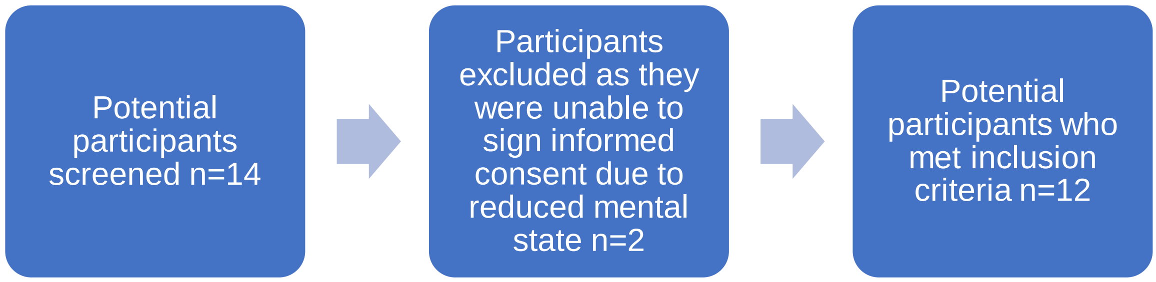

Figure 4.1. Flow diagram of selection of participants

The youngest participant was 27 years old and the oldest was 77 years. The mean age of the participants was 52.25 (± 15.51) years. The mean of months since stroke onset was 5.48 months (± 5.15) and the mean height was 173.50cm (± 10.20). The mean weight of the participants was 86.83kg (± 27.45), which was not normally distributed (as indicated with a kurtosis of greater than three in Table 7.3 – Appendix Q) and would normalize given a larger sample size.

4.3 Feasibility of the study

4.3.1 Time taken to recruit participants

Five private healthcare rehabilitation facilities were originally approached for permission to conduct this study at their facility. However, three out of the five private healthcare rehabilitation facilities in Durban were approached but either did not have appropriate potential participants or declined to have an external researcher on their premises due to the Covid-19 pandemic. Recruitment for 12 participants commenced in December 2020 and ended in October 2021 (ten months). Consecutive sampling was used to recruit potential participants.

4.3.2 Visit to facilities

Physiotherapists working at both rehabilitation units were asked to screen their patients for potential study participants, which included determining if their patients fit the inclusion criteria for the study. Phone calls to the two study settings were done biweekly to attain the names and contact details of the patients who fit the inclusion criteria and appointments were made for the data collection. Ten visits were done to the two study sites, and no more than two potential participants were identified at the same time, meaning that a cluster of testing could not be performed in a single visit.

4.3.3 Time taken to complete each assessment

The demographic information capture sheet took approximately five minutes to complete. The handheld dynamometry to assess muscle strength of the ankle was an easy-to-use outcome measure and is convenient, and the testing took less than one minute to complete and was completed first after the demographic information was collected. Testing spasticity using the Modified Tardieu Scale took approximately five minutes and was the second-completed outcome measure. A digital inclinometer on a smartphone was used to measure ankle joint passive range of motion. Ankle dorsiflexion was measured with an inclinometer while the participant performed a weightbearing lunge test against a wall, while ankle plantarflexion ROM was measured in a supine position. Three measures of the dorsiflexion lunge test and ankle plantarflexion ROM on both the affected and unaffected sides were recorded. This test was performed third and took approximately five minutes to test. The participant was asked to then walk a distance of 10 meters at their own chosen speed which took approximately two minutes to complete. The total time taken to complete the assessment was approximately twenty minutes.

4.4 Description of the biomechanics of the ankle complex

4.4.1 Muscle Strength

Muscle strength data of the unaffected and affected dorsiflexors and plantarflexors are depicted in Table 4.2 below and are normally distributed according to the Shapiro-Wilk test except plantarflexion muscle strength of the unaffected ankle (0.03) (Table 4.2). There was a significant difference between dorsiflexion muscle strength (F= 1.26; p= 0.27; Cohen's d= 3.56) and plantarflexion muscle strength (F = 0.38; p= 0.55; Cohen's d= 4.57) of the affected ankle as compared to the unaffected ankle, with the muscle strength of the unaffected side showing larger means than the affected side (Table 4.3). This is consistent with the hemiparetic clinical presentation.

Table 4.2 – Muscle strength of the ankle distribution data (n=12)

	Min	Max	Mean	Std. Dev.	Skewness		Kurtosis		Shapiro-Wilk		
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error	Statistic	df	Sig.
Dorsiflexion (unaffected)	4.00	20.00	11.67	4.15	.12	.64	.75	1.23	.97	12	.90
Plantarflexion (unaffected)	4.83	26.67	12.93	5.20	1.51	.64	4.73	1.23	.84	12	.03
Dorsiflexion (affected)	.00	10.00	6.08	2.85	-.750	.64	.53	1.23	.95	12	.69
Plantarflexion (affected)	.00	17.00	8.39	3.85	.14	.64	3.60	1.23	.85	12	.04

Table 4.3 – Comparison of muscle strength between affected and unaffected ankle joints

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Dorsiflexion	Equal variances assumed	1.26	.27	3.84	22	.001	5.58	1.454	2.57	8.60
Plantarflexion	Equal variances assumed	.38	.55	2.43	22	.02	4.54	1.87	.67	8.41

4.4.2 Muscle tone

Muscle tone of the tibialis anterior and gastrocnemius was assessed on the affected lower limb. Passive muscle tone of the gastrocnemius measured with a slow velocity had a mean of 1.03 (± 8.46), with a rapid velocity stretch had a mean of -6.25 (± 8.54), and the R2-R1 dynamic muscle tone measurement had a mean of 7.17 (± 7.26). Passive muscle tone of the tibialis anterior measured with a slow velocity had a mean of 42.64 (± 5.33), with a rapid velocity stretch had a mean of 41.59 (± 5.63), and the R2-R1 dynamic muscle tone measurement had a mean of 0.97 (± 1.47) (Table 4.4). The data of muscle tone of the ankle is normally distributed according to the Kolmogorov-Smirnov test except the dynamic muscle tone of tibialis anterior muscle (R2-R1) [highlighted in Table 7.4 – Appendix Q] (0.03). The quality of the muscle reaction was also measured for the affected tibialis anterior and gastrocnemius muscles. The gastrocnemius had more varied muscle reaction qualities ranging from zero to four, while the tibialis anterior was only given a zero or one rating (Table 4.5).

Table 4.5 - Quality of muscle reaction for tibialis anterior and gastrocnemius muscle tone

Quality of muscle reaction		Gastrocnemius n(%)	Tibialis anterior n(%)
0	No resistance throughout the course of the passive movement	3 (25)	6 (50)
1	Slight resistance through the course of passive movement; no clear ‘‘catch’’ at a precise angle	1 (8.3)	6 (50)
2	Clear catch at a precise angle, interrupting the passive movement, followed by release	7 (58.3)	0 (0)
3	Fatigable clonus (10s when maintaining the pressure) appearing at a precise angle	0 (0)	0 (0)
4	Un-fatigable clonus (more than 10s when maintaining the pressure) at a precise angle	1 (8.3)	0 (0)
5	Joint is immovable	0 (0)	0 (0)

4.4.3 Ankle range of motion

Joint range of movement (ROM) of the unaffected dorsiflexion had a mean of 29.62 (± 5.55), and its affected counterpart had a mean of 24.99 (± 7.12). The unaffected plantarflexion ROM had a mean of 33.40 (± 6.46), while the affected plantarflexion had a mean of 31.73 (± 7.64) (Table 7.5 – Appendix Q). The data of ROM of the ankle is normally distributed according to the Shapiro-Wilk test (Table 4.6). Comparing the affected versus unaffected ankles, there was not a significant difference between plantarflexion ROM (F= 2.15; p= 0.16) as well as dorsiflexion ROM (F= 0.43; p= 0.52) (Table 4.7).

Table 4.7 – Comparison of ROM between affected and unaffected ankle joints

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
ROM plantarflexion	Equal variances assumed	2.15	.16	.78	22	.45	2.24	2.89	-3.75	8.23
ROM dorsiflexion	Equal variances assumed	.43	.52	1.78	22	.09	4.63	2.61	-.78	10.04

4.3.4 Gait analysis: changes in knee angles during stance phase

The angle of the knee of the hemiparetic side was measured at each phase of stance phase during gait. Twenty five percent of participants presented with knee hyperextension during stance phase of gait. Initial contact phase had a mean knee angle of 10.51 (± 6.61), heel strike phase had a mean knee angle of 13.87 (± 10.03), midstance phase had a mean knee angle of 12.58 (± 11.29), terminal stance phase had a mean knee angle of 10.24 (± 11.06), and pre-swing phase had a mean knee angle of 18.76 (± 4.47) (Table 4.8). The data of the knee angles measured is normally distributed according to the Shapiro-Wilk test with the knee angles showing greater knee flexion during stance phase, according to the norms (Table 7.6- Appendix Q).

4.4.5 Association during gait stance phase between the ankle components assessed and knee hyperextension

The correlation tests between decreased tibialis anterior muscle tone and knee angles (increased knee flexion) showed a strong and positive relationship to the hemiparetic knee angles during stance phase of gait (R_{12} = .662; p-.019) (Table 4.9). There was a significant relationship between tibialis anterior muscle tone and knee angles at initial contact (p=0.04), terminal (p=0.01), or pre-swing (p=0.01), while there was no significance at loading response (p=0.09) and midstance (p=0.07). Gastrocnemius muscle tone was not significantly related to the knee angles at initial contact (p=0.32), loading response (p=0.29), midstance (p=0.54), terminal (p=0.13), or pre-swing (p=0.26).

Dorsiflexion muscle strength of the affected ankle was not significantly related to the knee angles at initial contact (p=0.12), loading response (p=0.43), midstance (p=0.99), terminal (p=0.65), or pre-swing (p=0.70). Plantarflexion muscle strength of the affected ankle was not significantly related to the knee angles at initial contact (p=0.97), loading response (p=0.98), midstance (p=0.98), terminal (p=0.38), or pre-swing (p=0.23). Dorsiflexion ROM was not significantly related to the knee angles at initial contact (p=0.49), loading response (p=0.68), midstance (p=0.87), terminal (p=0.58), or pre-swing (p=0.75). Plantarflexion ROM was not significantly related to the knee angles at initial contact (p=0.49), loading response (p=0.65), midstance (p=0.50), terminal (p=0.48), or pre-swing (p=0.20).

In the test between subject effects, there was no significance between the dependent and independent variables. However, it showed 38.2% variance in the hemiparetic knee angles from dorsiflexion muscle strength (R square=0.382), 29.9% in the hemiparetic knee angles from plantarflexion muscle strength, 53% variance in the hemiparetic knee angles from plantarflexion ROM, 18.3% in the hemiparetic knee angles from dorsiflexion ROM, 71.9% variance in the hemiparetic knee angles from gastrocnemius muscle tone, and 46.1% variance in the hemiparetic knee angles from tibialis anterior muscle tone (Table 4.11). A multiple regression was conducted and revealed that dorsiflexion and plantarflexion muscle strength; dorsiflexion and plantarflexion ROM; as well as tibialis anterior and gastrocnemius muscle tone did not impact the knee angles (Table 4.12). Further analysis also confirmed that none of the knee angles have statistically significant coefficients.

