RANDOMISED CROSSOVER TRIAL OF m. GLUTEUS MAXIMUS AND m. GLUTEUS MEDIUS ACTIVATION DURING REHABILITATION EXERCISES IN FEMALE HOCKEY PLAYERS

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2013099532

Dissertation submitted in accordance with the academic requirements for the Degree Magister Artium Human Movement Sciences in the School for Health and Rehabilitation Sciences in the Faculty of Health Sciences

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DECLARATION

I, Daretha Coetzee, declare that this dissertation and the work presented here are my own and have been generated by me as the result of original research.

I confirm that:

- This work was done while in candidature for a Master's degree (M.A. Human Movement Sciences) with a research component at this University;
- Where any part of this dissertation has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- Where I have consulted the published work of others, this is always clearly attributed;
- Where the works of others have been quoted, the source is always given. Apart from such quotations, this dissertation is entirely my own work; and
- I have acknowledged all of the main sources of help.

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ACKNOWLEDGEMENTS

I would like to express my utmost appreciation to:

- My supervisor, Prof. Derik Coetzee, for your dedicated guidance, support, and useful recommendations and all the freedom to pursue my research.
- My co-supervisor, Dr Colleen Sinclair, for all the hours you sacrificed in helping me to test each participant to collect the data.
- The study's Biostatistician, Prof. Robert Schall, for your time and invaluable assistance in doing the data analysis.
- My husband, Dr Eben Coetzee, has been instrumental and akin a research partner to me. Thank you for your continuous encouragement and enthusiastic willingness to help in any way. Without your support and wise guidance, this study would not have been the same.
- The participants of the UFS high-performance field hockey squad, for taking part in the study and making it possible.
- God Almighty, whom I thank for blessing me with the opportunity to undertake this research project by giving me the strength, ability and knowledge to persevere and complete it.

SUMMARY

Introduction: *Various researchers have focused on the activation capabilities of the gluteal muscles during different commonly used rehabilitation exercises. However, there is currently a lack of research in examining body weight rehabilitation exercises that elicit the highest percentage maximal voluntary isometric contraction (%MVIC) for both the m. gluteus maximus (mGmax) and m. gluteus medius (mGmed) in a high-performance athletic population. Field hockey predominantly requires maintaining a forward flexed posture, which places excessive stress on the lumbar spine of the players. Hence, it is necessary to assess the muscles that support the lumbar spine, especially the muscles that surround the hip, in order to prescribe strengthening exercises for this population. Knowledge of the percentage activation of the mGmax and mGmed elicited during body weight rehabilitation exercises may result in more specific exercise programme prescription during prehabilitation and the later stages of rehabilitation for high-performance female field hockey players.*

Objectives: *The aim of the study was first to establish which commonly prescribed body weight rehabilitation exercises from previous studies produced greater than 61%MVIC for both the mGmax and mGmed. Hereafter, the study examined the exercises that fall into this category to determine which exercise will elicit the highest %MVIC, defined as the peak normalised sEMG signal amplitude, in high-performance female field hockey players of the University of the Free State (UFS).*

Methods: *Surface electromyography (sEMG) was used to record the muscle activation of the mGmax and mGmed of four (4) body weight rehabilitation exercises on twenty-six (26) high-performance female field hockey players of the UFS. The %MVIC activation data of both the mGmax and mGmed were analysed using a three-way ANOVA, with 'participant', 'period' and 'exercise' as categorical variables in the model. Point estimates for the mean %MVIC for each exercise were reported, as well as point estimates, 95% confidence intervals (CIs) and p-values for the pairwise differences in peak %MVIC between the four body weight rehabilitation exercises. For each variable analysed, the overall F-test for the four body weight rehabilitation exercises is reported, as well as the partial effect size measure for ANOVA.*

Results: *The mean age of the participants was 20.15±1.59 years, the mean height was 164±0.07cm, mean body mass was 64.72±10.21kg, and mean BMI was 23.87±2.92kg.m². Side-plank hip abduction with dominant leg on bottom generated a 124.61±7.94%MVIC of the mGmax and a 126.07±14.16%MVIC of the mGmed. Side-plank hip abduction with* *dominant leg on top generated a 124.33±8.63%MVIC of the mGmax and a 124.52±11.37%MVIC of the mGmed. The single-leg squat generated a 125.65±10.13%MVIC of the mGmax and a 126.30±12.89%MVIC of the mGmed. Plank with hip extension generated a 122.73±9.37%MVIC of the mGmax and a 125.04±13.14%MVIC of the mGmed. Concerning the mGmax, there was no significant difference found in activation when side-plank hip abduction with dominant leg on bottom was compared to side-plank hip abduction with dominant leg on top (p=0.8475, d=0.28), the single-leg squat (p=0.4807, d=-1.03) and plank with hip extension (p=0.2000, d=1.88). Furthermore, no significant difference was found when side-plank hip abduction with dominant leg on top was compared to the single-leg squat (p=0.3685, d=-1.31) and plank with hip extension (p=0.2770, d=1.60). However, there was a significant difference between the single-leg squat and plank with hip extension (p=0.0487, d=2.91). Concerning the mGmed, there was no significant difference in activation when side-plank hip abduction with dominant leg on bottom was compared to the side-plank hip abduction with dominant leg on top (p=0.3272, d=1.54), the single-leg squat (p=0.8837, d=-0.23) and plank with hip extension (p=0.5134, d=1.03). Furthermore, no significant difference was found when side-plank hip abduction with dominant leg on top was compared to the single-leg squat (p=0.2606, d=-1.77) and plank with hip extension (p=0.7437, d=-0.52) or between the single-leg squat and plank with hip extension (p=0.4240, d=1.26). When the exercise effect is combined, the four body weight rehabilitation exercises did not significantly affect either mGmax (p=0.2558) or mGmed (p=0.6285) activation.*

Conclusion: *The four body weight rehabilitation exercises examined by the study generated very similar %MVIC activation of the mGmax and mGmed in high-performance female field hockey players. This research enables practitioners to apply evidence-based practice into programme prescription. Implementation of the findings of the current study could result in significant benefits during prehabilitation, injury prevention programmes and the later stages of rehabilitation for high-performance female field hockey players. The conditioning coach stands to benefit, especially given that these exercises can be executed on the playing pitch as part of a warm-up without the need for any equipment.*

Key terms: *Surface electromyography, m. gluteus maximus, m. gluteus medius, maximal voluntary isometric contraction, body weight rehabilitation exercises, high-performance female field hockey players*

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ABBREVIATIONS

Ag/AgCl	**Silver/silver chloride**
BMI	**Body mass index**
cm	**Centimetres**
CMRR	**Common-mode rejection ratio**
CPR	**Cardiopulmonary resuscitation**
dB	**Decibel**
DTS	**Direct Transmission System**
EMG	**Electromyography**
FIH	**International Hockey Federation**
g	**Gram**
GPS	**Global Positioning System**
GTA	**Gluteal-to-tensor fascia latae muscle activation**
Hz	**Hertz**
kg	**Kilogram**
$kg.m^2$	**Kilogram per square meter**
km/h	**Kilometres per hour**
m.	**Muscle**
m	**Metre**
max	**Maximum**
mGmax	**Gluteus maximus muscle**

mGmed	**Gluteus medius muscle**
min	**Minimum**
min.	**Minutes**
mm	**Millimetres**
mm^2	**Millimetre square**
MUAP	**Motor unit action potential**
mV	**Millivolt**
MVIC	**Maximal voluntary isometric contraction**
Q1	**Quartile one**
Q3	**Quartile three**
Ohm	**Electrical resistance and conductance**
PSIS	**Posterior Superior Iliac Spine**
RM	**Repetition maximum**
RMS	**Root-mean-square**
ROM	**Range of motion**
SAS	**Statistical Analysis System**
sEMG	**Surface Electromyography**
SENIAM	**Surface Electromyography for Non-Invasive Assessment of Muscles**
Std	**Standard deviation**
TFL	**Tensor fascia latae**
UFS	**University of the Free State**

μV	**Potential difference**
V	**Volt**
$\boldsymbol{\omega^2}$	**Partial omega square**

TERMS AND DEFINITIONS

Abdominal wall	**A wall of the abdomen consisting of three layers of muscle**
Abduction	**A limb movement away from the midline of the body**
Abductor	**A muscle that moves a limb or part away from the midline of the body**
Achilles tendinopathy	**An overuse injury of the Achilles tendon owing to repetitive energy storage and release accompanied by excessive compression**
Activation capabilities	**The force generated by individually recruited muscle fibres**
Adduction	**The movement of a body part towards the body's midline**
m. Adductor longus	**A skeletal muscle located in the thigh**
Adhesive gel electrodes	**A device which uses a gel to transfer an electric current from the skin to a measuring instrument**
Ambulation	**Walking**
Anterior	**Front**
Anterior pelvic tilt	**The front of the pelvis drops in relationship to the back of the pelvis**
Aponeurosis	**A sheet-like fibrous membrane that serves as a fascia to cover certain muscles or connect muscle to bone**

Artifacts	**Electrical noise generated by muscle activity near the electrode that corrupt the purity of the EMG signal**
Astro	**The surface on which field hockey is played**
Asymptomatic	**Presenting no symptoms of a disease**
Base of support	**The area around the outside edge of the parts of the body in contact with the ground**
m. Bicep femoris	**A muscle with two heads found on the back of the thigh**
Bilateral	**Relating to both right and left side of the body**
Biokineticist	**Exercise therapist/specialist**
Biomechanics	**The study of the structure, function and motion of the mechanical aspects of living organisms**
Body weight exercises	**Strength training exercises that use the individual's body weight as resistance against gravity**
Coccyx	**A small triangular bone in humans located at the base of the spinal column**
Collegiate athlete	**A student-athlete participating in a structured competitive sport sponsored by the educational institution in which the individual is enrolled**
Compensatory movements	**Movements used out of habit to perform functional motor skills when a normal movement pattern has not been established**
Conditioning	**The process of training to become physically fit by a regimen of exercise**

Contralateral	**The side of the body opposite to that on which a specific structure or disorder occurs**
Core stabilisation	**The ability to create extremity movement without compensatory movements of the spine or pelvis**
Cross-talk	**The sEMG signal identified over a non-active muscle and elicited by a nearby muscle**
Distal	**Situated away from the point of attachment**
Dribbling	**A action in hockey that refers to the player running with the ball while controlling it with the stick**
Dynamic	**Carrying out movements**
Eccentric	**The lengthening of an active muscle under resistance**
Electromyography	**Recording of the electrical activity elicited by muscle tissue with electrodes that are placed on the skin or inserted into the muscles**
Elite	**A handpicked group that is superior in terms of ability or qualities to the rest of a group**
m. Erector spinae	**A group of long muscles on each side of the vertebral column that originates close to the sacrum and extends vertically up the length of the back**
Extension	**A movement that straightens a limb and increases the angle between body parts**
Extensor	**Contraction of a muscle that extends or straightens a limb**

External rotation	**Rotation away from the centre of the body**
Fascia latae	**A tissue bandage underneath the skin that covers underlying tissues and separates different layers of tissue**
Femur	**The bone in the human body that extends from the hip to the knee**
Fine-wire EMG	**An electrode inserted into a muscle that has a surface electrode as a reference**
Flexion	**The action of bending a limb or joint**
Flicking	**An action performed in hockey referring to the lifting of the ball with the stick**
Frontal plane	**Any vertical plane dividing the body into ventral and dorsal (belly and back) segments**
Gait	**The distance from initial contact of one foot to the next initial contact of the same foot**
Gait normalisation	**A method allowing the uniform representation of the gait cycle for the purposes of comparison**
m. Gastrocnemius	**The chief calf muscle of the leg**
Gluteal	**Muscles of the buttocks**
Gluteal tuberosity	**The lateral ridge of the linea aspera of the femur that provides attachment to the gluteus maximus muscle**
m. Gluteus maximus	**The largest buttock muscle**

m. Gluteus medius	**The middle of the three muscles in each buttock**
Goniometer	**An instrument for the precise measurement of angles**
Gravity	**The force that attracts a body towards the centre of the earth or towards any other physical body having mass**
Greater trochanter	**A strong process overhanging the root of the femur neck**
High-performance	**A sport at the highest level of competition**
Hypoallergenic tape	**A tape that firmly adheres to the skin and that can be gently removed without the risk of damaging sensitive skin**
Iliac crest	**The curved superior edge of the ilium or pelvis**
m. Iliopsoas	**A joining of two muscles that runs from the lumbar portion of the vertebral column to the femur**
Iliotibial band friction syndrome	**The distal portion of the iliotibial band becomes inflamed which causes knee pain**
Ilium	**The large, broad bone that forms the upper portion of each half of the pelvis**
Inferior	**Lower in position**
Internal rotation	**Rotation towards the centre of the body**
Intramuscular EMG	**Detection of muscle signals with needles or wire inserted into the muscles**
Isometric	**A contraction that increases the tension in a muscle while the muscle length remains the same**

Joint stability	**The resistance obtained by several musculoskeletal tissues surrounding a skeletal joint**
Kinematics	**The study regarding the geometric and time-dependent phases of motion without examining the forces that produce the motion**
Kinetic chain	**Joints and segments have an effect on one another during movement**
Knee valgus	**A deviation where the knee forms an angle between the femur and tibia in which the knee angulates to the midline with the tibia angulating away from the midline**
Lateral	**Side**
m. Latissimus dorsi	**A broad, flat and superficial muscle mainly of the middle and lower back**
Lower extremity	**The part of the body that includes the leg, ankle and foot**
Lumbar spine	**Identified as the lower back comprising of five vertebrae**
Lumbo-pelvic	**The lower section of the spine moves in combination with the pelvis**
Manual resistance	**A form of exercise without any equipment**
Maximal voluntary isometric contraction	**A standardised method for measurement of muscle strength to determine the magnitude of muscle recruitment**
Medially rotates	**Joint movement around its long axis towards the body's midline**

Metronome	**A timing device set at a selected rate by giving a regular tick**
Mobility	**The ability to move freely**
Musculoskeletal	**Denoting the muscles and skeleton together**
M-wave	**The process whereby the earliest EMG response to motor nerve stimulation is traced**
Neuromuscular control	**The unconscious trained reaction of a muscle to a signal about dynamic joint stability**
Non-invasive electrodes	**Used to electrically interface the brain by placing electrodes on the subject's scalp**
Osteoarthritis	**Degeneration of the cartilage of a joint and the underlying bone which causes pain and stiffness mainly in the knee, hip and thumb joints**
Patella	**The kneecap**
Patellar displacement	**A knee injury in which the kneecap slips out of its normal position**
Patellofemoral pain	**A condition which is characterised by knee pain originating from the back of the patella – also known as 'runner's knee'**
Pathology	**The study of disease**
Peak normalised sEMG	**Normalising the surface electromyography data to the peak activity achieved from the activation in each muscle for each individual**

m. Pectoralis major	**A large muscle located in the upper chest**
Pelvic-femoral	**The articulation of the pelvis with the femur to form the hip joint**
Pelvic girdle	**The enclosing structure formed by the bony pelvis that connects the trunk and legs**
Pelvic stability	**The ability to coordinate activity between the lower trunk and proximal hip muscles during functional balance and mobility tasks for effective lower limb mobility**
Piriformis syndrome	**A condition involving the piriformis muscle, located in the buttock area, irritates the adjacent nerve that results in pain, numbness and tingling alongside the back of the leg**
Plinth	**A padded table for a patient to sit on or lie on while executing exercises or undergoing treatment**
Posterior	**Back**
Posterior superior iliac spine	**A projection at the posterior end of the iliac crest that serves as the attachment for ligaments and muscles**
Posterior tilting	**The front of the pelvis rises while the back of the pelvis drops**
Posterolateral surface	**Back and away from the midline**
Post-operative	**The period following a surgical operation**
Preamplifier	**An electric device that amplifies a weak signal and transmits it to a main amplifier**

Pre-gelled electrodes	**Disposable electrodes that can be used to measure EMG levels**
Prehabilitation	**A form of strength training with the purpose to prevent injuries**
Prone	**A body position in which the person lies flat with the chest on the bottom and the back up**
Proximal	**Located closely to the point of attachment**
Quadrilateral	**Four-sided**
Recreational level	**Competitive physical games such as basketball that are played for fun**
m. Rectus femoris	**A division of the quadriceps muscle lying in the front and middle region of the thigh**
Rehabilitation	**A process designed to diminish the loss related to acute injury or chronic disease to promote recovery and to maximise functional capacity**
Root-mean-square	**The square root of the arithmetic mean of the squares of a set of values**
Sacral vertebra	**Consists of five vertebral bones situated between the lumbar vertebrae and the coccyx**
Sacroiliac joint	**The joint between the sacrum and the ilium bones of the pelvis**
Sacrotuberous ligament	**A slender, fan-shaped ligament of the back of the pelvis located on either side of the body**

Sacrum	**A triangular bone in the lower back formed from fused vertebrae and located between the two hip bones of the pelvis**
Sagittal plane	**An anatomical boundary that divides the body into left and right**
m. Sartorius	**A long, narrow muscle running diagonally across the front of each thigh from the hip bone to the inside of the leg below the knee**
Scapula	**Shoulder blade**
Sedentary individuals	**A person living a lifestyle that involves sitting or lying down**
m. Semitendinosus	**One of three hamstring muscles at the back of the thigh**
SENIAM	**The project Surface Electromyography for Non-Invasive Assessment of Muscles is a European action in the Biomedical Health and Research Program of the European Union**
Slap shot	**The hardest shot one can perform in hockey**
Sport-specific adaptations	**The process where the body gets accustomed to specific demands of a training programme through repeated exposure and adapts to it**
Stadiometer	**A piece of medical equipment used for measuring human height**
Stance phase of gait	**The phase in the gait (stride) cycle during which the foot remains in contact with the ground**

Static	**No movement**
Submaximal	**Less than the maximum of which an individual is capable during exercise**
Superior	**Higher in position**
Synergist	**A muscle that stabilises a joint around the movement that occurs and helps to generate movement**
Synthetic surface	**Any human-made surface that does not rely on moisture to hold it together**
m. Tensor fascia latae	**A muscle which originates from the front part of the iliac crest which inserts into the iliotibial band and runs about one-third of the way down the thigh**
Thoracolumbar fascia	**A large, diamond-shaped area of connective tissue which encloses the intrinsic back muscles**
Torque	**A force that tends to cause rotation**
Transverse plane	**An imaginary plane dividing the body into upper and lower parts**
Trunk	**The human body apart from the head, neck, arms or legs**
Unilateral	**Only on the one side of the body**
Vector	**A quantity with direction and magnitude, chiefly to determine the position of one point in space in relation to another**

Ventrally	**The front part of the body which includes the chest, abdomen, shins, palms and soles**
Watt bike	**An exercise bike designed to mimic road cycling while recording power output in the form of watts**
Weight-bearing	**Exercises that force you to work against gravity, including walking, jogging and climbing stairs**
Wet-gel electrodes	**Electrodes made of silver/silver chloride material that use an electrolytic gel material as a conductor between the skin and the electrode**

CHAPTER 1 – INTRODUCTION AND PROBLEM STATEMENT

1.1 Introduction

Various researchers have recently examined the mechanical outcome of weak proximal musculature on the more distal parts of the lower extremity in the functioning of the entire kinetic chain (Ayotte *et al.*, 2007; Ekstrom, Donatelli & Carp, 2007; Distefano *et al.*, 2009; Boren *et al.*, 2011; Macadam, Cronin & Contreras, 2015; Ebert *et al.*, 2017; Macadam & Feser, 2019). These researchers focused explicitly on the activation capabilities of the gluteal musculature during various commonly used rehabilitation exercises. These studies aimed to provide practitioners with several evidence-based exercises, stratified by exercise type and muscular demand as a percentage of the maximal voluntary isometric contraction (%MVIC) that can be selected in an exercise protocol to strengthen the m. gluteus maximus (mGmax) and m. gluteus medius (mGmed) of a particular individual (Ebert *et al.*, 2017). Macadam *et al.* (2015) stated that although there are a variety of different gluteal strengthening exercises, a thoroughgoing knowledge of which exercises optimally target the mGmax and mGmed, as well as the magnitude of activation related with each exercise, need to be established. More in-depth knowledge regarding strengthening of the mGmax and mGmed will result in prescribing the most effective exercises for strengthening during prehabilitation and the later stages of rehabilitation (Boren *et al.*, 2011; Ebert *et al.*, 2017).

About 33% of the hip musculature comprises of the mGmax and mGmed (Ito *et al.*, 2003; Lehecka *et al.*, 2017). The mGmax primarily produces hip extension, which is a joint action involved in various daily activities such as walking, stepping and standing as well as actions in sport such as running, sprint-running and jumping (Macadam & Feser, 2019). Of all muscle groups involved in the movement of the hip, the hip extensor musculature can produce the highest torque (Macadam & Feser, 2019). The mGmax also assists in stabilising the knee in extension and plays a significant role in decreasing the load on the m. erector spinae during lumbar extension (Neumann, 2010; SENIAM, 2019). Van Putte, Regan and Russo (2014) reported that the lower portion of the mGmax produces abduction of the hip joint and is an external rotator of the thigh. However, the mGmed acts primarily to produce abduction at the hip joint and is critical for pelvic and lower limb (femur) stability during weight-bearing movements (Reiman, Bolgla & Loudon, 2012; Van Putte *et al.*, 2014; Ebert *et al.*, 2017; SENIAM, 2019). Both the mGmax and mGmed contribute mainly to weight-bearing movements through aiding the hip joint to transfer weight, maintain alignment of the hip and knee joints and provide local structural stability to the hip joint (Presswood *et al.*, 2008; Macadam *et al.*, 2015).

Considering the important role of both the mGmax and mGmed, it stands to reason that strengthening of these two muscles are essential for populations that are athletic, non-athletic and those receiving post-operative treatment (Macadam *et al.*, 2015; Lehecka *et al.*, 2017). Failure of the hip abductors and external rotators in generating sufficient torque through weight-bearing activities will result in compensatory movements at the lower back, hip and knee, notably a pelvic drop, excessive hip adduction, femoral internal rotation and an exaggerated knee valgus angle (Souza & Powers, 2009; Distefano *et al.*, 2009; Reiman *et al.*, 2012; Macadam *et al.*, 2015). According to Lehecka *et al.* (2017), muscle strength plays a prominent role in gait normalisation and posture, the prevention of injuries, pain reduction and enhancement in performance. Lee and Jo (2016) and Macadam and Feser (2019) found that weakness and imbalanced strength of the mGmax and mGmed could result in substitution by synergist muscles. Stastny *et al.* (2016) noted that a weak mGmed could disrupt movement, which may lead to adverse alterations in lower extremity kinematics that increases the injury risk in athletes and result in a deterioration in sport performance. As evidence of this, the likelihood of an injury in athletes who have greater hip abduction strength is less when compared to athletes with weaker hip abduction strength (Stastny *et al.*, 2016).

An established link exists between decreased performance of the mGmax and mGmed and various pathologies such as alteration in pelvic-femoral biomechanics that are related with lower back and lower extremity pathology (Reiman *et al.*, 2012; Macadam *et al.*, 2015; Stastny *et al.*, 2016; Ebert *et al.*, 2017). Weakness of the hip musculature may result in excessive hip internal rotation, a biomechanical deviation often related with patellofemoral pain syndrome (Earl & Hoch, 2011; Ferber, Kendall & Farr, 2011; Khayambashi *et al.*, 2012; Selkowitz, Beneck & Powers, 2016; Barton *et al.*, 2018). Similarly, another painful, debilitating condition, i.e., iliotibial band friction syndrome, is also characterised by excessive hip internal rotation, weakness of the gluteal musculature and diminished extensibility of the iliotibial band (Barton *et al.*, 2018). Weak hip abductors and external rotators cause a valgus knee position, which has been strongly associated with knee osteoarthritis (Barton *et al.*, 2018). Therefore, strengthening of the mGmax and mGmed has been incorporated in rehabilitation programmes for numerous disorders of the lower extremity. This includes piriformis syndrome (Tonley *et al.*, 2010; Selkowitz *et al.*, 2016), hamstring injuries (Wagner *et al.*, 2010; Selkowitz *et al.*, 2016) and achilles tendinopathy (Franettovich Smith *et al.*, 2014; Selkowitz *et al.*, 2016). According to Page, Frank and Lardner (2010), a connection between gluteal musculature inhibition and lower back pain exists. Wege, Bester and Crous (2006) and Barton *et al.* (2018) also indicated that a weak mGmax has generally been associated with chronic lower back pain. On their part, Jeong *et al.* (2015) illustrated that chronic lower back pain could be overcome by strengthening of the mGmax.

