THE EFFECT OF A FOAM ROLLER INTERVENTION ON THE ANTERIOR AND LATERAL THIGH ON GLUTEAL MUSCLE ACTIVITY IN HEALTHY FEMALES

Lisé-Mari Kotzé

A Dissertation submitted to the Physiotherapy faculty, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Masters in Physiotherapy.

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Declaration

I Lisé-Mari Kotzé declare that this Dissertation is my own, unaided work. It is being submitted for the Master of Physiotherapy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

Lisé-Mari Kotzé

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Name of candidate Signature of candidate

_____30___ day of _______June______ 2024______ in Pretoria_____

Dedication

All honour and glory to God for providing every step of the way during this project.

To my wonderful husband, Neil for all your love and support. My sons, Paul and Daniël, I love you to the moon and back and triple infinity. Thank you for giving me cuddles and forgiving me when I was spending time away from you.

Thank you to my wonderful family and friends who helped with prayers and looking after my kids. This would not have been possible without your help.

For every patient, I have the privilege to treat.

For every participant who took time out of her busy life to participate in the study.

Abstract

Objectives: The primary purpose was to compare gluteal muscle activity, mediolateral knee movement during a single leg squat and thoracolumbar side flexion pre- and post-foam roller intervention of the anterior and lateral thigh.

Methods: Healthy, active females aged between 18-65 years were invited to participate in the study. Surface electrodes were placed on the gluteus maximus muscles to measure muscle activity before and after foam roller intervention. The foam roller intervention targeted the anterior and lateral thighs. Maximum voluntary isometric contraction (MVIC) was established for the gluteal muscle to express the post-intervention measurement as a percentage of the pre-intervention MVIC. Electromyographic (EMG) data were analysed using a root-mean-square algorithm. Qinematic software and a Microsoft Kinect camera were used to capture and analyse mediolateral knee movement during a single-leg squat and thoracolumbar side flexion range of motion.

Results: Twenty-seven (median 37(range 35-41) years old) participated in the study. Post-intervention a total of four of the participants had left gluteal activity of MVIC≥100% and five had right gluteal activity of MVIC≥100%. There was no significant difference in mediolateral knee movement between pre-and post-intervention ($p<0.05$). There was a significant difference between left thoracolumbar side flexion pre- and post-intervention ($p=0.027$). There was a significant difference between pre- and post-intervention for right thoracolumbar side flexion ($p=0.0459$).

Conclusion: A foam roller intervention of the anterior and lateral thigh increased the thoracolumbar side flexion range of movement. The intervention reduced gluteal muscle activity post-intervention in most participants and did not alter the mediolateral knee movement post-intervention during a single leg squat.

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List of Abbreviations

ASIS-Anterior Superior Iliac Spine

AIIS-Anterior inferior Iliac Spine

BFL-Back Functional Line

ITB-Iliotibial Tract/Band

IQR-Interquartile range

EMG-Electromyography

TFL-Tensor Fascia Latae

FR-Foam Rolling

LL-Lateral Line

MAP-Myofascial Activated Posture

MR-Myofascial Rolling

MVIC- Maximum Voluntary Isometric Contraction

MVC-Maximum Voluntary Contraction

RMS-Root Mean Square

SLS-Single leg squat

Chapter 1 Introduction

1.1 Background

This section explored the importance of foam rolling and gluteal musculature and the use of electromyography (EMG) in this process. This investigation aided the researcher in seeing if there was a possible link between gluteal muscle activity after a foam roller intervention of the anterior and lateral thigh in healthy females.

Foam rolling was defined as a form of self-massage of different areas of musculature (Wiewelhove et al., 2019). These areas were targeted by rolling and compression (Wiewelhove et al., 2019). Hughes and Ramer (2019), agreed that body weight and different positions determined the desired treatment pressure and that foam rolling may increase range of motion (ROM) and reduce muscle stiffness (Monteiro et al., 2019). A systematic review concluded that foam rolling can be used before a training session in combination with an active warm-up and dynamics stretching (Hendricks et al., 2020).

The exact underlying physiological and mechanical mechanisms of foam rolling are still unclear. Various possible mechanisms include a reduction in tissue adhesions, increased blood flow, altered tissue stiffness, altered viscoelasticity of facia, and possible associated trigger-point breakdown (Wiewelhove et al., 2019; Connolly et al, 2020). The effect on a global pain modulatory system within the central nervous system could also be considered (Aboodarda, Spence and Button., 2015).

Wiewelhove et al 2019 reported the largest effect of pre-rolling was a short-term improvement in flexibility. The authors considered the effect of foam rolling on the central modulatory system, where continued pressure on the soft tissue may lead to the overload of skin receptors (Aboodarda, Spence and Button., 2015). This led to a lessening of pain sensation and an increased stretch tolerance. They (Wiewelhove et al., 2019) found the greatest effect of foam rolling was decreased perceived muscle pain.

Foam rolling might alter the ROM by changing the surrounding fascia's thixotropic properties. Fascia is comprised of colloidal substances (Connolly et al., 2020). If left undisturbed it became thicker and more viscous. By using the foam roller this area was stimulated by mechanical stress and softened. Abnormal adhesions due to inactivity or repeated strain of the soft tissue might lead to a decrease in ROM (Connolly et al., 2020). The thixotropic properties might be restored further if these adhesions are reduced, resulting in hydrated fascia (Connolly, et al. 2020).

Gluteal weakness was associated with patellofemoral pain syndrome, chronic ankle instability, and anterior ligament sprains. Gluteal weakness might have influenced how the joint is loaded and the muscle control of the lower extremity (Heick et al., 2020). In support, Selkowitz, Beneck and Powers, (2016) stated that strengthening of the gluteus maximus muscle was incorporated in rehabilitation programs for Achilles tendinopathy, hamstring injuries, piriformis syndrome, and patellofemoral pain.

Willson et al. (2011) reported that there might be a gender bias that existed where females were twice as likely to develop patellofemoral syndrome and that one of the most published findings with patellofemoral pain syndrome was a decrease in hip strength. They included female runners with a report of knee pain with insidious onset which was present for two months and increased with manual compression of the patella into the trochlear groove with the knee in 15˚ of flexion. They ((Willson et al., 2011) found no difference in gluteus maximus onset time or activation duration. The study suggested potential neuromuscular training and movement-based feedback to improve altered hip and knee kinematics, and not only a muscle strengthening program.

Electromyography (EMG) provided details about motor unit activity within a muscle. This was used to observe differences in muscle activity between populations and compare therapeutic exercises' potential to recruit certain muscles (Distefano et al., 2009).

When investigating whether short-term gluteal activation enhanced muscle performance, a study of twenty-four semi-professional male rugby players was done (Cochrane et al., 2017). The intervention group performed gluteal activation exercises thrice weekly before normal training sessions. A unilateral maximum isometric squat and unilateral closed kinetic chain hip extension were done by the participants as part of the pre-and post-testing procedure. The unilateral hip extension force and EMG were not enhanced after six weeks (Cochrane, Harnett and Pinfold, 2017).

Parr, Price and Cleather, (2017) explained that the purpose of a warm-up was to prepare the body for activity and that the improved activation of specific musculature might improve the kinematics of movement and performance. Research supported that a warm-up protocol would increase ROM and decrease injury risk caused by vigorous activity or sport (Connolly et al., 2020). The effect of a gluteal activation warm-up on explosive exercise performance was done on seventeen elite rugby union players. The exercises they used as part of the activation warm-up were three minutes of cycling on a stationary bike, inch worm, bodyweight squats, leg swing for each leg, prone plank with hip extension, side plank with hip extension, and single leg squat. They used one set of six repetitions, except for a single leg squat they used one set of three repetitions on each side. There was a tendency for larger hamstring and gluteus maximus forces after the activation warm-up. They hypothesised an increase in corticomotor excitability due to potentiated gluteal musculature driving a stronger response to a given neural signal (Parr, Price and Cleather, 2017).

When considering the research mentioned above by Parr, Price and Cleather, (2017) a new study focused on hip adductor muscles, intending to improve ROM without compromising strength by comparing static stretching to self-myofascial release (Connolly et al., 2020). Maximum Voluntary Contraction (MVC) was recorded on an electronic dynamometer and hip abduction ROM on a Cybex Adductor/Abductor Machine (CAAM). An optimal stretch for assessment of ROM was rated as 7/10 on a stretch sensation scale, this rating by the participant ensured that the researcher did not inconsistently apply force during the study for measurement. The stretch was held for 30 seconds while the participant relaxed and slowly practised abdominal breathing. In this study, they used a five-minute warm-up on a cycle ergometer. The foam rolling technique had the participants positioned in a prone position, propped up on their forearms and the opposite leg acting as a stabiliser. The targeted muscle group was foam-rolled from the groin to the knee for 60 seconds in total while applying enough body weight pressure to elicit a sensation of 7/10 on the stretch sensation scale. They

(Connolly et al., 2020) concluded that both interventions increased ROM without compromising MVC and could be used in warm-up programs to increase flexibility.

1.2 Problem Statement

Gluteus maximus weakness or delayed activation could lead to potential musculoskeletal problems (Selkowitz, Beneck and Powers, 2016). Selkowitz, Beneck and Powers, (2016) also stated that there was a lack of kinematic data in combination with EMG in studies. Literature has shown a myofascial link between the gluteus maximus and anterior and lateral thigh structures (Antonio et al., 2013). There was little evidence to prove if foam rolling has an impact on the muscle activity of the gluteus maximus muscle by targeting the anterior and lateral thighs (Wiewelhove et al., 2019). Research has suggested that females have a higher rate of knee injuries than men with a predisposition to patellofemoral pain (Zawadka et al., 2020) and females might be twice as likely to develop patellofemoral syndrome than males (Willson et al., 2011).The lack of evidence investigating the impact of a foam roller intervention on a healthy female population encouraged this study.

1.3 Aims and Objectives

We rely on clinical reasoning and the available research to treat patients effectively.

The objectives of this study were to:

1. compare the muscle activity of the gluteal muscles during a maximum voluntary contraction, before and after foam roller intervention of the anterior thigh and hip.

2. compare the mediolateral knee movement during a single leg squat of the left and right leg before and after a foam roller intervention of the anterior thigh and hip.

3. compare the thoracolumbar side flexion range of movement to the left and right before and after a foam roller intervention of the anterior and lateral thigh and hip

1.4 Significance

This information would add to available knowledge. The results could be used to advise and treat patients in a clinical setting by giving accurate information on whether a dosage of 40 seconds of foam rolling per area will affect gluteal muscle activity. There were numerous methods to measure thoracolumbar flexion. This study will extract values for participants who are healthy, female and active, thus providing a range to be compared with when using a similar methodology. By investigating the kinematics of single-leg squat with a focus on mediolateral knee movement, information can be used to plan an evaluation and treatment if an individual presents with a dynamic knee valgus.

1.5 Outline of this Research Dissertation

This dissertation consists of six chapters, a reference section and seven appendices. The outline of the thesis is shown in Figure 1.1.

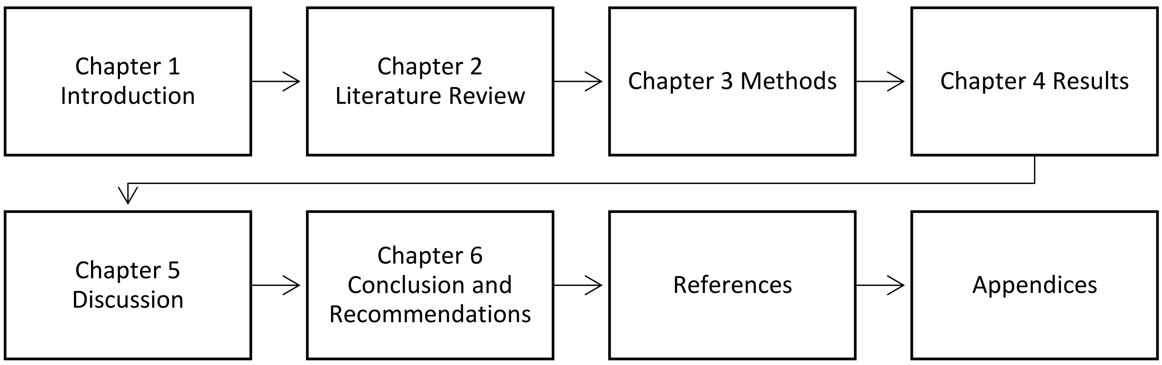

Figure 1.1. Outline of the thesis

Chapter 2 Literature Review

2.1 Introduction

This literature review will expand and guide you through the available research on fascial lines, anatomy and their connection with the gluteal musculature. Foam rolling and electromyography will be investigated, and limitations will be discussed.