Table 4.9 – Correlation between muscle tone of the ankle and hemiparetic knee angles during stance phase of gait (n=12)

		R2-R1 Ankle Plantarflexion	R2-R1 Ankle Dorsiflexion	Knee Angles
R2-R1 Plantarflexion	Pearson Correlation	1	.39	.66*
	Sig. (2-tailed)		.22	.02
R2-R1 Dorsiflexion	Pearson Correlation	.39	1	.33
	Sig. (2-tailed)	.22		.29
Knee Angles	Pearson Correlation	.66*	.33	1
	Sig. (2-tailed)	.02	.29	

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

Table 4.10 – Correlation data between ankle muscle strength, ankle range of motion, and hemiparetic knee angles during the stance phases of gait (n=12)

		Muscle strength dorsiflexion	Muscle strength plantarflexion	ROM plantarflexion	ROM dorsiflexion	Initial contact	Loading response	Midstance	Terminal stance	Pre-swing
Muscle strength dorsiflexion	Pearson Correlation	--								
Muscle strength plantarflexion	Pearson Correlation	.607**	--							
	Sig. (2-tailed)	.002								
ROM plantarflexion	Pearson Correlation	.245	.499*	--						
	Sig. (2-tailed)	.249	.013							
ROM dorsiflexion	Pearson Correlation	.447*	.056	-.229	--					
	Sig. (2-tailed)	.028	.793	.281						
Initial contact	Pearson Correlation	-.469	-.014	-.220	.222	--				
	Sig. (2-tailed)	.124	.966	.493	.488					
Loading response	Pearson Correlation	-.254	-.008	.146	.135	.654*	--			
	Sig. (2-tailed)	.426	.979	.651	.677	.021				
Midstance	Pearson Correlation	-.003	.009	.219	.055	.452	.850**	--		
	Sig. (2-tailed)	.993	.977	.495	.865	.140	.000			
Terminal stance	Pearson Correlation	.146	.277	.226	-.176	.307	.655*	.808**	--	
	Sig. (2-tailed)	.651	.384	.481	.584	.331	.021	.001		
Pre-swing	Pearson Correlation	-.124	.373	.398	-.105	.478	.470	.571	.670*	--
	Sig. (2-tailed)	.700	.233	.200	.745	.116	.123	.052	.017	

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

Table 4.11 – Tests between subject-effects (n=12)

Source	Dependent Variable	df	Mean Square	F	Sig.
Corrected Model	Muscle Strength DF	5	14.51	.74	.62
	Muscle Strength PF	5	17.79	.51	.76
	ROM_PF	5	48.60	1.35	.36
	ROM_DF	5	12.39	.27	.92
	R2-R1 Ankle Plantarflexion	5	3.44	3.07	.10
	R2-R1 Ankle Dorsiflexion	5	53.43	1.03	.48
Intercept	Muscle Strength DF	1	123.54	6.32	.05
	Muscle Strength PF	1	9.64	.28	.62
	ROM_PF	1	112.12	3.12	.13
	ROM_DF	1	360.27	7.79	.03
	R2-R1 Ankle Plantarflexion	1	.82	.73	.43
	R2-R1 Ankle Dorsiflexion	1	1.17	.02	.89
Initial contact	Muscle Strength DF	1	6.37	.33	.59
	Muscle Strength PF	1	3.96	.11	.75
	ROM_PF	1	165.80	4.62	.08
	ROM_DF	1	7.74	.17	.70
	R2-R1 Ankle Plantarflexion	1	2.66	2.38	.17
	R2-R1 Ankle Dorsiflexion	1	6.45	.12	.74
Loading response	Muscle Strength DF	1	11.32	.58	.48
	Muscle Strength PF	1	1.93	.06	.82
	ROM_PF	1	44.84	1.25	.31
	ROM_DF	1	.03	.001	.98
	R2-R1 Ankle Plantarflexion	1	.21	.19	.68
	R2-R1 Ankle Dorsiflexion	1	28.72	.55	.49
Midstance	Muscle Strength DF	1	4.49	.23	.65
	Muscle Strength PF	1	25.37	.73	.43
	ROM_PF	1	1.04	.03	.87
	ROM_DF	1	9.54	.21	.67
	R2-R1 Ankle Plantarflexion	1	.13	.11	.75
	R2-R1 Ankle Dorsiflexion	1	114.89	2.21	.19
Terminal stance	Muscle Strength DF	1	11.13	.57	.48
	Muscle Strength PF	1	18.35	.53	.50
	ROM_PF	1	26.21	.73	.43
	ROM_DF	1	24.02	.52	.50
	R2-R1 Ankle Plantarflexion	1	3.39	3.03	.13
	R2-R1 Ankle Dorsiflexion	1	134.05	2.58	.16
Pre-swing	Muscle Strength DF	1	5.13	.26	.63
	Muscle Strength PF	1	26.62	.77	.42
	ROM_PF	1	149.91	4.18	.09
	ROM_DF	1	1.98	.04	.84
	R2-R1 Ankle Plantarflexion	1	.24	.21	.66
	R2-R1 Ankle Dorsiflexion	1	.18	.003	.96
Error	Muscle Strength DF	6	19.54		

	Muscle Strength PF	6	34.71		
	ROM_PF	6	35.90		
	ROM_DF	6	46.24		
	R2-R1 Ankle Plantarflexion	6	1.12		
	R2-R1 Ankle Dorsiflexion	6	52.05		

Table 4.12 – Multiple regression and tests between subject-effects (n=12)

	Variance	F (df)	Significance
Muscle strength DF	38.2%	0.74 (5,6)	0.62
Muscle strength PF	29.9%	0.51 (5,6)	0.76
ROM DF	18.3%	0.27 (5,6)	0.92
ROM PF	53.0%	1.35 (5,6)	0.36
Muscle tone DF	46.1%	1.03 (5,6)	0.48
Muscle tone PF	71.9%	3.07 (5,6)	0.10

4.4 Summary of main results

This chapter presented descriptive and normative data of ankle muscle strength, ankle muscle tone, ankle ROM, and knee angles during stance phase of gait, and the correlations between these variables. There were positive associations between dorsiflexion and plantarflexion muscle strength of the affected lower limb ($p < 0.002$); dorsiflexion ROM and dorsiflexion muscle strength ($p < 0.03$); as well as tibialis anterior muscle tone and the hemiparetic knee angles during heel strike, terminal stance, and pre-swing phases ($p < 0.04$, $p < 0.01$ and $p < 0.01$ respectively). The results of the data analysis showed that there was no association between muscle strength and range of motion of the ankle, and knee hyperextension during stance phase of gait. Decreased tibialis muscle tone was seen in participants who presented with increased knee flexion during stance phase and does not seem to not play a role in knee hyperextension. But conclusions cannot be drawn from these results based on the small sample size and the heterogeneity of the participants. The next chapter will discuss these finding in relation to current literature.

Chapter 5 Discussion

5.1 Introduction

The aim of this study was to determine the association between ankle joint function and hyperextension of the knee in hemiparetic stroke patients during stance phase of gait as well as to determine the feasibility of the study design. Tibialis anterior and gastrocnemius muscle strength for ankle dorsiflexion and plantarflexion, respectively, were measured using a dynamometer for both the affected and unaffected lower limbs. Muscle tone of the ankle joint (tibialis anterior for ankle dorsiflexion, and gastrocnemius for ankle plantarflexion) was measured using the Modified Tardieu Scale (MTS). Range of motion of ankle dorsiflexion and plantarflexion was measured using an inclinometer. Knee joint angles during gait (stance phase) were measured using motion analysis software.

This chapter discusses the feasibility of this pilot study and the findings relating to ankle function and knee hyperextension in relation to available literature.

5.2 Recruitment procedures

Five private healthcare rehabilitation facilities were originally approached for permission to conduct this study at their facility to include most of Durban south, Durban central, Durban north, Umhlanga, Ballito, and Pinetown's catchment area. However, three out of the five private healthcare rehabilitation facilities in Durban were approached but either did not have appropriate potential participants or declined to have an external researcher on their premises due to the Covid-19 pandemic. Such ethical challenges have been experienced during the Covid-19 pandemic where access to hospitals and patients has been restricted to prioritise participant safety and to accommodate the requirement for social distancing to halt the spread of the virus (Bierer et al., 2020). For a larger study, it is advised that a large catchment area is included and perhaps to include both private and public healthcare facilities. The testing time was reasonable at approximately 20 minutes per participant and the time could be further shortened with the addition of a research assistant, who could set up the testing area and scribe while the researcher is performing the tests.

5.3 Sample size

For this pilot study, the rule of thumb is ten percent of the sample size calculated for the larger study. However, when there is no previous information to base the sample size on, 12 participants is the recommended size (Julious, 2005).

5.4 Inclusion and exclusion criteria

The inclusion criteria were designed to not exclude too many potential participants from the study, but still not have other variables affect the results. However, with the lack of participants (twenty five percent) presenting with knee hyperextension, it is advised that an additional inclusion criterion be that the participant should present with knee hyperextension on their hemiparetic side. Forty to 60% of the stroke population present with hyperextension of the knee while walking (Cooper et al., 2012), and therefore it should be added as an inclusion criterion.

5.5 Appropriateness of instruments

A demographic information capture sheet was used to document data on the participant's age, sex, months since stroke, affected side, type of assistive device used when walking, dominant side, height, weight and Covid-19 related questions (such as previous exposure and/or associated symptoms). Additional information could be added to this capture sheet to gain a better clinical presentation of the participant. Type of stroke, cause of stroke and co-morbidities should be asked to gain the clinical features of the participant. Balance, mobility status and the functional level of the participant should be measured with appropriate outcomes measures.

Handheld dynamometry to assess muscle strength of the ankle was an easy-to-use outcome measure and is convenient and appropriate method to test muscle strength with a high test-retest and inter-rater reliability in normal adult and in frail older population (Scott et al., 2004; Mentiplay et al., 2015). Isometric strength testing with the handheld dynamometer has also been established in the stroke population and it is for this reason that the researcher used the handheld dynamometer in this study (Mentiplay et al., 2018). Andrews and Bohannon (2003) found that the tester's muscle strength affected the reliability and validity of all the measurements using the handheld dynamometer if their strength was less than the participant's muscle they were testing. Thus, the tester must ensure that the strength of the participant's affected and unaffected lower limbs (Andrews and Bohannon, 2003). Each participant was asked to do three isometric contractions (maximal) for both muscle groups on both the affected and unaffected sides being tested. The isometric contractions were held for three seconds, and the average of the maximal isometric contractions was used for data analysis. Therefore, the testing took less than one minute to complete and was completed first.

The researcher used the Modified Tardieu Scale (MTS) as the outcome measure to test spasticity in this study due to its ability to determine dynamic muscle tone (Abolhasani et al., 2012) and to differentiate between the peripheral (soft tissue changes) and the neural contributions (overactive stretch reflex) of spasticity (Singh et al., 2011). Furthermore, the MTS is more effective than the Modified Ashworth Scale (MAS) in identifying spasticity and differentiating it from contracture (Glinsky, 2016). Three measurements were taken on the affected side. The quality of muscle reaction was measured using a grading system (Fayazi et al., 2014). This testing took approximately five minutes and was the second-completed outcome measure.

A digital inclinometer on a smartphone was used to measure ankle joint passive range of motion. Ankle dorsiflexion was measured with an inclinometer while the participant performed a weightbearing lunge test against a wall, while ankle plantarflexion ROM was measured in a supine position. Three measures of the dorsiflexion lunge test and ankle plantarflexion ROM on both the affected and unaffected sides were recorded. This test was performed third and took approximately five minutes to test.

Analysis of movement is an important clinical and research tool to assess joint kinematics and changes in ROM, and muscle activity during activities such as walking. The participant was asked to then walk a distance of 10 meters at their own chosen speed. The camera was placed at a 90-degree angle less than five metres away from the participant, at the level of their knee as they walked (Puig-Diví et al., 2017). The video was imported into Kinovea movement analysis software and the ankle, knee, and hip angles of the affected side were measured during the three different stance sub-phases. For better reliability and accuracy, the camera could be placed on a tripod with wheels so that it is kept at the same angle and distance from the participant's knee for the entire walk. Some literature reports that the use of reflective markers as used in optoelectronic systems such as Vicon is more accurate and could be considered in place of plain coloured stickers (Van der Kruk and Reijne, 2018). The knee angle norms were compared to accepted norms as per the literature normal range and zero line, however in hindsight, each patient to be analysed and compare their affected with unaffected side.