Against this background, Wege *et al.* (2006) stated that female field hockey players with weak mGmax have a higher risk to develop lower back pain. Furthermore, it was clearly noted that the synthetic surfaces on which high-performance field hockey players practise and play predominantly demand maintaining a forward flexed posture (semi-crouched/squatting) to optimally execute skills such as stopping, flicking and tackling (Wege *et al.*, 2006; Haydt, Pheasant & Lawrence, 2012). Training and playing on a synthetic surface could facilitate the development of lower back pain in this population owing to the inherent postural stresses placed on the musculoskeletal system (Wege *et al.*, 2006; Haydt *et al.*, 2012). Van Hilst *et al.* (2015) found that the prevalence of sport-related risk factors in the development of lower back pain was 3–5 times higher in young elite female field hockey players compared to the general age-related population. Considering the unique postural requirements of field hockey and the influence of these demands on a player's spine, the need for assessing the muscles that support the lumbar spine, especially the muscles that surround the hip, is highlighted (Wege *et al.*, 2006). Wege *et al.* (2006) further note that the muscles inferior to the pelvis (the hip and knee joint musculature) and the muscles superior to the pelvis (the lumbar spine and abdominal wall musculature) control the amount of forces within the lumbar spine. Accordingly, these muscles should function properly to reduce the forces through the lumbar spine (Wege *et al.*, 2006).

The thoracolumbar fascia is the mechanical link between the hip and lumbar spine muscles. The mGmax is one of various muscles that tense the fascia when contracted to contribute to stabilisation of the lumbar spine and pelvis (Wege *et al.*, 2006). However, as noted above, the mGmax is prone to weakness, and decreased muscle strength of the mGmax will result in decreased stability of the lumbar spine and sacroiliac joint (Wege *et al.*, 2006). Considering the significant role that the hip muscles, especially the mGmax, play to transfer forces from the lower extremity in the direction of the spine, it can be theorised that strengthening of these muscles would be appropriate (Wege *et al.*, 2006). Hence, the hip extensors and abductors that support the lumbar spine structures of high-performance female field hockey players warrant investigation. Barboza *et al.* (2018) stated that it is crucial to understand the magnitude and extent of injury risks to aid health practitioners to commence with appropriate injury prevention strategies for both recreational and professional levels of field hockey. According to Barboza *et al.* (2018), different studies in recent years have shown that structured exercise is the first step towards injury prevention in team sports; however, there is a dearth of evidence showing the implementation of this kind of programmes in field hockey. Therefore, exercise programmes that have proven to be effective and focus on preventing especially lower limb injuries should be introduced regularly to field hockey teams as part of their training schedule (Barboza *et al.*, 2018).

Strengthening of a particular muscle group necessitates the careful analysis of each muscle's function and origin to compile a systematic programme consisting of exercises that progress from low intensity to high intensity (Reiman *et al.*, 2012). The exercise programme prescribed by practitioners to strengthen a weaker muscle should always be gradually progressed to ensure development of the targeted area (Reiman *et al.*, 2012; Macadam *et al.*, 2015). The latter becomes particularly crucial if individuals exhibit compensatory movement patterns owing to muscle weakness or dysfunction (Macadam *et al.*, 2015). The progression of a particular exercise is affected by the plane of movement, the effects of gravity, the tempo of movement, the base of support (stable to unstable) and the type of muscle contraction (Reiman *et al.*, 2012; Lee & Jo, 2016). To prescribe an efficient programme, the practitioner should consider these factors when prescribing and implementing strengthening exercises for the gluteal musculature (Reiman *et al.*, 2012).

In keeping with the work of Ayotte *et al.* (2007), Distefano *et al.* (2009), Boren *et al.* (2011), Reiman *et al.* (2012)**,** Macadam *et al.* (2015), Ebert *et al.* (2017) and Macadam and Feser (2019), the aim of the current study was first to investigate which commonly prescribed body weight rehabilitation exercises from previous studies produced greater than 61%MVIC for both the mGmax and mGmed. Hereafter, the study examined the exercises that fall into this category through the peak normalised surface electromyography (sEMG) signal amplitude to determine which exercise will elicit the highest muscle activity presented as %MVIC. Four body weight rehabilitation exercises conducted by Boren *et al.* (2011) met the aim of the current study and were selected for examination. While Boren *et al.* (2011) selected healthy participants (i.e., those that can exercise for approximately one hour) to participate in their study, the current study selected a high-performance population, namely high-performance female field hockey players.

The outcomes of this study will assist practitioners with decision making for mGmax and mGmed strengthening during prehabilitation and the later stages of rehabilitation. Macadam *et al.* (2015) hypothesised that exercises that require a higher demand such as dynamic movements will lead to changes at various joint angles; hence, these exercises require better joint stability, which will produce a greater %MVIC. Knowledge of the percentage activation of the mGmax and mGmed elicited during specific body weight rehabilitation exercises may result in more specific exercise programme prescription during prehabilitation and the later stages of rehabilitation for high-performance female field hockey populations.

1.2 Problem statement

As mentioned above, various researchers (Ayotte *et al.*, 2007; Ekstrom *et al.*, 2007; Distefano *et al.*, 2009; Boren *et al.*, 2011; Reiman *et al.*, 2012; Macadam *et al.*, 2015; Ebert *et al.*, 2017; Macadam & Feser, 2019) have focused on the activation capabilities of the gluteal muscles during different commonly used rehabilitation exercises. However, there is currently a lack of research in examining body weight rehabilitation exercises that elicit the highest %MVIC for both the mGmax and mGmed in a high-performance athletic population. To the knowledge of the researcher, Cochrane, Gabriel and Harnett (2019) is the only study who examined sEMG signal amplitude that elicited a greater than 61%MVIC of the mGmax in an athletic population by focusing on healthy male rugby players. Sport-specific adaptations occur with sport played at a high level due to differences in strength of synergists that contribute to a specific sport, which is unlikely to be the case in sedentary individuals (Wege *et al.*, 2006). Moreover, field hockey is played in a posture where the muscles around the hip function in a closed kinetic chain, which contribute to the distribution of forces up the spine (Wege *et al.*, 2006). The current study will conduct the selected exercises on high-performance female field hockey players to determine the %MVIC activation of the mGmax and mGmed. A greater understanding of the %MVIC that the exercises exhibit will optimise future exercise programme prescription when selecting exercises. Thus, the field hockey community can benefit from this investigation and guidelines in order to implement exercise programmes that will strengthen the mGmax and mGmed during prehabilitation and the later stages of rehabilitation to prevent the possible risk of various injuries.

1.3 Aim of the study

The aim of the study was first to establish which commonly prescribed body weight rehabilitation exercises from previous studies produced greater than 61%MVIC for both the mGmax and mGmed. Hereafter, the study examined the exercises that fall into this category to determine which exercise will elicit the highest %MVIC, defined as the peak normalised sEMG signal amplitude, in high-performance female field hockey players of the University of the Free State (UFS).

1.4 Objectives of the study

The following objectives are set to accomplish the aim of the study, namely to:

- Determine the level of muscle activation of the mGmax and mGmed through sEMG analysis during four body weight rehabilitation exercises, namely:
    1. Side-plank hip abduction with dominant leg on bottom;
    2. Side-plank hip abduction with dominant leg on top;
    3. The single-leg squat; and
    4. Plank with hip extension.
- Provide clinical, evidence-based body weight rehabilitation exercises, stratified by muscular demand (%MVIC) to assist practitioners in an interprofessional team in rehabilitation and conditioning to make informed decisions regarding programme prescription for mGmax and mGmed strengthening during prehabilitation and the later stages of rehabilitation.

1.5 Significance of the study

Based on the outcome of the results of the study, the researcher will provide objective data of body weight rehabilitation exercises that maximally activate the mGmax and mGmed in high-performance female field hockey players. Practitioners will be equipped to make informed decisions concerning the basis for a graded mGmax and mGmed strengthening programme during prehabilitation and the later stages of rehabilitation in high-performance female field hockey players. An advantage of body weight exercises is that it can be performed without the need for any equipment, thus providing promising possibilities for implementing strength training on the playing surface of field hockey players (Serner *et al.*, 2014). However, the ideal number of sets, repetitions and frequency of the exercises are outside the scope of this study. Finally, this research will make a valuable contribution to the academic field in the understanding of gluteal musculature activation.

1.6 Structure of the dissertation

The dissertation consists of seven chapters, as illustrated in Figure 1 (below). Chapter 1 addressed the problem statement, the aim and objectives, as well as the methodological considerations of the study. The literature findings regarding body weight rehabilitation exercises, which elicit greater than 61%MVIC to strengthen the mGmax and mGmed, will be discussed in Chapter 2. The rationale for selecting female field hockey players will also be provided in this chapter. Chapter 3 will present the research design and methodology of the study. The results of the study will be reported in Chapter 4. Chapter 5 will consist of the discussion of the results (Chapter 4) concerning which body weight rehabilitation exercise exhibited the highest %MVIC activation of the mGmax and mGmed in high-performance female field hockey players of the UFS. Chapter 6 will elaborate on the recommendations for future research in this area and provide a conclusion. Chapter 7 will conclude the study by reflecting on the research process.

Hereafter, referencing is according to the Harvard method, which is provided in a list at the end of the dissertation. The dissertation was proposed for approval according to the UFS guidelines for postgraduate studies. In the interest of quality, and to facilitate examination, the font and spacing are consistent throughout the dissertation. Tables and figures can be found in the text.

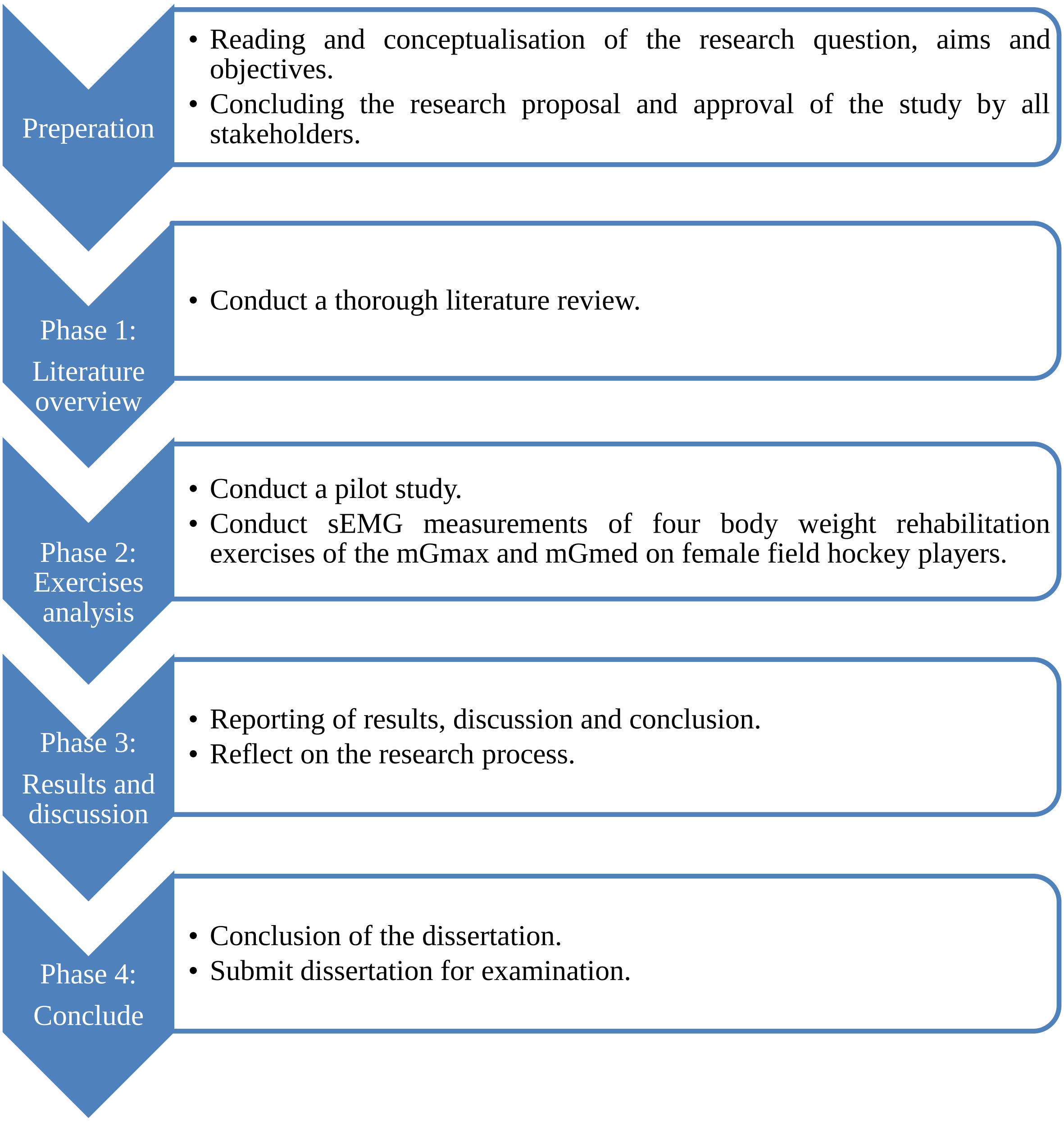

Figure 1: Summary of the research process

CHAPTER 2 – LITERATURE REVIEW

2.1 Introduction

This chapter describes field hockey as a sport, its specific demands and the physical characteristics of the game and the players. Furthermore, the chapter consists of background information of the muscles under investigation in the current study and the prominence of these muscles during different actions in field hockey. Lastly, it presents a review of the literature on previous studies that also conducted sEMG measurements of body weight rehabilitation exercises to activate the mGmax and mGmed optimally. The study consulted literature from electronic databases such as Kovsiekat, Pubmed, EbscoHost, ScienceDirect, as well as relevant academic journals and textbooks, to inform methodological considerations.

2.2 Description of field hockey

2.2.1 Background

Field hockey is a professional international team sport played with a stick and ball by both men and women at many levels, ranging from amateur to elite (Jennings *et al.*, 2012a; 2012b; McGuinness *et al.*, 2017). An artificial pitch (also known as an 'astroturf') serves as the official playing surface (Bandyopadhyay, Datta & Dey, 2019). Compared to grass, the introduction of this surface increased the overall match playtime, the number of ball touches per player, and the distance players run with the ball (Bandyopadhyay *et al.*, 2019). The premier international tournaments are the World League and World Cup that provide a pathway to qualify for the Olympic Games (Jennings *et al.*, 2012a; 2012b; McGuinness *et al.*, 2017). Competitive match play involves two teams of eleven players per side, comprising of a goalkeeper and ten outfield players (McGuinness *et al.*, 2017; The International Hockey Federation, 2019). Similar to soccer, these outfield players are categorised into three distinct positional groups, namely forwards, midfielders and defenders (Jennings *et al.*, 2012a; 2012b). The purpose of the match play is to outscore the opposition through the execution of offensive and defensive skills (McGuinness *et al.*, 2017).

In 2015, The International Hockey Federation (FIH) announced various rule changes to the format of the game. Before 2015, the duration of an international hockey match was 70 minutes, separated into 2-halves of 35 minutes continuous play, with a 10-minute half-time period (McMahon & Kennedy, 2017; The International Hockey Federation, 2019). Following the rule changes, the total playing time is now 60 minutes, consisting of four 15-minute quarters each separated by 2-minute intervals and a half-time interval of 5 minutes between quarters 2 and 3 (McMahon & Kennedy, 2017; McGuinness *et al.*, 2018; The International Hockey Federation, 2019). Field hockey players engage in different locomotion, such as high-speed running intertwined with accelerations, decelerations and direction changing (McGuinness *et al.*, 2017). Therefore, McGuinness *et al.* (2017) summarised that the movement patterns of field hockey players are stochastic. The brief recovery periods between quarters could facilitate aerobic recovery, while the shorter total game time could, in theory, result in players being capable of competing at higher intensities (McMahon & Kennedy, 2017). It is hypothesised that a similar phenomenon will result from the unlimited substitutions rule in the sport (McMahon & Kennedy, 2017). McMahon and Kennedy (2017) conducted a study to compare the activity profiles of elite international female field hockey players' pre and post the 2015 FIH rule changes. The significant findings of this study among all players from 2014 to 2015 were a substantial increase in the relative distance covered in each position, high speed running, surges and substitutions, while a relative decrease in low-speed running was observed. Hence, the current data suggest that the rule changes resulted in more intense matches (McMahon & Kennedy, 2017).

The physical demands of field hockey differ according to both age group and competition level (Vescovi & Frayne, 2015). Vescovi and Frayne (2015) stated that optimal training benefits would result from the reproduction of movement patterns and physiological demands in the day-to-day training environment. Therefore, an improved athlete-development programme can be provided given that the physical demands across all levels of a particular sport are known (Vescovi & Frayne, 2015). Global Positioning System (GPS) technology is a popular tool for quantitative analysis of the physical demands during training and competitive match play in field hockey (Gabbett, 2010; Jennings *et al.*, 2012a; Vescovi & Frayne, 2015; McMahon & Kennedy, 2017; McGuinness *et al.*, 2017). In elite and Olympic standard field hockey players, this technology revealed that the majority of the distance covered is at low to moderate intensity, interposed with high-intensity and maximal efforts (Vescovi & Frayne, 2015).

2.2.2 Physical demands of the 70-minute format

Considering the physiological and physical activity profiles, McMahon and Kennedy (2017), Perrotta, Held and Warburton (2017) and McGuinness *et al.* (2018) classify field hockey as a high intensity intermittent sport. McGuinness *et al.* (2017) analysed the match activity profiles of elite international female field hockey players (n=38) in 19 competitive matches during the 2014–2015 season. Their analysis indicated that players covered a total distance of 5530±425m. A high proportion (87%) of the distance covered was at low to moderate intensity (8.1–15.9km/h). High-speed (16–19.9km/h) running consisted of 11% of the match play, with sprinting (>20km/h) distance accounting for only 2%. Similar to McGuinness *et al.* (2017), Macutkiewicz and Sunderland (in McGuinness *et al.*, 2017) recorded the match activity profiles of international female field hockey players (n=25) during 13 international matches in 2007. They revealed that the average total distance covered by players were 5541±1144m, with 1653m at low (0–6km/h) intensity, 3006m at moderate (6.1–15.0km/h) intensity and 852m at high (15–29.5km/h) intensity respectively. The total match time spent at low, moderate and high intensities is, therefore, 38.1%, 55.5% and 6.4% respectively. Forwards performed the most running time at speed higher than 15km/h. On the other hand, the high-speed distance (>16km/h) of 852±268m in the study of Macutkiewicz and Sundeland was higher than that of McGuinness *et al.* (2017), who reported 587±129m. McMahon and Kennedy (2017) conducted a study on elite international female field hockey players to highlight the match activity profiles pre (2014) and post (2015) the 2015 FIH match rule changes at team and positional levels. Concerning the average total distance covered in 2014, the team covered 4879.9±935.6m, 5182.2±1051.9m by defenders, 5195.5±747.3m by midfielders and 4313.4±783.8m by forwards. Furthermore, the average high-speed running covered by defenders was 728.8±214.1m compared to midfielders (998.2±241.6m) and forwards (935.6±279.3m).

2.2.3 Physical demands of the four 15-minute quarters

According to McMahon and Kennedy (2017), the average total distance covered by the team for the 2015 season was 5167.4±1029.8m, 5228.4±1087.7m by defenders, 5431.3±961.4m by midfielders and 4789.6±969.7m by forwards. Moreover, the average high-speed running covered by defenders was 737.0±196.4m, 1089.1±294.0m by midfielders and 955.7±257.1m by forwards. McGuinness *et al.* (2018) recorded the physical activity and physiological profiles during the 2016–2017 season across the quarters of competitive match play. They reported that the average total distance covered was 4847±583m, with 2152±329m at a moderate intensity (8–15.9km/h) and 580±147m (>16km/h) completed at a high intensity, regardless of position. Furthermore, the high-speed distance decreased between the first and second quarters from 154±58m to 124±46m. A significant increase was observed among the second and fourth (156±49m) quarters. Defenders covered more total distance (5181±607m) compared to midfielders (4740±530m) and forwards (4549±546m). However, the work rate of forwards during match play was the highest, while defenders showed the lowest work rate (McGuinness *et al.*, 2018).

2.2.4 Physical characteristics of female field hockey players

Research regarding the physical characteristics of elite international female field hockey players is well documented. There is, however, a dearth of research on high-performance university-level players. Because there is no previous research conducted on the sEMG activation of the mGmax and mGmed on female field hockey players, literature regarding the physical characteristics (i.e., age, body mass, height and body mass index (BMI)) of studies that examined the physical demands of female field hockey players during match play through GPS technology are reported below. Naicker, Coetzee and Schall (2016) is the only study that did not utilise GPS technology, opting instead to prioritise the morphological and skill-related fitness components as potential predictors of injuries in the South African national women's field hockey team.

2.2.4.1 Age

Naicker *et al.* (2016) conducted a study on elite female field hockey players (n=30) with a mean age of 23.8±3.16 years. Perrotta *et al.* (2017) conducted a study on elite international female field hockey players (n=16) who had an average age of 22±2.1 years. On their part, McMahon and Kennedy (2017) recorded the match activity profiles of elite international female field hockey players (n=19) pre (2014) and post (2015) the 2015 FIH match rule change who had an average age of 23±4 years. McGuinness *et al.* (2017) recorded the match activity profiles of elite international female field hockey outfield players (n=38) who had an average age of 24±5 years. McGuinness *et al.* (2018) conducted another study during a major international female field hockey tournament on elite female field hockey players (n=27) during the 2016–2017 season who had an average age of 23±3 years. Vescovi, Klas and Mandic (2019) conducted a study on female field hockey players (n=16) from Canada's under 21 national team. The average age of this team was 18.8±1.2 years. The studies by Naicker *et al.* (2016), McMahon and Kennedy (2017) and McGuinness *et al.* (2018) reported a similar mean age. Hence, this confirms that the average mean age of studies who conducted research on female field hockey players is approximately 23 years.

2.2.4.2 Body mass

Naicker *et al.* (2016) reported a mean body mass of 62.6±8.45kg. Perrotta *et al.* (2017) reported a mean body mass of 61.3±5.7kg, while McGuinness *et al.* (2017) reported a mean body mass of 64±5kg. Furthermore, McMahon and Kennedy (2017) reported a mean body mass of 63.6±5.5kg, whereas McGuinness *et al.* (2018) reported a mean body mass of 66±6kg. On their part, Vescovi *et al.* (2019) reported a mean body mass of 64.6±9.3kg. According to previous studies, the mean body mass of female field hockey players seems to be approximately 64kg.

2.2.4.3 Height

Naicker *et al.* (2016) reported a mean height of 164.5±5.24cm, Perrotta *et al.* (2017) a mean height of 170 ± 3.5cm, McGuinness *et al.* (2017) a mean height of 163±5cm and McGuinness *et al.* (2018) a mean height of 163±13cm. On their part, Vescovi *et al.* (2019) reported a mean height of 166±6.3cm. According to these studies, the mean height is approximately 163cm to 164cm for female field hockey players.