2.2 Search Strategy

Two databases, PEDRO and Pubmed, were accessed via the University of the Witwatersrand's Health Sciences Library. Further articles were accessed on Google Scholar and the researcher's subscription to the Journal of Orthopaedic and Sports Medicine (JOSPT) was used. The researcher was assisted by librarians from the University of the Witwatersrand with interlibrary loans. Inter-library loans is a service available to registered students and staff of an institution to request books and articles, not available at their Home institution's libraries. Documents are requested from South African libraries as well as international libraries. It's governed by the Committee of Higher Education Libraries of South Africa agreement. Articles were selected in the English language. No inception date was imposed for publications. Publications until 22 June 2023 were considered. Boolean Operators were used during advanced searches with keyword combinations of foam rolling, fascia, gluteus maximus, gluteal muscle activity, electromyography, and surface electrode placement.

2.3 Anatomical connections between gluteal musculature and fascial lines

Delving deeper into the anatomy of various structures and their connections helped to put the puzzle pieces together and to see how one structure might influence another. The fascial system interpenetrates and surrounds all muscle, bones, organs and nerve fibres, endowing the body with a functional structure, and providing an environment that enables all body systems to operate in an integrated manner (Adstrum et al., 2017). The fascial system consists of the three-dimensional continuum of soft, collagen-containing, loose and dense fibrous connective tissues that permeate the body (Adstrum et al., 2017).

The Lateral Line (LL) creates side flexion in the body. This refers to lateral flexion of the trunk, abduction at the hip, and eversion of the foot. Postural compensation of this line may include genu varus and valgus or lumbar side bend limitations. Bony stations and myofascial tracks include 1st and 5th metatarsal bases, peroneal muscles, lateral crural compartment, fibular head, anterior ligament of head of the fibula, lateral tibial condyle, Iliotibial tract (ITB) /abductor muscles, Tensor fasciae latae (TFL), Gluteus maximus, Iliac crest, Anterior Superior Iliac Spine (ASIS), Posterior superior iliac spine, lateral abdominal obliques, ribs (Myers, 2009a, pp. 115–118).

The Back Functional Line (BFL) myofascial tracks and bony stations include the tibial tuberosity, subpatella tendon, patella, vastus lateralis, shaft of the femur, gluteus maximus, sacrum, sacral fascia, lumbodorsal fascia, latissimus dorsi and the shaft of the humerus. The BFL crosses the midline at the level of the sacrolumbar junction to connect with the opposite gluteus maximus fibres. Here, the lower fibres of the gluteus maximus pass under the edge of the ITB to attach to the posterolateral edge of the femur. There are fibres linking the vastus lateralis and gluteus muscle and in turn, fibres that connect to the patella (Myers, 2009b, pp. 171–172).

The gluteus maximus muscle originates from the ilium on the posterior gluteal line, on the dorsal surface of the sacrum and coccyx as well as the sacrotuberous ligament. Fibres attach to the gluteal tuberosity of the femur as well as the iliotibial band (ITB) that inserts into the lateral condyle of the tibia. The function of the gluteus maximus muscle is hip extension, hip abduction (Selkowitz, Beneck and Powers, 2016), hip lateral rotation, as well as knee stability in extension (Agur and Lee, 1999).

Antonio, et al. (2013) dissected six cadavers and found the gluteus maximus muscle is continuous with the TFL and the ITB. The TFL originates from the ASIS and the anterior part of the iliac crest. It attaches to the ITB (Agur and Lee 1999). Selkowitz, Beneck and Powers, (2013) expand that the TFL can influence the patella due to its attachment to the ITB, thus exerting a lateral force on the patella. They postulated that excessive internal rotation of the hip and lateral displacement of the knee might be linked to patellofemoral pain.

Research suggested that the gluteus maximus forms an important vector when considering knee movements and that an MRI demonstrated that a gluteal contraction caused a posteromedial displacement of the ITB (Antonio et al., 2013).

2.4 Effects of Foam Rolling

The exact physiology of foam rolling and the duration to affect change is still under debate. Initial myofascial rolling mechanisms suggested a reduction in fascial adhesions, improved fascial viscosity and mobility, and altered mechanoreceptor responses in the myofascial units (Connolly et al., 2020). Recently research suggested a global pain modulatory system in the central nervous system (Aboodarda, Spence and Button, 2015). A study (Aboodarda, Spence and Button, 2015) included in the systematic review (Hughes and Ramer, 2019) described a significantly smaller increase in pain experienced post-myofascial rolling intervention on the ipsilateral and contralateral limb, even though the intervention did not touch the contralateral limb. Aboodarda, Spence and Button (2015) described that psychological changes might be due to improved perceptions of recovery and well-being due to an activation of the parasympathetic response, an increase in plasma endorphins, and/or a placebo effect.

Hughes and Ramer (2019) conducted a systematic review that evaluated the available literature to investigate the optimum duration of foam rolling for recovery, performance, and ROM. They included 22 studies, where 17 measured ROM. Ten of 17 studies reported statistically significant ROM of some kind. The systematic review did not specify joints, but rather muscles treated. Twelve studies used a foam roller on the quadriceps muscles, and four targeted the iliotibial band. On completion, they could not recommend an optimal myofascial rolling time which improved ROM. However, they did recommend a minimum of 90 seconds to aid in muscle recovery and soreness

(Hughes and Ramer, 2019). In the following year, a systematic review was published recommending the optimum dose between 90-120 seconds for an improvement in flexibility (Hendricks et al., 2020). Flexibility was evaluated in eight of 49 studies. The flexibility was measured as part of recovery from a bout of exercise. Six of the eight studies found positive results for foam rolling improving flexibility. These studies included increased hip flexion ROM, knee flexion ROM, ankle dorsiflexion ROM and thoracolumbar mobility. A study (Macdonald et al., 2013) in the systematic review reported that effects lasted ten minutes post-application (Hendricks et al., 2020). This information was incorporated into the current study design when the retesting of the Maximum Voluntary Isometric Contraction (MVIC) was done immediately after the intervention in the 10-minute post-application period and the movement analysis was captured directly after the EMG measurement. The lack of evidence available on the impact of foam rolling on thoracolumbar side flexion ROM was evident in the literature and motivated the researcher to investigate.

When investigating if FR would alter hip adduction ROM, a different study targeted the ITB (D'amico, Silva and Gallo, 2021). Since long bouts (> 60 seconds) of static stretching may be detrimental to strength and power, foam rolling was chosen as an intervention tool. They used a counterbalanced, repeated measure design to assess how foam rolling the ITB would affect hip adduction ROM. The control treatment was a five-minute walk. The study showed that three sets of 20 seconds increased the hip adduction ROM measured by using the Ober's test. Secondly, they (D'amico, Silva and Gallo, 2021) found that the effect of the increase in range dissipated between three to ten minutes after the intervention.

2.5 Use, need and possible limitations of electromyography

Electromyography has been used as a research tool in different settings. It is important to reflect on how it has been used and its limitations when gathering data. The first four studies reflected on the use of EMG in assessing a change in activity and strength, followed by limitations and use in the current study's methodology.

An area of focus during knee joint rehabilitation was to enhance neuromuscular activation and to stimulate muscle hypertrophy to increase muscle strength (Andersen et al., 2006). They (Andersen et al., 2006) further elaborated that to gain muscle strength, muscle hypertrophy and enhance the neural drive to muscle fibres, heavy resistance exercise produces relatively high levels of neuromuscular activation.

An increase in strength during the early stages of resistance training is mostly attributed to neural changes (Cochrane, Harnett and Pinfold, 2017). The EMG amplitude has been reported to increase during resistance training with a parallel improvement in muscle performance. In the study they conducted with wireless surface EMG sensors they investigated 24 semi-professional male rugby players. They (Cochrane, Harnett and Pinfold, 2017) tested the MVIC in a closed chain hip extension position as they felt it was more sport appropriate making use of a hydraulic squat machine, portable force plate and 120˚ of hip and knee angle. Their gluteal intervention program three times per week consisted of seven exercises and lasted for 10 minutes. At the end of the study, they found no enhancement of EMG activity. They (Cochrane, Harnett and Pinfold, 2017) thought the reasons for this might be the hip and knee angle as the participants might have favoured Biceps femoris recruitment more than gluteus maximus and that the prescribed repetitions, sets, and frequency of the prescribed exercises using body weight were not appropriate to elicit significant changes during the six weeks of training (Cochrane, Hartnett and Pinfold, 2017).

The gluteus muscle can be divided into two portions inferior and superior (Selkowitz, Beneck, and Powers, 2016). The superior gluteus maximus showed the highest EMG signal amplitude during the clam exercise. A unilateral bridge resulted in an amplitude of 30% MVIC or greater for the superior portion. The inferior portion showed its highest EMG signal with a unilateral bridge exercise (Selkowitz, Beneck and Powers, 2016). Selkowitz, Beneck and Powers, (2013) conducted a study examining the relationship between the activation of TFL and the gluteal muscles. They developed a novel descriptive analysis in the form of the gluteal-to-TFL activation (GTA) index. They used this to compare the relative activation of the gluteal muscles and the TFL during specific exercises. They(Selkowitz, Beneck and Powers, 2013) found that the clam, sidestep and unilateral bridge demonstrated a GTA index of at least 50. This demonstrated a significantly greater normalized EMG in the superior gluteus maximus.

As with any tool, one must consider the recommendations and limitations. A limitation of surface EMG was cross-talk between muscle activity of adjacent muscles (Distefano et al., 2009). This was addressed by applying the electrodes and securing them to prevent movement and observation to ensure the electrodes were in position when collecting data. A second shortfall is the assumption that high EMG signal amplitudes represent large levels of muscle activity needed for muscle strengthening and further research in this area. EMG data was required to be combined with kinetic and kinematic data to enhance the interpretation of the differences in activity level among the exercises they researched (Distefano et al., 2009).

Boren et al. (2011) reported that Andrew Fry (2004) suggested that a higher percentage of MVIC values correlated with muscle hypertrophy. The study (Boren et al., 2011) recommended a front plank with hip extension with a 106 %MVIC, gluteal squeeze with an 81 %MVIC and a single leg squat at 71 %MVIC for gluteus maximus strengthening. In the next section, we will discuss the single leg squat and mediolateral knee movement.

2.6 Mediolateral knee movement and single leg squat

The single-leg squat (SLS) was a functional clinical test that could be used as part of the assessment of the lower limb, for screening and diagnosis (Weeks, Carty and Horan, 2012). Ressman, Barr and Grooten, (2020) also suggested that the SLS aimed to measure the medial displacement of the knee. A dynamic knee valgus was described where the knee moved medial to the foot in a loaded position. This dynamic knee valgus was characterised by foot pronation, tibial internal rotation, knee valgus, femoral internal rotation and an excessive pelvic drop. Female participants showed a higher internal rotation, hip adduction and knee valgus when doing a single-leg squat when compared to their male counterparts (Zawadka et al., 2020).

After a meta-analysis, researchers found that the visual assessment of the knee with the foot was valid and reliable for use in clinical and research settings for an asymptomatic adult population and video assessment increased the reliability

(Ressman, Grooten and Barr, 2019). Linking to the research on the use of a SLS in practice, Ageberg et al. (2010) investigated the validity and inter-rater reliability of mediolateral knee motion observed during a single limb mini squat. Here they focused on scoring a participant using either a knee-over-foot position or a knee-medial-to-toe position. A knee-medial-to-toe position was scored when the knee was placed medial to the second toe in three or more of the five trials. A knee-over-foot was scored when the knee was over or lateral to the second toe in three of the five trials. Ageberg et al. (2010) concluded that the inter-rater reliability of the observational clinical test was high. The single-limb mini squat test is a reliable and valid method to describe between those with knee-over-foot and knee-medial-to-toe. In the current study, the SLS was analysed using motion analysis software, but it could also be used by clinicians who did not have access to advanced equipment and was easy to administer in a clinical setting if necessary.

Hu et al. (2021) reported that the gold standard for assessing kinematic movement was the use of a 3D motion capture system with reflective markers. They (Hu et al., 2021) reported the limitations were high costs of equipment, space requirements, complex data acquisition and analysis procedures which might be impractical for clinicians in the field. They further elaborate that a dynamic valgus is where the knee shifts excessively in the medial direction and in the case of a SLS, this might predict a higher risk of future knee pain (Hu et al., 2021). The Microsoft Kinect is a markerless motion capture system. In the study by Hu et al. (2021) three functional movements: stair climbing, squatting and lunging were investigated. These movements were assessed using the Kinetic v2 and the VICON motion capture system with 16 reflective markers. Of the 30 participants, 2 were healthy females.