5.6 Participants

5.6.1 Demographic data

The study only included individuals poststroke who could walk independently, and the mean months since stroke onset was 5.48 months, and Veerbeek et al. (2011) found that 60 to 80% of stroke survivors can walk independently by six months following a stroke (Veerbeek et al., 2011). All of the participants were right-hand dominant while the hemiparetic side of the participants was distributed with majority of the participants having left-sided hemiplegia than right-sided hemiplegia. This distribution is not what has been seen in the literature as several studies have shown that left-sided strokes (right-sided hemiplegia) are more frequent than right-sided strokes (left-sided hemiplegia) (Foerch et al., 2005; Hedna et al., 2013; Hernández et al., 2003). The greater distribution of left hemiplegia among the predominant right-handed participants, means they would be less affected in unilateral fine motor tasks such as writing and eating but may still have difficulty in bilateral upper limb tasks such as doing up buttons and cutting food. Right-sided strokes may result in problems with visuo-spatial perception, which would affect their balance and mobility especially in more complex environments (John Hopkins Medicine, 2021).

5.7 Muscle strength

Both tibialis anterior and gastrocnemius muscles play an important role in gait. The tibias anterior is active during initial contact (eccentric), loading response (eccentric), and pre-swing (concentric) (Loudon et al., 1998; Chui et al., 2020). The gastrocnemius muscle is active during midstance (eccentric), terminal stance (eccentric), and pre-swing (concentric) (Loudon et al., 1998; Chui et al., 2020). The researcher found significant weakness of both gastrocnemius and tibialis anterior muscles in this sample when compared to their unaffected side. Muscle weakness of the gastrocnemius and tibialis anterior muscles have been shown to be linked to knee hyperextension during stance phase (Sheffler and Chae, 2015; An and Won, 2016; Cooper et al., 2012). Cooper et al. (2012) suggest that tibialis anterior is active in early stance phase of gait to control foot descent to the floor and control the loading response, and weakness of this muscle during these phases may contribute to knee hyperextension. The gastrocnemius muscle is thought to prevent rapid hyperextension of the knee, but the exact action of it in stance phase of gait is not well demonstrated in literature (Springer et al., 2013; Sheffler and Chae, 2015). While this study showed no significant relationship between muscle strength and the hemiparetic knee angles during stance phase of gait, muscle strength of the ankle showed 38.2% variance for dorsiflexion muscle strength, and 29.9% variance for plantarflexion muscle strength of the hemiparetic knee angles. As most of the participants presented during stance phase with increased knee flexion, this may show a greater link, during stance phase, between tibialis anterior muscle weakness and increased knee flexion, which is contradictory to Cooper et al. (2012).

5.8 Muscle tone

The researcher found a greater dynamic component of spasticity in the gastrocnemius of the affected lower limb compared to the tibialis anterior, and greater phasic tone of the gastrocnemius. This was also apparent with the subjective rating of the quality of the muscle reaction. The gastrocnemius had more varied muscle reaction qualities ranging from zero to four with most having a rating of two (n=7), while the tibialis anterior was only given a zero or one rating. A study by Fayazi et al. (2014) on stroke patients measured gastrocnemius muscle tone using the MTS, and all of their thirty participants rated either a muscle reaction of two (n=10) or three (n=20). Tibialis anterior muscle tone had a strong and positive relationship to the hemiparetic knee angles during stance phase of gait (R_{12} = .662; p-.019). Research suggests that increased muscle tone in the gastrocnemius muscle causes early contraction of the ankle plantarflexors at ‘initial contact’, pulling the tibia posteriorly while the femur travels forward, causing knee hyperextension (Balaban and Tok, 2014; Sheffler and Chae, 2015). This is not what was found in this study, as there was no significance between gastrocnemius muscle tone and knee hyperextension, however only 25 percent of participants presented with knee hyperextension and thus a conclusion cannot be drawn. This is further seen in the variance of the hemiparetic knee angles and muscle tone of the ankle. Gastrocnemius muscle tone created 46.1% variance, while tibialis anterior muscle tone created 71.9% variance in the hemiparetic knee angles. During stance phase, most of the participants presented with increased knee flexion, and so increased gastrocnemius muscle tone may still play a greater role in knee hyperextension than tibialis anterior muscle tone, which is what other literature states and what we see in clinical practice (Balaban and Tok, 2014; Sheffler and Chae, 2015; Higginson et al., 2006). Decreased tibialis muscle tone was seen in participants who presented with increased knee flexion during stance phase and therefore seems to not play a role in knee hyperextension.

5.9 Ankle joint range of motion

Although ankle ROM of the affected dorsiflexion and plantarflexion were less than the unaffected side, the researcher did not find any significant difference between the ankle ROM between affected and unaffected side. Nevertheless, decreased ankle ROM during stance phase of gait leads to the reduced ability to shift one's centre of mass, leading to instability and balance deficits during gait as well as soft tissue changes of the connective tissue and muscles of the ankle leading to biomechanical changes in gait (An and Won, 2016). The greater difference in ankle dorsiflexion ROM between the affected and unaffected lower limbs which the researcher observed ties in with the increased muscle tone of the gastrocnemius. Spasticity in the ankle plantarflexors results changes in ankle ROM, causing knee hyperextension at initial contact due to a lack of an antagonist muscle force (Higginson et al., 2006). While decreased ankle dorsiflexion ROM impedes the forward translation of the tibia over the foot, which leads to compensation at the knee and altered gait outcomes such as decreased step length, stride length, cadence, and walking speed (Ota et al., 2014). While this study showed no significant relationship between ankle ROM and the hemiparetic knee angles during stance phase of gait, ankle ROM of the ankle showed 53% variance for plantarflexion ROM, and 18.3% variance for dorsiflexion ROM on hemiparetic knee angles. As most of the participants presented with increased flexion of the knee rather than knee hyperextension during stance phase, it may show that a greater link with plantarflexion ROM and increased knee flexion.

5.10 Knee angles during stance phase of gait

In hemiparetic gait, knee hyperextension can occur during the heel strike/initial contact phase, loading response phase, and midstance phase (Richardson et al., 2012). Interestingly, the researcher only had one participant presenting with "true" knee hyperextension (less than anatomical zero) during gait. Although not "true" knee hyperextension, five participants presented with knee angles less than the norm during loading response (knee was more extended), and three participants had knee hyperextension during terminal stance phase. Regardless of the hyperextension being true or not, 40-60% of the stroke population present with hyperextension of the knee while walking (Cooper et al., 2012), which is similar to this researcher's findings. According to Balaban and Tok (2014) and Sheffler and Chae (2015), there are three distinctive knee patterns during stance phase in stroke patients: the first is increased flexion of the knee at initial contact, which is more commonly seen in the early poststroke period and is associated with poor quadriceps activation; the second is decreased knee flexion early on, followed by knee hyperextension in the later stance phases; and the third is excessive knee hyperextension throughout the entire stance phase, which is seen in more chronic stroke patients. The majority of participants presented with increased flexion of the knee in all the stance phases, with only decreased flexion of the knee in pre-swing. During pre-swing phase, all the participants had a more extended knee than the norm of 35-40°. This ties in with the early poststroke patients having increased flexion of the knee early on in stance phase.

5.11 Association between the ankle components assessed and knee hyperextension

Five participants presented with non-true knee hyperextension during loading response, and this may be due to lack of eccentric muscle strength of the tibialis anterior, while three participants presented with true knee hyperextension during terminal stance, which may be due to reduced eccentric gastrocnemius muscle strength, and all participants presented with non-true knee hyperextension in pre-swing, which may be influenced by both decreased gastrocnemius and tibialis anterior muscle strength.

Despite finding associations with dorsiflexion ROM and dorsiflexion muscle strength, both gastrocnemius and tibialis anterior muscle strength of the affected lower limb were not associated with the knee angles at initial contact, loading response, midstance, terminal, or pre-swing. During stance phase, most of the participants presented with increased knee flexion, and this may show a greater link between tibialis anterior muscle weakness and increased knee flexion. This is however contradictory to Cooper et al. (2012), who suggested that tibialis anterior is active in early stance phase of gait to control foot descent to the floor and control the loading response, and weakness of this muscle during these phases may contribute to knee hyperextension.

Plantarflexion and dorsiflexion ROM were also not associated with the knee angles at initial contact, loading response, midstance, terminal, or pre-swing in this study. This may be because passive ROM was measured in the study, and active ROM plays a greater role during walking. Literature suggests that decreased ankle ROM during stance phase of gait leads to the reduced ability to shift one's centre of mass, leading to instability and balance deficits during gait as it hinders the forward translation of the tibia over the foot, which leads to compensation at the knee and altered gait outcomes (An and Won, 2016; Ota et al., 2014).

The researcher confirmed dorsiflexion ROM and dorsiflexion muscle strength to be associated, which could suggest that if the tibialis anterior is strong enough, it may counteract the tone in the gastrocnemius and reduce the changes to ankle ROM into dorsiflexion. However, literature suggests that gastrocnemius spasticity causes reduced ankle dorsiflexion ROM as well as reduced plantarflexion muscle strength (Aggarwal et al., 2013; Ng and Hui-Chan, 2012), which is unsurprising as the gastrocnemius muscle is greater in size and can thus easily overpower the tibialis anterior muscle actions.

Tibialis anterior muscle tone had a strong and positive relationship to the hemiparetic knee angles during heel strike, terminal stance, and pre-swing phases, while gastrocnemius muscle tone was not significantly related to knee angles. The prevalence of spasticity post-stroke is suggested to be between 18 and 50% (Abolhasani et al., 2012; Singh et al., 2011). Literature suggests that increased muscle tone in gastrocnemius causes early contraction of the ankle plantarflexors at 'initial contact', pulling the tibia posteriorly while the femur travels forward, causing knee hyperextension (Balaban and Tok, 2014; Sheffler and Chae, 2015). However, this is not what the researcher found, as increased tibialis anterior muscle tone had a greater impact on the knee angles than gastrocnemius, but most of the participants presented with increased knee flexion during stance phase, and so increased gastrocnemius muscle tone may still play a greater role in knee hyperextension than tibialis anterior muscle tone, which is what we see in a clinical setting.

5.12 Summary of discussion

This chapter discussed the feasibility of this pilot study and the main findings of the study in relation to available literature. The next chapter concludes the study and give recommendation for the larger study.

Chapter 6 Conclusion and Recommendations

6.1 Conclusion

6.1.1 Aim of the Study

This pilot study's aim was to determine if the study design is feasible for a larger study to determine the association between ankle muscle strength, muscle tone, and joint range of motion, and hyperextension of the knee in hemiparetic stroke patients during gait stance phase. Due to the restrictions of the Covid-19 pandemic, permission to conduct research was restricted at some healthcare facilities, which reduced the study pool. Recruitment for 12 participants commenced in December 2020 and ended in October 2021 (ten months), with no more than two potential participants were identified at the same time, meaning that a cluster of testing could not be performed in a single visit. The outcome measures selected were easy to use and not time-consuming to administer, and the entire assessment took approximately twenty minutes to complete. The demographic information capture sheet lacked in additional information to understand the clinical presentation of the participant. The inclusion criteria were designed to not exclude too many potential participants from the study, but still not have other variables affect the results. However, there was a lack of participants (twenty five percent) presenting with knee hyperextension. The results of the data analysis suggests that there may be no association between muscle strength and range of motion of the ankle, and knee hyperextension during stance phase of gait. However, there was a correlation between tibialis anterior muscle tone and knee hyperextension. But conclusions cannot be drawn from these results based on the small sample size and the heterogeneity of the participants.

6.2 Limitations of the study and recommendation for future research

This being a pilot study, the researcher recommends that these results be considered with caution and not be generalised to the whole stroke population as this study was conducted with the purpose to precede a larger study. The smaller sample size may not have had a great enough statistical power to reduce a Type-II error. For a larger study, it is advised that a large catchment area is included and perhaps to include both private and public healthcare facilities.