2.2.4.4 BMI

None of the studies mentioned above provided any BMI values of their participants; however, the current study calculated it for comparative purposes. For this reason, the standard deviations from the studies mentioned above could not be provided. The study by Naicker *et al.* (2016) reported a mean BMI of 23.27kg.m², while Perrotta *et al.* (2017) reported a slightly lower mean BMI of 21.21kg.m². The study conducted by McGuinness *et al.* (2017) and McGuinness *et al.* (2018) reported a mean BMI of 24.09kg.m² and 24.84kg.m² respectively. Finally, Vescovi *et al.* (2019) reported a mean BMI of 23.44kg.m².

2.3 Anatomical background

2.3.1 The mGmax

The mGmax is the largest of the gluteal muscle group and the most superficial, contributing most of the mass that could be seen as the buttocks (Winter, 2005; Reiman *et al.*, 2012; Van

Putte *et al.*, 2014). The mGmax is a "broad, thick, and fleshy mass with a quadrilateral shape", located in the posterior region of the hip just superior to the hamstring muscle group, which constitutes 16% of the entire cross-sectional part of the hip (Winter, 2005; Reiman *et al.*, 2012; Rainsford, 2015). The origin of the mGmax consists of several anatomical landmarks. These anatomical landmarks include the posterior gluteal line of the ilium, the segment of the bone superior and posterior to the posterior surface of the inferior portion of the sacrum, lateral coccyx, m. erector spinae's aponeurosis, sacrotuberous ligament and gluteal aponeurosis (Kendall, McCreary & Provance, 2005; Reiman *et al.*, 2012; Kang *et al.*, 2013; Van Putte *et al.*, 2014; SENIAM, 2019). Importantly, the thoracolumbar fascia attaches the mGmax to the lumbar m. erector spinae and the sacrotuberous ligament attaches the mGmax to the m. bicep femoris (Leinonen *et al.*, 2000; Rainsford, 2015). This clarifies the function of the mGmax in lower extremity movements, pelvic and core stabilisation (McKenzie *et al.*, 2010; Rainsford, 2015).

The fibres of the mGmax run diagonally, lateral and inferior (Kang *et al.*, 2013). The larger proximal portion of the mGmax, as well as the superficial fibres of the distal portion of the muscle, insert at the iliotibial tract of the fascia latae (SENIAM, 2019). The deeper fibres of the distal portion insert at the gluteal tuberosity of the femur (Reiman *et al.*, 2012; SENIAM, 2019). According to Reiman *et al.* (2012), 80% of the mGmax attaches at the iliotibial band, while the remainder inserts on the distal section of the gluteal tuberosity.

2.3.2 Functions of the mGmax

The primary function of the mGmax is hip extension (Neumann, 2010; Van Putte *et al.*, 2014; Rainsford, 2015). More particularly, Van Putte *et al.* (2014) identified that the mGmax functions at its maximal force during extension of the thigh. Neumann (2010), Van Putte *et al.* (2014) and Rainsford (2015) reported that the mGmax also produce hip abduction and is an external/lateral rotator of the thigh. On their part, Selkowitz *et al.* (2013) stated that the superior part of the mGmax functions as a hip extensor, external rotator and abductor, while the inferior portion is primarily active as a hip extensor. The inferior portion also assists in adduction of the hip joint (Kendall *et al.*, 2005). The mGmax plays a vital role in its ability to decrease the strain on the m. erector spinae in lumbar extension and assists also in stabilising the knee in extension by its insertion into the iliotibial tract (Kendall *et al.*, 2005; Neumann, 2010; Rainsford, 2015; SENIAM, 2019).

2.3.3 The mGmed

The mGmed consists of a smaller muscle mass, located just superior and lateral to the mGmax (Van Putte *et al.*, 2014). The mGmed originates on the ilium's posterior surface, dorsally in the centre of the iliac crest and posterior gluteal line, and ventrally anterior to the gluteal line and on the gluteal aponeurosis (Van Putte *et al.*, 2014; SENIAM, 2019). The mGmed fibres run diagonally and laterally inferior to insert on the posterolateral surface of the femur's greater trochanter (Neumann, 2010; Van Putte *et al.*, 2014).

2.3.4 Functions of the mGmed

The mGmed functions primarily to produce hip abduction (Van Putte *et al.*, 2014; Ebert *et al.*, 2017; SENIAM, 2019). The mGmed is also a medial rotator of the thigh that assists to tilt the pelvis in order to maintain the trunk in an upright posture during walking and when the foot of the contralateral limb is elevated (Van Putte *et al.*, 2014). Without this action of the mGmed and m. gluteus minimus (which also contribute to this action), the pelvis tends to sag inferior on the unsupported side (Van Putte *et al.*, 2014). For this reason, the mGmed is indeed important to tilt the pelvis towards the supported side (Van Putte *et al.*, 2014).

Anatomically, the mGmed consists of three parts, i.e., (1) anterior, (2) middle and (3) posterior that separately branch from the superior gluteal nerve (Reiman *et al.*, 2012; SENIAM, 2019). The function of the three anatomical parts is subject to the fibre orientation (Reiman *et al.*, 2012). The anterior fibres medially rotate and may contribute in hip flexion (SENIAM, 2019). Also, the anterior fibres of the mGmed are activated with bridging, single-leg squatting and lateral step-up owing to the base of support being the least during these exercises (Boudreau *et al.*, 2009; Reiman *et al.*, 2012).

The posterior fibres of the mGmed play a secondary role to produce extension and lateral rotation of the hip (Reiman *et al.*, 2012; SENIAM, 2019). The mGmed is prominent in maintaining pelvic stability relative to the femur in the frontal plane (Neumann, 2010). Lastly, the mGmed assists in preventing adduction of the femur during dynamic tasks (Hollman, Ginos & Kozuchowsk, 2009; Rainsford, 2015). Altogether, the mGmed provides femur and pelvis stability in weight-bearing activities (Reiman *et al.*, 2012). Maximal mGmed activation is generated in the stance phase of gait (Gottschalk, Kourosh & Leveau, 1989; Reiman *et al.*, 2012).

2.4 Muscle activity classification

Andersen *et al*. (2006) and Macadam *et al.* (2015) illustrated that the minimum effort necessary to stimulate strengthening of a muscle is about 40% to 60% of the muscle's MVIC. Therefore, Ayotte *et al.* (2007), Escamilla *et al.* (2010) and Ebert *et al.* (2017) hypothesised that strength improvements of the activated muscle(s) could be obtained when the sEMG activity is beyond 40%MVIC. Studies by Escamilla *et al*. (2010) and Ebert *et al.* (2017) concerning the classification of low and high muscle activity, categorised 0% to 20%MVIC as "low" muscle activity, 21% to 40%MVIC as "moderate", 41% to 60%MVIC as "high", and more than 61%MVIC as "very high". Evidently, informed knowledge of exercises that produce very high activation levels will enable the practitioner to prescribe the most efficient exercise(s) to load the mGmax and mGmed as part of a prehabilitation programme or during the later stages of rehabilitation (Ebert *et al.*, 2017). Muscle recruitment of 25%MVIC or less implies that the muscle functions in an endurance mode or provides stability (Escamilla *et al.*, 2010; Youdas *et al.*, 2014). As has been noted, Krause *et al*. (2009) confirmed that the use of sEMG to quantify hip muscle activation during several exercises could theoretically imply that greater sEMG activity will produce improvements in strength.

2.5 Literature findings of studies that investigated the activation capabilities of the mGmax and mGmed during various rehabilitation exercises

Table 1 summarises the findings from previous studies that investigated the activation capabilities of the mGmax and mGmed during various rehabilitation exercises. Table 1 also provides information regarding the study's proposed sample, methodology, protocol sequence, method of sEMG collection, selected exercises, %MVIC and standard deviation (note, however, that Boren *et al.* (2011) is the only study that did not provide standard deviation). The temporal demarcation of the study focuses solely on studies completed in the period from 2003 to date. Exercises that fall into the category of very high (>61%MVIC) muscle activation were the only ones included in support of the aim of the study, i.e., to first establish which body weight rehabilitation exercises from previous studies elicited greater than 61%MVIC for both the mGmax and mGmed and, secondly, to examine these exercises.

It is also important to note that for some of these exercises, either the mGmax or the mGmed did not elicit greater than 61%MVIC. Where the %MVIC was less than 61% for either of these two muscles, no mention thereof was made in the table. Additionally, the table only presents studies that examined body weight rehabilitation exercises performed without any additional external load, such as a barbell, dumbbell, band and machine. Plyometric or hopping movements have also been excluded due to the higher acceleration outcome in performing these movements that will result in eliciting high levels of gluteal excitation (Macadam & Feser, 2019). Furthermore, plyometric exercises are prescribed during the final stages of rehabilitation and may only be incorporated when an individual reveals prerequisite eccentric strength levels, including mobility and stability (Macadam & Feser, 2019). Each exercise is stratified by exercise type and muscular demand (%MVIC) and, therefore, selection of these exercises can commence in prehabilitation or the later stages of rehabilitation to appropriately load the mGmax and mGmed to achieve strength gains (Boren *et al.*, 2011; Ebert *et al.*, 2017).

Table 1: Studies on activation capabilities of the mGmax and mGmed

Author and date	***Sample***	***Methodology (MVIC position, data processing, amplitude presentation, evaluated limb)***	***Protocol sequence***	***Method of sEMG collection***	***Exercises evaluated***	***mGmax %MVIC & Standard deviation (Std)***	***mGmed %MVIC & Std***
Zeller, McCrory & Ben (2003)	9 males (20.3±1 years; 182±5cm; 78.8±4.0kg) 9 females (22±8.6 years; 170±6cm; 64.3±5.5kg)	Prone hip extension against manual resistance with 90˚ knee flexion		Placement not specified	The single-leg squat	62.7±43 (male) 81.2±28 (female)	
Ayotte et al. (2007)	16 males, 7 females (31.2±5.8 years; 173.1±10.1cm; 77.0±13.9kg)	Supine hip extension against fixed resistance pad placed proximal to the popliteal fossa from 30˚ hip flexion		Placement: one-third of the distance from the second sacral vertebra to the greater trochanter	Forward step up (15.2cm height) Single-leg wall squat, other leg knee extended	74±43 86±43	

Boren et al. (2011)	26 healthy individuals (21 years and older) who were able to exercise for approximately 1 hour	MVIC testing in side-lying position mGmax: Prone hip extension against manual resistance at 0˚ of hip flexion Root-mean-square (RMS): 11.7-millisecond moving window Dominant limb (preferred leg to kick a ball)	Electrode placement, warm-up: 5min submaximal cycle, video-based exercise familiarisation, MVIC testing, exercise testing, re-evaluation of MVIC	sEMG over mGmax and mGmed	Clamshell 2		62.4
					Clamshell 3		67.6
					Clamshell 4		76.8
					Plank with hip extension	106.2	75.1
					Gluteal squeeze	80.7	
					Lateral step up	63.8	
					Side-plank hip abduction dominant leg on bottom	72.8	103
					Side-plank hip abduction dominant leg on top	70.9	88.8
					Single-leg squat	66.2	62.9
					Skater squat		82.3

Simenz, Garceau & Lutsch (2012)	15 females, 20.8±1.56 years, 1.66±0.07m, 64±6.92kg	mGmax: Prone hip extension at 70˚ hip flexion on a decline bench mGmed: Side-lying hip abduction at 25˚ against fixed resistance RMS: 125-millisecond moving window			Lateral step up Cross-over step up	113±89.5 103±63.6	
Webster and Gribble (2013)	9 (1 male, 8 females); 22.9±4.5 years; 1.64±0.65m; 65.4±10kg	mGmax: Prone hip extension against manual resistance with 90˚ knee flexion mGmed: Side-lying hip abduction against manual resistance Average sEMG of 3 trials			Rotation single-leg squat Transverse lunge	78±45 58±3	68±15 68±62

Lee, Cynn & Kwon (2014)	19 healthy subjects (8 males, 11 females) with a mean age 21±1.73 years; mean body mass 59.97±9.61kg; mean height 166±0.7cm; mean BMI 21.54±2.56kg.m²	MVIC testing in side-lying, with the hip in slight extension, lateral rotation and 50% of subject's hip abduction range of motion Dominant limb (preferred leg used to kick a ball)	5 min submaximal jogging warm-up, session familiarisation, electrode placement, MVIC testing, exercise testing	mGmed: sEMG directly superior to the greater trochanter, one-third of the distance between the iliac crest and greater trochanter	Side-lying hip abduction with internal hip rotation equal to 50% of the subject's maximal internal hip rotation range of motion		61.34
MacAskill, Durant & Wallace (2014)	20 healthy asymptomatic females (mean age 21.7±1.6 years; mean body mass 58.1±6.2kg; mean height 163.2±6.7cm) and 14 males (mean age 21.2±1.8 years; mean body mass 77.1±8.9kg; mean height	MVIC testing in side-lying with hip in 50% of hip abduction range of motion Dominant limb (preferred leg to kick a ball)	Exercise familiarisation: 2 weeks before data collection, electrode placement, MVIC testing, exercise testing	mGmed: sEMG, 2-3cm distal to the midpoint of the iliac crest	Forward step up onto a 15cm height box Lateral step up onto a 15cm height box		63±18 61±20

	177.8±15.3cm) with no recent history of lower limb resistance training in the past 6 months						
Kim & Yoo (2015)	18 males (23.3±1.8 years; 177.4±5.3cm; 74.2±7.2kg)	Prone hip extension against manual resistance with 90˚ knee flexion		Placement not specified	Prone hip extension with upper body on table	62.3±27.1	
Jeon, Kwon & Weon (2016)	16 males (25.4±4.2 years; 174.7±2.8cm; 73.1±2.1kg)	Prone hip extension against manual resistance with 90˚ knee flexion		Placement: midpoint of the line extending between the greater trochanter and sacrum	Prone hip extension with upper body on table and flexed contralateral knee joint on a chair	66.4±25.8	
Cochrane et al. (2019)	10 healthy male rugby players (20.4±2.7 years; 184.8±6.6cm; 97.2±13.0kg)	Three MVIC techniques: modified prone hip extension, standing gluteal squeeze and single-leg squat Statistical analysis: superior and inferior	Electrode placement, 3 reps of each MVIC technique in random order held for 4 sec separated with 2 min rest	sEMG over superior and inferior mGmax Superior mGmax: superior and lateral to midpoint of posterior superior iliac	Modified prone hip extension Standing bilateral hip extension (standing gluteal squeeze) Single-leg squat	100±0 51.6±14.5 88.8±15.5	

		mGmax were pooled together Sagittal plane: 60˚ knee flexion, 60˚ hip flexion Frontal and transverse planes: 0˚ hip angle RMS: 100-millisecond moving window Dominant limb (preferred leg to kick a ball)		spine (PSIS) and posterior greater trochanter Inferior mGmax: inferior and medial to midpoint between PSIS and posterior greater trochanter			

Differences in participants' characteristics resulted in variations in the standard deviation obtained from the mGmax and mGmed activation within studies. Therefore, Boren *et al.* (2011) concluded that a well-conditioned individual might present a %MVIC that reveals a low load, while the same exercise might be a greater challenge and of advanced load for a physically inactive individual.

Table 1 revealed that Boren *et al.* (2011) is the only study that reported sufficient %MVIC during exercises that met the aim of the current study. Only four of their exercises fall into the criterion of eliciting a greater than 61%MVIC for both the mGmax and mGmed, namely:

- Side-plank hip abduction with dominant leg on bottom (70.96%MVIC of mGmax; 103.11%MVIC for mGmed),
- Side-plank hip abduction with dominant leg on top (72.87%MVIC of mGmax; 88.82%MVIC of mGmed),
- The single-leg squat (82.26%MVIC of mGmax; 70.74%MVIC of mGmed), and
- Plank with hip extension (106.22%MVIC of mGmax; 75.13%MVIC of mGmed).

Macadam and Feser (2019) conducted the most recent systematic review of rehabilitation exercises that recruit the mGmax. The purpose of the latter study was to describe the sEMG activation of the mGmax during body weight rehabilitation exercises that apply hip extension. The following findings were reported:

- The single-leg wall squat produced an 86%MVIC of the mGmax from the study by Ayotte *et al.* (2007), which was found to be the exercise that elicited the highest %MVIC of the mGmax in the vertical vector.
- The plank with hip extension produced a 106.22%MVIC from the study by Boren *et al.* (2011), which was found to be the exercise that elicited the highest %MVIC of the mGmax in the horizontal vector.

Considering these findings of Macadam and Feser (2019), the current study included the plank with hip extension exercise of Boren *et al.* (2011) due to the very high (>61%MVIC) muscle activation which was produced by both the mGmax (106.22%MVIC) and the mGmed (75.13%MVIC) in this exercise. Although Ayotte *et al.* (2007) reported a very high %MVIC elicited by the mGmax during the single-leg wall squat (86%MVIC), the mGmed only produced a 52%MVIC during this exercise. Therefore, the latter does not support the aim of the study and hence the reason for the exclusion of this exercise. However, the single-leg squat version conducted by Boren *et al.* (2011) did meet the aim of the current study and was therefore included.

As shown in Table 1, Cochrane *et al.* (2019) conducted a study on male rugby players to evaluate the mGmax during different MVIC techniques. The modified prone hip extension produced a 100%MVIC, whereas the single-leg squat produced an 88.8%MVIC. The latter findings are similar to that of Boren *et al.* (2011) for these two exercises; however, the exercise positions in which the participants executed the exercises varied among these two studies. Furthermore, Cochrane *et al.* (2019) only evaluated the mGmax, whereas Boren *et al.* (2011) also evaluated the activation of the mGmed during these exercises. For this reason, the current study opted to replicate the plank with hip extension and the single-leg squat exercises as conducted by Boren *et al.* (2011).

Ebert *et al*. (2017) conducted the most recent systematic review on rehabilitation exercises that activate the mGmed with the purpose to present evidence-based exercises that progressively load this muscle. The latter reported that the side-plank hip abduction with dominant leg on bottom from Boren *et al.* (2011) elicited the highest activation of the mGmed compared to all previous literature, indicating that it is currently the best exercise to strengthen the mGmed. It is for this reason that this exercise was included in this study.

2.6 Joint position angles during exercises

Jeon *et al.* (2016) suggested that 90˚ of knee flexion is an effective strategy to inhibit the m. bicep femoris and m. semitendinosus in order to produce higher sEMG signal amplitude of the mGmax. Furthermore, prone hip extension executed in 90˚ knee flexion and 30˚ hip abduction results in maximal mGmax activation and minimal m. bicep femoris and m. semitendinosus activation compared to the 0˚ hip abduction position (Jeon *et al.*, 2016). Rainsford (2015) found that prone hip extension executed at 0º knee flexion recruited significantly higher activation of the m. bicep femoris compared to 60º, 90º and 110º of knee flexion in which mGmax activation was more pronounced. Prone hip extension commencing at 20˚ hip flexion contributed to greater mGmax and lower m. bicep femoris activation compared to 0˚ and 45˚ of hip flexion (Jeon *et al.*, 2016). Nevertheless, Macadam and Feser (2019) reported that when participants were instructed to activate their gluteal musculature from 30° hip flexion during prone hip extension, the mGmax elicited a higher activation level (21.6% vs 9.7%MVIC) compared to the non-instructed version. Previous studies incorporated various hip extension angles during prone hip extension exercises, e.g., 0˚ to 10˚ hip extension (Jeon *et al.*, 2016). However, findings of the study by Jeon *et al.* (2016) during the prone table hip extension with knee flexion exercise showed increased compensation in the lumbo-pelvic region when the participants performed the exercise in 10˚ of hip extension.

Therefore, Jeon *et al.* (2016) stated that hip extension should be 5˚, cautioning that the tension of the m. rectus femoris and m. iliopsoas may disturb the ultimate execution of exercises. Ebert *et al.* (2017) stated that mGmed muscular activity is unaffected by several hip flexion angles (0º, 20º, 40º, 60º or 80˚) during isometric hip abduction. However, mGmax and m. tensor fascia latae (TFL) muscular activity considerably increased or decreased with an increased hip flexion angle. Furthermore, a medially rotated hip position produced higher mGmed muscular activity in comparison to a laterally rotated hip position that produced higher m. TFL muscular activity during side-lying hip abduction (McBeth *et al.*, 2012; Ebert *et al.*, 2017). The current study implemented these literature findings regarding the joint position angles, given that the study by Boren *et al.* (2011) did not specify the angles in which exercises were undertaken.

2.7 Choice of study population

The rationale for selecting field hockey as sport code to evaluate the level of muscle activation of the mGmax and mGmed derives from a study conducted by Kingman (1999), which illustrated the superiority of the mGmax in different actions of roller hockey. Seeing that no previous studies could be found that evaluated the activation of the mGmax and mGmed during the different actions performed in field hockey, the activation of the mGmax in actions of roller hockey was reported. Kingman (1999) monitored sEMG activity of two upper extremity muscles, i.e., the m. pectoralis major and m. latissimus dorsi, and six lower extremity ones, i.e., the mGmax, m. semitendinosus, m. adductor longus, m. sartorius, m. rectus femoris and m. gastrocnemius. In total, 734 actions were analysed during the training sessions of six individuals (Kingman, 1999). The overall aim of Kingman's (1999) study was to examine the muscular demands of roller hockey match play in order to assist English players' match performance by improving their training techniques. Table 2 below presents the mean and standard error of the peak values of sEMG activity of the lower extremity muscles for all participants expressed as a percentage of maximal dynamic contractions during roller hockey actions. However, the table excludes the results of the upper extremity, given that these muscles have no relevance for the current study.

Table 2: Peak values of sEMG activity

		mGmax µV	m. Semitendinosus µV	m. Adductor longus µV	m. Sartorius µV	m. Rectus femoris µV	m. Gastrocnemius µV
Forehand slap shot	**Mean**	79.31	70.81	73.13	69.60	64.19	55.13
	SE	2.43	2.13	1.73	3.00	2.83	2.86
Sprinting	**Mean**	72.97	74.00	70.30	75.09	71.57	62.02
	SE	1.46	1.22	1.20	1.43	1.44	1.20
Backhand flick shot	**Mean**	73.70	82.30	71.18	57.66	46.11	35.64
	SE	3.11	5.32	3.96	8.70	4.52	5.60
Backhand slap shot	**Mean**	80.52	68.65	60.87	51.85	56.53	62.57
	SE	3.55	2.66	3.03	5.00	4.46	4.40
Tackling	**Mean**	59.12	57.85	63.75	61.27	64.49	48.40
	SE	2.67	2.65	3.13	2.66	2.81	2.25
Dribbling	**Mean**	62.91	57.47	60.49	53.17	51.58	50.98
	SE	3.72	3.38	3.14	4.12	3.46	3.11
Forehand flick shot	**Mean**	50.46	58.06	45.48	41.54	41.93	40.72
	SE	4.89	3.70	3.15	4.55	4.21	3.58
Pushing	**Mean**	57.35	50.98	53.83	52.04	46.30	50.69
	SE	2.62	2.49	3.03	2.76	2.43	2.35
Pass	**Mean**	39.77	39.72	41.87	36.30	31.85	31.67
	SE	3.05	2.37	2.81	2.60	2.64	2.38

Receiving pass	**Mean**	39.11	36.30	38.25	35.84	34.21	29.60
	SE	4.45	2.97	3.09	3.73	3.63	3.24
Slide stop Inside leg	**Mean**	32.48	40.36	42.95	44.66	29.53	42.33
	SE	2.51	2.60	2.67	3.36	2.68	2.99
Slide stop outside leg	**Mean**	32.36	33.97	44.42	37.15	30.90	30.90
	SE	2.95	2.06	2.59	2.91	2.52	2.29
TOTAL	**Mean**	56.67	55.87	55.53	51.35	47.43	45.05
	SE	4.77	3.98	3.03	2.98	3.68	2.63

[1]Mean and standard error of the peak values of sEMG activity for every participant expressed as a percentage of maximal dynamic contractions during different actions of roller hockey.