Hu et al. (2021) collected data concurrently with both systems. Kinect's depth information used a dynamic link library with a .NET framework and customised MATLAB code and the VICON system was processed through Nexus software. This study found during squats, lunges and ascending and descending stairs there was good to excellent consistency in agreement in evaluating knee flexion and valgus angle in comparison with the VICON system. Upon closer inspection, the results show there was a significant difference in assessing knee kinematics in almost all tasks. An error of ≤2% was acceptable, and errors >2% and ≥5% were deemed acceptable, but errors

>5% may lead to misinterpretation by clinicians. They (Hu et al., 2021) reported that the results for knee valgus and knee flexion for ascending and descending stairs were within the acceptable range. The absolute difference between squats and lunges ranged between acceptable results possibly leading to misinterpretation. The limitations were the possible hip occlusion during the squatting and lunging activities. The recommendation to correct this was the use of multiple Kinect cameras and deep-learning models. These recommendations come with their difficulties namely camera crosstalk, more time spent with setup and more hardware demands (Hu et al., 2021).

The VICON motion analysis system was used again in a study where they compared experienced physiotherapists to student physiotherapist ratings of a SLS in a healthy adult population (Weeks, Carthy and Horan, 2012). Of the 22 participants, nine were women. Their data revealed no significant differences except for peak knee flexion. The knee mediolateral displacement (mm) as a group was 46.0±16.1mm with a range of 15.1-89.8mm. Female participants' knee mediolateral displacement was 52.2 ±22.7mm (Weeks, Carthy and Horan, 2012). They concluded that the SLS was a tool both experienced and student physiotherapists could use, but they recommend future work to investigate gender differences (Weeks, Carthy and Horan, 2012).

The quadriceps angle (Q-angle) provided an estimate of the resultant vector between the patella tendon and the quadriceps muscle group. It is formed by the intersection of two lines. The one is drawn from the ASIS to the mid-point of the patella. The second one is drawn from the mid-point of the patella to the tibial tubercle (Herrington and Nester, 2004). When this angle exceeds 15-20˚ it may contribute to knee extensor mechanism dysfunction and patellofemoral pain (Herrington and Nester, 2004). Their study consisted of asymptomatic adults (51 male and 58 female) and aimed to investigate the patella's frontal plane position and the magnitude of the Q-angle. They (Herrington and Nester, 2004) wanted to determine the normative values for the Q-value and adjust these values per the individual relative mediolateral patella displacement. For male subjects, the mean left knee mean Q-angle was 11.6˚ and the right knee was 11.3˚. For females, the mean Q angle for the left knee was 14.4˚ and the right knee was 13.3˚. This was consistent with previous studies where females have a greater Q-angle than males. Numerous authors have described lateral placement of the patella in patients with patellofemoral pain syndrome PFPS (Herrington and Nester, 2004) and this led to the importance of considering the anatomical connections and the change in Q-angle that may occur when influencing these structures. The difference in movement strategies during a single-leg squat between females and males was suggested in the literature (Graci et al., 2012). They reported that during a single-leg squat females flexed their trunks less than males and rotated their trunks and pelvis toward the weight-bearing limb more than males (Graci et al., 2012).

2.7 Qinematic and Moovment Software

Grooten et al. (2018) suggested that 3D motion analysis equipment was expensive. Microsoft initially released Kinect for the 360 Xbox as a game controller. This low-cost sensor was able to track the profile of the human body in 3D (Grooten et al., 2018). The idea to use the Kinect together with a refined movement analysis system led to the development of “Qinematic”. Qinematic is an interactive movement analysis system that can assist with objective body motion analysis by health and wellness service providers in gyms, workplaces and clinics.

The order of position and movements evaluated by the Qinematics are #1 Standing balance; #2 Side bending; #3 Squat (double leg squat);4# Balance on the right leg with arms crossed over the chest;#5 Balance on the left leg with arms crossed over the chest; #6 SLS on the right leg with arms crossed over the chest and #7 SLS on the left leg with arms crossed over the chest (Grooten et al., 2018).

In a recent study (Grooten et al., 2018) the Qinematics (version 2.1.20) system was used, the sample was larger than 100 people, ranging between 15 and 69 years of age, both males and females. They (Grooten et al., 2018) state reasons for discrepancies when comparing their results to previous studies were that they used standardised instructions, some subjects had ongoing pain, high sample frequency, the use of absolute and relative statistics, and methodological differences. They (Grooten et al., 2018) were further limited by time; they were doing three data collections with different study designs to establish test-retest reliability for posture, balance and side bending, construct validity, and discriminative validity. The BTS-Elite system was used to capture kinematic data. To determine the construct validity, variables from the BTS-Elite system were compared to the Qinematics data. Higher reliability was found for side-bending, but only to the left. Poor psychometric properties were present for the measurement of posture and balance. The researchers suggested that further research on the Qinematics system was needed (Grooten et al., 2018).

Identifying the need for further research on the system, Ressman, Barr and Grooten, (2020) embarked on investigating the reliability and validity of the Qinematics program for the measuring of a SLS with the same version of the software (version 2.1.20). Once again focusing on the test-rest reliability and construct validity. Additionally, they aimed to identify the angle of medial knee displacement measured by the software. In this study (Ressman et al., 2020), the Qinematics system was compared to a visual assessment of knee over foot or knee medial to foot position. The specific instructions for the SLS were: “Stand on your left leg and lift your right leg in front of you. Bend your left knee and rise again.” This instruction was repeated to the other side. The non-weight-bearing limb was not allowed to cross the midline. The procedure was repeated a maximum of three times if the software was not satisfied (guided by the software’s ability to accurately capture the necessary data), then the participant was asked to perform on easy mode where the non-tested leg was placed on the ground for support. If this still was not satisfactory the movement was recorded as a missing value (Ressman et al., 2020). The visual assessment for the construct validity study was done by two experienced researchers who assessed the video recordings that we recorded in parallel to the Qinematics procedure. The rating was categorized as a participant having a pass when the knee was over the foot position (lateral to the second toe) and failing when the knee was medial to the foot (medial to the second toe). For the validity study, they focused on the “*way down*” for the comparison of visual assessment.

When considering the results for test-retest, three variables namely *left knee down, right knee down,* and *right knee up* produced a substantial reliability, whereas *left knee* up a moderate reliability (Ressman et al., 2020). The Standard Error of Measurement (SEM) and Smallest Detectable Change (SDC) indicate absolute reliability was relatively high for all four variables, which shows that they are less appropriate for use on an individual level (Ressman, Barr and Grooten, 2020). The most appropriate knee angle of medial knee displacement was found to be 6˚and a moderate agreement was found between the visually assessed SLS and the Qinematic measures when this was the cut-off point. The difficulties within this study (Ressman et al., 2020) include that there was a systematic difference between test occasions one and two for the *way up* for the left leg and thus this movement was not included in the validity study, as well as the absence of a gold standard 3 D kinematic measurement and analysis. The trajectory angle feature was not recommended to assess a knee medial to foot position.

Another consideration within the literature (Olivier et al., 2019) is the position of the non-weight bearing knee when using the SLS as an evaluation tool. It has been found that the amount of knee flexion of the non-weight bearing knee influences the gluteus maximus muscle activity. Data was captured at 60˚ of knee flexion in three different single-leg squat positions (Olivier et al., 2019). The 30˚ squat position is the closest to the single squatting position demonstrated in the Qinematics software. This position also showed the least centre of mass displacement, thus forming a good starting position for rehabilitation. The gluteus maximus activation when standing on the dominant leg was 5.46%MVIC and 8.06%MVIC when standing on the non-dominant leg during the single-leg squat.

Considering research (Grooten et al., 2018; Ressman et al., 2020) it is important to weigh the benefits and difficulties when considering the Qinematics system for further research. The researcher of the current study minded the recommendation to use it in group comparisons and measured the knee movement in relation to the foot.

Chapter 3 Methods

3.1 Study Design

This study used a repeated measure design where participants served as their control, before and after intervention. This was an experimental design.

3.2 Study Setting

The study took place at Physiospinamics Physiotherapy practice. The address was 500 Botterklapper street, Office at Nature, Block C1, Die Wilgers, Pretoria.

3.3 Participants

3.3.1 Source of Participants

The researcher tried to recruit active and healthy females in Pretoria. The researcher used an approved social media advertisement that was circulated using the WhatsApp platform, word of mouth, and e-mail in the MAP instructors' and Pilates groups in the area. MAP is an acronym for Myofascial Activated Posture and is a rehabilitation tool used by qualified MAP trainers who completed the MAP trainer course to re-educate movement patterns, especially focusing on movement in the various fascial planes. The researcher is not a MAP trainer but participates in a weekly class in person or online.

3.3.2 Sample Population

The sample population consisted of 29 South African females who were staying in Pretoria.

3.3.3 Sample Size

The sample size was calculated with the assistance of the University of the Witwatersrand Biostatistics department. The study consisted of 27 healthy female participants.

3.3.4 Sample Selection

The researcher is based in Pretoria East, Gauteng, South Africa. It was decided to recruit participants who resided in the Pretoria area who would be willing to travel once off. Participants were recruited via social media and e-mail via groups, thus interested participants had to have access to either a computer or smartphone.

An information leaflet was sent to the interested participant after the researcher received either an e-mail or a WhatsApp message requesting further information after seeing the advertisement. If the participant was interested in participating in the study, the information leaflet was sent to the participant. If after the participant had read the information leaflet and wanted to continue the participant had to complete the two surveys. Two surveys were sent via Redcap to the participant’s email address to gather data regarding inclusion/exclusion criteria, physical activity, and time spent foam rolling (Harris et al., 2009). Hypermobility criteria was not specified on the Redcap survey, but only asked if known to the interested participant. The same applied to known neurological and auto-immune disorders and no additional screening tests were done. After the participant met the inclusion criteria the informed consent letter was either completed electronically or in hard copy on the day of the study. The study was conducted on weekends. The participant then indicated the time and date she was available, and a time was scheduled. The inclusion and exclusion criteria are represented in Table 3.1.

3.3.4.1 Inclusion Criteria

The female participants ranged between 18-65 years. She must be able to read, write, and understand English. The reason for the proficiency in the English language was that the movement software used English voice commands. She had to be recreationally active for at least 30 minutes three times a week (Hughes and Ramer, 2019). The participant must have used a foam roller before or be willing to use one for the study. In situations where the participant has not yet used a foam roller, the researcher would demonstrate the movements to her and assist her when needed.

3.3.4.2 Exclusion Criteria

The exclusion criteria included pregnancy, the use of anti-coagulant medication, hypermobility, neurological (Selkowitz, Beneck and Powers, 2013) and auto immune disorders, current pain in the lower limbs or lower back during activities of daily living. Pain during the 30 minutes of moderate activity three times per week. Surgery on the lower limb in the past six months (Olivier et al., 2019) and injury of the lower limb in the past six weeks (Selkowitz, Beneck and Powers, 2016).

Table 3.1: Inclusion and exclusion criteria of the participants

Inclusion criteria	Exclusion criteria
Female	Pregnancy
18-65 years	Using ani-coagulant medication
English proficient	Hypermobility
Recreationally active for 30 minutes 3 times a week.	Neurological disorders
Used a foam roller before or willing to use a foam roller in the study.	Auto-immune disorders
	Current pain in the lower limbs or lower back during activities of daily living. Pain during the 30 minutes of moderate activity three times per week
	Surgery of the lower limb in the past six months
	Injury to the lower limb in the past six weeks

3.4 Instrumentation and Outcome Measures

3.4.1 Gluteal muscle activity

Gluteal muscle activity was assessed before and after the foam rolling intervention. The researcher was trained in the use of the Delsysworks and DelsysworksAcquisition by a physiotherapist with expertise and experience in using EMG as well as further online resources provided by Delsys.

The participant was positioned prone. The buttock area was inspected and shaved with a single-use razor. The area was cleaned with alcohol swabs and left to dry before the electrodes were placed on the skin. The electrodes were placed according to SENIAM guidelines for gluteus maximus on the right and left buttocks. The electrodes were placed halfway on a line between the sacral vertebrae and the greater trochanter of the femur (Hermens et al., 2024).

The electrodes were orientated in the direction of the line running from the posterior iliac spine to the middle of the posterior aspect of the thigh according to SENIAM guidelines. The electrodes were fixed to the participant using double-sided wig tape between the sensor and the electrode, as well as additional tape over the electrode for further downward pressure. The electrodes were connected to the SEMG equipment, the 8-Sensor Trigno Wireless EMG System. The Delsys EMGWorks was used to plot the information. The aim was to generate a recordable and reliable surface EMG signal, thus the electrodes were left in place during the intervention so that the same area could be remeasured after the intervention.