In terms of the inclusion criteria, the criteria were designed to not exclude too many potential participants from the study, but still not have other variables affect the results. However, with the lack of participants (twenty five percent) presenting with knee hyperextension, it is advised that an additional inclusion criterion be that the participant should present with knee hyperextension on their hemiparetic side.

The demographic lacked information to accurately describe the participant’s current clinical picture and level of disability. Additional information should be added to the demographic capture sheet to gain a better clinical presentation of the participant. Type of stroke, cause of stroke and co-morbidities should be asked to gain the clinical features of the participant. Balance, mobility status and the functional level of the participant should be measured with appropriate outcomes measures.

In terms of the other instrumentation and outcome measures, the tester must ensure that their upper limb strength is greater than the strength of the participant’s affected and unaffected lower limbs when performing the handheld dynamometry muscle strength testing for greater reliability and validity of the outcome measure (Andrews and Bohannon, 2003). For the gait analysis recording, the camera should be placed on a tripod with wheels so that it is kept at the same angle and distance from the participant’s knee for the entire walk, for greater reliability and accuracy. The use of reflective markers as used in optoelectronic systems such as Vicon is more accurate and could be considered in place of plain coloured stickers (Van der Kruk and Reijne, 2018). It is also important to note that knee hyperextension occurs in individuals without hemiplegia as well, and care should be taken to measure the unaffected knee to establish a patient’s baseline as well as comparing them to the norm (Bains et al., 2019).

The researcher has shown feasibility of the methodology described in this study for a larger study to be conducted and we recommend that this research be conducted with modifications as stated above with a larger sample size to determine, during gait stance phase, the association between ankle joint function and knee hyperextension in hemiparetic stroke patients during gait stance phase.

6.3 Clinical/Practical Recommendations

Due to this study aimed to inform the methods for a larger study, the researcher does not recommend these findings for clinical practice. However, from the experience gained through data collection, the researcher recommends that the MTS is used over the MAS to test spasticity in this study due to its ability to determine dynamic muscle tone (Abolhasani et al., 2012) and to differentiate between the peripheral (soft tissue changes) and the neural contributions (overactive stretch reflex) of spasticity (Singh et al., 2011). Furthermore, the MTS is more effective than the Modified Ashworth Scale (MAS) in identifying spasticity and differentiating it from contracture (Glinsky, 2016). With the improvement and convenience of smartphones, a clinician is able to perform outcome measures such as ROM with an inclinometer application on their smartphone, and it has been found to be a valid and reliable tool to measure joint ROM and both easily accessible and inexpensive (Konor et al., 2012).

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Appendices

A. Phases of gait
B. Demographic capture sheet
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Appendix A – Phases of Gait:

Table 7.1 - The Joint Angles, Muscle Action and Ground Reaction Forces of the Pelvis, Hip, Knee, and Ankle During the Stance Phase of Gait: (Loudon et al., 1998; Chui et al., 2020)

Gait Phase	Joint angle and muscle action	Pelvis/Hip	Knee	Ankle
Heel strike	Joint angle	Level pelvis, 30° hip flexion, some degree of external rotation	0-5° knee extension	0° dorsiflexion
	Muscle action	Gluteus medius, hip adductors (eccentric), gluteus maximus (eccentric), hamstrings	Hamstrings (concentric), iliotibial band (eccentric), vastus lateralis, medialis and intermedius	Tibialis anterior, long toe extensors (pretibial muscles) (eccentric)
	Ground reaction force	Flexion moment (GRF vector lies anterior to the hip joint)	Passive extensor moment (GRF vector lies anterior to the knee joint)	Plantarflexion moment (GRF vector lies posterior to the ankle joint)
Loading response	Joint angle	Pelvic drop on contralateral side, 20-30° hip flexion, some internal rotation	15-18° knee flexion	0-10° plantarflexion
	Muscle action	Gluteus medius, tensor fascia latae (eccentric), gluteus maximus, hamstrings, adductor magnus (concentric)	Quadriceps (eccentric), some hamstring activation	Tibialis anterior, long toe extensors (pretibial muscles) (eccentric)
	Ground reaction force	The vertical GRF magnitude exceeds the body weight during this phase, and this is absorbed by the knee flexing and ankle plantarflexing, with the calcaneal tuberosity acting as a pivot point for the tibia and foot to move and allows the foot to pronate towards the ground to absorb the body weight and preserve forward momentum		
Midstance	Joint angle	Level pelvis, hip moves from 30° hip flexion to 10° hip flexion	0-5° knee flexion	8-10° plantarflexion moving into 5° dorsiflexion

	Muscle action	Gluteus medius (concentric), tensor fascia latae (concentric)	Early quadriceps activity (concentric)	Gastrocnemius and soleus (eccentric)
	Ground reaction force	Reduced demand on the hip extensors as the GRF vector lies posterior to the hip joint	Passive extensor moment (GRF vector lies anterior to the knee joint)	Dorsiflexion moment (GRF vector lies anterior to the ankle joint)
Terminal stance	Joint angle	Anterior pelvic tilt, 20° hip extension with external rotation and abduction	0° Extension	5-10° dorsiflexion
	Muscle action	Rectus abdominis, tensor fascia latae (eccentric),	Hamstrings (eccentric), gastrocnemius	Soleus, gastrocnemius (eccentric)
	Ground reaction force	Passive hip extensor moment (GRF vector lies posterior to the hip joint)	Passive extensor moment (GRF vector lies anterior to the knee joint)	Increased dorsiflexion moment (GRF vector lies further anterior to the ankle joint)
Pre-swing	Joint angle	Lateral pelvic tilt on the ipsilateral side, hip flexion with external rotation	35-40° knee flexion	20° plantarflexion
	Muscle action	Iliopsoas (concentric), hamstrings (eccentric), adductor longus (eccentric)	Rectus femoris (eccentric), popliteus (concentric)	Gastrocnemius and soleus (concentric) followed by tibialis anterior (concentric)
	Ground reaction force	The GRF vector passes through the hip joint	Passive flexor moment (GRF vector lies posterior to the knee joint)	The GRF vector is present at the metatarsophalangeal joints

Appendix B - Demographic Capture Sheet:

Demographic Capture Sheet	
Participant code	
Consent form signed (Y/N)	
Age	
Sex	
Physical home address	
Employment	
How many months has it been since your stroke?	
Which is your affected side? (left/right)	
What type of walking aid, if any, do you use when walking?	
Which is your dominant side? (which leg would you use to kick a ball with before you had your stroke?)	
Have been infected with covid-19? (Y/N)	
If yes, was it before or after your stroke?	
If after your stroke, has your stroke symptoms worsened since testing positive for covid-19?	
Height (to be measured during assessment)	
Weight (to be measure during assessment)	

Appendix C – Participant Data Capture Sheet:

Participant code:___________
Date:____________________

1. Muscle Strength Testing

Muscle group	**Unaffected side**			**Affected side**		
Ankle Dorsiflexors						
Ankle Plantarflexors						

2. Muscle Tone Testing

Muscle group	**First measure: movement through maximum passive ROM (R2)**			**Second measure: movement of the muscle group from its shortest to longest position using a rapid velocity stretch (R1)**			**R2-R1**			**Quality of muscle reaction X:**		
Ankle Dorsiflexors												
Ankle Plantarflexors												

3. Ankle Joint Range of Motion:

Joint range	**Unaffected side**			**Affected side**		
Ankle Dorsiflexion						
Ankle Plantarflexion						

Appendix D – Muscle Strength Testing of the Ankle (Cooper et al., 2012):

Muscle group	Patient position	Limb position	Manually stabilised body part	Dynamometer placement
Ankle dorsiflexors	Supine	Hip and knee extended	Lower leg proximal to ankle	Proximal to metatarsophalangeal joints on dorsal surface of foot
Ankle plantarflexors	Supine	Hip and knee extended	Lower leg proximal to ankle	Proximal to metatarsophalangeal joints on plantar surface of foot

Appendix E – Muscle Tone Testing:

Two measures of ROM are taken of the same muscle group, where ‘R2’ is the movement through maximum passive ROM at the slowest possible speed (V1), the second measure, ‘R1’, is the movement of the muscle from its shortest to longest position using a rapid-velocity stretch (V3) (Banky at al., 2019).

The ankle dorsiflexors and ankle plantarflexors will be test as follows:

Muscle group	**Patient position**	**First measure: movement through maximum passive ROM (R2) at slowest possible speed (V1)**	**Second measure: movement of the muscle group from its shortest to longest position (R1) using a rapid velocity stretch (V3)**	**Body part stabilised**
Ankle dorsiflexors	Supine with pillow under distal end of lower leg	Ankle dorsiflexed through full range	Ankle dorsiflexed through full range at a rapid velocity	Proximal to ankle on anterior surface of lower leg
Ankle plantarflexors	Prone with foot off plinth	Ankle plantarflexed through full range	Ankle plantarflexed through full range at a rapid velocity	Proximal to ankle on posterior surface of lower leg

Quality of muscle reaction is rated as follows: (Banky at al., 2019)

- 0: No resistance throughout the course of the passive movement
- 1: Slight resistance through the course of passive movement; no clear ‘‘catch’’ at a precise angle
- 2: Clear catch at a precise angle, interrupting the passive movement, followed by release
- 3: Fatigable clonus (10s when maintaining the pressure) appearing at a precise angle
- 4: Un-fatigable clonus (more than 10s when maintaining the pressure) at a precise angle
- 5: Joint is immovable

Appendix F – Ankle Range of Motion Testing

Wall lunge test procedure:

The participant will be placed standing in front of a wall, they will use the wall as a support, and then be asked to lunge their knee as far as possible over their foot without the heel lifting off the floor. An inclinometer will be placed on the anterior aspect of the tibia, and at the maximum lunge point the angle of the tibia to the vertical will be recorded to measure of ankle dorsiflexion ROM. The participant was allowed to hold the wall to assist with their balance and a second person could be made available to assist the participants to help with fear or confidence.

Ankle plantarflexion ROM procedure:

Ankle plantarflexion ROM will be tested by asking each participant to maintain a long sitting position on a plinth. A pillow will be placed under the distal tibia to allow the fibula to be parallel to the surface of the plinth and to allow terminal knee extension. A mark will be made on the patient using a marker pen posterior to the proximal head of the fifth metatarsal. The inclinometer will be calibrated to the surface of the plinth, and the phone is then held in line with the fifth metatarsal, the patient's foot is then asked to plantarflex, and the measurement is taken. If the participant was unable to plantarflex in a gravity-dependent position, the test was modified to a side-lying position.

Appendix G - Video Capturing of Gait over Ten Metres:

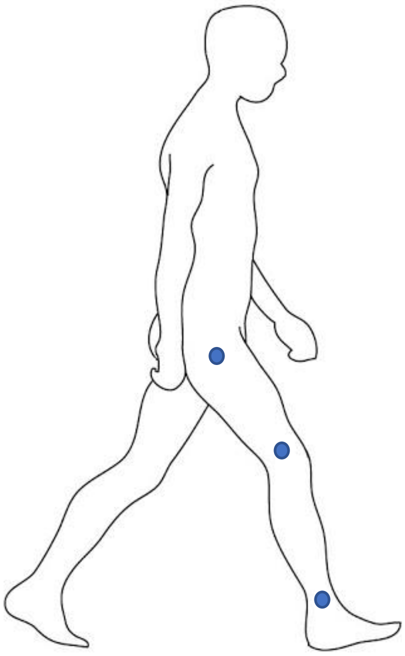

Figure 7.1 - Marker placement on participants to mark specific landmarks

<u>Appendix H – Information Sheet:</u>

Study Information Sheet

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Title: The Association Between Ankle Joint Function and Knee Hyperextension During the Stance Phase of Gait in Hemiparetic Stroke Patients – Information Sheet

Dear:____________________

Good day, my name is Catherine, and I am currently completing my Masters in Physiotherapy at the University of the Witwatersrand. Part of completing my degree includes a study in an area of interest. I would like to invite you to participate in my study, which is concerned with the effects the association between knee hyperextension (bending backwards) and factors affecting the ankle joint when walking in individuals who have suffered a stroke.