The results of Kingman's (1999) study illustrated that the m. pectoralis major (although excluded in the table above due to being a muscle of the upper extremity) exhibited the highest mean peak sEMG value during all actions, followed by the mGmax (as illustrated by Table 2). The superiority of the mGmax over other lower extremity muscles clearly illustrates the importance of the mGmax during different actions performed in roller hockey. Although these findings are based on roller hockey, whereas the current study focuses on field hockey, the different actions performed in hockey are universal.

Kingman (1999) further noted that the mGmed is essential to various actions performed in roller hockey, especially with slide stopping. The latter study, however, omitted to examine the mGmed and, accordingly, advised future researchers to include a thorough examination of the mGmed during various actions in roller hockey. Importantly, in both roller hockey and field hockey, hip abduction primarily produced by the mGmed is essential for the various actions performed, such as tackling, flicking and receiving of the ball. This indeed indicates the importance of the mGmed and the applicability of examining the sEMG activation capabilities of the mGmed of high-performance field hockey players.

CHAPTER 3 – RESEARCH METHODOLOGY

3.1 Introduction

The aim of the study was first to establish which commonly prescribed body weight rehabilitation exercises from previous studies produced greater than 61%MVIC for both the mGmax and mGmed. Hereafter, the study examined the exercises that fall into this category to determine which exercise will elicit the highest %MVIC, defined as the peak normalised sEMG signal amplitude, in high-performance female field hockey players of the UFS.

This chapter will elaborate on the study design and methodology used to address the research aim and objectives. A framework is provided that will describe the selected body weight rehabilitation exercises that will be examined, the participants included in the study and the eligibility criteria for these high-performance female field hockey players. Furthermore, insight into the research process, including the participants, data collection and analysis procedure, equipment used and the predicted implementation of the findings from the study, is provided.

3.2 Study design

The study used a randomised crossover trial to investigate four body weight rehabilitation exercises for activation of the mGmax and mGmed (see Table 3 below).

3.3 Study population and sampling

The high-performance female field hockey squad (n=26) of the UFS served as the study population.

Lewis *et al.* (2018) note that it is commonly thought that weakness or a decline in activation of the abductors and external rotators of the hip joint would result in lower extremity musculoskeletal injury, especially among females. Based on two systematic reviews (Prins & Van der Wurff, 2009; Van Cant *et al.*, 2014), strong evidence was found of weakness in hip abduction, external rotation, and extension between females presenting with patellofemoral pain relative to healthy control participants. Lewis *et al.* (2018) further reported that a prospective study among collegiate athletes persisting with lower extremity injuries through a competitive season indicated weaker hip abductors and external rotators compared to athletes who did not sustain an injury. Moreover, the study noted that the injury rate was higher for female (35%) athletes compared to male (22%) athletes. With this in mind, the current study focused exclusively on females to determine which body weight rehabilitation exercise produced the highest %MVIC activation of the mGmax and mGmed. In doing so, invaluable insight was gained regarding the best body weight rehabilitation exercise to incorporate into a prehabilitation programme for optimal strengthening and injury prevention in high-performance female field hockey players.

3.3.1 Inclusion criteria

The study included individuals who met the following requirements:

- Apparently healthy females who were part of the UFS high-performance field hockey squad.
- Females who consented to participate in the study.

3.3.2 Exclusion criteria

Females from the UFS high-performance field hockey squad were excluded based on:

- Self-reported lower back-, lower extremity- or pelvic girdle injuries.
- A history of any lower extremity surgery within the past two years.
- Known allergies to the material applied to the skin, such as tape or electrolyte gel (Brock, 2017).
- Skin lesions such as a rash, scarring or scabbing, given that surface electrodes should not be applied to areas with broken skin (e.g., cuts or abrasions) (Brock, 2017).

3.3.3 Ethical aspects

The researcher applied for approval from different UFS authorities after the Health Sciences Research Ethics Committee (HSREC) granted conditional approval to do so. Permission to conduct the research was obtained in writing from the following UFS authorities:

- The HSREC of the UFS;
- The Department of Exercise and Sport Sciences of the UFS;
- The Vice-Rector: Research and Dean of Student Affairs of the UFS;
- The Director of Kovsie Sport; and

- The participants involved in the study.

Permission to use the facilities of the Exercise and Sport Sciences Centre was requested from the Head of the centre, Ms Karabelo Mpeko (Appendix E). Permission to test the high-performance female field hockey players of the UFS was requested from the Director of Kovsie Sport, Mr DB Prinsloo (Appendix F), the Dean of Student Affairs, Mr Pura Mgolombane (Appendix G), and the Vice-Rector: Research, Prof. Corli Witthuhn (Appendix H). The research proposal was submitted to the HSREC of the Faculty of Health Sciences for approval prior to commencement of the study. The researcher informed the UFS head of hockey and team manager regarding the study after approval was granted from the above-mentioned UFS authorities.

The researcher conveyed information regarding the aim, problem and methodology of the study to each participant during an information session. A written informed consent form (Appendix C) was provided to each of the participants that outlined the risks emanating from the procedures administered and the equipment used during the study. These risks were also communicated to the participants verbally. Notwithstanding this agreement between the facility and the individuals making use of it, the researcher remained responsible for the protection of the participants.

The study was voluntary and individuals did not receive any financial compensation for their participation. Participants will be informed in advance if the results of the study will be published. If the study is published, the data will be presented in group format; hence, no individual will be identifiable. Any information obtained during the study that might identify participants was kept strictly confidential and will only be disclosed upon the permission of the participant. Confidentiality was maintained through assigning codes to the data. All results of the tests were stored under a code, with a list linking the names and the codes kept separate on a master list only available to the researcher. All results were made available only to the study supervisor and Biostatistician of the Department of Exercise and Sport Sciences at the UFS.

The participants were informed of the nature of each material that was applied to the skin with the aim to establish the occurrence of allergies. Skin irritation may result from cleaning the skin with alcohol or through the application of sEMG recording electrodes with electrolyte gel. The possibility of skin irritation was minimised by proper skin preparation. New, clean materials were used for the preparation and application of electrodes for each participant. Before the testing procedure, participants were informed of the exact placement of electrodes to allay possible concerns about encroaching on the participants' personal space. The participants were allowed to stop the testing procedure whenever they experienced discomfort, pain, fatigue, or any other symptoms that may be detrimental to their health. All participants were allowed to terminate their participation in the study at any time without prejudice.

In the case of skin irritation, the following safety procedures would have been followed:

- The researcher would immediately discontinue the electrodes on that area.
- The researcher would wipe the skin with water to wash the electrolyte gel from the skin surface.
- The participant would receive unscented skin lotion that can be applied to minimise the irritation.
- A qualified Biokineticist, who completed a level two first aid course, would apply first aid as necessary.

If an adverse event or an injury occurred, medical treatment would have been provided to each participant as needed. A qualified Biokineticist, who completed a level two first aid course, would have provided first aid, CPR, and follow-up care similar to that provided to a member of the general public under similar circumstances. The participant would have been prompted to seek immediate medical attention if an adverse event or an injury occurred. The researcher would have referred the participant, who was still ambulatory and required urgent medical assistance, to the Kovsie Health Centre located on the UFS campus to receive treatment. The researcher would have called the Health Centre's medical emergency services on 051 401 2603 and informed them of the adverse event or injury. A General Practitioner or Professional Nurse would have offered medical services to the patient and, if necessary, the patient would have been referred to a specialist to continue with treatment. In an emergency, where the participant is non-ambulatory and requires immediate emergency treatment or transport to a hospital, the researcher would have called ER 24 on 0800 051 051 to request that an emergency vehicle with trained personnel be sent to the emergency scene at the UFS

Exercise and Sport Sciences Centre. All incurred medical expenses would have been the responsibility of the participant or the participant's third-party payer.

3.4 Measuring instrument

Surface electromyography (sEMG) quantified the activation level of the mGmax and mGmed. Electromyography (EMG) is a tool that provides understanding into how the neuromuscular system acts through amplitude information considering the timing characteristics and levels of muscle activation for a certain recording condition (Macadam & Feser, 2019). Konrad (2006) and Chowdhury *et al.* (2013) define sEMG as "the study of muscle function through the inquiry of collective electrical signals which is controlled by the nervous system and produced during muscle contraction." Konrad (2006) further notes that sEMG is an experimental technique about developing, recording and analysing the myoelectric signals (implying the formation of physiological differences in the muscle fibre membranes). Therefore, an sEMG signal is the recording of the electrical activity produced by the muscle's motor units of which two types exist: sEMG and intramuscular EMG (Chowdhury *et al.*, 2013; Brock, 2017). Although debate about the application of sEMG in a practical context rages on, the literature shows that it is a commonly implemented method (Cho *et al.*, 2018; Macadam & Feser, 2019; Huseth *et al.*, 2020). Therefore, sEMG may be used as a guideline to contribute to understanding musculature activation levels (Macadam & Feser, 2019). Accordingly, analysing the muscle recruitment of exercises may expand the understanding of neuromuscular control during activities and contribute to the evaluation, selection and scientific progression of exercises (Brandt *et al.*, 2013; Macadam *et al.*, 2015).

Surface-detected signals have recently become a preferred method to gather information regarding the timing or intensity of activation from superficial muscles (Chowdhury *et al.*, 2013). The sEMG signals are recorded from the muscle with non-invasive electrodes placed onto the surface of the skin (Brock, 2017). The signal is a representation of the muscles' anatomical and physiological properties (Chowdhury *et al.*, 2013). Recording of sEMG signals is the elementary method for understanding the behaviours of the human body during normal and pathological circumstances (Chowdhury *et al.*, 2013). The focus of sEMG is the objective assessment to study the voluntary neuromuscular activation of muscles in different settings, e.g., postural tasks, functional movements, rehabilitation, work situations and sports training (Konrad, 2006; Cho, Kim & Park, 2018).

Surface EMG was recorded from the mGmax and mGmed with the Telemyo Direct Transmission system (DTS) hardware (Noraxon, Scottsdale, Arizona, USA) which transmits data directly from the electrode or sensor side to the receiver (Concordia University PERFORM Centre, 2016). The concept of direct transmission simplifies the organisation of sEMG measurements that reduce the requirement to position cable connections among sEMG electrodes and the sEMG amplifier (Concordia University PERFORM Centre, 2016). Brock (2017) advises that passive or active non-conducting electrodes should be used to record voluntary or involuntary activity. The current study used the wireless retransmission mode to record signals in real-time to a Noraxon USB receiver (transmission range up to 100m) (Concordia University PERFORM Centre, 2016). The TeleMyo DTS is equipped with EMG preamplifiers and has the capacity to operate up to 16 channels. The sEMG signals were recorded using the MyoResearch XP (version 1.08) Master software acquisition system (Noraxon, Scottsdale, Arizona, USA). The detailed technical information of the Noraxon sEMG apparatus is presented in Appendix A.

The gluteal musculature can be sufficiently engaged if the approximate %MVIC activation of both the mGmax and mGmed during various exercises is known (Boren *et al.*, 2011). Therefore, findings will be expressed as a percentage of the participant's MVIC. Boren *et al*. (2011) demonstrated the acceptability of using the MVIC values in establishing a %MVIC for a body weight exercise. Appendix K represents an example of a Noraxon data report.

3.4.1 Description of what the current study intended to measure

The Noraxon Standard sEMG analysis was used for the testing procedure. The mean and peak area of each period for each of the four body weight rehabilitation exercises was collected, which represented the %MVIC which each exercise produced. In order to establish %MVIC and report the peak normalised sEMG signal amplitude for each exercise performed by an individual participant, the average of the peak normalised sEMG signal amplitude from the last five repetitions of each exercise was used (Boren *et al.*, 2011; Serner *et al.*, 2014).

3.4.2 Skin surface electrodes

Silver or silver chloride (Ag/AgCl) pre-gelled electrodes are commonly used and are therefore recommended (Konrad, 2006). The advantages of using this disposable electrode type are that it eliminates concerns over hygiene while also allowing quick and easy handling

(Konrad, 2006). The conductive area comprises the diameter of the electrode and should not exceed 1cm (Konrad, 2006; SENIAM, 2019). Commercial disposable electrodes are manufactured as either wet-gel electrodes or adhesive gel electrodes (Konrad, 2006). Usually, wet-gel electrodes have superior conduction and lower impedance settings compared to adhesive gel electrodes (Konrad, 2006; Concordia University PERFORM Centre, 2016). However, repositioning of the latter is an advantage in the event of errors (Konrad, 2006). The current study made use of Kendall Meditrace Ag/AgCl pre-gelled electrodes (Konrad, 2006; Merletti, 2015; SENIAM, 2019). Pre-gelled electrodes reduce electrode-skin impedance (Hermens *et al.*, 2000; Konrad, 2006; Concordia University PERFORM Centre, 2016).

3.4.3 Anatomical placement of electrodes

3.4.3.1 mGmax

The current study applied the following guidelines, according to SENIAM (2019):

Starting posture: Lying down in a prone position on a plinth.
Electrode size: Should be 10mm in the direction of the muscle fibres orientation.
Electrode distance: 20mm
Location: half-way between the sacrum and greater trochanter – greatest prominence of the middle of the buttocks, superior to the visible bulge of the greater trochanter.
Orientation: directly in line with the PSIS and the posterior aspect of the thigh.
Fixation on the skin: use double-sided tape or elastic bands.

3.4.3.2 mGmed

The current study applied the following guidelines, according to SENIAM (2019):

Starting posture: Side-lying on a plinth.
Electrode size: Should be 10mm in the direction of the muscle fibres orientation.
Electrode distance: 20mm
Location: half-way between the iliac crest and greater trochanter.
Orientation: directly in line with the iliac crest and greater trochanter.
Fixation on the skin: use double-sided tape or elastic bands.

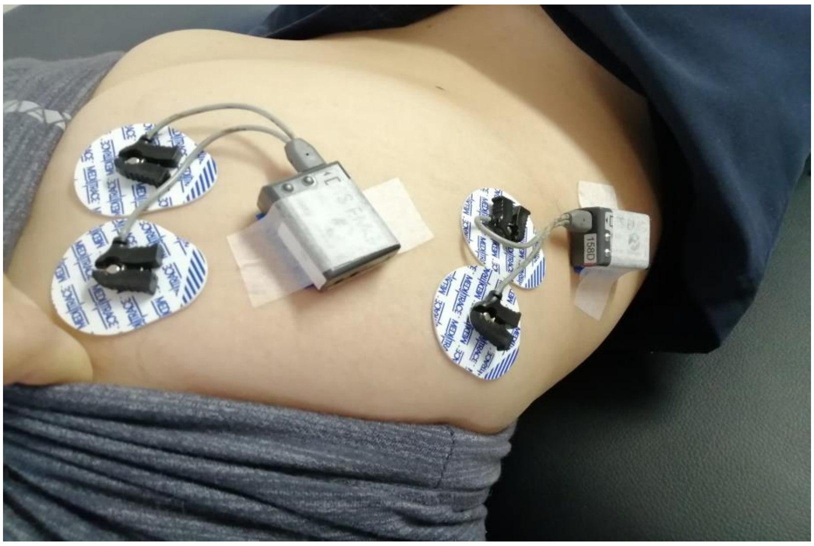

Figure 2: Placement of the electrodes on the mGmax and mGmed

3.4.4 Skin preparation

Konrad (2006) specified that correct skin preparation and electrode positioning are of paramount importance to ensure a quality sEMG measurement. The key strategy of skin preparation is constant electrode contact and low skin impedance to achieve better fixation of the electrodes (Konrad, 2006). The surface of the skin beneath the electrode and the transmitter needs to be cleaned to ensure proper signal transmission (Concordia University PERFORM Centre, 2016). To improve the sEMG recording in terms of amplitude character, it is important to ensure sufficient electrode-skin contact (Konrad, 2006; SENIAM, 2019). Proper electrode-skin contact will result in minimal and smaller artifacts (electrical interference) and reduced possibility of imbalance among electrode impedances, which lead to smaller signal disturbances and less noise (SENIAM, 2019). Concordia University PERFORM Centre (2016) and SENIAM (2019) confirmed that an alcohol and a gauze pad are sufficient to use for cleaning the surface of the skin. The current study followed the guidelines from SENIAM (2019), which recommend cleaning the skin with alcohol and allowing the alcohol to vaporise in order for the skin to be dry before placement of the electrodes. Regardless of the preferred method used, the skin will typically have a light red colour, indicating good skin impedance, when proper skin preparation and electrode application is applied (Konrad, 2006).

3.4.5 sEMG reliability

Compared to single sEMG measurements, Gaudet *et al.* (2016) and Jang *et al.* (2018) stated that higher reliability could be obtained during repeated sEMG measurements. Furthermore, to increase reliability, testing in the lower limb is superior over the upper limb (Jang *et al.*, 2018). In a study by Carnacho-Castano, Lopez-Lastra and Maté-Muñoz (2015) that evaluated the validity and reliability of the Telemyo DTS system, the authors discovered high intra-class correlation coefficients that range from 0.85–0.99, thus establishing that the sEMG instrument is reliable for measuring the velocity of movement and estimated power output.

Bernard *et al.*'s (2017) hypothesis – namely, the question of whether the position of the hip joint and the MVIC test learning curve will affect the sEMG signal amplitude during mGmax, mGmed, m. TFL and m. sartorius MVIC, could not be confirmed. Bernard *et al.* (2017) reported that there were no statistical differences among the three sessions completed in a one-week interval for each MVIC test – hence, no learning effect induced by training was observed, which also suggest that MVIC tests are reliable for measuring maximal sEMG activity in the mGmax and mGmed. Furthermore, Lee and Jo (2016) stated that MVIC is a method of great importance with high reliability for measuring and evaluating muscle activity or strength. Tabard-Fougère *et al.* (2018) reported that the use of an isometric manual muscle strength test is a reliable method for normalising sEMG data. On their part, Huseth *et al.* (2020) found that normalisation through MVIC is a biological constant procedure that can be undertaken in a reproducible manner for lower extremity muscles. Results of different studies can be compared, given that sEMG studies used the SENIAM sensor placement recommendations (Bernard *et al.*, 2017).

3.4.6 sEMG validity

The researcher should check all sEMG investigations to determine the quality and validity of the sEMG signals, irrespective of the selected method for skin preparation and electrode application technique (Konrad, 2006).

In order to ensure the validity of the sEMG signal, the following basic questions arise and should be addressed: "Did I measure the right muscle?" and "Can I see valid signals at all?" (Konrad, 2006). The latter author stated the following guidelines to establish sEMG signal validity:

- Ensure that all connections are correct by rechecking each connection.
- The sEMG signal can be confirmed by conducting a particular manual muscle strength test for that specific muscle.
- Check the sensitivity of an electrode location alongside cable movement, limb movements and local pressure when placing the electrodes throughout the quality check of the sEMG baseline.
- Detection locations over very thick subcutaneous adipose tissue (e.g., beyond 4cm) may either result in no visible sEMG signal or a poor sEMG to baseline ratio.
- Explicit or isolated static test contractions based on muscle function tests can provide greater clarity by revealing whether the data recorded from the sEMG is valid and if the participant can activate the muscle.

Surface EMG validity and reliability are well-accepted in movement systems and psycho psychological analysis and familiar in professional practice guidelines (Morrish, 1999; Pullman *et al.*, 2000; American Physical Therapy Association, 2001; Kasman & Wolf, 2002).

3.4.7 Limitations

The results of the current study were based on sEMG technology to determine the level of muscle activation of the mGmax and mGmed. Surface EMG is subject to limitations due to various factors that influence the sEMG signal, e.g., the thickness of tissue layers, potential cross-talk, electrode shifting, and alterations in the conductivity of muscle tissue (Serner *et al.*, 2014, Barton *et al.*, 2018). Cross-talk especially is an inherent limitation of all sEMG studies and, therefore, the mGmax and mGmed could be affected by muscle activity beyond the targeted muscles being studied (Barton *et al.*, 2018; Cochrane *et al.*, 2019). However, the current study used standardised and optimal placement of the pairs of electrodes in close proximity for the mGmax and mGmed that may have reduced the extent of the cross-talk (Cochrane *et al.*, 2019). Two advantages of sEMG are its non-invasive nature and that a broad sampling of motor units can be obtained (Chowdhury *et al.*, 2013). The same tester conducted the preparation of all participants to reduce variability.

3.5 Data collection

Data were collected from high-performance female field hockey players from the squad of the UFS. The researcher acquired consent from both the head of hockey and the team manager of the women's hockey team of the UFS to arrange an information session with the squad at the UFS astroturf. During this session, the squad was informed of the purpose of the intended study and the testing procedures to be administered. Emphasis was placed on the voluntary nature of the study and that participation in the study will in no way influence the players' position in the UFS hockey squad. The researcher provided available time slots for the testing procedure that commenced during the following week. Each player willing to participate in the study selected a suitable time slot to attend the testing. The researcher took the participants' contact details to remind each participant one day before the testing procedure of their selected time slot via a personal cellphone message. The testing procedure commenced inside the Exercise and Sport Sciences Centre of the UFS. Directions to the facility were provided to the players during the information session.

Two trials of one week each were conducted to collect the data. The first trial commenced during October 2019 on 14 participants, whereas the last trial was completed in February 2020 that involved 12 participants. Hence, the study was conducted on 26 participants in total. The data obtained from the two trials were averaged according to the peak normalised sEMG signal amplitude.

The recruited cohort of high-performance female hockey players (hereafter referred to as participants) reported to the Exercise and Sport Sciences Centre in the selected time slot. The researcher tested each participant who met the inclusion criteria of this study with the assistance from a registered Biokineticist. The testing was conducted in a private evaluation room to ensure the confidentiality and privacy of the participants. The researcher received each participant upon their arrival at the UFS Exercise and Sport Sciences Centre and indicated the room where commencement of the testing proceeded. The researcher briefly explained the procedures of the study and the content of documents that each participant had to sign. The required documents consisted of an informed consent form (Appendix C) and a health screening document (Appendix D).

Appendix D contains the following information: age, dominant leg, exercise frequency, type of physical activity and injury history, as well as a comprehensive self-reported lower quarter screening to identify exclusion criteria (see section 3.3.2). After the participant signed the informed consent form and completed the health screening document, the researcher conducted the height and weight measurements of the participant according to the guidelines of the World Health Organisation (2017):

A portable height/length measuring board (Stadiometer) was used to measure the height of participants (World Health Organisation, 2017).

The steps below were followed to measure the height of each participant:

STEP	ACTION
1	The participant should remove the following: • footwear such as shoes or sandals • headgear such as a hat, cap, hair bows, ribbons, etc.
2	The participant should stand on the board and face the researcher.
3	Ask the participant to stand in the following way: • feet together to distribute weight equally on both feet; • heels should touch the base of the vertical backboard; • posterior aspect of the head, scapulae and buttocks should also be positioned to be in contact with the vertical backboard; • arms hang relaxed next to the sides of the participant's trunk with hand palms facing toward the participant's thighs; and • knees should be straight.
4	The participant should look straight ahead and avoid tilting their head upwards.
5	Ensure that the eyes are level to the ears.
6	Gently move the measure arm inferior onto the head of the participant and request the participant to breathe in and stand upright.
7	Read the exact height in centimetres at the point to the nearest

	millimetre.
8	Request that the participant step off the Stadiometer.
9	Document the height measurement in centimetres on the participant's screening form.

To measure weight, an electronic digital weighing scale is required. The scale was calibrated beforehand.