The researcher demonstrated and explained to the participant that she would lie on her stomach with a bent knee and lift the foot and knee towards the ceiling-extending the hip and pushing into the rigid band. The participant was positioned prone on a height-adjustable plinth. A rigid band, providing resistance, was positioned over the distal posterior femur bilaterally. The participant's head was placed in a face hole, and her arms were relaxed next to her body.

To capture the MVIC before the intervention which served as a baseline measurement for the participant, the participant was instructed to push as hard as they could against the band towards the ceiling for three seconds. The Delsys software provided a countdown feature to prepare the participant, which was done out loud by the researcher for five seconds before each contraction. The participant did three maximum contractions on the right with one minute rest between each contraction and repeated on the left. The electrodes were left in place between pre- and post-intervention measurements to ensure the same area was used to capture the results. After the intervention, the same sequence was followed to measure the MVIC for the right and left gluteus maximus. The electrodes were removed after the post-intervention before the post-intervention movement analysis was done.

EMGAnalysis software was used to calculate the Root Mean Square (RMS) and percentage of the MVIC in comparison to the pre-intervention MVIC for each contraction for the participant. An average was calculated by taking the highest amplitude in the three-second window for the three repetitions left and right, producing a mean average amplitude for right and left gluteal activity.

The current study will compare the same MVIC movement before and after the intervention. To investigate if the foam rolling intervention affected the gluteal activity, either increasing it to ≥100%MVIC or decreasing it to <100%MVIC.

3.4.2 Mediolateral knee movement during a single-leg squat

The secondary purpose of the study was to compare the mediolateral knee movement during a SLS of the left and right leg before and after a foam roller intervention.

A review and meta-analysis of the inter-rater and intrarater reliability for the visual assessment of movement quality in the SLS test were conducted by Ressman, Grooten and Barr. (2019). They evaluated 31 studies where 65% of the subjects were healthy and active, aged between 18-37 years. Nine studies used a three-point rating scale, and five studies used a mixed two- and three-point rating scale. The study also revealed that a visual assessment captured on video increased reliability (Ressman et al., 2019), thus Qinematics software was incorporated into the study methodology.

For the current study, Moovment lab and Moovment scan software were downloaded onto a laptop by accessing https://www.moovment.pro/quick-start. and https://app.moovment.pro. The laptop specifications included Windows 10, a 15-inch screen, Nvidia Geforce RTX 2060, 2070, or 2080, and an Intel Quad Core i7 or better. The 3D camera is a Microsoft Azure Kinect. The hardware components included a high-speed internet connection (> 1 Mbps), a mount for the laptop, a mounting clamp for the camera, and a steady tripod. (Qinematic, 2020)

The Qinematics pre-scan checklist and calibrations were followed. The screen height was between 120 - 150 cm. The sensor height was between 80 - 100 cm. There was a solid non-reflective backdrop with a flat and non-reflective floor. The area was at least 3x4m.

All participants were barefoot, with hair fixed behind their heads in a bun. They wore form-fitting clothes that revealed their body outline. The Qinematics program guided the participants via visual and verbal instructions to follow various movements, which were first demonstrated on screen.

The program formed an onscreen green highlighted block on the floor on the laptop screen where the participant must stand to capture the data. The movements took place in the green block to ensure accurate and valid data capture. Posture was captured first. This was followed by side bending to the left and right and a squat, balancing on 1 leg and a single leg squat on each side.

The program assessed participants going through the featured movements. Two reports were generated. One before intervention and one after intervention. The program could generate data separately for mediolateral knee movement during the downward and upward movement of a SLS. Down was defined as the maximum horizontal shift during down movement with the reference position of the starting position of the knee. Up was defined as the maximum horizontal shift during up movement with the reference position of the turning position of the knee (bottom of the squat). During the movement, the software instructed the participants to cross their arms across their bodies copying the model demonstrating the movement on the program for the exact position. The non-weight wearing knee flexion position was copied from the model on the software by the participant. The software would correct the participant if the leg position differed-for example if the non-weight bearing knee and foot crossed the midline. This assisted with a standardized non weight bearing knee position and arm position during the single leg squat movement.

Raw data from the software was de-identified. This was done pre-and post-intervention. The scans were discussed with a Qinematics engineer to ensure the quality and validity of the data after each weekend. The data was prepared for further analysis by subtracting the ankle position for the left and right ankle respectively. Figure 3.1 shows the mediolateral movement of the weight-bearing knee during the downward and upward movement. Data was divided into two sets, one for up and one for down. The data was either positive or negative depending on the direction of movement. Deidentified data was sent to Dr Yah for further statistical analysis using STATA software.

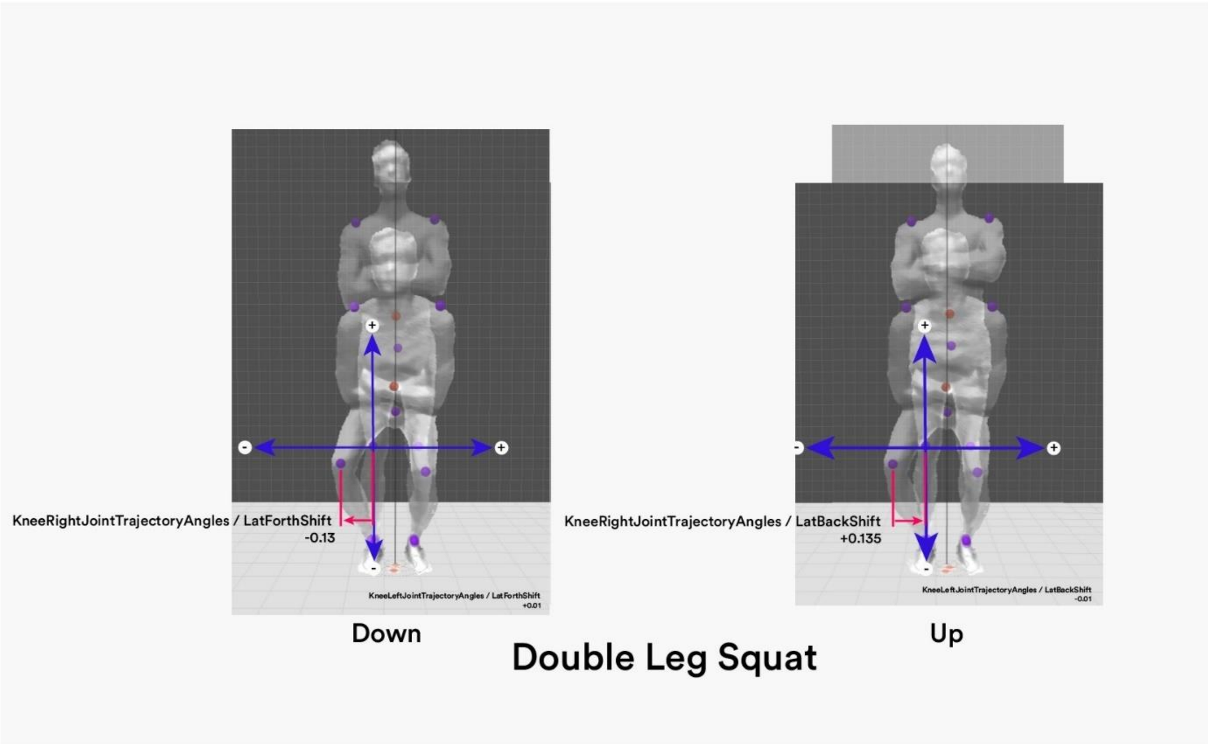

Figure 3.1: Infographic showing horizontal or medial-lateral knee movement

3.4.3 Thoracolumbar side flexion

The third outcome measure of the study was to compare the left and right thoracolumbar side flexion before and after a foam roller intervention.

Available research reports that an individual's body proportions will affect the measurement when using the fingertip-to-floor method and that it should be used to compare repeated measurements for a single individual and not for comparison between individuals (Norkin and White, 2016). Norkin explains the individual is standing with her feet shoulder-width apart and arms hanging freely at the sides of the body. The individual is instructed to bend as far as possible while keeping her back and shoulders against the wall and both feet on the ground with extended knees. At the end of ROM, the distance between the floor and the tip of the middle finger is measured. (Norkin and White, 2016)

The Moovment lab and Moovment scan software were used to evaluate thoracolumbar side flexion before and after the intervention (Qinematic, 2020). The participant followed the visual and verbal instructions from the software on the laptop. The researcher placed a 20cm marker on the ground before pre-intervention testing to ensure the distance between feet was standardised between all participants with pre- and post-intervention testing. The marker also helped to standardise foot placement with regards to external or internal rotation, both feet were facing straight forward. The researcher referred to the method described by Norkin and White (2016), checked and corrected if the participant rotated or flexed forward instead of a pure side flexion movement. The participant copied the model on the software screen with hands positioned with palms facing forward towards the screen, thumbs turned away from the body. The software would correct the participant during the movement when the hands touched the thigh inhibiting an accurate measurement.

The data was captured by the software system. All data was de-identified. The engineer for Qinematics exported the necessary data to the researcher and the data was analysed with assistance from Dr. C Yah from the University of the Witwatersrand.

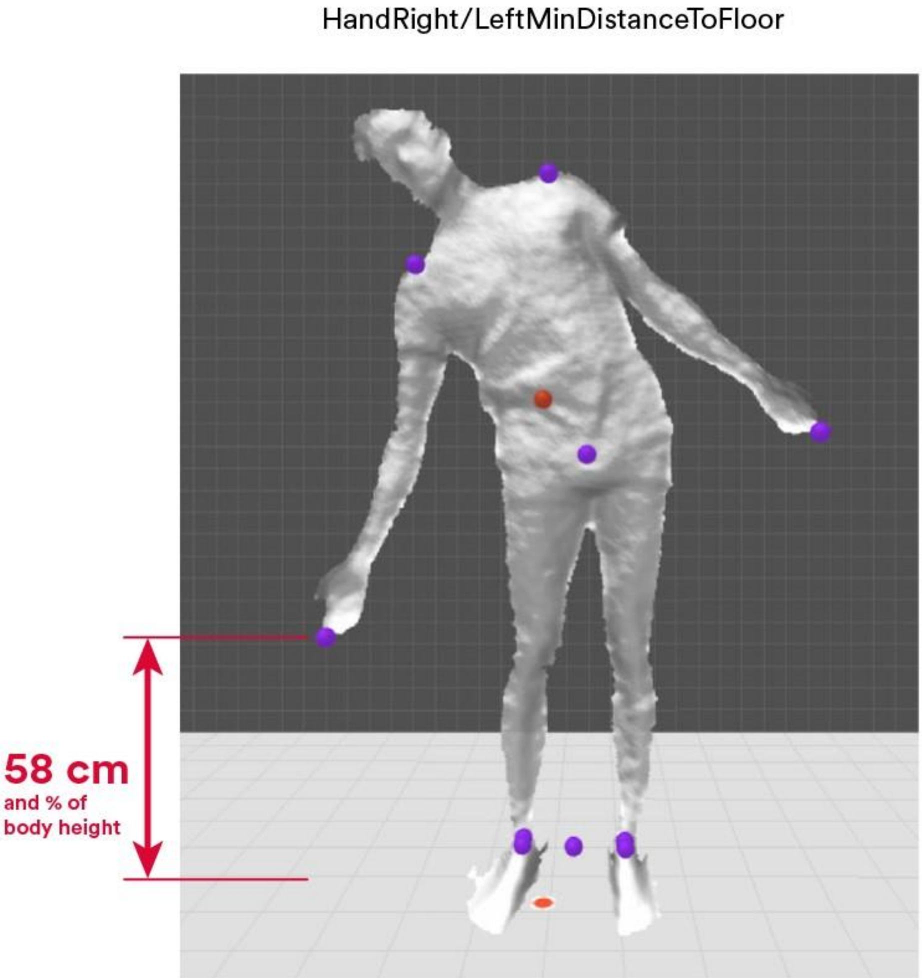

Figure 3.2: Infographic showing the minimum distance between fingertip and floor

3.5 Procedure

3.5.1 Pilot Study

The pilot study aimed to test and refine the methodology of the three outcome measures, focusing on time management and participant experience and feedback.

The pilot study was conducted on 20 August 2023 at Physiospineamics at 500 Botterklapper street, Die Wilgers. The three participants were recruited by word of mouth. All three participants read the information leaflet and completed the informed consent form.