Why am I doing this study?

The study is part of my masters of physiotherapy degree requirements at the University of the Witwatersrand. I want to add to the existing research in this area, that looks at why some individuals who have suffered a stroke will walk with knee hyperextension (bending backwards), and this research will help to show healthcare professionals working in this field which factors of the ankle joint have an association with knee hyperextension, which can help to develop treatment protocols for managing and preventing knee hyperextension in individuals following a stroke.

What will you have to do if you agree to take part?

I will visit you at the hospital where you are currently being treated. I will organise with you and your treating physiotherapist an appropriate date and time to assess you. Once you have read through the information sheet and asked any questions that you want to ask, you will sign the information sheet and consent form.

How much of your time will participation involve?

The study involves a once-off assessment, which will not be longer than 30 minutes.

Will your participation in the project remain confidential?

If you agree to take part, you will be assigned a participant code and your name will not be recorded on the assessment forms and results – instead your code will be used, and your information will not be disclosed to other parties. You can be assured that if you take part in the project your identity will remain anonymous. All data collected in the course of the study will be securely retained for two (2) years, if a scientific publication arises from the study and six (6) years if there is no publication. Thereafter it will be destroyed accordingly.

What are the advantages of taking part?

You may find the study interesting and relevant to you. Once the study is finished it could provide information about the effects of factors affecting the ankle joint which are associated with knee hyperextension, and will add new information to the existing body of research, and may be used in further research into developing and modifying existing treatment approaches.

Are there any disadvantages of taking part?

Your safety and comfort are very important, and steps have been taken to ensure there is minimal risk of falling or injury if you are assessed for the study. If you are experiencing any pain in your knee, it is important to have it assessed and treated by either your Physiotherapist or by a doctor. The tests that will be completed in this study should not cause any pain to your knee or ankle, however, if you experience any pain during the assessment please inform me, and I will, with your permission, contact your doctor at the facility where you are currently being treated and inform them. If you do not have a doctor who is currently seeing you, please see below contact details of general practitioners close to you:

- Umhlanga Hospital Medical Centre (Umhlanga) – Drs Ferreira, Troskie and Broughton
  Contact details: 031 582 5303, admin@umhlangagp.net
- Nurture iLembe (Ballito) – Dr MJ van Jaarsveld
  Contact details: 032 648 0015

Do you have to take part in the study?

No, your participation in this project is entirely voluntary. If you do not wish to take part, you do not have to give a reason and you will not be contacted again. Similarly, if you do agree to participate you are free to withdraw at any time during the project if you change your mind.

What happens now?

You will be assessed at a time which suits you and your treating physiotherapist. I will conduct the assessments and record your data. You will be asked to complete a questionnaire, and then I will test the muscle strength of the muscles in your ankle, the muscle tone of the muscles in your ankle, and test the range of movement of your ankle joint. Lastly, you will be asked to walk a distance of 10 metres with or without an assistive device. You will be recorded with a camera while you are walking. Only your lower body will be recorded, and your face will not be included in order to protect your identity.

Covid-19 Considerations:

The global pandemic Sars-CoV-2 (also known as the coronavirus/covid-19) has resulted in 16 million infections, over 650 thousand deaths and 10 million recoveries worldwide (WHO, 2020). Primarily, the virus causes respiratory and cardiovascular symptoms, but neurological complications can also occur. New evidence has emerged that the coronavirus can cause neurological complications such as a stroke or worsening the effects of a stroke that a person has previously suffered.

There is an available pamphlet on coronavirus and neurological complications – please ask me if you are interested.

Ethical Clearance:

This study has been approved by the Human Research Ethics Committee (Medical) of the University of the Witwatersrand, Johannesburg (“Committee”). A principal function of this Committee is to safeguard the rights and dignity of all human subjects who agree to participate in a research project and the integrity of the research.

If you have any concern over the way the study is being conducted, please contact the Chairperson of this Committee who is Professor Clement Penny, who may be contacted on telephone number 011 717 2301, or by e-mail on Clement.Penny@wits.ac.za. The telephone numbers for the Committee secretariat are 011 717 2700/1234 and the e-mail addresses are Zanele.Ndlovu@wits.ac.za and Rhulani.Mukansi@wits.ac.za

Thank you for reading this Study Information Sheet.

[December 2020]

Researcher:

Catherine Cawood, Master of Physiotherapy student from the University of the Witwatersrand

Contact details: 071 955 5517, email: cathcawood@gmail.com

Supervisor:

Miss Kholofelo Mashola, School of Physiotherapy, University of the Witwatersrand

Contact details: 011 717 3702, email: Kholofelo.mashola@wits.ac.za

Appendix I –Consent Form:

Faculty of Health Sciences
Physiotherapy department

6.3.1 Consent form – Participation in the study: *The Association Between Ankle Joint Function and Knee Hyperextension During the Stance Phase of Gait in Hemiparetic Stroke Patients*.

1. I have been given a Participant Information Sheet which explains the nature and processes involved in this study, which is attached hereto;
2. I was given time to read it, or had it read to me, in the language I best understand;
3. I was given time to ask any questions I wanted to and found any answers given to me to be reasonable and satisfactory;
4. I believe I fully understand why the study is being conducted and what the intended outcomes will be;
5. I understand that there will be no immediate benefit to me, should I agree to participate, nor will I receive any payment; conversely, participation will not cost me anything but my time;
6. I understand that, even if I initially consent to take part in the study, I may subsequently withdraw at any time and would not be required to give any reasons; if that happened, any data collected about me for the purposes of the study would immediately be destroyed, unless I give consent for it to be retained
7. I have been given a range of contact details, listed below. If I require further information or become concerned about any aspect of this study, I am free to speak to any of these contacts.

I, ______________________________ hereby give University of the Witwatersrand Masters Physiotherapy student Catherine Cawood my permission to assess me as part of her study on the association between knee joint hyperextension and factors affecting the ankle joint during the stance phase of gait in hemiparetic stroke patients.

I give Catherine Cawood permission to video me while walking a short distance. My face will not be included and to footage will not be distributed to a third party and will only be utilised for the purposes of this research study only.

I give Catherine Cawood permission to utilise my information for the purposes of this research study only.
I fully understand the nature of this study and what will be required of me.

Researcher:

Catherine Cawood, Master of Physiotherapy student from the University of the Witwatersrand
Contact details: 071 955 5517, email: cathcawood@gmail.com

Supervisor:

Miss Kholofelo Mashola, School of Physiotherapy, University of the Witwatersrand
Contact details: 011 717 3702, email: Kholofelo.mashola@wits.ac.za

Ethics Committee Contact Details:

Professor CB Penny, Chairperson of the Human Research Ethics Committee (Medical) at the University of Witwatersrand, on telephone no. 011 717 2301, or by e-mail at Clement.Penny@wits.ac.za.
Ms. Z Ndlovu or Mr Rhulani Mkansi, Committee Secretariat, telephone nos.: 011 717 2700 or 1234, or by e-mail at: Zanele.Ndlovu@wits.ac.za or Rhulani.Mkansi@wits.ac.za

Name of Participant: ___________________
Signature/mark: ________________
Date: ____________________
Place: ____________________

Witnessed by:
Name of Witness: ___________________
Signature: ________________
Date: ____________________

Appendix J – Ethical Clearance Certificate:

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

R14/49 Ms C Cawood

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
CLEARANCE CERTIFICATE NO. M200916

NAME: (Principal Investigator)	Ms C Cawood
DEPARTMENT:	School of Therapeutic Sciences Department of Physiotherapy Medical School University
PROJECT TITLE:	The association between ankle joint function and knee hyperextension during the stance phase of gait in hemiparetic stroke patients
DATE CONSIDERED:	2 October 2020
DECISION:	Approved unconditionally
CONDITIONS:	Approval applies to those study sites listed in Annex 1 to this Clearance Certificate Others may be added on receipt by the HREC (Med) of evidence of management approval
SUPERVISOR:	Ms K Mashola
APPROVED BY:	CB Penny Dr CB Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	23 November 2020

This clearance certificate is valid for 5 years from the date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary on the 3rd Floor, Phillip Tobias Building, Parktown, University of the Witwatersrand, Johannesburg.
I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to submit details to the Committee. **I agree to submit a yearly progress report**. When a funder requires annual re-certification, the application date will be one year after the date when the study was initially reviewed. In this case, the study was initially reviewed in **September** and will therefore reports and re-certification will be due early in the month of **September** each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Cawood
Principal Investigator Signature

23/11/2020
Date

Annex 1

Protocol No. M200916

List of approved study sites

1. Rehab Matters Durban
2. Nurture iLembe

Dr CB Penny
Chair: HREC (Medical)
University of the Witwatersrand, Johannesburg

Date: 2020/11/23

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG	HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

2021/09/27

Ms C Cawood
School of Therapeutic Sciences
Department of Physiotherapy
Medical School
University

Sent by e-mail to: cathcawood@gmail.com

Dear Ms Cawood

Re: **Protocol Ref No:** M200916
Protocol Title: *The association between ankle joint function and knee hyperextension during the stance phase of gait in hemiparetic stroke patients*
Principal Investigator: Ms C Cawood

Thank you for your letter of 2021/09/06.

Your progress report has been noted and accepted.

Thank you for keeping us informed.

Yours Sincerely

I. Burns

....

Mr I Burns
For the Human Research Ethics Committee (Medical)

CB Penny

....

Dr CB Penny, Chairperson, Human Research Ethics Committee (Medical)

Appendix K – Signed Permission Letters:

Faculty of Health Sciences
Physiotherapy department

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

05/11/2020

To the Clinical Manager

I am a master's student of physiotherapy from the University of the Witwatersrand, looking to conduct research at your hospital.

I would like to request permission to go ahead with this study, which would involve assessing the association between knee joint hyperextension and factors affecting the ankle joint during the stance phase of gait in hemiparetic stroke patients using a cross-sectional observational study design.

Please find attached an information sheet explaining the type of research I would like to conduct at this hospital.

Any feedback would be much appreciated, and if you have any questions, please do not hesitate to contact me.

This study has provisional approval from the Human Research Ethics Committee (Medical) of the University of the Witwatersrand, Johannesburg ("Committee"), subject to obtaining permission from the relevant authorities at the hospital sites where the study will be conducted. A principal function of this Committee is to safeguard the rights and dignity of all human subjects who agree to participate in a research project and the integrity of the research.

If you have any concern over the way the study is being conducted, please contact the Chairperson of this Committee who is Professor Clement Penny, who may be contacted on telephone number 011 717 2301, or by e-mail on Clement.Penny@wits.ac.za. The telephone numbers for the Committee secretariat are 011 717 2700/1234 and the e-mail addresses are Zanele.Ndlovu@wits.ac.za and Rhulani.Mukansi@wits.ac.za

Many thanks,

Researcher:

Catherine Cawood, Master of Physiotherapy student from the University of the Witwatersrand
Contact details: 071 955 5517, email: cathcawood@gmail.com

Supervisor:

Miss Kholofelo Mashola, School of Therapeutic Sciences, Department of Physiotherapy, University of the Witwatersrand
Contact details: 011 717 3702, email: Kholofelo.mashola@wits.ac.za

I, Carmen Reed , hereby grant University of the Witwatersrand Masters Physiotherapy student Catherine Cawood permission to use *Rehab Matters Durban* as a study site to complete her study titled: *The Association Between Ankle Joint Function and Knee Hyperextension During the Stance Phase of Gait in Hemiparetic Stroke Patients*.