The steps below were followed to start operating the scale:

STEP	ACTION
1	Place the scale on a firm, level surface.
2	Connect the electric plug to the main power line.
3	Switch on the scale and wait until the scale's display indicates 0.0.

To measure the weight of each participant, the following steps were followed:

STEP	ACTION
1	Request that the participant remove their footwear (shoes, sandals, etc.) and socks. The participant should take off any heavy belts and remove their mobile phone, wallet and coins in their pocket.
2	Request that the participant step onto the centre of the scale with one foot on each side of the scale's platform.
3	Request that the participant: • stand still; • face frontward; • Arms hang freely next to the side; and

	• step off when asked.
4	Document the weight in kilograms on the participant’s screening form.

After the completion of each measurement, the researcher documented the height and weight measurements on each participant’s health screening form (Appendix D).

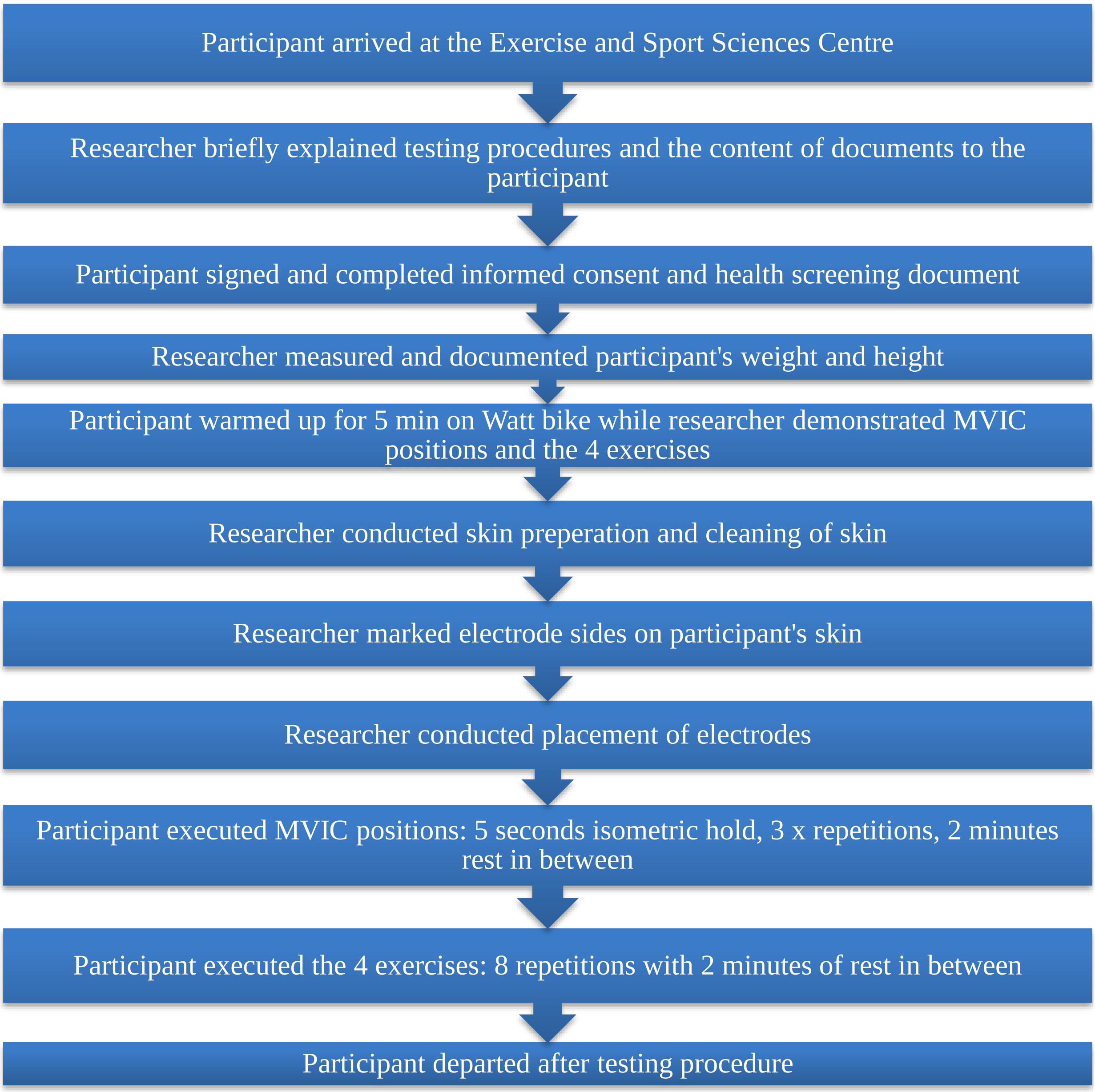

Figure 3: Schematic representation of the data collection process

The following information describes the testing procedure:

1. Before the initiation of the pilot study and the official testing, the researcher commenced with the calibration, setup and testing of the sEMG equipment to ensure proper signal transmission and reception.
2. The researcher received and welcomed each participant upon their arrival at the UFS Sport Sciences Centre and indicated the room where commencement of the testing would take place.
3. The researcher explained the procedures to be followed to each participant for the sEMG testing of the mGmax and mGmed.
4. The researcher guided the participant to the stationary Watt bike in the testing room and adjusted the seat accordingly. The participant was requested to perform a submaximal warm-up for five minutes without resistance, while the researcher demonstrated the exercises to be performed to familiarise the participant with the exercise technique.
5. After the warm-up, the researcher requested the participant to remove her shoes. This was done to prevent any possible variations that may occur owing to footwear (Boren *et al.*, 2011; Barton *et al.*, 2018).
6. The researcher then instructed the participant to lie in a prone position on the plinth in the testing room.
7. The researcher had Appendix D of the participant close by to identify whether the sEMG electrodes should be placed on the left or right side's gluteal area of the participant. Throughout the entire testing procedure, the dominant side of each participant was used to collect and analyse the sEMG data. The particular leg used by the participant to kick a ball was identified as the dominant side (Boren *et al.*, 2011; Lee *et al.*, 2014; MacAskill *et al.*, 2014; Cochrane *et al.*, 2019).
8. To prepare the skin, the researcher requested the participant to reposition their pants slightly to expose the area where the electrodes were to be placed.
9. The researcher cleaned the participant's skin with an isopropyl alcohol swipe before the landmarks and electrodes were applied (Concordia University PERFORM Centre, 2016; SENIAM, 2019).
10. To determine the exact location of the electrodes on the skin, the researcher measured the landmarks on the skin by using a thumb and index finger over the underlying mGmax and mGmed to determine where the electrodes should be applied on the skin.

11. The researcher marked each landmark on the skin of each participant with an eyeliner pencil.
12. The researcher conducted the placement of the electrodes on the allocated landmarks of the mGmax and mGmed. Pre-gelled electrodes (designed to reduce electrode-skin impedance) were used (Hermens *et al.*, 2000; Konrad, 2006; Concordia University PERFORM Centre, 2016).
13. The researcher then connected the preamplifier (electrode detection side) and two snaps that are connected to the cables to the pre-gelled electrodes.
14. To secure the electrodes in place throughout testing, hypoallergenic tape was used and applied by the researcher; however, care was taken to avoid too much tension (Konrad, 2006). It is essential to secure the electrodes and preamplifiers on the skin, especially in studies that require dynamic movements to help avoid cable movement artifacts and minimise the risk of separating the electrodes from the skin (Concordia University PERFORM Centre, 2016). Direct tape over the electrodes is not recommended in order to ensure constant application pressure for all electrodes and, therefore, reduce unwanted noise in recorded signals (Concordia University PERFORM Centre, 2016).
15. Connection of the electrodes to the sEMG equipment commenced after this.
16. Kendall *et al.* (2005) and SENIAM (2019) recommend a manual muscle strength test for each muscle. The participant then performed this test, according to the recommendations of Kendall *et al.* (2005), to establish a reference MVIC value that was used for normalisation of the four exercises (refer to section 3.5.1 for a full description of normalisation and the selected testing positions for MVIC of the mGmax and mGmed). Confirmation of electrode placement was made by using electrical stimulation as well as observation of the sEMG signal during voluntary isometric contractions in the specific directions in which the section of the muscle is known to act (Boren *et al.*, 2011).
17. After the participant executed the MVIC trials, the researcher demonstrated the first exercise to the participant.
18. The researcher administered a metronome set at 60 beats per minute to standardise the rate of movement across participants (Boren *et al.*, 2011).
19. The researcher instructed the participant to start with the execution of the first exercise.

20. Participants performed eight repetitions of each exercise. Before data collection, the first three repetitions of each exercise constituted of practice repetitions to ensure a proper exercise technique – necessary verbal and tactile cues were used as well as coaching points by the researcher to ensure that the correct methodology was applied (Boren *et al.*, 2011). The subsequent five repetitions were used for data collection (Boren *et al.*, 2011). The researcher counted from the first repetition, while a qualified Biokineticist (who completed a formal training course presented by Noraxon manufacturers regarding the use of the sEMG apparatus and computer program) administered the computer (Dell Technologies). The qualified Biokineticist pressed 'record' on the sEMG program as soon as the participant reached the fourth repetition and then pressed 'finish' when the participant completed the eighth repetition.
21. The sampling frequency was 1000 Hertz (Hz) and the sEMG signals were smoothed, rectified and analysed using an RMS algorithm for the determination of the peak activation for the mGmax and mGmed. The average of the five repetitions was used for statistical analysis (Boren *et al.*, 2011).
22. The sEMG signals were transmitted to the TeleMyo DTS receiver and stored on a computer (Dell Technologies).
23. The raw sEMG data were analysed for the intensity of activation of the muscles using the myoResearch 3.12 software.
24. To replicate a clinical setting, the researcher chose to use visual analysis of movement to ensure a proper exercise technique. Movement analysis software such as Dartfish or Electrogoniometer was not available in the clinical setting and, therefore, only visual analysis was used.
25. Each participant completed four body weight rehabilitation exercises (a description of each exercise may be found in section 3.5.2) in randomised order to reduce bias (Boren *et al.*, 2011).
26. The researcher provided verbal encouragement for each trial (Ayotte *et al.*, 2007; Boren *et al.*, 2011).
27. After the participant executed each exercise, a two-minute rest period followed to minimise the influence of fatigue (Boren *et al.*, 2011; Barton *et al.*, 2018). According to Wege *et al.* (2006), consecutive sets with rest periods in between will reduce fatigue during sEMG measurements.
28. During the two-minute rest period, the researcher demonstrated to the participant the exact procedures to be followed with the next exercise.

29. After completion of all the exercises, the participant was asked to reposition her pants on the dominant side for the researcher to remove the electrode stickers.
30. Upon removal of the electrodes, the skin was wiped with isopropyl alcohol to remove any signal conductance gel. Water was also used on the area to minimise skin irritation and dryness (refer to section 3.3.3 for a description of the procedures to be followed if any skin irritation or dryness occurred).
31. The participant departed after completion of the exercise testing.

All the information gathered after each session with each participant was downloaded and stored on a password protected Excel spreadsheet and was sent to a Biostatistician at the UFS for analysis.

3.5.1 Normalisation and MVIC positions

Normalising sEMG signals of a particular muscle is required due to the influence of individual differences, and anatomical and physiological factors on the level of the sEMG (Ball & Scurr, 2013; Cho *et al.*, 2018). Therefore, a standardised assessment method should be applied to aid in the interpretation of results (Ball & Scurr, 2013; Lee & Jo, 2016; Huseth *et al.*, 2020). No consensus exists on which type of muscle activity should be executed for optimal normalisation of sEMG data in order to produce maximal activation in any given muscle of each individual (Halaki & Ginn, 2012; Tabard-Fougère *et al.*, 2018; Cho *et al.*, 2018; Huseth *et al.*, 2020). However, the most common method used is MVIC (Halaki & Ginn, 2012; Tabard-Fougère *et al.*, 2018; Cho *et al.*, 2018; Huseth *et al.*, 2020). Therefore, normalisation is generally obtained with sEMG recordings from the same muscle through the gold standard of MVIC as the reference value (Halaki & Ginn, 2012; Tabard-Fougère *et al.*, 2018; Cho *et al.*, 2018; Huseth *et al.*, 2020). Halaki and Ginn (2012) refer to normalisation as "the conversion of the EMG signal to a scale relative to a known and repeatable value".

Normalisation of sEMG is of paramount importance to allow comparisons of sEMG activity between muscles, or of sEMG activity of the same muscle on different days, or in different individuals owing to the anthropometric and musculoskeletal variability between individuals (Burden, 2010; Halaki and Ginn, 2012; Tabard-Fougère *et al.*, 2018; Huseth *et al.*, 2020). To reduce inter-individual variability, the researcher can use the peak or mean sEMG as the normalised reference value of the action under examination (Burden, 2010). To achieve normalisation of sEMG signals, the sEMG signals during an action are divided by a discrete reference sEMG value (mean or peak) produced by the same muscle (Burden, 2010; Halaki & Ginn, 2012; Tabard-Fougère *et al.*, 2018). Millivolt (mV) is the original unit that presents the sEMG magnitude during the task; however, the normalised sEMG signal amplitude is instead expressed as a %MVIC of the reference value (Burden, 2010; Tabard-Fougère *et al.*, 2018). The MVIC is dependent on training and can be influenced by the psychological factor, namely, motivation (Tabard-Fougère *et al.*, 2018). Providing that the same electrode configuration is used to normalise to a reference sEMG value, the factors that affect the sEMG signals while performing the action and the reference contraction will also be similar (Halaki and Ginn, 2012). The selected method of normalisation is vital for interpretation of the sEMG signals, given that it will affect the sEMG signal amplitude and pattern (Halaki & Ginn, 2012; Cho *et al.*, 2018).

Various methods have been used to achieve normalisation reference values, such as:

1. Maximal (peak) activation levels during maximal contractions
2. Peak or mean activation levels obtained during the task under investigation
3. Activation levels during submaximal isometric contractions
4. Peak to peak amplitude of the maximal M-wave.

The literature is inconsistent in the description of MVIC's for the mGmax and mGmed. Huseth *et al.* (2020) found no significant difference in evaluating the normalised MVIC recorded as the peak sEMG signal amplitude in supine versus standing positions on various muscles, including the mGmed. However, considerable inter-individual variability during the MVIC tests was found, indicating that the diversity among individuals resulted in unique efferent neuromuscular activation patterns in performing specific movement tasks (Huseth *et al.*, 2020). Consequently, the MVIC manual muscle strength test position was chosen as the position in which the majority of the exercises in the current study were performed. Huseth *et al.* (2020) further reported that The International Society of Electrophysiology and Kinesiology (ISEK) suggested undertaking either isometric or dynamic contractions for normalisation of the recorded sEMG signal amplitude; however, currently, there are no general guidelines or consensus.

The sEMG from an isometric MVIC is recognised as the normalised reference value (Burden, 2010). Ball and Scurr (2013) advised undertaking the isometric MVIC in a position as close as possible to the intended muscle action in the task under investigation. However, Huseth *et al.* (2020) stated that isometric MVIC testing does not represent optimal normalisation in the case of evaluating dynamic muscle activities. Furthermore, the use of dynamic sEMG normalisation necessitates that participants have consistent and exceptionally steady movement skills (Huseth *et al.*, 2020). Therefore, the use of isometric sEMG normalisation through MVIC is more suitable for study populations with diminished movement skills (Huseth *et al.*, 2020).

Normalisation through MVIC's requires identification and execution of a reference test (manual muscle strength test) that elicits a maximal contraction in the selected muscle (Halaki & Ginn, 2012; Tabard-Fougère *et al.*, 2018). Halaki and Ginn (2012), Tabard-Fougère *et al.* (2018) and Huseth *et al.* (2020) recommend that each participant should execute at least three repetitions of the test to ensure that the recorded values are a reflection of the maximal neural activation levels. The highest value obtained from the three attempts of executing the MVIC test from the recorded muscle should be used as the normalisation value (Halaki & Ginn, 2012). Two minutes of separation between tests should be provided to minimise the effects of fatigue (Boren *et al.*, 2011; Halaki & Ginn, 2012). Calculation of the mean value of the three MVIC trials and all sEMG signals will express the percentages of the MVIC (Jeon *et al.*, 2016). After the MVIC trials, the sEMG signals are processed, either by high-pass filtering, rectification and smoothing or through calculating the RMS of the signal (Halaki & Ginn, 2012). The reference value for normalising the sEMG signal is then determined from the maximal value achieved from the processed signals throughout all repetitions of the test from the selected muscle (Halaki & Ginn, 2012). Accordingly, assessment of the level of activity during the task under investigation can be compared to the maximal neural activation capacity of the muscle (Halaki & Ginn, 2012).

High repeatability of sEMG recordings during MVIC's require proper guidance to individuals to ensure that each repetition of a test is performed identically, produces a maximal effort and avoids fatigue (Halaki & Ginn, 2012). All tested muscles among individuals should achieve maximal neural activation to ensure that MVIC is a highly reliable method for normalising sEMG data and to compare activity between muscles, tasks and individuals (Halaki & Ginn, 2012). Therefore, sets of MVIC tests that elicit maximal activation in the muscle of interest should be identified (Halaki & Ginn, 2012).

3.5.1.1 Testing position to establish MVIC of the mGmax

Kendall *et al.* (2005) recommend that the manual muscle strength test be executed in hip extension with 90˚ knee flexion. Zeller *et al.* (2003), McBeth *et al.* (2012), Webster and Gribble (2013), Kim and Yoo (2015) and Jeon *et al.* (2016) are examples of studies which also selected prone hip extension with the knee flexed at 90˚, thus confirming that this is the general position used to establish MVIC of the mGmax. Although the current study replicated a study from Boren *et al.* (2011), who used prone hip extension in a neutral hip position, recent research showed that hip extension should be 5˚ to achieve optimal activation of the mGmax (Jeon *et al.*, 2016; Macadam & Feser, 2019). Therefore, the current study executed the manual muscle strength test according to the guidelines of Kendall *et al.* (2005), i.e., in a position of 90˚ knee flexion and, according to Jeon *et al.* (2016), 5˚ hip extension. The current study executed the manual muscle strength test to establish the MVIC three times for five seconds and with two minutes of rest in between (Boren *et al.*, 2011; Halaki & Ginn, 2012; Jeon *et al.*, 2016).

Figure 4: MVIC testing position of the mGmax

3.5.1.2 Testing position to establish MVIC of the mGmed

McBeth *et al.* (2012) recommended that the manual muscle strength test be executed in a position of hip abduction to approximately 35˚, slight hip extension and medial rotation of the hip. Ebert *et al.* (2017) reported that a medially rotated hip position elicited higher mGmed activity compared to a laterally rotated hip position that elicited significant m. TFL activity. Previous studies, however, made use of various positions to establish MVIC of the mGmed (refer to Table 1). Given that Boren *et al.* (2011) did not specify the hip abduction range of the side-lying position to determine MVIC of the mGmed, the current study followed the recommendations of McBeth *et al.* (2012) and Ebert *et al.* (2017). The current study executed the manual muscle strength test to establish the MVIC three times for five seconds and with two minutes of rest in between (Boren *et al.*, 2011; Halaki & Ginn, 2012; Jeon *et al.*, 2016).

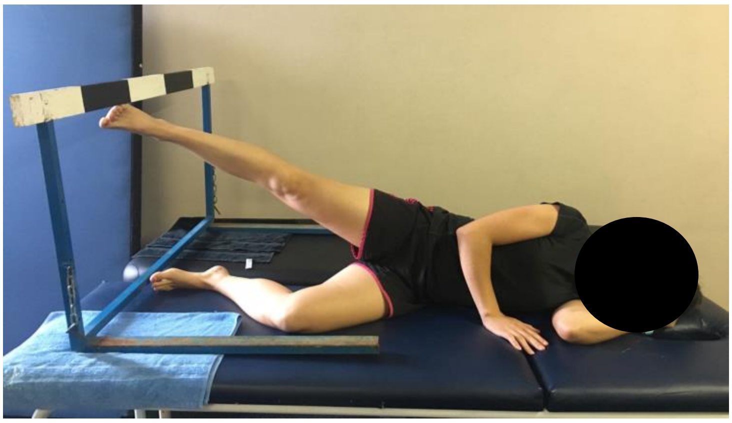

Figure 5: MVIC testing position of the mGmed

Each participant commenced with the four body weight rehabilitation exercises after the execution of the MVIC trials.

3.5.2 Selected exercises and order of testing

Exercise order was randomised to avoid any order bias owing to fatigue (Boren *et al.*, 2011). The biostatistician provided the randomisation schedule.

Movement dysfunction or decreased activation of the mGmax can result from excessive stimulation of the m. erector spinae and m. bicep femoris due to an alteration to the pattern in which these muscles activate (Jeon *et al.*, 2016). Thus, incorrect execution of mGmax strengthening exercises may result in undesirable activation of adjacent muscles (Jeon *et al.*, 2016). Therefore, it is of paramount importance that execution of the exercises should strengthen the mGmax, while simultaneously decreasing activation of the m. bicep femoris and m. erector spinae (Jeon *et al.*, 2016). Given this, the current study implemented the latest research to conduct each exercise at a certain angle to eliminate activation of adjacent muscles.

The following four body weight rehabilitation exercises (Table 3) were used to gather the intended data: side-plank hip abduction with dominant leg on bottom; side-plank hip abduction with dominant leg on top; the single-leg squat; and plank with hip extension. These exercises produced the highest %MVIC in a study conducted by Boren *et al.* (2011) and were therefore ranked as the top-rated gluteal exercises. Considering the literature, the top mGmax body weight rehabilitation exercise is the plank with hip extension (106.22%MVIC) (Boren *et al.*, 2011; Macadam & Feser, 2019). Concerning the mGmed, the literature indicates that the top mGmed body weight rehabilitation exercise is side-plank hip abduction with dominant leg on bottom (103.11%MVIC) (Boren *et al.*, 2011; Ebert *et al.*, 2017). Table 3 presents the four selected body weight rehabilitation exercises from the study by Boren *et al.* (2011) with their %MVIC and rank order, respectively:

Table 3: Four selected exercises from the study by Boren *et al.* (2011) with the %MVIC and rank order

Exercise	mGmax %MVIC	Rank order	mGmed %MVIC	Rank order
Side-plank hip abduction with dominant leg on bottom	70.96	4	103.11	1
Side-plank hip abduction with dominant leg on top	72.87	3	88.82	2
The single-leg squat	70.74	5	82.26	3
Plank with hip extension	106.22	1	75.13	4

mGmax and mGmed peak %MVIC activation during the side-plank hip abduction with dominant leg on bottom, side-plank hip abduction with dominant leg on top, the single-leg squat and plank with hip extension as found by Boren *et al.* (2011).

The four body weight rehabilitation exercises were performed accordingly:

1. **Side-plank hip abduction with dominant leg on bottom:** The participant started in a side-lying position with the dominant leg on the bottom. The participant was instructed to flex the lowermost leg at the hip and knee to 45º to assist in stabilising the pelvis against anterior or posterior tilting (Kendall *et al.*, 2005; Tabard-Fougère *et al.*, 2018). In Boren *et al.'s* (2011) study, the position of executing this exercise was such that participants were instructed to maintain their shoulders, hips, knees and ankles in line bilaterally. The current study, however, altered this position slightly to avoid compensatory movements. The participant subsequently rose to a plank position with the hips raised from the plinth, while the participant was allowed to use the upper extremity for support (Boren *et al.*, 2011). The researcher instructed the participant to abduct the non-dominant leg for the researcher to measure a 35˚ hip abduction angle with a universal goniometer (McBeth *et al.*, 2012; Ebert *et al.*, 2017). Hereafter, the researcher adjusted a hurdle that was used as a target bar to ensure that the participant executed the exercise within the 35˚ angle. The participant relaxed the abducted leg to avoid fatigue, while the researcher adjusted the hurdle. Finally, the participant was instructed to abduct the non-dominant leg for two beats and then to lower the leg for two beats, while maintaining the side-plank position throughout all repetitions (Boren *et al.*, 2011). The participant's foot touched the hurdle bar on the second beat upwards in abduction and the plinth on the second beat downwards in adduction to complete one repetition. Although the researcher measured all angles for standardisation among participants, the researcher could not control if the participant slightly lowered or elevated their trunk position during the execution of all eight repetitions. This could affect the optimal position of executing this exercise, but care was taken to minimise this by consistently providing verbal cues.