The set-up of the movement software was done according to the Qinematics infographic. The area required three meters by four meters with a non-reflective surface. The equipment set-up and separate room preparation were satisfactory and did not need to be changed between the pilot and the main study. Each participant was informed to wear form-fitting clothing and tie her hair in a bun according to the guidelines. All three participants were tested barefoot.

The participant first created a profile on the Moovment software. The participant then completed the six positions and actions, first practising along with the demonstration. Posture, side-bending, bilateral squats, standing on one leg, and unilateral squat were assessed. The report was sent to the participant's e-mail address. The researcher decided to rather create QR codes to identify the participants on the Moovment software in the main study to further protect the participants' information. The participant was asked if they would like to receive the scan after all data collection was complete. The researcher sent the specific scan report after the completion of the data collection of the study. The researcher also added the option to schedule a discussion session if something on the report caused the participant any uncertainty. The importance of the researcher's focus on stance width was emphasised, as the software did not correct this feature.

The electrodes were placed according to SENIAM guidelines for the gluteus maximus muscle. They were fixed with double-sided wig tape to ensure contact and further secured with additional tape.

Each participant completed three MVICs in prone with knee flexion and hip extension with the researcher applying manual pressure on the distal thigh. After the pilot study, it was decided to rather use a rigid band or belt tied around the bed to give distal thigh pressure to ensure that every participant had the same amount of resistance when doing the MVIC in prone.

In supine, a plot and track graph were used to measure three repetitions of bilateral bridging, followed by three unilateral bridges right and then left. After the pilot study, the researcher decided to only do the three MVIC measurements in prone and not to also plot and track unilateral and bilateral bridging before and after the intervention to decrease the chance of fatigue. Thus, contracting for three seconds resting for one minute, and repeating it three times on the right and then three times on the left.

The researcher reminded the participants that they were in control of the pressure on the foam roller and that they should roll slow and steady, walk forward and backwards on their elbows, keep their heads and necks relaxed, and breathe in and out through their noses. The verbal command of “melting over the foam roller” was issued.

The first area that was targeted was the middle quad, thus keeping the toes of the feet in the middle. The 2nd area was the medial quadriceps with toes pointing out and then 3rd was the lateral quadriceps area with toes pointing in. Each area was targeted for 90 seconds and rated on the numeric pain scale (NPS) afterwards.

Next, the participant turned onto their right side with the right elbow on the mat supporting the right shoulder. The left hand is placed in front of the body to help with balance and weight shift. The right leg is straight, resting on the foam roller and mat. The left leg was in front for balance and to aid the participant in lifting their weight if there was a specific spot which is very uncomfortable. This area was foam-rolled from the greater trochanter to the lateral knee for 90 seconds. The participant was then asked to turn unto his left side and was repeated on the left side for 90. The participant was encouraged to breathe through their nose and to adjust their weight as needed.

It was decided to decrease the foam rolling interval from 90 seconds to 40 seconds per area. There was an overlap of the quadriceps area. This reduced the chance of rolling an area for longer than two minutes which may lead to a decrease in performance. The total time the quadriceps muscle group was targeted was 120 seconds thus within the recommended threshold for a positive effect on ROM (Hendricks et al., 2020).

The researcher also changed previous use of a foam roller as an exclusion criteria to just a recommendation, thus if a participant wanted to participate in the study and met the rest of the criteria the researcher would demonstrate the foam rolling and correct the participant if needed. The exclusion criteria of “no pain” was also better defined as no pain with rest or during activities of daily living.

At the end of the pilot study, it was confirmed that one hour per participant was adequate for the data collection and cleaning of equipment. Participants were scheduled hourly.

3.5.2 Main Study

The social media advertisement was sent out on 31 August 2023. The researcher sent it to known contacts and asked people to forward it to possible participants. The advertisement was also sent out to local Pilates groups and the MAP instructors’ group.

A potential participant would then be sent the information leaflet via e-mail with the instructions if they would like to continue, the researcher would send the exclusion form via the Redcap platform (Harris et al., 2009). If the participant met the necessary inclusion and exclusion criteria, a follow-up survey was sent via Redcap, and a time on a weekend was scheduled.

The sample population was 29 Female participants, and the study was conducted from 9 September 2023 to 21 October 2023. Informed consent was obtained from each participant, and each participant received an R50 transport allowance. Each participant was informed in the information leaflet to wear form-fitting clothing.

The set-up of the movement software was done according to the Qinematics infographic. The area required 3mx4m with a non-reflective surface. The laptop and sensor height were placed between the parameters provided. The Quickstart guide recommends 120-150cm for screen height and 80-100cm for sensor height.

Before the study day, each participant was created as a child on the researcher's Moovment software app-capturing age and gender. A QR code was generated for each participant's first scan. This code was valid for 72 hours. A second code was generated by the researcher on the day of the second scan. The study started when each participant was identified by a specific QR code. The participant then filled in demographic data about weight, handedness, and history of falling in the past year on the Qinematics software app.

The participant then completed the movements on the software in the pre-determined order barefoot. The software has both verbal and visual instructions. The software would verbally and visibly correct participants where necessary. The researcher reminded participants of the necessary stance width of 15 cm, close to hip distance.

The next step was the measurement of surface EMG. The process of preparing the area was once again explained the same as in the information leaflet. Before the patient was positioned prone the researcher demonstrated the movement that was going to be assessed and that the rigid band would be placed over the distal femur of the left and right leg. A mulligan belt with a buckle was used.

The participant was placed in prone on a moveable plinth with the head in a face hole and arms next to the body. The left and right buttock area was exposed. Fresh water was boiled in preparation for use with each participant. A single-use razor and shaving cream were used to shave the buttock areas. The alcohol swabs were used to clean the area after shaving. The electrodes were placed according to SENIAM guidelines for the gluteus maximus muscle, placed in the middle, of the line between the sacral vertebrae and the greater trochanter. The electrodes are orientated in the direction of the posterior superior iliac spine. The electrodes were fixed with double-sided wig tape to ensure contact and further secured with additional tape.

A folder, on the password-protected laptop, for each participant was created beforehand to save the EMG data. The folder was selected to store the captured data. EMGworks Acquisition was used to set up left and right electrode placement as well as a workflow. The researcher then followed the prompts to cue the participant accordingly. Each participant started with right-sided hip extension with knee flexion against the band. There was a five-second preparation countdown. Then the participant was asked to pull as much as possible up toward the ceiling for three seconds. After the three seconds, the participant was then left to rest for one minute. This process was repeated three times on the right and three times on the left.

After the first surface EMG was captured. The electrodes were kept on in the same positions but now covered with the participants' pants.

The foam rolling area was set up with a 90cm medium softness OTG active foam roller and an exercise mat. The targeted areas for intervention were explained by showing them on the researcher's body as well as pointing to the areas on the participant's body, referring to the ASIS, the top of the kneecap (patella), and the greater trochanter.

For participants who had not foam rolled before the movements were demonstrated by the researcher on the mat with the foam roller.

The researcher explained the numeric pain scale (NPS) to the participant. Explaining 0 as no pain and 10 as the worst pain. After foam rolling each for 40 seconds the participant would be stopped to rate the specific area on the NPS.

The researcher reminded the participants that they were in control of the pressure on the foam roller and that they should roll slowly and steadily and walk themselves forward and backward on their elbows and melting over the roller. Keeping their head and neck relaxed and breathing in and out through their nose.

The first area that was targeted was the middle quad, thus keeping the toes of the feet in the middle. The 2nd area was the medial quadriceps with toes pointing out and then 3rd was the lateral quadriceps area with toes pointing in. Each area was targeted for 40 seconds and rated on the NPS afterwards.

Next, the participant turned onto their right side with the right elbow on the mat supporting the right shoulder. The left hand is placed in front of the body to help with balance and weight shift. The right leg is straight resting on the foam roller and mat. The left leg is in front for balance and to aid the participant in lifting their weight if there is a specific spot that is very uncomfortable. This area was foam-rolled from the greater trochanter to the lateral knee for 40 seconds. The participant was then asked to turn unto his left side and was repeated on the left side for 40 seconds. The participant was encouraged to breathe through their nose and to adjust their weight as needed. The areas were also rated on the NPS (Table 4.6).

After the intervention was completed, the participant returned to the room prepared for the surface EMG. The participant was positioned prone, with arms next to the body, face in the face hole and the band around the distal femur. The electrodes were exposed by opening the pants, this helped to check if the electrodes were in the correct positions. The same testing procedure was followed post-intervention testing the right side first and the left second. Holding each MVIC for three seconds, with one minute rest in between. The participant was to pull up and hold as cued by the researcher.

Upon completion of the third MVIC on either side, the electrodes were removed, and the participant moved to the room where the movement analysis was set up. The participant was identified and verified using the second generated QR code. The same set of movements was done and recorded following the visual and audible instructions.

In January 2024 the Qinematic generated report for each participant was sent to all 29 subjects who participated in the study. They were given the option to contact the researcher if they had any questions. None contacted the researcher with any further questions.

3.6 Ethical Considerations

Ethical clearance was granted by the University of the Witwatersrand Human Research Ethics Committee (Medical) on 18/5/2023 with the reference number M220459 (Appendix C). All participants signed an informed consent after receiving and reading the information leaflet. The informed consent was signed electronically or in hard copy before study enrolment. All collected personal information was treated in the strictest confidence. Data was securely stored by password protection on accounts and equipment. Only the principal researcher had access to the contact details and full names. Two QR codes were generated per participant, instead of identifiable data for the pre-and post-intervention movement scans. All data was de-identified for EMG, thoracolumbar side flexion and knee mediolateral movement. De-identified data was used when data was exported and analysed.

The well-being and safety of each participant was important. One participant was seen at a time. No other clinicians or patients were in the practice. The practice was situated in a safe area, inside an office park with access control. Data collection was done in good lighting and the areas and equipment were cleaned between every participant. Water was available and each participant received a transport fee of R50.

All participants had the option to withdraw at any time during the study without any repercussions. No participants were injured or withdrew during testing. No participant used the option to discuss the movement report which was sent to them after data collection. The meeting opportunity was created to address any uncertainty caused by the generated report. Information obtained from participants was only used for this study and not disseminated any further.

3.7 Data Reduction

EMGworks software (Delsys Inc) program was used to obtain the highest Root Mean Square (RMS) for each repetition, the mean of the three repetitions was calculated and used for statistical analysis. For statistical comparison, EMG signal amplitudes were expressed as a percentage of the EMG obtained when compared to the MVIC (Selkowitz, Beneck and Powers, 2016).

Two participants' data were excluded due to faulty data on one limb due to incomplete data collection pre-intervention and one due to electrode movement due to increased sweat, which led to the movement of one of the placed electrodes.

3.8 Statistical Analyses

The study used both descriptive and inferential statistics. For the descriptive statistics, all categorical variables were reported as proportions or frequencies. Numerical variables were tested for normality distribution using histograms, pnorm and qnorm tests, and finally the Shapiro Wilk-test. If the Shapiro Wilk test was less than 0.05 then data was evaluated as non-parametric (abnormal distribution) data and if the p values were bigger than 0.05 then the data was considered parametric (normally distributed) data. The parametric data were described using the mean and standard deviation while the non-parametric data was described using the interquartile range (IQR) to depict the spread of data.

In inferential statistics, the paired t-test was used to estimate the association for normally distributed continuous variables, while the Wilcoxon-signed rank test was used to compare the median of non-normally distributed variables. The data was analysed by the STATA 18 statistical program by StataCorp; 4905 Lakeway Drive; College Station, Texas 77845, USA.

Chapter 4 Results

4.1 Participants

Twenty-nine participants volunteered to participate in the study. Two of the EMG readings were disregarded due to inaccurate readings, from two separate participants. The researcher reviewed captured EMG data on a laptop with the DELSYS software from each participant after the pre-and post-intervention directed after each session to ensure that all 3 MVICs were captured, left and right. For one of the participants, the electrode on the right buttock had moved due to sweat and did not capture the MVIC fully, which was evident on inspection in the DELSYS system on the laptop. The other participant, the left post-intervention was only partially captured. The EMG and kinematic data from these two participants were excluded from the study. The study consisted of 27 healthy female participants.

Most participants were between 28 and 37 years old. The age ranges, height and weight of participants are shown in Table 4.1.