Signature:

Date: 6/11/2020

Place: Sandton

Faculty of Health Sciences
Physiotherapy department

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

09/11/2020

To the Clinical Manager

I am a master's student of physiotherapy from the University of the Witwatersrand, looking to conduct research at your hospital.

I would like to request permission to go ahead with this study, which would involve assessing the association between knee joint hyperextension and factors affecting the ankle joint during the stance phase of gait in hemiparetic stroke patients using a cross-sectional observational study design.

Please find attached an information sheet explaining the type of research I would like to conduct at this hospital.

Any feedback would be much appreciated, and if you have any questions, please do not hesitate to contact me.

This study has provisional approval from the Human Research Ethics Committee (Medical) of the University of the Witwatersrand, Johannesburg ("Committee"), subject to obtaining permission from the relevant authorities at the hospital sites where the study will be conducted. A principal function of this Committee is to safeguard the rights and dignity of all human subjects who agree to participate in a research project and the integrity of the research.

If you have any concern over the way the study is being conducted, please contact the Chairperson of this Committee who is Professor Clement Penny, who may be contacted on telephone number 011 717 2301, or by e-mail on Clement.Penny@wits.ac.za. The telephone numbers for the Committee secretariat are 011 717 2700/1234 and the e-mail addresses are Zanele.Ndlovu@wits.ac.za and Rhulani.Mukansi@wits.ac.za

Many thanks,
Researcher:

Catherine Cawood, Master of Physiotherapy student from the University of the Witwatersrand
Contact details: 071 955 5517, email: cathcawood@gmail.com

Supervisor:

Miss Kholofelo Mashola, School of Therapeutic Sciences, Department of Physiotherapy, University of the Witwatersrand
Contact details: 011 717 3702, email: Kholofelo.mashola@wits.ac.za

I, Pamela Groenewald_______________, hereby grant University of the Witwatersrand Masters Physiotherapy student Catherine Cawood permission to use *Nurture iLembe* as a study site to complete her study titled: *The Association Between Ankle Joint Function and Knee Hyperextension During the Stance Phase of Gait in Hemiparetic Stroke Patients.*

Signature: _______________

Date: 11/11/2020__________

Place: Nurture iLembe________

Appendix L – Infographic Coronavirus Neurological Complications:

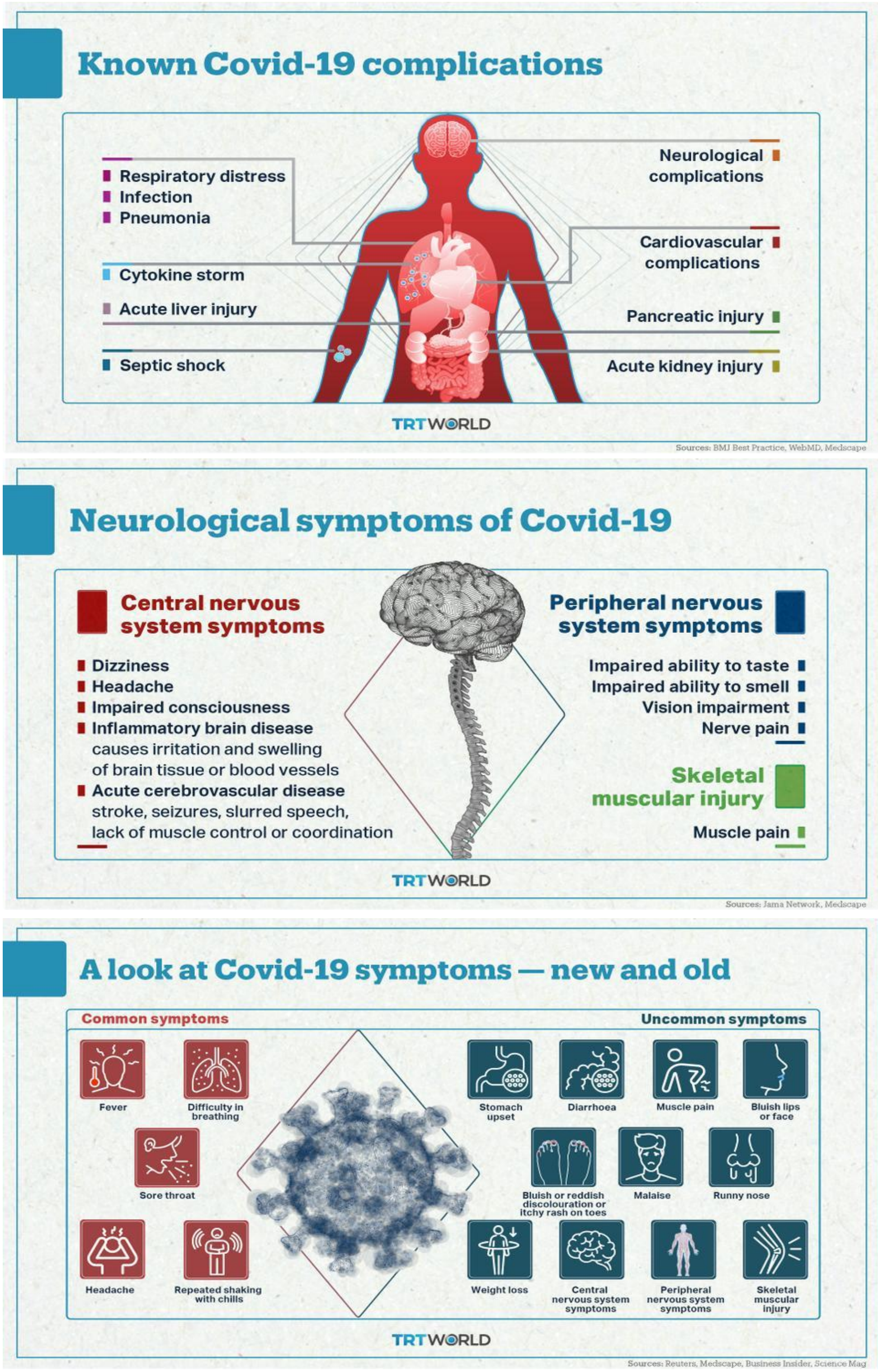

Figure 7.2 - Infographic Coronavirus Symptoms and complications

Appendix M – Budget:

Table 7.2 - Detailed budget of the proposed study

Description of item	Cost of item (R)	Number/amount required	Number/ amount purchased	Total cost (R)
Telephone costs				
MTN voice bundle	R135.00 (100 minutes talk time)	10 minutes per telephonic call to rehabilitation unit therapists to enquire about patients who fit inclusion criteria (20x10 mins= 200 mins) Total= 200 mins		R270.00
Printing and Stationery				
Printing - (Student pricing https://www.wits.ac.za/mywits/printing/) - Demographic capture sheet (1 page), Participant data capture sheet (1 page), information sheet (3 pages), consent form (1 page), letters to hospitals/units (1 page), infographic coronavirus (1 page) - 60 participants	43 cents per sheet (A4 single sided, black and white) R2.99 per sheet (A4 single sided, colour)	Outcome measure assessment forms, information sheet, consent form printed in black and white - 360 pages Permission letter printed in colour – 1 page x 4 copies Infographic printed in colour – 1 page x 40		R154.80 + R11.96 + R119.60 = R286.36
Measuring tape 10m – Builder's	R98.00	1		R98.00
Colour stickers 19mm – Makro	R17.80 (250 per box)	1		R17.80
Marker pen - Makro	R10.80	1		R10.80
Equipment				
Handheld dynamometer	R0.00 (Wits Physiotherapy Department may be able to provide) R22 550.35 BioFET (HiTech Therapy) R20 500.00 BioFET (3J Medical)	1		R0.00

	R49 666,20 microFET 2 digital dynamometer (Mobility Solutions)			
Instruments owned by research: - Inclinometer - Goniometer - Scale (bathroom scale) - Video recorder – researcher's phone - Kinovea Software (researcher's computer) – free software	R0.00	1		R0.00
Petrol and Transport				
Petrol and transport costs	SARS travel rate = R3.98 per km	Travel to Life Entabeni Hospital: 17km, travel to Nurture iLembe: 25km, travel to Highway Subacute and Rehabilitation Hospital: 47km x 1 trip to each facility per week x 6 months (24 weeks)		89km x 24 weeks x R3.98 = R8501.28
Personal protective equipment				
Box of gloves	R100.95 ARO Latex Gloves (1 x 100's)	1		R100.95
Box of surgical masks	R500.00 3-Ply Surgical Mask 50 pcs	1		R500.00
Plastic aprons	R89.95 ARO Disposable Aprons (100 per packet)	1		R89.95
Alcohol sanitiser	R99.95 Dismed D-germ Alcohol & Chlorhexidine Hand Rub 500ml	1		R99.95

Paper towel to wipe down equipment and surfaces	R17.45 ARO Roller Towels White (1 x 2's)	1		R17.45
Face shield	R0.00 (owned by researcher)	1		R0.00
Grand Total:				**R9 992.54**

Appendix N – Turnitin Report:

Cawood C 808850 Research Report

ORIGINALITY REPORT

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Appendix O – Study Protocol:

Research Report Protocol Submission

The Association Between Ankle Joint Function and Knee Hyperextension During the Stance Phase of Gait in Hemiparetic Stroke Patients

Student: Catherine Cawood 808850

Supervisor: Miss Kholofelo Mashola, School of Physiotherapy, University of the Witwatersrand

Table of Contents

1. Background and Need

1.1 Introduction

Restoration of walking is one of the main physiotherapy goals for many patients following a stroke, in order to be more functional in daily life and allow for greater community participation (Cooper et al., 2012). Sixty to 80% of stroke survivors can walk independently by six months following a stroke (Veerbeek et al., 2011). However, stroke survivors are often left with functional limitations such as changes in joint range of motion (ROM), muscle tone, motor control, muscle strength, and sensation (Lucareli and Greve, 2008). These functional limitations result in reduced standing balance, increased energy expenditure, joint deformity, pain, and muscle wasting (Cooper et al., 2012), which all then impact on the individual's gait.

The stance phase of gait can be described as the moment when the foot is in contact with a surface and includes the 'weight acceptance' phase and the 'single limb support' phase (Richardson et al., 2012). These two phases can be further classified into 'initial contact' and 'loading response' in the weight acceptance phase, and 'midstance', 'terminal stance' and 'pre-swing' in the single limb support phase. According to Li et al. (2018), individuals with stroke usually present with a shorter stance phase and increased swing phase on the hemiparetic side. Throughout the single limb support phase, the knee remains extended, although there is a small amount of knee flexion that occurs early in the stance phase (Balaban and Tok, 2014). In hemiparetic gait, knee hyperextension can occur during the heel strike/initial contact phase, loading response phase, and midstance phase (Richardson et al., 2012).

Knee hyperextension can be described as extension of the hemiparetic knee past 'anatomical zero' (Cooper et al., 2012). According to Cooper et al. (2012), 40 to 60% of the stroke population present with hyperextension of the knee while walking, although there is no clear consensus as to the cause of hyperextension of the knee. There is evidence that the ankle joint plays a role in knee hyperextension, with a number of factors causing altered ankle joint functioning that have an impact on the knee joint in stroke patients during gait (An and Won, 2016). Increased muscle tone in the ankle plantarflexor muscles causes early contraction of the ankle plantarflexors at 'initial contact', pulling the tibia posteriorly while the femur travels forward, causing knee hyperextension (Sheffler and Chae, 2015). Spasticity in the ankle plantarflexors (and even shortening of the Achilles tendon) may result in changes in ankle ROM, causing knee hyperextension at initial contact due to a lack of an antagonist muscle force (Higginson et al., 2006). Reduced ankle ROM during stance phase of gait leads to the reduced ability to shift one's centre of mass, leading to instability and balance deficits during gait as well as soft tissue changes of the connective tissue and muscles of the ankle leading to biomechanical changes in gait (An and Won, 2016). Maximal ankle dorsiflexion of ten degrees is achieved at midstance phase of gait, and terminal stance phase (Ota et al., 2014). However, reduced dorsiflexion ROM hinders the forward translation of the tibia over the foot, which leads to compensation at the knee and altered gait outcomes such as decreased step length, stride length, cadence, and walking speed (Ota et al., 2014). Less than eight degrees of ankle dorsiflexion during stance phase of gait leads to changes in knee biomechanics and gait parameters (Ota et al., 2014).