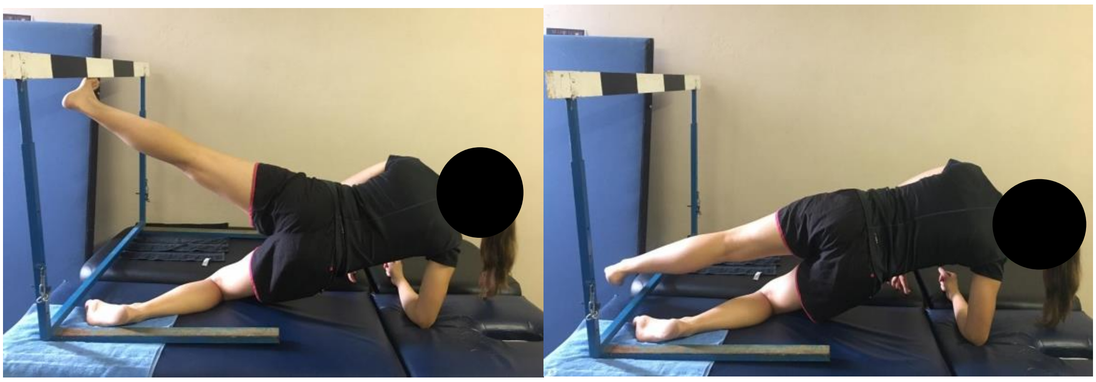

Figure 6: Side-plank hip abduction with dominant leg on bottom

2. **Side-plank hip abduction with dominant leg on top:** The participant started in a side-lying position with the dominant leg on top. The participant was instructed to flex the lowermost leg at the hip and knee to 45º (Kendall *et al.*, 2005; Tabard-Fougère *et al.*, 2018). In Boren *et al.'s* (2011) study, the position of executing this exercise was such that participants were instructed to maintain their shoulders, hips, knees and ankles in line bilaterally. The current study, however, altered this position slightly to avoid compensatory movements. After this, the participant was requested to rise to a plank position with the hips raised from the plinth, while the participant was allowed to use the upper extremity for support (Boren *et al.*, 2011). The researcher instructed the participant to abduct the dominant leg for the researcher to measure a 35˚ hip abduction angle with a universal goniometer (McBeth *et al.*, 2012; Ebert *et al.*, 2017). Hereafter, the researcher adjusted a hurdle that was used as a target bar to ensure that the participant executed the exercise within the 35˚ angle. The participant relaxed the abducted leg to avoid fatigue, while the researcher adjusted the hurdle. Finally, the participant was instructed to abduct the dominant leg for two beats and then to lower the leg for two beats, while maintaining the side-plank position throughout all repetitions (Boren *et al.*, 2011). The participant's foot touched the hurdle bar on the second beat upwards in abduction and the plinth on the second beat downwards in adduction to complete one repetition. Although the researcher measured all angles for standardisation among participants, the researcher could not control if the participant slightly lowered or elevated their trunk position during the execution of all eight repetitions. This could affect the optimal position of executing this exercise, but care was taken to minimise this by consistently providing verbal cues.

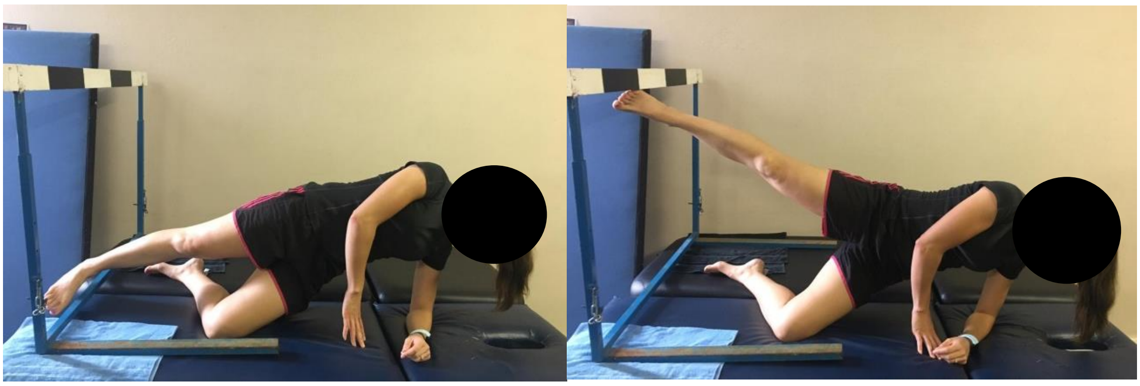

Figure 7: Side-plank hip abduction with dominant leg on top

3. **The single-leg squat:** The participant was requested to stand on the dominant leg, 15cm away from the chair (used for standardisation among all participants), with the knee of the non-dominant leg extended and the hip flexed to avoid the heel of the contralateral leg touching the floor during the execution of the exercise. The participant was then asked to flex the dominant leg's knee for two beats, touch a chair of 47cm in height with the buttocks and then extend back to the upright position for two beats (Boren *et al.*, 2011). A mirror was placed in front of the participant to provide visual feedback of the (correct) position of the head and trunk, and to prevent tilting of the trunk towards the weight-bearing leg to compensate for mGmed weakness throughout the execution of the exercise (Han *et al.*, 2018).

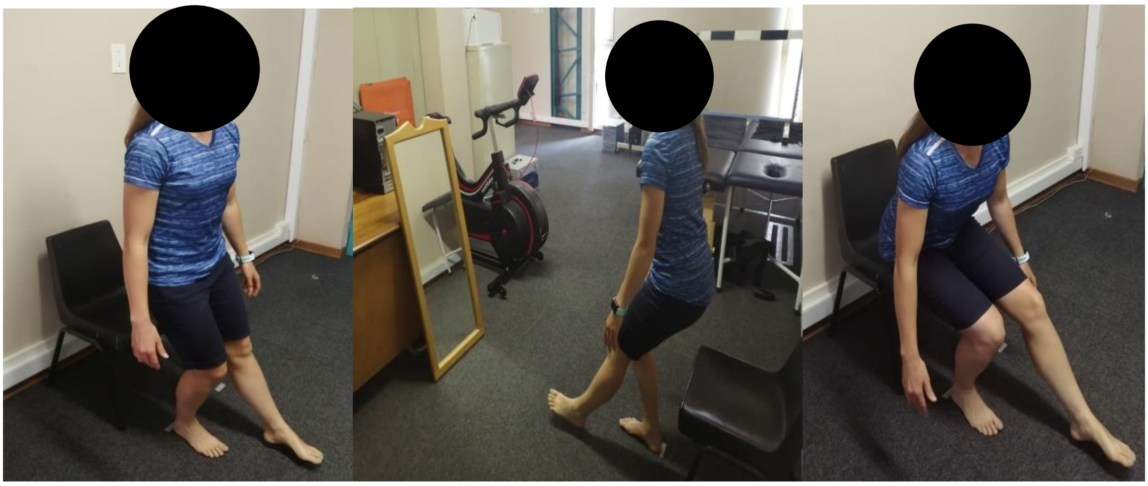

Figure 8: The single-leg squat

4. **Plank with hip extension:** The participant started prone on their elbows in a plank position with the trunk, hips, and knees in neutral alignment. The participant was

requested to lift the dominant leg off the plinth to perform a prone active straight leg raise from the plank position and then flex the knee of the dominant leg. This was followed by elevating the heel toward the ceiling in a kick back action to extend the hip. The researcher then measured and established a hip extension angle of 5˚ and a knee flexion angle of 90˚ with a universal goniometer (Jeon *et al.*, 2016; Macadam & Feser, 2019). The hurdle target bar was adjusted accordingly to provide feedback to the participant and to ensure that the participant execute the exercise in a 5˚ hip extension and 90˚ knee flexion range.

At the start of the exercise, the researcher instructed the participant to perform a dominant leg lift in a position of 90˚ knee flexion (Macadam & Feser, 2019). Hereafter, the participant initiated the movement action from 30˚ hip flexion towards 5˚ hip extension (Macadam & Feser, 2019) for two beats and then slowly returned the dominant leg back to 30˚ hip flexion for two beats to complete one repetition. To ensure that the participant maintains the correct hip flexion angle, the hip flexion angle was measured in such a way that the participant should touch the plinth with their dominant leg's knee at the end of the repetition. Although the researcher measured all angles for standardisation among participants, the researcher could not control if the participant slightly lowered or elevated their trunk position during the execution of all eight repetitions. This could affect the optimal position of executing this exercise, but care was taken to minimise this by consistently providing verbal cues.

Figure 9: Plank with hip extension

3.6 Measurement and methodological errors

A qualified Biokineticist, who completed a formal training course presented by the Noraxon manufacturers regarding the use of the sEMG apparatus, assisted the researcher. The assistant was solely responsible for recording the sEMG data. Errors were minimised by training and utilising the same assistant for the recording of readings. The assistant has subject-specific knowledge and was trained in the accurate execution of standard sEMG testing before the conduct of the testing. The researcher measured the exact location of the landmarks on the skin over the underlying Gmax and Gmed muscles and proceeded to place the electrodes on the allocated landmarks.

To further minimise errors, each participant was fully informed of the exact movement pattern of the exercise and what the researcher intends to measure. The researcher demonstrated each exercise correctly to the participants.

3.7 Pilot study

A pilot study with four participants from the UFS high-performance female hockey squad was conducted during October 2019 to determine if crucial components such as the planning and execution of the testing procedures were suitable for the main study. Each subject completed an informed consent form (Appendix C) prior to participation in the study.

The pilot study consisted of testing the sEMG protocol to determine the effectiveness of the proposed data sheets, equipment and protocols. Additionally, the duration of testing per participant, as well as the continuity of testing, were evaluated to plan testing schedules for the study properly. The data gathered from the pilot study were included in the main study.

3.8 Statistical analysis

Data were captured electronically in a Microsoft Excel sheet (Microsoft Office 2007) for import into a Statistical Analysis System (SAS) data set. A Biostatistician conducted the statistical analysis. The sEMG signal amplitude was normalised to MVIC and was measured on each participant for both the mGmax and mGmed during four body weight rehabilitation exercises, namely side-plank hip abduction with dominant leg on bottom, side-plank hip abduction with dominant leg on top, the single-leg squat and plank with hip extension. All data were rectified and smoothed using an RMS algorithm and smoothed with a time reference. The sEMG bandwidth was 20–450Hz, common-mode rejection ratio (CMRR) >100 decibel (dB) at 60Hz, input impedance >100 electrical resistance and conductance (Ohm), baseline noise <1 potential difference (μV) RMS, effective sEMG signal gain 400 Volts (V) at a sample frequency of 1000Hz. To determine the MVIC, the highest peak value from the three trials recorded of the manual muscle strength tests for the mGmax and mGmed was used. To determine the %MVIC produced by the exercises, sEMG data of the last five repetitions of each exercise for each participant were recorded (Boren *et al.*, 2011). The highest peak sEMG signal out of these repetitions was then divided by the normalised MVIC value to calculate the %MVIC. The peak %MVIC of each exercise was averaged between all participants to report the findings of each muscle.

According to the ANOVA, F-statistics was used with fixed effects, i.e., 'participant', 'period' (referring to the randomised order in which exercises was conducted) and 'exercise' to determine whether there was a statistically significant difference in activation of the mGmax and mGmed during the four body weight rehabilitation exercises. The Least Square Means (LSMEANS) in the SAS procedure was calculated for both the mGmax and mGmed during each exercise. Furthermore, pairwise comparisons were performed to test the differences between the activation of the mGmax and mGmed for each exercise to report the *p*-values. Effect sizes of pairwise comparisons between the mGmax and mGmed with each exercise were calculated as the difference in means between the peak normalised sEMG signal amplitude of the four body weight rehabilitation exercises which was divided by the standard deviation of each exercise.

3.8.1 Descriptive Statistics

All quantitative variables were summarised using descriptive statistics (mean, std, minimum, quartile one (Q1), median, quartile three (Q3), maximum), the anthropometric data overall for the whole sample, but the activation data of the mGmax and mGmed separately for the four body weight rehabilitation exercises. The analysis was conducted using the SAS procedure TABULATE (SAS Institute, 2017).

3.8.2 Analysis of variance (ANOVA)

The %MVIC activation data of both the mGmax and mGmed were analysed using a three-way ANOVA, with 'participant', 'period' and 'exercise' as categorical variables in the model. Based on this three-way ANOVA model, point estimates for the mean %MVIC for each exercise were reported, as well as point estimates, 95% confidence intervals (CIs) and *p*-values for the pairwise differences in peak %MVIC between the four body weight rehabilitation exercises. For each variable analysed, the overall F-test for the four body weight rehabilitation exercises is reported, as well as the partial effect size measure for ANOVA (SAS Institute, 2017). The analysis was conducted using the SAS procedure GLM, i.e., "the method of least squares to fit general linear models" (SAS Institute, 2017).

3.9 Withdrawal of study participants

Participation in this study was voluntary; hence, participants could withdraw at any time without any consequences. The investigator could withdraw a participant from this research if circumstances arose that warranted doing so. These circumstances included injury, sickness and failure to adhere to the exercises. Non-participation in the study did not influence the player's position in the UFS hockey squad.

CHAPTER 4 – RESULTS

4.1 Introduction

This chapter presents the results of the study. Twenty-six participants met the inclusion criteria and consented to participate in the current study. The aim of the study was, firstly, to establish which commonly prescribed body weight rehabilitation exercises from previous studies produced greater than 61%MVIC for both the mGmax and mGmed. Hereafter, the study examined the exercises that fall into this category to determine which exercise will elicit the highest %MVIC (defined as the peak normalised sEMG signal amplitude) in high-performance female field hockey players of the UFS. A randomised crossover trial of four body weight rehabilitation exercises was examined through sEMG analysis. All the participants completed all the exercises for data analysis. The descriptive statistics and ANOVA analysis are presented in this chapter. Anthropometric data (age, height, body mass and BMI) of 26 participants are also reported. Furthermore, comparisons between the study by Boren *et al.* (2011) and the current study are presented, given that the current study replicated the exercises from the study by Boren *et al.* (2011). The interpretation and discussion of the findings will follow in Chapter 5.

4.2 Descriptive statistics

The following section provides information regarding the physical characteristics of participants, the normalised peak sEMG signal amplitude findings of each exercise for the mGmax and mGmed, and a comparison between these findings and those of Boren *et al.* (2011).

4.2.1 Physical characteristics of participants

Table 4 provides the descriptive statistics (mean, std, minimum, Q1, median, Q3 and maximum) for the anthropometric data (n=26) of the total group of study participants, namely age, height, body mass and BMI.

Table 4: Physical characteristics of participants: Descriptive statistics

Anthropometric data				
	Age (y)	**Height (cm)**	**Body mass (kg)**	**BMI (kg.m²)**
Mean	20.15	164	64.72	23.87
Std	1.59	0.07	10.21	2.92
Min	18	151	51.2	19.39
Q1	19	157	55.4	22.27
Median	20	165	62.6	23.06
Q3	21	170	71.4	25.95
Max	24	177	87.2	31.58

Std: standard deviation; Min: minimum; Q1: quartile one; Q3: quartile three; Max: maximum.

4.2.1.1 Age, height, body mass and BMI

As shown in Table 4, the mean age of the participants was 20.15±1.59 years (range=18–24 years), the mean height was 164±0.07cm (range=151cm–177cm), mean body mass was 64.72±10.21kg (range=51.2kg–87.2kg) and mean BMI was 23.87±2.92kg.m² (range=19.39kg.m²–31.58kg.m²).

4.2.2 mGmax and mGmed activation during the four body weight rehabilitation exercises

Table 5 presents the descriptive statistics of the peak normalised sEMG signal amplitude, expressed as the %MVIC during each exercise.

Table 5: Peak %MVIC activation data (n=26): Descriptive statistics

Muscles		Exercises: Side-plank hip abduction dominant leg on bottom	Side-plank hip abduction dominant leg on top	The single-leg squat	Plank with hip extension
	N	26	26	26	26
mGmax (%MVIC)	**Mean**	124.61	124.33	125.64	122.73
	Std	7.94	8.63	10.13	9.37
	Min	114	110	106	109
	Q1	117	117	115	114
	Median	124.50	125.50	127.50	121
	Q3	130	131	133	129
	Max	142	138	141	143
mGmed (%MVIC)	**Mean**	126.07	124.52	126.30	125.04
	Std	14.16	11.37	12.89	13.14
	Min	109	109	107	109
	Q1	116	115	117	115
	Median	123.50	124.50	125	122
	Q3	135	132	131	130
	Max	160	153	158	153

Std: standard deviation; Min: minimum; Q1: quartile one; Q3: quartile three; Max: maximum.

As outlined in Table 5, the following averaged peak normalised %MVIC findings were reported:

- Side-plank hip abduction with dominant leg on bottom generated a 124.61±7.94%MVIC of the mGmax and a 126.07±14.16%MVIC of the mGmed.
- Side-plank hip abduction with dominant leg on top generated a 124.33±8.63%MVIC of the mGmax and a 124.52±11.37%MVIC of the mGmed.
- The single-leg squat generated a 125.64±10.13%MVIC of the mGmax and a 126.30±12.89%MVIC of the mGmed.
- Plank with hip extension generated a 122.73±9.37%MVIC of the mGmax and a 125.04±13.14%MVIC of the mGmed.

Variations in the standard deviation of mGmax and mGmed activation emphasise the individual characteristics of each participant.

4.2.3 Comparison between the findings of the current study and Boren *et al.* (2011)

Table 6 lists the average of the peak normalised sEMG signal amplitude, expressed as %MVIC, of the mGmax and mGmed during each exercise as found in the current study and by Boren *et al.* (2011).

Table 6: Comparison of exercises for activation of mGmax and mGmed between the current study and Boren *et al.* (2011): Descriptive statistics

Exercises	Current study		Boren *et al.* (2011)	
	mGmax peak %MVIC & (N)	**mGmed peak %MVIC & (N)**	**mGmax peak %MVIC & (N)**	**mGmed peak %MVIC & (N)**
Side-plank hip abduction with dominant leg on bottom	124.61 (26)	126.07 (26)	70.96 (21)	103.11 (21)
Side-plank hip abduction with dominant leg on top	124.33 (26)	124.52 (26)	72.87 (22)	88.82 (22)
The single-leg squat	125.65 (26)	126.30 (26)	70.74 (22)	82.26 (22)
Plank with hip extension	122.73 (26)	125.04 (26)	106.22 (22)	75.13 (23)

mGmax and mGmed peak %MVIC activation during the side-plank hip abduction with dominant leg on bottom, side-plank hip abduction with dominant leg on top, the single-leg squat and plank with hip extension in high-performance female field hockey players of the UFS of the current study compared to Boren *et al.* (2011). N = number of participants.

As outlined in Table 6, the following averaged peak %MVIC findings were reported by the current study and by Boren *et al.* (2011):

- Side-plank hip abduction with dominant leg on bottom generated a 124.61%MVIC of the mGmax and a 126.07%MVIC of the mGmed in the current study, while Boren *et* *al.* (2011) reported a 70.96%MVIC of the mGmax and a 103.11%MVIC of the mGmed.

- Side-plank hip abduction with dominant leg on top generated a 124.33%MVIC of the mGmax and a 124.52%MVIC of the mGmed, while Boren *et al.* (2011) reported a 72.87%MVIC of the mGmax and an 88.82%MVIC of the mGmed.
- The single-leg squat generated a 125.65%MVIC of the mGmax and a 126.30%MVIC of the mGmed, while Boren *et al.* (2011) reported a 70.74%MVIC of the mGmax and an 82.26%MVIC of the mGmed.
- Plank with hip extension generated a 122.73%MVIC of the mGmax and a 125.04%MVIC of the mGmed, while Boren *et al.* (2011) reported a 106.22%MVIC of the mGmax and a 75.13%MVIC of the mGmed.

Boren *et al.* (2011) included 26 participants in their study; however, a different number of participants are reported in Table 6 owing to the advanced level of these four exercises that resulted in the inability of some participants to execute each exercise successfully. Furthermore, the study of Boren *et al.* (2011) did not provide information regarding the standard deviation of their exercises. Therefore, the standard deviations from Boren *et al.*'s (2011) study could not be provided in Table 6.

4.3 Analysis of variance (ANOVA)

The following section summarises the information regarding the participant's effect, period effect (the randomised order in which exercises were undertaken) and exercise effect on the average peak normalised sEMG signal amplitude of the mGmax and mGmed during the four body weight rehabilitation exercises that were examined.

4.3.1 Analysis of variance of mGmax and mGmed

Table 7 presents the analysis of variance results for the variables' average peak normalised sEMG signal amplitude of the mGmax and mGmed, namely F-statistics and *p*-values associated with the model effects 'participant', 'period' and 'exercise'; the effect size statistic for exercise effect is also provided.

Table 7: Analysis of variance of mGmax and mGmed

Dependent Variable	Effect	F-statistic (denominator df=72) [a]	Numerator (df)	*p*-value[a]	Effect Size[a]	
					Partial ω^2	$\omega = \sqrt{\omega^2}$
mGmax [%MVIC]	Participant	9.00	25	<0.0001		
	Period	2.33	3	0.0816		
	Exercise	1.38	3	0.2558	0.0108	0.10
mGmed [%MVIC]	Participant	18.19	25	<0.0001		
	Period	2.66	3	0.0542		
	Exercise	0.58	3	0.6285	-0.0122	0

[a]F-statistics, *p*-values and effect size statistic from three-way analysis of variance (ANOVA) model with 'participant', 'period' and 'exercise' as fixed effects.

Table 7 shows the participant effect was statistically significant in the analysis of both mGmax and mGmed activation (*p*<.0001). While significant differences between participants are both expected and not the focus of this study, those differences motivate why mGmax and mGmed activation were studied in a crossover trial where control can be exercised over the large variability due to the participants.

Period was "borderline" significant for mGmax (*p*=0.0816) and mGmed (*p*=0.0542), again motivating the crossover trial, which allows one to control for period differences in the trial.

Table 7 shows that 'exercise' does not significantly affect either mGmax (*p*=0.2558) or mGmed (*p*=0.6285) activation. Estimated effect sizes are close to zero as characterised by the partial ω^2: for the mGmax the partial ω^2 is 00108, so that ω =0.10. Since the magnitude of ω can be interpreted as the size of a correlation, the effect of 'exercise' on the mGmax is negligible. According to McLeod (2019), Cohen reported that the value of the effect size of Pearson r correlation varies between –1 (a perfect negative correlation) to +1 (a perfect positive correlation). Consequently, r is considered as low if it varies around 0.1, medium if it varies around 0.3 and large if it varies more than 0.5. For mGmed, the estimated partial $\boldsymbol{\omega^2}$ is negative, therefore ω, and thus the effect of 'exercise' on mGmed can be considered zero.

4.3.2 Pairwise comparisons of exercise effect

Table 8 presents a summary display of the statistical significance of all pairwise comparisons of the four body weight rehabilitation exercises concerning mGmax and mGmed.

Table 8: Mean values of mGmax and mGmed and summary display of pairwise comparisons concerning exercise effect

Variable	Exercise	Mean[a]	Significance of pairwise comparison of exercises[b]
mGmax [%MVIC]	3	125.65	A
	1	124.61	AB
	2	124.33	AB
	4	122.73	B
mGmed [%MVIC]	3	126.30	A
	1	126.07	A
	4	125.04	A
	2	124.52	A

[a]Mean estimates (for effect of 'exercise') from three-way analysis of variance (ANOVA) model with 'participant', 'period' and 'exercise' as fixed effects.