Table 4.1: Description of healthy female adults who participated in the study

Variables	**n**	**%**	**Median (IQR)**	**Mean±SD**
Age				-
28-37 Years	16	59.26	-	-
38-63 Years	11	40.74	-	-
Total	27	100	37 (35-41)	-
Height (m)	27	-	-	1.69±0.05
Weight (kg)	27	-	61 (54-70)	-

4.2 Gluteal Muscle Activity

Four of 27 participants had a ≥100%MVIC on the left and 5 on the right after the foam rolling intervention, which means these participants showed increased gluteal activity. In Table 4.2. the preMVIC represents 100% and the post-intervention values are expressed as a percentage of this value.

Table 4.2: Gluteal muscle activity after the foam roller intervention

Variables	**n**	**%**
Mean Average Amplitude Left		
Participants post-intervention <100%	23	85.19
Participants post-intervention ≥100%	4	14.81
Total	27	100
Mean Average Amplitude Right		
Participants post-intervention <100%	22	81.48
Participants post-intervention ≥100%	5	18.52
Total	27	100

4.3 Mediolateral knee movement during a single-leg squat

The Qinematics software program could divide the SLS into two measurements. Down was defined as the maximum horizontal shift during down movement with the reference position being the starting position of the knee. Up was defined as the maximum horizontal shift during up movement with the reference position being the turning position of the knee (bottom of the squat). The direction of the movement could be interpreted by using Figure 3.1. The difference between the minimum and maximum value was seen as the mediolateral movement of the knee.

The results for the right knee can be found in Table 4.3 and the results for the left knee can be found in Table 4.4. None of the comparisons were significant between pre-and post-intervention during the downward or upward movement.

Table 4.3: Medio-lateral movement of the right knee during the single-leg squat while standing on the right leg, measured in meters

	25th percentile (m)	**50th percentile (median) (m)**	**75th percentile (m)**	**z**	**p-value**
Downward pre-intervention	-0.04	-0.02	-0.01	-0.53	0.6
Downward post-intervention	-0.03	-0.02	-0.02		
Upward pre-intervention	0.01	0.02	0.03	-0.26	0.79
Upward post-intervention	0.01	0.02	0.03		

- indicating lateral movement of the right knee

Table 4.4: Mediolateral movement of the left knee during the single-leg squat while standing on the left leg, measured in meters

	25th Percentile (m)	50th Percentile (median) (m)	75th Percentile (m)	z	p-value
Downward pre-intervention	0.02	0.02	0.03	-1.08	0.28
Downward post-intervention	0.02	0.03	0.04		
Upward Pre-intervention	-0.03	-0.02	-0.02	-1.44	0.15
Upward post-intervention	-0.03	-0.02	-0.02		

- indicating medial movement of the left knee

4.4 Thoracolumbar side flexion

Thoracolumbar flexion was measured bilaterally pre-and post-intervention. The distance between the fingertip and the floor was calculated and is presented in Table 4.5. There was a significant difference between the pre- and post-intervention thoracolumbar side flexion on the right and left.

Table 4.5: Comparison of left and right-side flexion (fingertip to floor distance) before and after a foam roller intervention in meters

	Right minimum distance to the floor (m)	**Left minimum distance to the floor (m)**
Variable description	**Mean±SD**	**Mean±SD**
Side flexion pre-intervention	0.45±0.04	0.46± .04
Side flexion post-intervention	0.46±0.04	0.46±0.04
Difference	0.01±0.04	0.01±0.04
P-value	p=0.027	p=0.0459

The NPS reports of twenty-seven participants are reflected in Table 4.6. These areas were targeted with foam rolling for 40-second intervals. The highest range on the NPS was over the left and right ITB areas.

Table 4.6: The participants' self-reported pain using the Numeric Pain Scale during a foam rolling intervention

	Left	**Right**
Variable Area	Median, IQR (IQ1 to IQ3)	Median, IQR (IQ1 to IQ3)
Middle quadriceps	1 (0-3)	1 (0-3)
Medial Quadriceps	2 (0-5)	2 (1-5)
Lateral Quadriceps	3 (0-4)	2 (0-4)
ITB	4 (3-6)	5 (3-6)

The results of the three study objectives were represented in Chapter 4. There was a marked decrease in gluteal activity after the intervention. There was no significant change post-intervention in the medio-lateral movement of the weight-bearing knee during a SLS. There was an increase in ROM in thoracic side flexion post-intervention. The data NPS reports of the participants ranged from one to six out of 10.

Chapter 5 Discussion

5.1 Introduction

The next section considered the available literature and results produced during this study when considering the three objectives. I will endeavour to discuss the results concerning each objective area.

5.2 Gluteal muscle activity

Numerous studies were done directly targeting the gluteus maximus musculature to investigate muscle activity (Andersen et al., 2006; Selkowitz, Beneck, Powers, 2013; Selkowitz, Beneck and Powers, 2016). This study aimed to investigate the effect of foam rolling antagonistic and connected (Antonio et al., 2013) structures to see if it influences gluteal muscle activity. The left side had four participants above or equal to 100%MVIC and the right had five participants. These results reflect a low percentage of increased gluteal activity. This might be explained by a study (Cavanaugh, Aboodarda, Hodgson and Behm, 2016) in the systematic review (Hendricks et al., 2020) where foam rolling of a muscle may alter the antagonist muscle activity, by reciprocal inhibition due to increased agonist pain perception. Cavanaugh, Aboodarda, Hodgson and Behm, (2016) found a significant decrease in biceps femoris activation after foam rolling quadriceps. The pain was rated 5.9 ±0.49 over the quadriceps area, where the highest reported rating on the NPS in this study was five.

Wilczyński, Zorena and Ślęzak. (2020) describe fatigue as a reduction in the underlying physiological function. This may lead to a change in movement patterns and altered movements. Peripheral fatigue refers to the reduced ability to generate strength and central fatigue is defined by reduced muscular activity (Wilczyński et al., 2020). Monteiro et al. (2019) conducted a study with 12 recreationally active women. One of the objectives was to investigate knee extension fatigue using the Fatigue index after foam rolling the hamstring between three sets of maximum knee extensions. The Fatigue index is a practical and non-invasive method of measuring neuromuscular fatigue and in this study was calculated by repetition performance in resistance exercise (Monteiro et al., 2019). Their results showed a detrimental effect on performance which was dose-dependent, where the foam roller for 120 seconds had a bigger impact than foam rolling for 60 seconds. In the current study, the 3 MVIC measurements per leg were done again post-intervention but reflected the decrease in muscle activity participants found by Monteiro et al. (2019).

When reflecting on the results of this study different theories can be considered. An increase in autogenic inhibition. Here the increase in pressure directly on the muscle may lead to relaxation. The pressure is provided by body weight on the foam roller, and this stimulates the Golgi tendon organ. The stimulation results in a reflexive decrease in muscle tension (Connolly et al., 2020). In this study, it would be the quadriceps muscle group, especially rectus femoris as this muscle spans over the hip and knee joint, and tensor fascia lata.

Foam rolling influences fascia. Fascia is comprised of colloidal substances; it may become more viscous and thicker when left undisturbed (Connolly et al., 2020). There is a change in the thixotropic property of the fascia surrounding tissue when the area is targeted by foam rolling. Heat and mechanical stress restore the thixotropic properties of the fascia and increase soft tissue compliance (Connolly et al., 2020). Combining the research (Antonio et al., 2013; Myers, 2009a, 2009b) that the gluteus maximus muscle is fascially connected to the vastus lateralis, TFL and ITB, it stands to consider by influencing the structures connected to the fascia of the gluteus maximus by a foam rolling intervention like in this study, the changes in gluteal activity could be linked to the change in thixotropic properties of the fascial line of which it forms part.

A possible warm-up effect of the pre-intervention movement analysis by the Qinematics which was done before EMG testing can be considered relevant. A single leg squat and wall squat have been shown to produce gluteal muscle activity of 59%MVIC (Distefano et al., 2009) and 86%MVIC (Boren et al., 2011) respectively. One repetition was done to practice the movement as guided by the software and one was done for motion capture. This was not repeated post-intervention as the EMG measurement was done directly after the intervention. Previous research mentioned a possible dissipation of the ROM gained between three to ten minutes (D’amico,Silva and Gallo, 2021).

A reduced gluteus maximus activation was found to be partly associated with an increased peak knee medial-to-foot placement/knee abduction angle and they concluded that improving this component may improve the quality of knee movements in healthy individuals (Cronström et al., 2016). Furthermore, gluteal muscle weakness has been associated with injuries that include patellofemoral pain syndrome, chronic ankle instabilities, and anterior cruciate sprains (Heick et al., 2020) and the female population has been reported to be twice as likely to develop patellofemoral pain syndrome than males (Willson et al., 2011). The current study showed a decrease in gluteal activity post foam roller intervention, possibly due to reciprocal inhibition due to increased agonist pain perception (Cavanaugh, Aboodarda, Hodgson and Behm, 2016) , fatigue (Monteiro et al., 2019) or autogenic inhibition (Connolly et al., 2020) of the quadriceps muscle.

5.3 Mediolateral knee movement during a single-leg squat

The software (Qinematic, 2020) can separate the downward and upward movement of the SLS, referring to the weight-bearing leg. The mediolateral knee movement was calculated as the difference between the minimum and maximum horizontal movement during the downward and upward movements. There was no significant difference between the comparison of the pre-and post-intervention mediolateral knee movement during the SLS.

Numerous studies support the usefulness of a SLS as an observational and assessment tool in clinical practice (Ageberg et al., 2010; Weeks, Carty and Horan, 2012; Ressman, Barr and Grooten, 2020). The current study provided results concerning the mediolateral knee movement during a SLS.

It is interesting to consider the EMG results together with the kinematic data. Only 9 results were ≥100%MVIC post-intervention. This left 45<100%MVIC post-intervention, thus showing a decrease in gluteal activity for most participants. The function of the gluteus maximus muscle is hip extension and lateral rotation (Selkowitz, Beneck and Powers, 2013; Selkowitz, Beneck and Powers, 2016). There are also anatomical connections between the gluteus maximus muscle and the iliotibial tract as well as the lateral intermuscular septum, we can postulate that it is an important vector for knee movements (Antonio et al., 2013). Taking this into account the decreased gluteal activity did not lead to a significant change in mediolateral movement post-intervention due to the possible dissipation of the effect of the foam roller reported in the literature (D’amico,Silva and Gallo, 2021) lasting 10 minutes after intervention.

If there is a change in the mediolateral knee movement one can also consider a change in the proprioceptive mechanism which assists in the stabilization of joints. Proprioceptive abilities can be reduced by muscle fatigue anywhere along the pathway related to muscle contraction (Wilczyński, Zorena and Ślęzak, 2020). Altered mechanisms of proprioception might also be considered as the Golgi tendon organs were stimulated in the quadriceps muscles. This may lead to difficulty stabilising the knee during a single-leg squat, causing more medial movement.

The study by Weeks, Carty and Horan, (2012) included healthy males and females aged 23.8±3.1 years. They did separate the values by sex, but each leg was not individually reported. They included the knee mediolateral displacement for the upward and downward movement as a single value. The average was 5.22±2.27cm. Future studies need to be conducted to accurately provide further data for more accurate comparisons of the upward and downward movements between different participants.

It is also important to discuss the equipment used to capture the mediolateral knee movement during the SLS movement in the current study. Research mentions that the gold standard for measuring knee movement is the use of a 3D motion capture system with reflective markers (Hu et al., 2021) and the VICON motion analysis system can be used to record and analyse the mediolateral knee movement of participants. In the current study, the researcher used the Moovment software from Qinematics and a

Microsoft camera to record the SLS of each participant before and after the foam roller intervention. The Qinematic infographic (appendix E) provided was easy to follow for the set-up and the software itself was found to be user-friendly. An obstacle experienced during the study was the repeated time for set-up as the study ran for three months only over the weekend. The research area was used as an outpatient physiotherapy treatment area during the week and there was no space to leave the equipment in a set-up position. Another obstacle in South Africa at the time of the study was load shedding as the equipment needed electricity and WIFI to function supply. This affected the scheduling of a participant but was managed using the load-shedding schedule and rescheduling participants if needed by phone. In a clinical setting where patients are booked according to their work schedule, it is good to have alternative reliable methods to evaluate and capture data.

5.4 Thoracolumbar side flexion

The side-flexion values on the left in our study range between 42-50cm and 41-49 cm on the right before the intervention. Representing the minimal distance between the fingertip to the floor (Figure 3.2) this vertical measurement was captured by the Qinematics Moovment software. The was also a significant difference ($p<0.05$) between the pre-and post-intervention measurements for right thoracolumbar side flexion ($p=0.027$) and left thoracolumbar side flexion ($p=0.0459$).