Muscle weakness of the quadricep, hamstring, and both ankle dorsiflexor and plantarflexor muscles of the hemiparetic lower limb has been shown to have an impact on hyperextension of the during stance phase of gait (Sheffler and Chae, 2015; An and Won, 2016; Cooper et al., 2012). Weakness of the quadricep muscles leads to reduced weight bearing ability (Cooper et al., 2012) while weakness of the hamstring muscle has an influence on knee hyperextension, especially if there is spasticity in the quadricep muscle of the hemiparetic lower limb (Springer et al., 2013). The gastrocnemius and hamstring muscles are thought to work in tandem, during the stance phase of walking, to prevent rapid hyperextension of the knee, but the exact action of the gastrocnemius and hamstring muscles in stance phase of gait is not well demonstrated in literature (Springer et al., 2013; and Sheffler and Chae, 2015). Cooper et al (2012) suggest that tibialis anterior muscle weakness may also contribute to knee hyperextension during stance phase of gait, as the ankle dorsiflexor muscles are active in early stance phase of gait to control foot descent to the floor and control the loading response.

During stance phase of gait, knee hyperextension can allow individuals with stroke a certain amount of stability and provide a mechanism to control their affected lower limb, however, there is a potential for injury to the posterior capsular and ligamentous structures which may lead to pain, ligament laxity, and bony deformity (Richardson et al., 2012; Cooper et al., 2012).

1.2 Problem Statement

During the stance phase of gait, knee hyperextension is common, both in acute and chronic patients with stroke. There is a current lack of consensus as to the cause of hyperextension of the knee during stance phase of gait in stroke patients (Cooper et al., 2012), despite the high rate of ambulating stroke patients presenting with knee hyperextension during gait (40 to 60%) (Cooper et al., 2012). Literature has reported a variety of possible factors that may cause knee hyperextension as mentioned above, however, it is not clear which of these factors affecting ankle joint function has the greatest impact on knee hyperextension. The goal for physiotherapy is to restore an efficient gait, where the patient is able to ambulate independently and safely. To do this, the physiotherapist must establish the causes of the patient's altered gait pattern in order to deliver the most effective and appropriate therapy. Hyperextension of the knee has the potential to negatively impact gait therapy, with a peak angle of 22 degrees of knee hyperextension gait (particularly in the stance phase of gait). This repeated abnormal hyperextension of the knee may cause injury to the posterior structures of the knee causing pain, ligamentous damage, and bony changes. This study therefore aims to investigate, during stance phase of gait, the association between ankle joint function and hyperextension of the knee in hemiparetic stroke patients.

1.3 Significance of the Study

Results from this study will add to the existing body of research, and may be used in further research into developing and modifying existing treatment approaches, and a treatment protocol for knee hyperextension in relation to ankle joint function in stroke patients can be designed which will effectively reduce knee hyperextension. Prevention and management of knee hyperextension in the stroke population will help prevent and minimise the development of knee pain as well as risk of injury to the posterior capsular and ligamentous structures of the knee, which will reduce the need for expensive orthoses, aids and surgery. Better understanding of the association of the factors affecting the ankle joint and hyperextension of the knee during gait in patients with stroke will lead to an improvement in targeted therapy techniques, and thus improve stroke survivors' outcomes in terms of walking speed, stride length, step length, and amount of support through hands needed. There is currently a dearth of literature on the association between ankle joint function and hyperextension of the knee in stroke patients during stance phase of gait, particularly in the South African population. This study will therefore provide research in a local population, as well as adding to existing research.

1.4 Research Question

What is the association between ankle joint function and hyperextension of the knee during the stance phase of gait in stroke patients with a hemiparetic gait pattern?

1.5 Aim of the Study

This study's aim is to determine the association between ankle joint function and hyperextension of the knee in the stance phase of gait in hemiparetic stroke patients.

1.5.1 Objectives of the Study

- To determine tibialis anterior and gastrocnemius muscle strength for ankle dorsiflexion and plantarflexion, respectively.
- To determine the muscle tone of the muscles of the ankle joint (tibialis anterior for ankle dorsiflexion, and gastrocnemius for ankle plantarflexion).
- To determine the joint range of motion of ankle dorsiflexion and plantarflexion.
- To analyse knee joint angles during the first three stance phases of gait (initial contact/heel strike, loading response, and midstance).
- To determine the association between the ankle joint components assessed and hyperextension of the knee in the stance phase of gait.

2. Methodology

2.1 Type of Study

A cross-sectional observational study.

2.2 Subjects

2.2.1 Source of Subjects

Participants of this study will be sourced from four rehabilitation units in Durban, South Africa. *Rehab Matters Durban* is an outpatient therapy unit providing physiotherapy, occupational therapy, and speech therapy neurorehabilitation services in the Umhlanga area. *Nurture iLembe* is a facility in the Ballito area, which provides acute and sub-acute inpatient and outpatient rehabilitation services. *Life Entabeni Hospital* is in Berea, Durban, and has a 312-bed capacity, with an additional 50 beds in the rehabilitation unit. *Medicross Highway Sub-acute and Rehabilitation Hospital*, in Hillcrest, is a 30-bed sub-acute facility which offers rehabilitation services for a wide range of conditions, including neurological conditions. Due to the Covid-19 pandemic, priority source of patients will be *Rehab Matters Durban* (as the researcher is employed at this outpatient practice) to limit travelling between multiple hospitals. Furthermore, only one facility will be visited on one day, in order to further minimise the risk of transmission to different facilities.

2.2.2 Sample Selection

Consecutive sampling will be used in this study where all patients at the abovementioned facilities, who fit the inclusion criteria, will be approached to take part in the study. Participants will be assessed at the facility where they are currently receiving inpatient or outpatient therapy. The following inclusion and exclusion criteria will be used to determine suitable participants for the study:

Inclusion Criteria

- Unilateral hemiplegia from a single clinical stroke,
- Able to walk independently (minimum of ten metres) either with or without an assistive device,
- No pathologies of the lower limb joints such as joint arthroplasty, fractures, osteoarthritis, or rheumatoid arthritis,
- Consenting adults (18 years and above)

Exclusion Criteria

- Unable to follow verbal instructions and demonstration

2.2.3 Sample Size Calculation

Von Hoorhis & Morgan (2007) suggests that for regression equations with at least six predictors, a sample of a minimum of 10 participants per variable is appropriate. This study will have six predictors as the three factors of the ankle being measured, ankle muscle strength, muscle tone and ankle ROM, are subdivided into ankle dorsiflexion and ankle plantarflexion components. Therefore, the sample size is collected to be 6 x10 participants per predictor variable = 60 participants.

2.3 Instrumentation and Outcome Measures

A demographic capture sheet (Appendix A) will be used to document data on the participant's age, gender, months since stroke, affected side, type of assistive device used when walking, dominant side, height, weight and covid-19 related questions (such as previous exposure and/or associated symptoms). The participant data capture sheet (Appendix B) will be used to document the information the below.

<u>2.3.1 Muscle strength of the muscles of the ankle:</u>

Ankle dorsiflexion and ankle plantarflexion muscle strength will be recorded using a handheld dynamometer (Appendix C). The test-retest and inter-rater reliability for handheld dynamometer testing were high in normal adult and in frail older population (Scott et al., 2004; Mentiplay et al., 2015).

<u>2.3.2 Muscle tone of the muscles of the ankle:</u>

Muscle tone will be assessed using the Modified Tardieu Scale (MTS) (Appendix D). The test-retest reliability and inter-rater reliability in patients with hemiparetic stroke was assessed by Li et al. (2014). Li et al. (2014) compared the Modified Ashworth Scale (MAS) and the MTS on the ankle plantarflexor and elbow flexor muscles. For the ankle plantarflexors, the MTS showed an inter-rater reliability of 0.82 while the MAS showed an inter-rater reliability of 0.48. The intra-rater reliability of the MTS for the ankle plantarflexors was 0.79 compared to the MAS, which was 0.48 (Li et al., 2014). The MTS showed an inter-rater intraclass correlation of 0.80 for R1 values, 0.88 for R2 values, and 0.62 for R1-R2 values (Li et al., 2014). The intra-rater intraclass correlation of 0.77 for R1 values, 0.75 for R2 values, and 0.66 for R1-R2 values (Li et al., 2014). Furthermore, Singh et al. (2011) found that the intra-rater reliability of the MTS was very good when measuring values for R1, R2, and R2-R1 of the ankle plantarflexors. The final MTS score (intraclass correlation coefficient > 0.85, P<0.0001) was very good for ankle plantarflexor muscle tone assessment over two different sessions. The MTS was therefore selected as the preferred reliable clinical tool to measure spasticity in ankle plantarflexors in this study.

2.3.3 Ankle joint passive range of motion:

A digital inclinometer will be used to assess the ankle passive joint ROM in this study (Appendix E). According to Konor et al. (2012), a digital inclinometer on a smartphone is one of the most valid and reliable tools to measure joint ROM and both easily accessible and inexpensive for the researcher. According to Konor et al. (2012), the results indicate that the digital inclinometer resulted in higher reliability coefficients (intraclass correlation coefficient = 0.96-0.99), while the goniometer had an intraclass correlation coefficient =0.85-0.96, and indicate that the digital inclinometer was more sensitive to ROM changes (minimal detectable change = 3.8°) compared to the goniometer (minimal detectable change = 7.7°). Vohralik et al. (2015) compared an inclinometer application installed on a phone (*iHandy Level*) and an inclinometer on ankle dorsiflexion ROM of 20 participants using a weight-bearing lunge test. The intra-rater and inter-rater reliability of both was assessed. Intraclass correlation coefficients of the digital inclinometer on a smartphone demonstrated excellent intra-rater (0.97) and inter-rater reliability (0.76). Both studies show excellent reliability of the test.

2.3.4 Video analysis of knee joint hyperextension during gait:

Kinovea movement analysis software (Appendix F) will be used to analyse knee hyperextension during gait. Kinovea is an open-access, 2D motion analysis software, which has been used in sports, research work, and in clinical settings (Puig-Diví et al., 2017). Puig-Diví et al. (2017) assessed the validity and reliability of angular and distance data measured using Kinovea movement analysis software. They simulated angles of the joints of the lower limb during walking and captured and analysed at four different perspectives – 45, 60, 75, and 90 degrees. The results indicate that Kinovea software is an accurate and reliable instrument when measuring angular and distance data up to five metres from the object and at an angle of 90 degrees.

2.4 Study Procedure

2.4.1 Pilot Study

In order to determine the feasibility of the data collection process in the main study, a pilot study will be conducted. It will also allow the researcher to determine the time taken to perform the tests. During the pilot study, any errors or difficulties will be evaluated, and the relevant changes made to the protocol to allow for the smooth running of the main study. The pilot study will be conducted at a single rehabilitation facility who grants permission for the study to be conducted. The sample size for the pilot study will be 10% of the total sample size (i.e. six participants), and their results will be included into the main study only if there are no changes and the key features of the of the main study are preserved in the pilot study.