[b]Means sharing the same letter are not statistically different from each other at 0.05 significance level; pairs of means that do not share a letter differ statistically significantly.

Table 8 shows that with one exception, all pairwise mean differences between exercises are not statistically significant, concerning both the mGmax and mGmed. The single exception is the difference between Exercise 3 (the single-leg squat) and Exercise 4 (plank with hip extension) concerning the mGmax; here Exercise 3 has significantly higher activation than Exercise 4 (p=0.0487; see Table 9 below).

Table 9 presents detailed statistics about the pairwise differences between the four body weight rehabilitation exercises concerning mGmax and mGmed, namely the mean difference, 95% CI for mean difference and p-values associated with the effect of ‘exercise’ on mGmax and mGmed.

Table 9: mGmax and mGmed: Pairwise mean differences between exercises

Variable	Pair of Exercises[a]	Mean difference[b]	95% CI for mean difference[b]	*p*-value[b]
	1 vs 2	0.28	-2.61 to 3.17	0.8475
	1 vs 3	-1.03	-3.94 to 1.87	0.4807
mGmax	1 vs 4	1.88	-1.02 to 4.77	0.2000
[%MVIC]	2 vs 3	-1.31	-4.21 to 1.58	0.3685
	2 vs 4	1.60	-1.31 to 4.50	0.2770
	3 vs 4	2.91	0.02 to 5.80	0.0487
	1 vs 2	1.54	-1.57 to 4.66	0.3272
	1 vs 3	-0.23	-3.36 to 2.90	0.8837
mGmed	1 vs 4	1.03	-2.09 to 4.14	0.5134
[%MVIC]	2 vs 3	-1.77	-4.89 to 1.34	0.2606
	2 vs 4	-0.52	-3.64 to 2.61	0.7437
	3 vs 4	1.26	-1.86 to 4.37	0.4240

[a]Exercises: Exercise 1: Side-plank hip abduction with dominant leg on bottom; Exercise 2: Side-plank hip abduction with dominant leg on top; Exercise 3: The single-leg squat; Exercise 4: Plank with hip extension.

[b]Mean differences, 95% CI for mean differences and *p*-values (for effect of 'exercise') from three-way analysis of variance (ANOVA) model with 'participant', 'period' and 'exercise' as fixed effects.

CHAPTER 5 – DISCUSSION OF THE RESULTS

5.1 Introduction

The purpose of the study was two-fold. Firstly, it set out to establish which commonly prescribed body weight rehabilitation exercises from previous studies elicited greater than 61%MVIC for both the mGmax and mGmed. Secondly, it examined the exercises that fall into this category to determine which exercise will elicit the highest %MVIC (defined as the peak normalised sEMG signal amplitude) in high-performance female field hockey players of the UFS. Previous studies theorised that strength gains will be accomplished from exercises that elicit an sEMG signal amplitude equal to or greater than 40%MVIC (Ayotte *et al.*, 2007; Escamilla *et al.*, 2010; Reiman *et al.*, 2012; Ebert *et al.*, 2017). However, to determine an optimal exercise for strengthening of the mGmax and mGmed in high-performance female field hockey players, the study only selected exercises that generate a 'very high' (>61%MVIC) muscle activation threshold (Escamilla *et al.*, 2010; Ebert *et al.*, 2017). The only exercises that fell into this category were four body weight rehabilitation exercises evaluated by Boren *et al.* (2011) and, accordingly, these exercises were selected to be examined. Surface EMG was used to record the muscular activity of each exercise. The peak amplitude of the last five repetitions of each exercise was analysed to exhibit the %MVIC activation of the mGmax and mGmed. Prior to these last five repetitions, the participants had three practice repetitions in order to master the movements with the necessary control that would elicit higher activation and, consequently, result in recording the %MVIC as accurately as possible.

To the knowledge of the researcher, the current study is the first one to conduct this type of research on high-performance female field hockey players. Field hockey, as noted in Chapter 2, is a popular competitive team sport played worldwide (Jennings *et al.*, 2012a; 2012b; McGuinness *et al.*, 2017). The various actions performed in roller hockey were outlined in Table 2 of Chapter 2. There the emphasis was placed on the high activation of the mGmax during various actions. Seeing that no previous studies could be found that evaluated the activation of the mGmax and mGmed during the different actions performed in field hockey, the activation of the mGmax in actions of roller hockey was reported. Knowledge regarding exercises that can be performed on the field without any equipment can assist conditioning coaches in strengthening the muscles that most actions of the sport demand and, additionally, better prepare the players for competition.

This chapter will discuss the results of the study as presented in Chapter 4. Firstly, the physical characteristics of participants will be reported and compared with previous studies on elite international female field hockey players. Secondly, the manual muscle strength test positions used to determine the normalised MVIC will be discussed and compared to the study that was replicated (i.e., Boren *et al.*, 2011). Lastly, the results for activation of the mGmax and mGmed during the four body weight rehabilitation exercises examined will be compared to the findings of previous studies and, concurrently, explanations will be provided for the similarities and differences across various studies.

5.2 Physical characteristics of participants

The current study investigated and reported the physical characteristics of 26 high-performance female field hockey players of the UFS and provided the averaged values of the data that will be compared with elite international female field hockey players as discussed under section 2.2.4. Because there is no previous research conducted on the sEMG activation of the mGmax and mGmed on female field hockey players, comparisons were drawn across studies that examined the physical demands of female field hockey players during match play through GPS technology. However, the study by Naicker *et al.* (2016) was conducted on the morphological and skill-related fitness components as potential predictors of injuries in the South African national women's field hockey team.

5.2.1 Age

The current study reported a mean age of 20.15±1.59 years for high-performance female field hockey players. This age is slightly less when compared to previous studies, possibly since elite international female field hockey players are more established and experienced than high-performance university-level players. Another possible explanation stems from universities mandating that only players 25 years and younger are allowed to compete at this level. The youngest age reported in a previous study that falls into the age category of university-level players (18–25 years) was Vescovi, Klas and Mandic (2019), who conducted a study on the Canadian under 21 women's field hockey team (n=16). The average age of this team was 18.8±1.2 years. Naicker *et al.* (2016) reported a mean age of 23.8±3.16 years (n=30). Perrotta *et al.* (2017) conducted a study on elite international female field hockey players (n=16) who had an average age of 22±2.1 years. On their part, McMahon and Kennedy (2017) recorded the match activity profiles of female field hockey players (n=19) who had an average age of 23±4 years, while McGuinness *et al.* (2017) recorded the match activity profiles of elite international female field hockey outfield players (n=38), who had an average age of 24±5 years. McGuinness *et al.* (2018) conducted another study on elite female field hockey players (n=27) during the 2016–2017 season who had an average age of 23±3 years.

5.2.2 Body mass

The current study reported a mean body mass of 64.72±10.21kg for high-performance female field hockey players. This mean body mass is remarkably similar when compared to previous studies. Naicker *et al.* (2016) reported a mean body mass of 62.6±8.45kg. Vescovi *et al.* (2019) reported a mean body mass of 64.6±9.3kg, while McGuinness *et al.* (2017) reported a mean body mass of 64±5kg. Furthermore, McMahon and Kennedy (2017) reported a mean body mass of 63.6±5.5kg, whereas McGuinness *et al.* (2018) reported a mean body mass of 66±6kg. On their part, Perrotta *et al.* (2017) reported the lowest mean body mass (61.3±5.7kg) compared to all these studies due to conducting their study on under 21's that also had a lower mean age as presented above.

5.2.3 Height

The current study reported a mean height of 164±0.07cm for high-performance female field hockey players. Compared to previous studies, Naicker *et al.* (2016) reported a mean height of 164.5±5.24cm, while McGuinness *et al.* (2017) reported a mean height of 163±5cm. In an altogether different study, McGuinness *et al.* (2018) reported a mean height of 163±13cm, more or less similar to the current study. Furthermore, Vescovi *et al.* (2019) reported a slightly higher mean height of 166±6.3cm and Perrotta *et al.* (2017) reported a mean height of 170±3.5cm.

5.2.4 BMI

The current study reported a mean BMI of 23.87±2.92kg.m² for high-performance female field hockey players. The studies that will be compared did not provide any BMI values of their participants; however, the current study calculated it for comparative purposes. For this reason, the standard deviations from these studies could not be provided. Compared to previous studies, a mean BMI of 23.27kg.m² was reported by Naicker *et al.* (2016), 23.44kg.m² by Vescovi *et al.* (2019), 24.09kg.m² by McGuinness *et al.* (2017) and 24.84kg.m² by McGuinness *et al.* (2018), with all of the above in line with the mean BMI of the current study. Finally, Perrotta *et al.* (2017) had a slightly lower BMI of 21.21kg.m² given that their study examined a population with a younger mean age.

5.3 MVIC normalisation

As noted in Chapter 3 (section 3.5.1), normalisation of the sEMG signal amplitude is of paramount importance owing to various influences on the sEMG signal, such as individual differences, and anatomical and physiological factors (Ball & Scurr, 2013; Cho *et al.*, 2018). Hence, a standardised assessment method is required through the execution of a manual muscle strength test as a reference contraction to determine the MVIC of a particular muscle before executing each exercise (Ball & Scurr, 2013; Lee & Jo, 2016; Cho *et al.*, 2018; Huseth *et al.*, 2020). Boren *et al.* (2011) executed the manual muscle strength test of the mGmax in a neutral hip position (0º) and 90º knee flexion. The current study executed the manual muscle strength test according to the latest research, which illustrated that a 5º hip extension angle and 90º knee flexion angle result in optimal activation of the mGmax (Jeon *et al.*, 2016). Boren *et al.* (2011) failed to specify the hip abduction angle in which they executed the side-lying manual muscle strength test for the mGmed to determine the normalised MVIC. The current study used a 35º hip abduction range for the mGmed with slight hip extension and a medially rotated hip (McBeth *et al.*, 2012; Ebert *et al.*, 2017). Variations in the manual muscle strength tests to determine the normalised MVIC made it difficult to draw comparisons with Boren *et al.*'s (2011) study.

As illustrated in Table 5, the researcher found that all four body weight rehabilitation exercises presented peak %MVIC's that were higher than the normalised MVIC. This phenomenon was observed in two of the exercises by Boren *et al.* (2011), namely with side-plank hip abduction with dominant leg on bottom (103.11%MVIC of the mGmed) and plank with hip extension (106.22%MVIC of mGmax), as indicated in Table 6. Boren *et al.* (2011) argued that three factors may have contributed to this phenomenon. Firstly, participants might have lacked sufficient motivation to execute a proper maximal contraction during the MVIC manual muscle strength test, irrespective of verbal encouragement given to all participants. Secondly, previous studies reported that a true maximal contraction would only result if the researcher can superimpose an interpolated twitch (an electrically stimulated contraction) beyond the MVIC. To achieve this, sensitive interpolated twitch techniques should be established. Finally, all of these body weight rehabilitation exercises are challenging to undertake and require a high degree of core stabilisation. Therefore, the higher %MVIC can be the result of synergist co-contraction of the core musculature (Boren *et al.*, 2011). However, similar to Boren *et al.* (2011), the manual muscle strength test positions were executed with the pelvis stabilised against the surface of the plinth without external support that generates relative isolated muscle activation. Accordingly, Boren *et al.* (2011) argued that greater sEMG signal amplitudes could occur due to an increased requirement of stabilisation. Hence, it will not be appropriate to introduce these four body weight rehabilitation exercises to a population with weak core musculature during the initial stages of rehabilitation.

5.4 Findings and comparisons

While various body weight rehabilitation exercises are prescribed clinically to strengthen the mGmax and mGmed, no evidence exists about the efficacy of these exercises in high-performance female field hockey players. Table 5 presents the findings of the four body weight rehabilitation exercises examined in this study, whereas Table 6 compares these findings to those referenced by Boren *et al.* (2011). The findings of the study were only compared to those of Boren *et al.* (2011), seeing as the latter was the only study which previously evaluated the four body weight rehabilitation exercises selected for this study. However, Boren *et al.* (2011) only reported the peak %MVIC activation. In contrast, the current study reported descriptive statistics (mean, std, min, Q1, median, Q3 and max of the peak %MVIC activation) as well as ANOVA data about the four body weight rehabilitation exercises. Similar to Boren *et al.* (2011), all of these body weight rehabilitation exercises produced a peak normalised sEMG signal amplitude of greater than 61%MVIC, suggesting that these exercises are sufficient for strengthening of the mGmax and mGmed (Ayotte *et al.*, 2007; Escamilla *et al.*, 2010; Reiman *et al.*, 2012; Ebert *et al.*, 2017). The use of normalised sEMG signal amplitude to measure muscle activity provides an estimate of exercise intensity (Distefano *et al.*, 2009). Besides, this enables the study to discuss the relative contribution of the mGmax and mGmed during the four body weight rehabilitation exercises that can be prescribed for prehabilitation as well as the later stages of rehabilitation in high-performance female field hockey players.

The current study selected a high-performance sport population owing to a lack of sEMG signal amplitude research of the mGmax and mGmed activation on such populations. In contrast, Boren *et al.* (2011) conducted their study on 26 healthy individuals without specifying their sex. The term ‘healthy individuals’ in their study referred to individuals who were able to exercise for approximately one hour. However, the latter description is vague and fails to give an account of the physical conditioning and physical activity history of the participants. As against this, the use of the term ‘high-performance’ in this study denotes individuals marked by an exceptional degree of physical conditioning. The majority of the high-performance partakers in this study were in a good physical conditioning state given that they were exposed to more hours of intense training in the gym and on the field. Concerning the engagement in physical activity of the 26 participants, 65.38% indicated that they are physically active for more than 7 hours per week, while the remaining 34.62% indicated that they are physically active for 5–6 hours per week.

Despite the different study populations used, the study attempted to apply the methodology of Boren *et al.* (2011) as far as possible; however, some critical information, such as the joint position angles used to determine MVIC as well as those used during each exercise, were omitted in their study. Macadam and Feser (2019) stated that the following variables should at least be similar to draw comparisons between two studies: MVIC positions, electrode site placement, data processing and amplitude presentation. The range of motion, relative load and the tempo of exercises should also be similar (Macadam & Feser, 2019). Although numerous factors influence the sEMG signal amplitude across studies, Ebert *et al.* (2017) stated that the range of loads (%MVIC) displayed by a particular exercise in different studies can still be used by practitioners to determine if it is appropriate for programme prescription. Therefore, interpretation of results regarding similarities and differences across studies will predominantly address the %MVIC values found for both the mGmax and mGmed during each exercise.

Although no other studies, except that of Boren *et al.* (2011), investigated the four body weight rehabilitation exercises examined in this study, the findings of Zeller *et al.* (2003), Ayotte *et al.* (2007), Webster and Gribble (2013), Kim and Yoo (2015) and Jeon *et al.* (2016) will also be reported. The latter studies evaluated different versions of two exercises included in the current study, namely the single-leg squat and prone hip extension. Although these exercises were conducted differently in these studies and on healthy individuals, all of these exercises produced greater than 61%MVIC for either the mGmax, mGmed or both. Furthermore, the findings of Cochrane *et al.* (2019) will be reported and compared, given that it was the only study that previously conducted sEMG research of the mGmax on a high-performance population group through evaluating the single-leg squat and prone hip extension exercises. It should be noted, however, that the latter study evaluated different versions of the single-leg squat and prone hip extension exercises than those examined in the current study.

The study examined the activation capabilities of the mGmax and mGmed of the participants' dominant side. Previous studies (Boren *et al.*, 2011; Lee *et al.*, 2014; MacAskill *et al.*, 2014; Cochrane *et al.*, 2019) only reported values of the dominant side from their participants; hence, the current study also compared findings of the participants' dominant side. Twenty-five participants were right dominant and one was left dominant. A comprehensive description of each exercise will follow in the sections below.

5.4.1 Side-plank hip abduction with dominant leg on bottom

Exercises that involve hip abduction are typically prescribed for strengthening of the mGmed, with the most common version being side-lying hip abduction (Distefano *et al.*, 2009; Reiman *et al.*, 2012; Ebert *et al.*, 2017). However, the current study examined a side-plank version of hip abduction given that Boren *et al.* (2011) illustrated that this version generated the highest %MVIC activation of the primary function of the mGmed, namely hip abduction. Boren *et al.* (2011) is the only study who previously conducted this exercise in a side-plank version. Therefore, it is the only reference that can be used to compare the findings of the current study directly.

As presented in Table 6, the current study found a 124.61%MVIC elicited by the mGmax and 126.07%MVIC elicited by the mGmed, while Boren *et al.* (2011) reported a 70.96%MVIC of the mGmax and 103.11%MVIC of the mGmed. Boren *et al.* (2011) concluded that compared to all the other exercises examined in their study, the 103.11%MVIC exhibited by the mGmed was the highest. Hence, the latter authors found that this exercise is the best exercise for strengthening of the mGmed. In the most recent systematic review on mGmed activation, Ebert *et al.* (2017) confirmed the latter. In contrast with this, the current study found that side-plank hip abduction with dominant leg on bottom is the second-best exercise for strengthening of the mGmed given that it elicited a %MVIC slightly less than the single-leg squat (126.30%MVIC). However, as shown in Table 9, no significant difference in mGmed activation was found between the side-plank hip abduction with dominant leg on bottom and the single-leg squat (p=0.8837, d=-0.23).

The 70.96%MVIC activation elicited by the mGmax in Boren *et al.* (2011) was found to be the fourth-best exercise for strengthening of the mGmax. In contrast with this, the current study found that side-plank hip abduction with dominant leg on bottom is the second-best exercise to prescribe for strengthening of the mGmax, owing to the single-leg squat (125.65%MVIC) eliciting slightly higher activation of the mGmax. However, as shown in Table 9, no significant difference in mGmax activation was found between the side-plank hip abduction with dominant leg on bottom and the single-leg squat (p=0.4807, d=-1.03).

Importantly, it should be noted that the position of execution of side-plank hip abduction with dominant leg on bottom was slightly adjusted by the current study to provide better pelvic stabilisation and to avoid compensatory movements (as discussed in section 3.5.2). Compared to Boren *et al.* (2011), whose participants executed this exercise with the shoulders, hips, knees and ankles in line bilaterally, the current study followed Kendall *et al*.'s (2005) instruction to flex the bottom leg at the hip and knee to provide greater stability. Therefore, contradictory findings between the current study and Boren *et al.* (2011) may be attributed to the latter adjustment as well as differences in methodology, such as the study population (high-performance versus healthy individuals) and joint position angles used to execute this exercise (35º of hip abduction range versus no reported data regarding this).

The 'very high' (as referenced by Ayotte *et al.*, 2007; Escamilla *et al.*, 2010; Reiman *et al.*, 2012; Ebert *et al.*, 2017) muscle activation of the mGmed emphasises this muscle's primary role as a hip abductor (Van Putte *et al.*, 2014; Ebert *et al.*, 2017; SENIAM, 2019). On its part, the very high activation of the mGmax emphasises this muscle's secondary role as a hip abductor (Van Putte *et al.*, 2014; Rainsford, 2015). The dynamic nature of the exercise further demands greater activation of the mGmed to maintain pelvic stability.

Functionally relevant positions of exercises should be considered when selecting an exercise for strengthening in field hockey. Although the position in which this exercise was executed is not functional in nature or executed in a position that directly simulates an action in field hockey, hip abduction is one of the most essential requirements of field hockey. A player has to step to the side (a pure concentric hip abduction movement) to perform basic actions of field hockey, such as passing a ball, receiving a ball, shooting for goal and engaging in a tackle. Despite the difference in findings with regards to the %MVIC produced in the current study and that of Boren *et al.* (2011), it is not surprising that the %MVIC findings of the mGmax and mGmed in this high-performance population were higher, considering the basic actions performed in field hockey. Given that hip abduction is the primary function of the mGmed, the very high %MVIC generated from the side-plank hip abduction with dominant leg on bottom exercise in female field hockey players can be attributed to the exceptional demands of field hockey in this position. Therefore, the study recommends that Biokineticists and conditioning coaches incorporate this exercise as part of a prehabilitation programme owing to the hip abduction demands of field hockey.

5.4.2 Side-plank hip abduction with dominant leg on top

Similar to the previous exercise, this exercise is commonly prescribed in a side-lying position for strengthening of the mGmed, given that hip abduction is the primary function of this muscle (Distefano *et al.*, 2009; Reiman *et al.*, 2012; Van Putte *et al.*, 2014; Ebert *et al.*, 2017; SENIAM, 2019). However, in contrast with the dominant leg on bottom version of this exercise where the mGmax and mGmed functioned in a stabilising state, the dominant leg on top version has to overcome the gravity barrier during concentric hip abduction (Lee & Jo, 2016). Seeing that Boren *et al.* (2011) is the only study that previously conducted this exercise in a side-plank version, it is the only reference that can be used to compare the findings of the current study.

As presented in Table 6, the current study indicated a 124.33%MVIC elicited by the mGmax and 124.52%MVIC elicited by the mGmed, while Boren *et al.* (2011) reported a 72.87%MVIC of the mGmax and 88.82%MVIC of the mGmed. Considering that the previous exercise was similarly executed (yet with the dominant leg on bottom), no significant difference was found between the two side-plank hip abduction versions in high-performance female field hockey players for both the mGmax (p=0.8475, d=0.28) and mGmed (p=0.3272, d=1.54) as shown in Table 9. Concerning both side-plank hip abduction versions, the %MVIC findings suggest that the mGmax and mGmed activation in high-performance female field hockey players are basically equal with the unilateral leg in an isometric, stabilising state (dominant leg is on bottom) and with the contralateral leg in an isotonic state (dominant leg is on top) to perform concentric hip abduction. As against this, Boren *et al.*'s (2011) study revealed that their healthy participants elicited greater activation only of the mGmed during the side-plank hip abduction with dominant leg on bottom in which the mGmax and mGmed function in an isometric, stabilising state.

Furthermore, Boren *et al.* (2011) concluded that compared to all the other exercises examined in their study, the 88.82%MVIC elicited by the mGmed was found to be the second-best exercise to prescribe for strengthening of the mGmed. In contrast with this, the current study found that side-plank hip abduction with dominant leg on top elicited the lowest activation of the mGmed compared to the other three exercises. Therefore, the current study concludes that this exercise is the fourth-best exercise to prescribe for strengthening of the mGmed in high-performance female field hockey players. The 72.87%MVIC elicited by the mGmax in the study by Boren *et al.* (2011) was found to be the third-best exercise to prescribe for strengthening of the mGmax. Similarly, the current study also found that this exercise is the third-best exercise to prescribe for strengthening of the mGmax in high-performance female field hockey players.

As with the dominant leg on bottom version, the current study also adjusted the dominant leg on top version slightly to provide better pelvic stabilisation and to avoid compensatory movements. Compared to Boren *et al.* (2011), whose participants executed this exercise with the shoulders, hips, knees and ankles in line bilaterally, the current study instructed the participants to flex the bottom leg at the hip and knee following Kendall *et al.* (2005). Again, contradictory findings between the current study and Boren *et al.* (2011) may stem from differences in the study populations (high-performance versus healthy individuals) and joint position angles used to undertake each exercise (35º of hip abduction range versus no reported data regarding this). Finally, the adjustment made by the current study to conduct the exercise in a position that provides better stability may also have resulted in more isolated mGmax and mGmed activation. The very high muscle activation of the mGmed emphasises this muscle's primary role as a hip abductor. In contrast, the very high muscle activation of the mGmax emphasises this muscle's secondary role as a hip abductor. The dynamic nature of the exercise further demands greater activity of the mGmed to maintain pelvic stability.