Two interesting areas arose when exploring the evidence regarding thoracolumbar side flexion. One was the influence of age on thoracolumbar side flexion and the second was the varying methodology and results when measuring thoracolumbar side flexion.

Let us first consider the influence of age on lateral flexion. The age distribution for the current study is 37 (35-41) years. Van Herp et al. (2000) like McGregor, McCarthy and Hughes, (1995) investigated lumbar spinal kinematics. The participants were pain-free, and data was separated according to sex, thus enabling comparison. They did, however, use degrees to represent ROM, whereas our studies use a vertical measurement between the fingertip and the floor. The studies report a decrease in lateral flexion as age increases. Our values come close to the results found in a previous study (Hecimovich and Hebert, 2017), but the age group in their study was 13-16 years. The Front foot side flexion measured at 44.23±5.07 cm (39-49cm) and the Back foot side flexion was 43.98±4.59 (39-47) cm. None of the participants in the current study reported participating in cricket as one of their moderate activities, but one can hypothesise that both sample populations were active and pain-free, and the data is relevant for discussion. Instead of the left and right side, they used the Back foot and Front foot. This was categorised according to the participant's bowling side (throwing side). There were 27 males and seven females, the samples differed in sex, and this must just be noted as there is evidence that sex does affect lumbar ranges (McGregor, McCarthy and Hughes, 1995). This did not affect our study's results as all our participants were female. Sixteen participants in our study were aged between 28-37 years and 11 between 38-63 years, thus the decreasing lumbar motion found in lateral side flexion due to increased age when comparing it to the study by Hecimovich and Hebert (2017) is normal in line with the available evidence (Moll and Wright, 1971).

Various methods have been described when measuring thoracolumbar side flexion. Each method will provide a different set of results. Some use motion analysis equipment and software (McGregor, McCarthy and Hughes, 1995; Grooten et al., 2018;) and others use a tape measure to measure the travelled distance, between anatomically marked points on the lateral side of the body (Moll and Wright, 1971). Mellin (1986) felt there was a need for a convenient, quick and inexpensive method. They used the same starting position with the feet 20cm apart like in our current study. The first marked point was the fingertip on the thigh in an upright position and the second was the range after sliding on the thigh while doing full lateral flexion. The distance was measured between the two points. The means for the first measurements were 21.9 (5.1) cm for the left and 21.2 (5.6) cm for the right for 39 participants. The difference in methodology is very important when comparing results, as one of the instructions on the Qinematics software is to ensure not to touch the thigh during movement to provide an accurate measurement. Figure 3.1 shows how the measurement is made. Hecimovich and Hebert (2017) compared the tip of the finger to the floor method to the use of a digital inclinometer. This produced comparable results, but the difference in methodology was that the participant touched the thigh and measured along the body contours of the participant.

The lateral line assists in creating a lateral bend in the body, and side flexion of the trunk (Myers, 2009b, pp. 115–118). The ITB, TFL and ASIS form part of the myofascial tracts and body stations of the Lateral line. The vastus lateralis forms part of the Back functional line. In this study, these areas were targeted with the foam rolling intervention. There was a significant difference between left pre- and post-intervention side flexion. The was also a significant difference between the pre-and post-intervention measurements for right-side flexion. Thus 40 seconds per left and right lateral ITB areas and 120 seconds over the anterior lateral area covering the TFL and quadriceps muscles proved successful, confirming the increase in ROM found in other literature (Connolly et al., 2020).

5.5 Pain rating of participants

In the current study, the quadriceps muscle group was foam-rolled for a total of 120 seconds. In the systematic review by Hughes and Ramer (2019) the population of the participants where pain/soreness was investigated 63.4 % were male and 36.6% female. The typical participant was a recreationally active (moderately active two to three times a week) adult, aged between 18-47 years. These demographics were reflected in the current study where the average age was 37 years. Hughes and Ramer (2019) suggest that rolling a single muscle group for less than 45 seconds may be insufficient for adequate recovery from muscle pain and better results have been seen between 90-600 seconds per muscle group.

To investigate the effect of foam rolling on pain and muscle soreness was not one of the objectives of the study. The numeric pain scale was used during the study to capture the participants’ experience of pain while foam rolling. The safety and wellness of each participant were of utmost importance, and this also enabled the researcher to guide first-time users to adjust their body weight on the foam roller if it was too uncomfortable. The information can be found in Table 4.6. The information gained here can be used by clinicians when prescribing foam rolling to a healthy, active female for the first time to manage her expectation of pain or muscle soreness during the intervention.

Chapter 6 Conclusion and Recommendations

6.1 Conclusion

This study aimed to examine three objectives. The objectives were achieved as follows:

1. **Compare the muscle activity of the gluteal muscles before and after foam roller intervention of the anterior thigh and hip.**

   Four participants on the left and five participants on the right had gluteal muscle activity of ≥100%MVIC after intervention, while the rest of the measures were <100%MVIC. The decreased gluteal muscle activity must be considered when using a foam roller over the anterior and lateral thigh.

2. **Compare the mediolateral knee movement during a single leg squat of the left and right leg before and after a foam roller intervention of the anterior thigh and hip.**

   There was no significant difference between mediolateral knee movement before and after the foam roller intervention. Additional research is needed to collect measurements for the downward and upward data of the SLS to allow comparison between different participants between studies.

3. **Compare the thoracolumbar side flexion to the left and right before and after a foam roller intervention of the anterior and lateral thigh and hip**

   The results show that for left and right, thoracolumbar side flexion there was a significant difference between the pre-and post-intervention measurements. This enforces the recommendation that foam rolling can be used to increase thoracolumbar side flexion ROM.

6.2 Clinical/Practical Recommendations

A foam rolling intervention of the anterior and lateral thigh has shown a decrease in gluteal activity. This should be noted when using a foam roller to improve the range of motion, the reciprocal inhibition may lead to a change in muscle activity in the antagonistic muscle. This information should be considered by healthcare and wellness professionals who are utilising and recommending foam rolling as a treatment tool. A reduced gluteus maximus activation was found to be partly associated with an increased peak knee medial-to-foot placement/knee abduction angle. They concluded that improving this component may improve the quality of knee movements in healthy individuals (Cronström et al., 2016).

The numeric pain scale data could be used when discussing the level of discomfort, a patient could expect if she was attempting foam rolling for the first time, if she met all the inclusion criteria of this study. The study showed an increase in thoracolumbar side flexion ROM after the foam roller intervention. This reflects what is available in evidence that foam rolling can be used to increase flexibility in patients in a clinical setting (Hendricks et al., 2020).

A single-leg squat is a reliable tool that can be used in clinical practice to evaluate knee-over-foot or knee-medial-to-foot positions with or without 3D motion analysis equipment (Ageberg et al., 2010; Hu et al., 2021; Weeks,Carty and Horan 2012). If a knee-medial-to-foot position is observed further evaluation is needed to establish the involvement of gluteal weakness or other structural involvement. A single-leg squat can be used in a clinical setting without advanced equipment.

Thoracolumbar side flexion can be measured with various approaches. The gold standard uses 3-D motion capture technology, but research highlights various others that are less expensive and reliable (Hecimovich and Hebert, 2017; Mellin, 1986; Moll and Wright, 1971). If a clinician does not have access to funds for 3-D motion capture, various methods are explained and can be used to measure thoracolumbar side flexion with a tape measure. It is just important to note that the measurements differ between methodologies and should be documented correctly for accurate follow-up.

6.3 Recommendations for Future Research

When using foam rolling to increase ROM of the knee or hip by targeting the anterior and lateral thigh one must consider the effect on gluteal activity. To recommend the investigation for combination with high activating gluteal exercises like a single leg squat producing 71%MVIC and a front plank with hip extension at 106%MVIC (Boren et al., 2011) or leg press 60%±16%MVIC and squat 55%±14%MVIC (Andersen et al., 2006) to counteract the possible decrease in gluteal activity. Hendricks et al. (2020) recommend that it should be used in combination with dynamic stretching and active warm-up before a training session (Hendricks et al., 2020) if you aim to improve ROM.

6.4 Strengths and Limitations

A strength of the study was that EMG data as well as kinematic data (Distefano et al., 2009), were gathered. The mediolateral knee movement range was collected for the downward and upward movement of a SLS in a healthy, active female population before the intervention and can be used for future studies. The MVIC is conducted in a prone non-weight bearing position. To see how the EMG data influences an activity like a SLS (kinematic data) which mimics an activity of daily life like climbing down a step, is important to focus on the participant holistically and not only on a single muscle activity. There was a decrease in gluteal activity for most participants after the intervention, but no significant change in the mediolateral movement. The thoracolumbar side flexion range in healthy females can be compared to others and used in future studies using the same methodology.

The study is limited by the small sample size, thus generalisations as to the findings beyond those meeting the specific criteria of this study can’t be made. The study only included females and this limits generalisation. The females were all healthy and the results may not apply to patients with pain and pathology.

A study limitation to consider is the absence of a control group where a different intervention or placebo was incorporated, and the results compared. This might also form part of a recommendation for future research.

A limitation in the selection process is that no additional screening was done for undiagnosed neurological and auto-immune disorders or hypermobility, the researcher took the participant at her word.

A recommendation for future research is to specify that no additional exercise be undertaken on the day before the testing to standardise this influencing factor.

All care was taken to avoid cross-talk between muscle activity of adjacent muscles. This was addressed by applying the electrodes according to the provided guidelines (Hermens et al., 2024) and using wig tape to improve surface contact. Additionally, the electrodes were secured with extra tape to prevent movement and observed to ensure the electrodes were in position when collecting data. The two participants' data sets were not included in the study due to sweat causing a gliding movement of the electrode after the intervention.

The VICON system is more expensive than the Qinematics system. The Qinematics system is easy to use but requires space and time to set up. Further research is required as there is mixed evidence if the system can be used to measure side-bending and knee movement adequately (Grooten et al., 2018; Ressman, Barr and Grooten, 2020; Hu et al., 2021).

Some females may not have been included due to the exclusion criteria of reading and speaking English, as the software instructions were in English. In the future, when using the system, the instructions might be translated into other languages spoken in South Africa to be more inclusive. Most of the communication happened via e-mail or telephone, thus people who did not have access to certain technology were inadvertently excluded.

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Appendix

Appendix A An Information Sheet

Study title: The effect of a foam roller intervention of the anterior and lateral thigh on gluteal muscle activity in healthy females.

18 August 2023

Dear Reader

I, Lisé-Mari Kotzé, am a student completing my Master of Science in Physiotherapy at the University of the Witwatersrand. Research is a process used in seeking new knowledge. I am investigating the muscle activity of the gluteal muscle after a foam roller intervention of the anterior and lateral thigh.

The gluteal muscles are the muscles found over the largest area of your buttock. Surface electrodes and software will be used to measure the activity of the muscle during specific testing positions and movements. Rolling on the foam roller with your lower body (front and sides of your thighs) will be used as the intervention. Movement software will be used to evaluate different movements. This will be an once-off assessment and treatment and will take about 60 minutes of your time. The testing and intervention will be conducted once off in Pretoria at Physiospineamics practice Office @ Nature, 500 Botterklapper street, Block C1, Die Wilgers, Pretoria on a Saturday or Sunday between September-November 2023. Time slots will be available, and each participant will indicate the time that suits him or her the best.

I would be most grateful if you would allow for your data, which includes movement analysis and the muscle activity of the gluteal muscles before and after intervention, be used as part of this study.

Who is eligible?

Female participants aged between 18 and 65 years. Participants must be able to understand English. You must be pain free in the lower back, abdomen, and lower extremities. You have to perform 30 minutes of mild to moderate activity 3 times per week and preferably used a foam roller before.

What is involved in the study?

You will be invited to complete demographic and lifestyle questionnaire that takes about 10-15minutes. If you prefer to complete the questionnaire via hard copy, contact me and I will make special arrangements. Once you agree to participate in the study, the assessment and intervention process, it will take about an hour to complete. Participants will be asked to wear form fitting short sleeved clothes for the testing process. The skin of the buttock area will be exposed to place the surface electrodes directly onto the skin. The skin will prepared for effective measurements by shaving and cleaning with an alcohol swab.

Are there any risks of taking part in the study?

During the intervention the participant may experience mild to moderate discomfort over the area targeted by the foam roller. A numeric pain scale (rating your pain out of 10) will be used for feedback by the patient during intervention. The participant can adjust the pressure on the foam roller to decrease discomfort and can stop if uncomfortable. If needed further physiotherapy care will be provided to the participant in case of an adverse event by the researcher in the form of strapping, ice, and electrotherapy modalities. COVID protocols will be observed. The equipment used for the study will be cleaned with alcohol surface spray in between participants. The skin areas will also be cleaned as per protocol. Adequate privacy will be maintained as only 1 participant will be tested at a time.