2.4.2 Main Study

2.4.2.1 Participant Recruitment:

Physiotherapists working at the various rehabilitation hospitals or units will be asked to screen their patients for potential study participants, this would include determining if their patients fit the inclusion criteria for the study. Phone calls to the various locations will be done biweekly to attain the names and contact details of the patients who fit the inclusion criteria and to make appointments for the data collection. This will be done until the estimated sample size of 60 participants has been reached. On the day of the appointment, the researcher will explain the study and give all potential participants a study information sheet (see Appendix G) in the presence of the treating physiotherapist or unit manager (as a witness). The potential participants will be allowed to have time to read through the information sheet. The study will be explained to potential participants in a language that they understand. The researcher is fluent in English and Afrikaans and a translator will be made available should the participants not understand the abovementioned languages. Potential participants may also ask any questions they would like clarification on regarding the study. If the potential participants agree to participate in this study, they will sign a consent form and all their data will be recorded by the researcher (see Appendix H).

2.4.2.2 Data collection procedure:

2.4.2.2.1 Muscle strength testing of the ankle:

Each participant will be asked to do three isometric contractions (maximal) for both muscle groups being tested. The isometric contractions will be held for three seconds and the average of the maximal isometric contractions used for data analysis.

2.4.2.2.2 Muscle tone testing of the ankle:

The MTS identifies the point in the muscle's range where velocity-dependent spasticity occurs (Cerebral Palsy Alliance, 2018). The dynamic spasticity of a muscle is the relationship between

R1 and R2 and is calculated by subtracting R1 from R2. Three measurements will be taken, and the average of these measurements will be used for data analysis. The quality of muscle reaction is measured using a grading system (Fayazi et al., 2014) specified in Appendix D.

2.4.2.2.3 Ankle joint range of motion testing:

Three measures of the dorsiflexion lunge test and ankle plantarflexion ROM will be recorded, and for data analysis, the average of these measures of both tests will be used (Cox et al., 2018).

2.4.2.2.4 Video capturing of gait over a distance of ten metres:

Three coloured stickers will be placed on the participant's paretic lower limb: over the greater trochanter, over the lateral femoral epicondyle, and over the lateral malleolus (Cooper et al., 2012) (Appendix F). The participant will be asked to then walk, at their own chosen speed, a distance of ten metres. The camera will be placed less than five metres away from the participant with an angle of 90 degrees, at the level of their knee as they walk (Puig-Diví et al., 2017). The video will be imported into Kinovea movement analysis software and ankle, knee, and hip angles will be measured during initial contact, loading response, and midstance phases.

2.4.2.2.5 Data Management:

After all outcome measures have been completed, the data will be recorded on an Excel spreadsheet.

2.4.2.2.6. Health safety:

The researcher and the research assistant will adhere to the strictest infection control protocol and wear the required personal protective equipment. All equipment and working surfaces used during data collection will be sanitised before and after testing. The coloured stickers will not be reused and will be disposed of after each use.

Chapter 7 2.5 Novel Considerations

The global pandemic Sars-CoV-2 (also known as the coronavirus/covid-19) has resulted in 16 million infections, over 650 thousand deaths and 10 million recoveries (WHO, 2020). Primarily, the virus causes respiratory and cardiovascular complications, however, neurological complications also occur in patients with coronavirus and add to the morbidity and mortality (Bridwell et al., 2020). Acute cerebrovascular disease is one of the main neurological complications seen in covid-19 patients. According to Bridwell et al (2020), there are thought to be multiple factors which cause a stroke in covid-19 patients. The virus causes a widespread inflammatory response and the coagulability of the blood increases. In Italy, the rate of ischaemic stroke in hospitalised covid-19 patients was 2.5% with prophylactics for thromboembolism, whereas China was estimated to be 5%, and 3.7% in the Netherlands. Covid-19-related ischemic strokes have been seen in a younger population, with large vessel occlusion, and reduced cerebral oxygenation due to severe hypoxia in older patients (Bridwell et al., 2020). Participants in this study will be asked covid-related questions as part of the demographic information to be collected (Appendix A).

2.6 Ethical Considerations

Ethical clearance will be applied for from the University of the Witwatersrand Human Research Ethics Committee (HREC). Written permission to include potential participants will be obtained from the hospital manager and clinical heads of the rehabilitation units (Appendix I). Prior to commencing the study, written informed consent will be obtained from potential participants. Participants will be informed that they can withdraw from this study at any point, without any ramifications. The outcome measures used in this study will be performed in a safe, clinical setting, and will not pose harm to the participants. Participants will be made to feel comfortable, and no areas of the body will be unnecessarily exposed, and areas will only be exposed with the participant's consent and done so in a professional and respectful manner. Care will be made to ensure participants' safety by remaining close to the participant during the assessment session to ensure there is reduced risk of falling and injury and ensuring that the environment in which the assessment in taking place is well lit and free of any hazardous or obstacles. If the participants experience any pain at the affected knee during the assessment, the patient will be given the contact details of a general practitioner at the hospital where they are currently receiving therapy, or the nearest facility, if there is no general practitioner at that facility. The treating physiotherapist will also be notified about the participant's knee pain, if they are not aware of it already, for further management. The contact details of the general practitioners will be included in the information sheet.

The video recording will not include their face in order to protect their identity. Information collected during this study will only be used for the intended purpose of this study and no personal information relating to the participants will be divulged. All participants will be allocated a participant code. The researcher will keep possession of the key to the participant codes allocated.

In light of the Covid-19 pandemic, extra precaution will be taken to ensure participant safety. Any potential participants who present with signs and symptoms of Covid-19 such as fever, sore throat, shortness of breath, fatigue, loss of smell and taste, discolouration of fingers and toes (WHO, 2020) and with a travel history to high risk areas will only be assessed after a self-quarantine period of 10-14 days and a negative Covid-19 test.

3. Data Analysis

Statistical analysis will be performed with *Statistical Package for the Social Sciences* (SPSS) with significant level set at $p < 0.05$. Appendix K includes specific statistical tests for each objective.

4. Time Frame of the Project

	January-April 2020	May-July 2020	August 2020	November-December 2020	January-June 2021	July 2021	August - September 2021	October 2021
Proposal development								
Protocol submission								
Ethics application								
Pilot study								
Main study								
Data analysis								
Write up of research report								
Submission								

5. Budget

Funding for this study will be applied for from the *Medical Faculty Research Endowment Fund*, the *South African Society of Physiotherapy* as well as the *South African Neurological Rehabilitation Association.* See Appendix L for the budget of this study.

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Appendix P – Raw data:

MS Unaff DF	MS Unaff PF	MS Aff DF	MS Aff PF
15,67	12	5,33	6,33
13	15,33	7	11,67
20	14,67	9	8
13	26,67	7,33	17
13,33	13	9	9
10	13	10	8,67
4	4,83	0	8,67
8,67	12	4,33	8,67
12,33	13,67	2,67	0
13,33	11	5	7,33
7,33	8	6,33	7,33
9,33	11	7	8

R2 DF	R1 DF	R2-R1 DF	DF: Quality of muscle reaction
-4,33	-5	-0,67	0
-15,67	-16,67	1	1
8,33	-1	9,33	2
12,33	-5,33	17,67	2
1,67	-4,67	6,33	2
6,33	6,33	0	0
0	-4,67	4,67	2
8,67	-13,67	22,33	2
0	-9,33	9,33	4
-5,33	-15,67	10,33	2
9,33	10	-0,67	0
-9	-15,33	6,33	2

R2 PF	R1 PF	R2-R1 PF	PF: Quality of muscle reaction
45	44,67	0,33	0
45,33	45	0,33	0
36,33	36	0,33	1
39,67	36,67	2	1
38,67	34,67	4	1
38,33	38,67	-0,33	0
44,33	44	0,33	0
49,33	47,67	1,67	1
40	37	3	1
35	36	-1	0
49,67	50	-0,33	0
50	48,67	1,33	1

ROM Unaff DF	ROM Unaff PF	ROM Aff DF	ROM Aff PF
28,17	28,6	27,7	26,43
34,93	37,97	34,57	36,47
33,07	40,47	21,83	39,23
22,63	41,47	10,53	40,2
29,83	32,4	28,3	22,67
28,87	45,07	26,6	42,6
21,57	36,07	16,23	36,07
35,8	33,73	23,97	37,63
36,8	26,47	20,8	24,47
32,73	32,83	29,97	27,2
30,53	24,23	35,23	21,27
20,53	28,27	24,17	26,47

Knee angles: HS	LR	MS	TS	PrS
4,5	0,7	1,1	2	11,3
12,8	3,8	3,4	-7,4	19,9
4	16,7	25,7	22,9	17,5
11,6	13,2	7,7	19,3	23,3
14,1	26,8	24,7	24,3	23,5
6,1	21,9	22,1	10,2	20,7
13,9	14	13,2	14	21,7
21,3	29,9	22,4	14,7	19
18,3	16	19,4	18,8	24
-1,6	-3,3	-11,1	-5,4	13,7
14,3	17,5	6,5	-2,8	11,5
6,8	9,2	15,9	12,3	19
0-5°	15-18°	0-5°	0°	35-40°

Appendix Q – Data tables:

Table 7.3 - Age, height, weight, and months since stroke of study sample (distribution of data)

	Age in years	Height (cm)	Weight (kg)	Months since stroke
Mean	52.25	173.50	86.83	5.48
Std. Deviation	15.51	10.20	27.45	5.15
Skewness	.30	.65	2.33	.47
Std. Error of Skewness	.64	.64	.64	.64
Kurtosis	-.90	1.22	6.63	-1.70
Std. Error of Kurtosis	1.23	1.23	1.23	1.23
Range	50	39	108	12.75
Minimum	27	157	57	.25
Maximum	77	196	165	13.00

Table 7.4 – Muscle tone of the ankle distribution data (n=12)

	Min	Max	Mean	Std. Dev.	Skewness		Kurtosis		Kolmogorov-Smirnova		
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error	Statistic	df	Sig
R2 Dorsiflexion – Passive ROM	-15.67	12.33	1.028	8.46131	-.55	.64	-.39	1.23	.15	12	.20*
R1 Dorsiflexion – ROM with rapid stretch	-16.67	10.00	-6.25	8.53647	.58	.64	-.32	1.23	.18	12	.20*
R2-R1 Dorsiflexion	-.67	22.33	7.17	7.25799	.89	.64	.33	1.23	.17	12	.20*
R2 Plantarflexion – Passive ROM	35.00	50.00	42.64	5.32850	.14	.64	-1.46	1.23	.19	12	.20*
R1 Plantarflexion – ROM with rapid stretch	34.67	50.00	41.59	5.63211	.21	.64	-1.76	1.23	.21	12	.17
R2-R1 Plantarflexion	-1.00	4.00	.97	1.47345	.83	.64	.11	1.23	.25	12	.03

Min: minimum; max: maximum; Std. Dev.: Standard deviation

Table 7.5 – ROM of the ankle distribution data (n=12)

	Min	Max	Mean	Std. Dev.	Skewness		Kurtosis		Shapiro-Wilk		
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error	Statistic	df	Sig
ROM dorsiflexion (unaffected)	20.53	36.80	29.62	5.55	-.50	.64	-.96	1.23	-	-	-
ROM plantarflexion (unaffected)	24.23	45.07	33.97	6.46	.18	.64	-.91	1.23	-	-	-
ROM dorsiflexion (affected)	10.53	35.23	24.99	7.12	-.51	.64	.28	1.23	.95	24	.25

ROM plantarflexion (affected)	21.27	42.60	31.73	7.64	.01	.64	-1.83	1.23	.95	24	.33

Table 7.6 – Hemiparetic knee angles during the stance phases of gait distribution data (n=12)

	Minimum	Maximum	Mean	Std. Deviation	Shapiro-Wilk		
	Statistic	Statistic	Statistic	Statistic	Statistic	Df	Sig.
Initial contact	-1.6	21.3	10.51	6.61	.97	12	.87
Loading response	-3.3	29.9	13.87	10.03	.97	12	.94
Midstance	-11.1	25.7	12.58	11.29	.93	12	.37
Terminal stance	-7.4	24.3	10.24	11.06	.92	12	.25
Pre-swing	11.3	24.0	18.76	4.47	.90	12	.15