What are the benefits of taking part in the study?

Non-identifiable, generalised results will be made available to all participants at the end of the study. The participant can request to receive the movement analysis report, which will be sent after the study's data collection period has been completed to an e-mail address of the participant's choice. If the participant has any questions about the report, a time can be scheduled where the report can be discussed. The participant will receive a once-off R50 travel reimbursement.

The information gathered will assist clinicians to prescribe foam rolling as a treatment tool to assist gluteal muscle activation during exercise and rehabilitation.

How will access to the information be controlled?

Identifying information, such as your name, surname, and contact details, will be removed from your data and a study number will be allocated to your data. The link between the study number and the identifying information will be kept in an access-controlled database which is only accessible by the researcher supervisor (Benita Olivier, Benita.Olivier@wits.ac.za) and data manager. If you have further questions, feel free to contact the data manager, Lisé-Mari Kotzé .

The primary researcher, Lisé-Mari Kotzé will have access to the raw data that will be exported for research analysis. No information such as name, surname and contact information will be exported, only the allocated study numbers will be used. You can request that your responses be withdrawn from the study by e-mailing the primary researcher Lisé-Mari Kotzé (2611130@students.wits.ac.za). I ask that you do this within a month after you have completed the study. You will suffer no repercussions if you decide to withdraw from the study at any time.

Information related to the use of your data in future research projects:

Will access to my data be controlled?

Identifying information, such as your name, surname, and contact details, will be removed from your data and a study number will be allocated to your data. The link between the study number and the identifying information will be kept in an access-controlled database which is only accessible by the data manager and researcher supervisor (Benita Olivier, Benita.Olivier@wits.ac.za). If you have further questions, feel free to contact the data manager, Lisé-Mari Kotzé via e-mail address below.

Where will my data be stored?

Your data will be stored on a secure platform called REDCap (Research Electronic Data Capture) which is hosted by the University of the Witwatersrand. This platform is access-controlled, secured on two different servers and only a data manager and research supervisor will have access to the data.

How will researchers gain access to my data in the future?

If any researchers would like to use your data in a future research project, they will apply for ethical clearance. The motivation, intention and a sound protocol will be considered by the data manager and research supervisor. If both are satisfied with the intentions of use, access will be granted to your data. Your data might be linked to other datasets and merged with multiple sources of data. Upon completion of the project, the researcher will be required to upload the modified datasheet onto the REDCap system and remove the copies from his/her computer, whereafter the researcher’s access to REDCap will be terminated.

Should you prefer not to allow for your data to be used in either the current or future research projects, or both, you will not lose out on any benefits that you are entitled. If you would like to withdraw your consent for re-use of your data in future research projects you are free to do so by sending an email to the primary researcher, Lisé-Mari Kotzé (2611130@students.wits.ac.za).

For further information, you are welcome to contact me, Lisé-Mari Kotzé, on 0722475747 or send an email 2611130@students.wits.ac.za.

For more information regarding any ethical queries: Human Research Ethics Committee of the University of the Witwatersrand. 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 your consideration.

Lisé-Mari Kotzé

Appendix B Consent Form

INFORMED CONSENT FORM: Participant

Study title: The effect of a foam roller intervention of the anterior and lateral thigh on gluteal muscle activity in healthy females.

I____________________________(e-mail address: ________________________ and cell phone number:____________________) hereby agree to for my data to be used as stipulated below:.

I agree for my data to be used as part of the research project described in the information sheet and titled: "**The effect of a foam roller intervention of the anterior and lateral thigh on gluteal muscle activity in healthy females**."

☐ Yes

☐ No

I am aware that I can request for my data to be withdrawn from this research study. This should be done within a month (30 days) from participating in the study. I am aware that I won't suffer any repercussions during withdrawal.

☐ Yes

☐ No

I understand that there are no monetary rewards for allowing my data to be used as part of this research study and that participation is voluntary and I am not in any way obliged to take part.

☐ Yes

☐ No

I agree for my data, after my name, surname and contact details have been removed, be re-used in future research projects without my additional informed consent (tick all that apply).

☐ Yes, my data can be stored and re-used for an unlimited period.

☐ Yes, my data can be stored and re-used for a limited period with an end date specified here: ________________________(DD/MM/YYYY).

☐ Yes, my data can be re-used as part of a project of any type which has been approved by the data access control committee except for topics such as: __________________________________(leave blank if not applicable).

☐ Yes, my data can be used in commercial or device development projects.

☐ No, I do not agree for my data to be used in future research projects.

Signature of participant_________________________ Date: _____________________

Signature of researcher _______________________

For office use only:
Study

Appendix C Ethical Clearance Certificate

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

R49 Ms L-M Kotzé

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M220459

NAME: (Principal Investigator)	Ms L-M Kotzé
DEPARTMENT:	School of Therapeutic Sciences Department of Physiology Medical School University
PROJECT TITLE:	*The effect of a foam roller intervention of the anterior and lateral thigh on gluteal muscle activity in healthy females* Change of study title noted on 2023/05/18
DATE CONSIDERED:	2022/04/29
DECISION:	Approved unconditionally
CONDITIONS:	
NOTE:	If contact information regarding student study participants is required, please contact the Registrar's office - <Nicoleen.Potgieter@wits.ac.za>
SUPERVISOR:	Professor B Olivier
APPROVED BY:	CB Penny Dr CB Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	2022/09/07

This Clearance Certificate is valid for 5 years from the date of approval. An extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office secretariat 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 **April** and therefore reports and re-certification will be due in the month of **April** each year. Unreported changes to the study may invalidate the clearance given by the HREC (Medical).

L Kotze　　　　30/06/2024

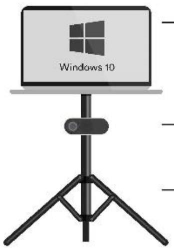
Signature of Principal Investigator　　　　Date

Appendix D Qinematics Moovment Quick Start Guide

Moovment®

Quick Start

I Hardware



Laptop, Desktop PC or AIO

Screen: Minimum 15 inch
GPU: Nvidia GeForce RTX 2060, 2070 or 2080
CPU: Intel Quad Core i7 or better

3D camera

Option 1: Microsoft Xbox Kinect One (v2)
Option 2: Microsoft Azure Kinect

Hardware components

Highspeed internet connection (> 1 Mbps)
Tabletop or mount for PC
Mounting clamp for camera
Steady Tripod

II Software

Moovment® subscription for your organisation
Subscribe via www.moovment.pro/subscribe

Moovment.Pro web app registration
Organisation's Administrator is registered by Qinematic
Specialist is registered by Organisation's Administrator

Installed software
- **Moovment Scan** - 3D Recording software
- **Moovment Lab** - 3D Scan review software
- **Moovment.Pro** - web app via Chrome or EDGE

III Login and software download

Go to https://app.moovment.pro in your browser
Click **Sign in** and enter your email address and password.

Note that you should have received an email with a first-time password after you got set up by Qinematic staff or your organisations administrator.

Download Moovment Scan and Moovment Lab

At the bottom right of the window you will find download links for the latest software (Windows 10 required).

Allow installation

Your settings may have extra protection against third party software. You may see this notification window.
Click More info.

You will see extended information.
Check that the publisher is Qinematic AB.

Click Run anyway

IV Calibration and preparation

Pre scan checklist

We have summarised the key information for good practice on a one page document (see **Moovment** Scan Pre Scan Checklist)
Please carefully read and follow all instructions.

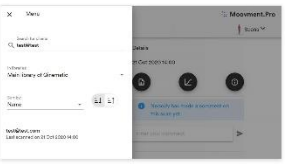
V After the scan

Instant feedback availability

Animated Feedback and a Summary report can be viewed on the scan computer once. Thereafter, they can be viewed only in Moovment Lab and Moovment Pro. Optional features like Print, Send, and onscreen Feedback can be added/removed in Settings in Moovment Scan. Press ESC to access Settings in the Moovment Scan menu bar.

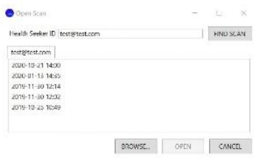
VI

Moovment.Pro



Only an authorised Specialist can access an Organisation's scan library. They gain access through Moovment Lab software and the Moovment.Pro webapp.
The Specialists needs to know the Identifier (e.g. email) of the Health Seeker that was scanned. These details can be found in the Moovment Pro app by scan date or name.

Moovment Lab

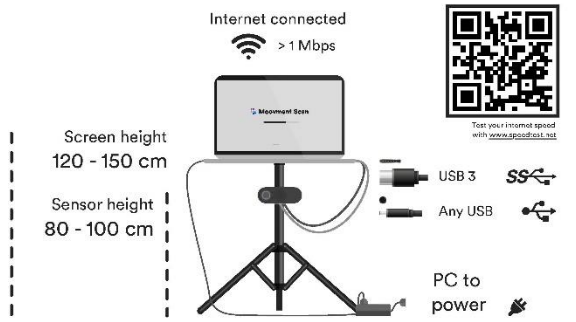


End-users can register as a Client in the **Moovment.Pro** web app. In the app, they can view their scans, reports, exercises, health survey results and goals.

Moovment® Scan

Pre Scan Checklist

I Hardware setup



II Software

Keep Windows updated
Update Windows well before scanning commences.

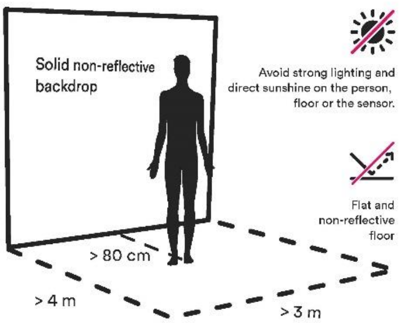
Keep Moovment® software updated
Always check for updates before scanning.

Switch off files-on-demand
Cloud services (esp. Microsoft One Drive) decrease computing power of your PC and influence the scan. Also check for other services that may impact the power of your PC.

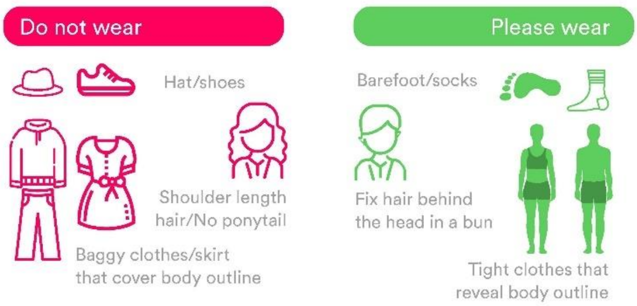
III Calibration

1. Clean scan area without any objects
   No person in the field of view
2. Start the Moovment Scan software
   Stand beside the PC and do not cover the camera
3. Wait until all check boxes are green
   then proceed with scan

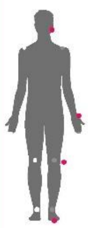
IV Scan area



V Clothing & Preparation



What happens if the steps above are ignored?



Recognition errors during the scan process.

Body outline is inaccurate, causing poor tracking.

You are urged to follow each step (I-V) carefully, to avoid error and repeat testing.

Poor Scan Quality
Final result

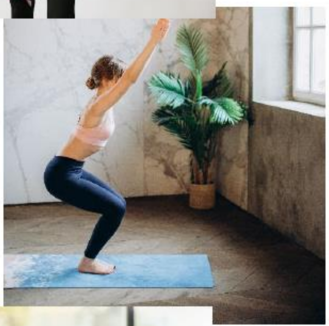
Appendix E Advertisement

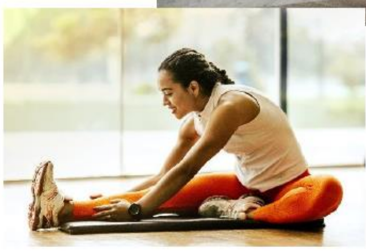
Dear Reader

I would like to invite you to participate in my Masters in Physiotherapy research study titled: “The effect of a foam roller intervention of the anterior and lateral thigh on gluteal muscle activity in healthy females.”

The study will take place with a once off assessment and measurement on a Saturday or Sunday between June 2023 and September 2023 at PhysioSpineAmics in Die Wilgers Pretoria.

If you would like to find out more about the study, please contact Lisé-Mari Kotzé at 2611130@students.wits.ac.za





Appendix F Turnitin Report

The effect of a foam roller intervention on the anterior and lateral thigh on gluteal muscle activity in healthy females 24 Oct no appendixes

ORIGINALITY REPORT

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