As with the side-plank hip abduction with dominant leg on bottom, this exercise is also not functional in nature or executed in a position that simulates an action in field hockey.

However, as stated in the previous section, concentric hip abduction is a movement performed in all the basic actions of field hockey. It is therefore not surprising that the %MVIC findings of the mGmax and mGmed in this high-performance population are higher than that of Boren *et al.* (2011). Since hip abduction is the primary function of the mGmed, the very high %MVIC generated from the side-plank hip abduction with dominant leg on top in female field hockey players can be attributed to the exceptional demands of field hockey in this position. Exercises that involve hip abduction should, therefore, be included in all prescribed programmes for high-performance female field hockey players.

5.4.3 The single-leg squat

Previous studies on the single-leg squat were conducted by various researchers, with Cochrane *et al.* (2019) being the only study to evaluate this exercise on a high-performance population. As shown in Table 2, Zeller *et al.* (2003) reported an 81.2±28%MVIC of the mGmax during the single-leg squat. Ayotte *et al.* (2007) reported an 86±43%MVIC of the mGmax for the single-leg wall squat and highlighted that the free leg should be extended from the knee to elicit a higher %MVIC of the mGmax. Similarly, the current study also extended the contralateral (free) leg. Distefano *et al.* (2009) reported a 64±24%MVIC of the mGmed during the single-leg squat. Webster and Gribble (2013) reported a 78±45%MVIC of the mGmax and a 68±15%MVIC of the mGmed during a rotation single-leg squat. Cochrane *et al.* (2019) reported an 88.8±15.5%MVIC of the mGmax for the single-leg squat.

As presented in Table 6, the current study found a 125.65%MVIC elicited by the mGmax and 126.30%MVIC elicited by the mGmed, while Boren *et al.* (2011) reported a 70.74%MVIC of the mGmax and 82.26%MVIC of the mGmed. As shown in Table 9, considering the mGmax, there was no significant difference found in activation between the side-plank hip abduction with dominant leg on bottom (p=0.4807, d=-1.03) and side-plank hip abduction with dominant leg on top (p=0.3685, d=-1.31) when compared to the single-leg squat. However, there was a significant difference between the single-leg squat and plank with hip extension (p=0.0487, d=2.91). When all four body weight rehabilitation exercises are considered, the single-leg squat required the most balance, which resulted in greater activation of the mGmax. To confirm this, Macadam and Feser (2019) stated that a unilateral version of a vertically orientated exercise such as a single-leg squat result in greater mGmax %MVIC compared to the bilateral squat version. Concerning the mGmed, there was no significant difference in activation between the side-plank hip abduction with dominant leg on bottom (*p*=0.8837, *d*=-0.23), side-plank hip abduction with dominant leg on top (*p*=0.2606, *d*=-1.77) and plank with hip extension (*p*=0.4240, *d*=1.26) when compared to the single-leg squat.

In their study, Boren *et al.* (2011) concluded that the single-leg squat was the fifth-best exercise to prescribe for strengthening of the mGmax and the third-best exercise to strengthen the mGmed. In contrast with this, the current study found that the single-leg squat elicited the highest %MVIC activation of both the mGmax and mGmed compared to the other three exercises. This shows that the greater movement complexity of the single-leg squat required that the body had to change the joint angles of the hip and knee joints during execution of the action that resulted in greater %MVIC for both the mGmax and mGmed. The current study concludes that the single-leg squat is the best exercise to prescribe for strengthening of both the mGmax and mGmed in high-performance female field hockey players.

A systematic review by Macadam and Feser (2019) stated that possibilities for ranges in %MVIC of the single-leg squat across studies could be attributed to differences in the depth of the squat, the position of the contralateral leg and the experience of the participant with the execution of the exercise. Cochrane *et al.* (2019) executed the single-leg squat in a position of 60º hip and knee flexion. As against this, the current study replicated the position of Boren *et al.* (2011) that required of the participants to execute the single-leg squat by touching a chair of 47cm in height with their buttocks. Each participant's dominant leg was 15cm away from the chair. Boren *et al.* (2011) failed to specify the distance from the chair that their participants had to stand. Squatting to a predominant height of 47cm during the single-leg squat created a greater challenge for taller participants (Boren *et al.*, 2011). Therefore, it is recommended that participants instead perform the single-leg squat to a predominant knee and hip flexion angle in order to standardise the challenge for participants.

The imposed demands of this vertically orientated exercise result in the mGmed to function in its primary role as a hip abductor, whereas the mGmax functions in its secondary role as a hip abductor to maintain stability of the pelvis. Furthermore, the mGmax functions as a hip lateral rotator to minimise knee valgus collapse that results from hip internal rotation and adduction (Distefano *et al.*, 2009; Reiman *et al.*, 2012; Macadam *et al.*, 2015). Rainsford (2015) confirmed this by stating that the vertical force vector in which the single-leg squat is executed may place increased demands on the gluteal muscles to maintain lower extremity alignment. Lee and Jo (2016) stated that muscle activation from muscles of the lower extremity differs according to the size of the base of support as well as the height of the centre of gravity. Moreover, movement of the pelvis away from the body's base of support requires higher activation of all muscles around the hip, especially the mGmed (Ayotte *et al.*, 2007; Reiman *et al.*, 2012). Against this background, it can be concluded that the very high mGmax and mGmed activity is also generated due to the base of support being shifted away from the body's centre of mass. With this in mind, and as against Cochrane *et al.* (2019), the body's centre of mass of the participants in both Boren *et al.*'s (2011) study and the current one was closer to the ground. Furthermore, the gravitational forces result in substantial hip adduction torque during the single-leg squat that the mGmed must resist to maintain lower extremity alignment (Distefano *et al.*, 2009). This explains the greater activation of the mGmed to stabilise the pelvis and knee in this position. In summary, the high level of activation is typical as it involves all the major functions of the mGmax and mGmed, such as balancing on a single limb, stability of the lumbo-pelvic region and control over isotonic movements, eccentrically during hip flexion and concentrically during hip extension (Distefano *et al.*, 2009).

Macadam and Feser (2019) also found that females elicit higher %MVIC values during a single-leg squat compared to males. These differences can result from structural differences between males and females, with females having an increased pelvic width to femoral length ratio (Macadam & Feser, 2019). Another possibility is the difference in muscle strength of males and females, specifically hip abductor strength, that will require greater mGmax and mGmed excitation in a unilateral exercise to stabilise the pelvis (Macadam & Feser, 2019).

Of the four exercises examined in this study, the single-leg squat is the only one that is entirely functional in nature. Squatting applies in all actions of field hockey, especially while tackling and receiving the ball. To support this, Wege *et al.* (2006) stated that the synthetic surfaces on which high-performance field hockey players' practise and play demand maintaining a low body (squatting) position for optimal execution of skills such as stopping, flicking and tackling. Therefore, given that this action is often performed in field hockey, it is also not surprising that the %MVIC findings of the mGmax and mGmed in this high-performance population are higher than those of other studies.

The study recommends that the single-leg squat should be incorporated in the prehabilitation programme prescription of high-performance female field hockey players given that this exercise exhibited the highest activation of both the mGmax and mGmed. However, Biokineticists and conditioning coaches should use discretion when female field hockey players undertake this advanced exercise. Of the four body weight rehabilitation exercises examined, this is the exercise that can result in the most compensatory movements, such as an anterior pelvic tilt or hip adduction and femoral internal rotation, which results in knee valgus. One suggestion for modification of the single-leg squat is to increase the chair or target bar height to a height level that does not result in compensatory movements. Because the single-leg squat generated equally high activation of the mGmax and mGmed in the current study, the practitioner can substitute this exercise for a basic bilateral squat. This will decrease the demands on the lower extremity to maintain alignment. The bilateral squat can be gradually progressed by lowering the target bar heights that the player should touch and eventually the unilateral version can be introduced. Due to the degree of difficulty to execute the single-leg squat to a chair height of 47cm, Biokineticists and conditioning coaches should provide proper instructions and feedback before, during and after executing the exercise. Physical feedback can be done through corrective cueing and visual feedback can be given by providing a mirror to ensure that the player executes the exercise correctly. Modifications and progression of the exercise should always be in accordance with the capabilities of the player.

Importantly, the single-leg squat should not be prescribed during the early stages of rehabilitation. Reiman *et al.* (2012) stated that to achieve strengthening in any muscle group entails systematic progression from less to more challenging exercises. In early rehabilitation cases or when compensatory movements occur during the execution of this exercise, the Biokineticist should instead prescribe basic exercises that produce lower %MVIC (consult Ayotte *et al.* (2007), Distefano *et al.* (2009) and Reiman *et al.* (2012) for examples) and gradually progress to the single-leg squat. Ayotte *et al.* (2007) and Reiman *et al.* (2012) stated that lower-level activation exercises facilitate neuromuscular control that establishes the proprioceptive sense critical to prevent secondary injuries. Proper balance and lower extremity alignment are the predominant requirements for execution of the single-leg squat.

5.4.4 Plank with hip extension

Given that hip extension is the primary function of the mGmax, exercises that involve hip extension are typically prescribed for strengthening of this muscle (Neumann, 2010; Van

Putte *et al.*, 2014; Rainsford, 2015; Macadam & Feser, 2019). Boren *et al.* (2011) is the only study that previously conducted this exercise in a plank version. Therefore, Boren *et al.* (2011) is the only reference that can be used to compare the findings of the current study directly. As shown in Table 1, Kim and Yoo (2015) reported a 62.3±27.1%MVIC of the mGmax during the "prone hip extension with upper body on table" exercise. Jeon *et al.* (2016) reported a 66.4±25.8%MVIC of the mGmax during the "prone hip extension with upper body on table and flexed contralateral knee on a chair" exercise. Cochrane *et al.* (2019), the only previous study conducted on a high-performance population regarding activation of the mGmax, reported a 100±0%MVIC activation during the "modified prone hip extension" exercise. Although Cochrane *et al.* (2019) is the only study who previously examined a hip extension exercise version on a high-performance population, direct comparisons could not be drawn due to the current study executing a different version of this exercise.

As presented in Table 6, the current study found a 122.73%MVIC elicited by the mGmax and 125.04%MVIC elicited by the mGmed, while Boren *et al.* (2011) reported a 106.22%MVIC of the mGmax and 75.13%MVIC of the mGmed. The very high activation levels of the mGmax found by both Boren *et al.* (2011) and the current study suggest that greater mGmax recruitment is required when an individual has less ground contact points and is only supported by one foot and both elbows (Macadam & Feser, 2019). The 106.22%MVIC exhibited by the mGmax in the study by Boren *et al.* (2011) was the highest for this muscle; hence, they concluded that plank with hip extension is the best exercise for strengthening of the mGmax. Macadam and Feser (2019) conducted the most recent systematic review of mGmax activation. They confirmed that the plank with hip extension by Boren *et al.* (2011) is currently the best body weight rehabilitation exercise for strengthening of the mGmax. In contrast with this, the current study found that the plank with hip extension elicited the lowest mGmax activation; hence, the fourth-best exercise to prescribe for strengthening of the mGmax. As shown in Table 9, concerning the mGmax, the study found no significant difference in activation between the side-plank hip abduction with dominant leg on bottom (p=0.2000, d=1.88) and side-plank hip abduction with dominant leg on top (p=0.2770, d=1.60) when compared to the plank with hip extension. However, a significant difference was found between the single-leg squat and plank with hip extension (p=0.0487, d=2.91). Concerning the mGmed, plank with hip extension was found to be the third-best exercise for strengthening of this muscle. Furthermore, there was no significant difference in activation between the side-plank hip abduction with dominant leg on bottom (p=0.5134, d=1.03), side-plank hip abduction with dominant leg on top (p=0.7437, d=-0.52) and the single-leg squat (p=0.4240, d=1.26) when compared to the plank with hip extension.

Differences in the execution of this exercise made accurate comparisons between Boren *et al.* (2011) and the current study difficult. The current study executed the plank with hip extension with a 5º hip extension angle. According to Jeon *et al.* (2016) and Macadam and Feser (2019), a 5º hip extension angle should be used to elicit the highest sEMG signal amplitude of the mGmax to prevent compensatory movements of the lumbo-pelvic region. Importantly, it should be noted that Boren *et al.* (2011) failed to provide the hip extension angle that they used to execute this exercise. Consequently, this lack of information in the methodology of Boren *et al.* (2011) made proper replication difficult and may account for the difference in %MVIC values across the two studies. Also, in contrast with the current study, Cochrane *et al.* (2019) executed the "modified prone hip extension" from a neutral (0º) hip angle.

Considering the basic actions performed in field hockey, it is not surprising that the %MVIC findings of the mGmax and mGmed in this high-performance population are higher than those of other studies. As mentioned, squatting and side-stepping actions in field hockey require muscle activity of both the mGmax and mGmed. Furthermore, performing lunge actions to engage in a tackle or to pass the ball, as well as the kick back action during running with the ball, are all examples of actions in field hockey that involve hip extension. Given that hip extension is the primary function of the mGmax, the very high %MVIC generated from the plank with hip extension exercise in field hockey players can be attributed to the exceptional demands of field hockey in this position. Therefore, strengthening a player in this position is crucial for optimal performance.

Rainsford (2015) stated that the prone hip extension exercise is not functional in nature. This also accounts for the plank version of this exercise. Sport populations, especially, should incorporate exercises that simulate the movement patterns of the sport. This study showed that the plank with hip extension exercise exhibited adequate activation for strengthening of both the mGmax and mGmed. Since a 5º hip extension range initiated from 30º of hip flexion with 90º knee flexion elicited very high activation of both the mGmax and mGmed, the researcher recommends that a functional version with these joint position angles should be incorporated by Biokineticists and conditioning coaches in the prehabilitation programmes for field hockey players. To ensure that the joint position angles are implemented, the Biokineticist should measure it with a goniometer and set a target bar accordingly.

Importantly, compensatory movements, such as an excessive lumbar lordotic curvature, can result if the player lacks adequate core stability. Therefore, Biokineticists and conditioning coaches should first ensure that the player has a high degree of core stability before introducing the plank with hip extension. If this exercise is included in the prehabilitation programme, the practitioner should remain vigilant for this type of compensation. Sufficient core stability is the absolute requirement for the plank with hip extension exercise.

5.5 Summary of exercise effect on the mGmax and mGmed

A key observation in the current study was that 'exercise' did not significantly affect either mGmax (p=0.2558) or mGmed (p=0.6285) activation, as shown in Table 7. Concerning the estimated effect sizes that can be interpreted as the size of a correlation, the ω=0.10 found for the mGmax indicates that the effect of 'exercise' on mGmax can be considered as low. This suggests that there was only a small variation in mGmax activation during all four body weight rehabilitation exercises. This small variation occurred due to the significant difference between the single-leg squat and plank with hip extension (p=0.0487, d=2.91). To the knowledge of the researcher, Cochrane *et al.* (2019) is the only previous study that investigated the sEMG signal amplitude of the mGmax during different body weight rehabilitation exercises on a high-performance population. Cochrane *et al.* (2019) conducted a modified prone hip extension (open kinetic chain) and single-leg squat (closed kinetic chain) with the same hip and knee angles on rugby players. Cochrane *et al.* (2019) concluded that there was no significant difference (p>0.05) found in mGmax sEMG signal amplitude between the modified prone hip extension and the single-leg squat exercises. These findings indicate that regardless of the body's orientation in two different techniques, namely an open versus a closed kinetic chain, activation of the mGmax was not significantly influenced (Cochrane *et al.*, 2019).

However, the results of the current study show that the direction in which force was applied during the single-leg squat (closed kinetic chain) and plank with hip extension (open kinetic chain) did significantly influence the %MVIC of the mGmax in high-performance female field hockey players (p=0.0487, d=2.91). Therefore, the study found that the closed kinetic chain single-leg squat is distinctly superior to the open kinetic chain plank with hip extension concerning activation of the mGmax in high-performance female field hockey players. However, this phenomenon was not noted in mGmax activation between the two other open kinetic chain exercises, namely side-plank hip abduction with dominant leg on bottom and side-plank hip abduction with dominant leg on top exercises examined in the study.

Concerning the mGmed, the estimated effect size was negative; therefore, the effect of ‘exercise’ on the mGmed can be considered as zero. Consequently, it is clearly indicated that the mGmed exhibited similar levels of activation during all four body weight rehabilitation exercises in high-performance female field hockey players. This suggests that there is no distinct superiority in mGmed activation when performing the open or closed kinetic chain exercises examined in this study. Except for the mGmax activation during the single-leg squat, findings of the mGmed suggest that all four exercises may have similar strengthening effects in high-performance female field hockey players.

5.6 Implementation of findings

The findings of this study will enable practitioners in an interprofessional team to select the body weight rehabilitation exercise that elicits the highest %MVIC to activate the mGmax and mGmed. Practitioners, moreover, will be equipped to make informed decisions regarding programme prescription for mGmax and mGmed strengthening during prehabilitation and the later stages of rehabilitation. A great benefit of these exercises is that they can be performed without the need of any equipment, thus provide promising possibilities for implementing strength training on the astroturf for field hockey players (Serner *et al.*, 2014).

CHAPTER 6 – CONCLUSION AND FUTURE RESEARCH

6.1 Introduction

To optimise the performance of high-performance female field hockey players, it is necessary that practitioners in the interprofessional team (especially Biokineticists and conditioning coaches) have the knowledge to select the body weight rehabilitation exercise that elicits the highest %MVIC to result in strength gains of the mGmax and mGmed. For practitioners to gain this knowledge, evidence-based research is required. Chapter 2 illustrated that several researchers had previously examined the activation capabilities of the mGmax and mGmed during commonly prescribed rehabilitation exercises, although mainly on healthy populations. The current study selected a high-performance population (female field hockey players) to determine the activation capabilities of the mGmax and mGmed during four body weight rehabilitation exercises, the findings of which were compared with healthy participants of previous studies. Given that this study is the first of its kind to examine the effect of these exercises on high-performance female field hockey players, Biokineticists and conditioning coaches can benefit by incorporating the findings into the programme prescription during prehabilitation or the later stages of rehabilitation for this population. This chapter will provide a conclusion to the study and, by elaborating on the limitations of the study, point towards future avenues for research.

6.2 Conclusion

The current study replicated a study by Boren *et al.* (2011) by examining the peak normalised sEMG signal amplitude elicited by the mGmax and mGmed during four body weight rehabilitation exercises on high-performance female field hockey players. Surface EMG activity for the mGmax ranged from 122.73–125.65%MVIC and from 124.52–126.30%MVIC for the mGmed. When considering the %MVIC activation of the mGmax, the single-leg squat generated the highest activation. Therefore, the current study concludes that the single-leg squat (125.65%MVIC) is the best body weight rehabilitation exercise to prescribe for strengthening of the mGmax in high-performance female field hockey players. This is followed by the side-plank hip abduction with dominant leg on bottom (124.61%MVIC), then the side-plank hip abduction with dominant leg on top (124.33%MVIC) and, lastly, the plank with hip extension (122.73%MVIC).

Concerning the mGmed, the single-leg squat (126.30%MVIC) generated the highest activation and is therefore recommended as the best body weight rehabilitation exercise to prescribe for strengthening of the mGmed in high-performance female field hockey players. This is followed by the side-plank hip abduction with dominant leg on bottom (126.07%MVIC), then plank with hip extension (125.04%MVIC) and, lastly, the side-plank hip abduction with dominant leg on top (124.52%MVIC). These small variations in average peak normalised sEMG signal amplitude among the four body weight rehabilitation exercises suggest that these exercises may have similar strengthening effects for both the mGmax and mGmed in high-performance female field hockey players.

When combining the exercise effect on the mGmax (p=0.2558) and mGmed (p=0.6285), no statistically significant difference was noted in the average peak normalised sEMG signal amplitude across the four body weight rehabilitation exercises. However, when the exercise effect on each exercise is considered individually, it was found that the activation of the mGmax during the single-leg squat was significantly higher than that of the plank with hip extension (p=0.0487, d=2.91). Changes in body position concerning the direction in which force was applied resulted in significantly higher %MVIC of the mGmax during the single-leg squat compared to the plank with hip extension. This suggests that the single-leg squat (closed kinetic chain) is distinctly superior to the plank with hip extension (open kinetic chain). However, there was no distinct superiority in mGmax activation when the single-leg squat was compared to the other two open kinetic chain exercises in this study, namely, side-plank hip abduction with dominant leg on bottom and side-plank hip abduction with dominant leg on top. Additionally, no distinct superiority was found between the one closed kinetic chain exercise (the single-leg squat) and the three open kinetic chain exercises (side-plank hip abduction with dominant leg on bottom, side-plank hip abduction with dominant leg on top and plank with hip extension) in eliciting maximal sEMG activity of the mGmed in high-performance female field hockey players.

Compared to the healthy participants of Boren *et al.* (2011), the current study found that high-performance female field hockey players elicited greater activation of the mGmax and mGmed during all four body weight rehabilitation exercises. As mentioned in the discussion of each exercise, there are several possibilities for differences in the findings between the study by Boren *et al.* (2011) and the current one. Although both studies examined the same exercises, it was observed that differences in population group, as well as the different versions in which exercises were executed, influenced the sEMG activity levels across different studies. This resulted in different manual muscle strength test positions used to determine MVIC that affected the normalised sEMG signal amplitude of the mGmax and mGmed, differences in joint position angles and subtle variances in the manner in which a particular exercise was executed, all of which affected the %MVIC activation levels. These differences in %MVIC across studies solidify the individuality of each participant and each population group.

Anderson *et al.* (2006), Ayotte *et al.* (2007), Escamilla *et al.* (2010), Reiman *et al.* (2012) and Ebert *et al.* (2017) previously reported that higher sEMG signal amplitude would result in more significant muscle strengthening effects. Therefore, evidence regarding the %MVIC that is produced during various body weight rehabilitation exercises can be prescribed for strengthening of the mGmax and mGmed. Biokineticists and conditioning coaches should not include these exercises in the programme prescription of players who are in the early stages of rehabilitation owing to the advanced level and difficulty of these exercises as well as the stabilisation required. All four body weight rehabilitation exercises are reserved for a prehabilitation programme or the later stages of rehabilitation.

To conclude, the four body weight rehabilitation exercises investigated in the current study generated very similar average peak normalised sEMG signal amplitude of both the mGmax and mGmed in high-performance female field hockey players. The optimal amount of repetitions and sets of each exercise are beyond the scope of this study. Statistically, this research enables practitioners to apply evidence-based practice into programme prescription. Implementation of the findings of this study could result in significant benefits during prehabilitation, injury prevention programmes and the later stages of rehabilitation. Hence, the researcher recommends that the Biokineticists and conditioning coaches should include these four body weight rehabilitation exercises in the prehabilitation programme for optimal strengthening in high-performance female field hockey players. The conditioning coach, especially, can benefit given that these exercises can be performed on the playing pitch as part of a warm-up without the need for any equipment.

6.3 Limitations and future research

Some limitations emerged that could be beneficial for future studies. The current study was conducted on high-performance female field hockey players only and therefore limits generalisation to this group. Consequently, the researcher cannot conclude that the results apply to males, athletes in a different sport code, players with pathologies or sedentary individuals. Future studies can compare the findings between males and females and investigate different high-performance sport codes given that there is a lack of this kind of research in such populations.

The current study only provided data on the participants' dominant side. Future studies should investigate the differences between the stabilising limb and the limb performing the exercise, which may provide a greater understanding of how to activate the mGmax and mGmed maximally.

The sEMG onset of muscle activity, a component of muscle control in rehabilitation, was not investigated by the current study. Future investigators can consider this component to provide information regarding the activation sequence of muscles. Furthermore, future studies may include this factor to compare its effects on each exercise for rehabilitation and prehabilitation purposes.

The use of sEMG is associated with limitations due to various influences on the sEMG signal amplitude such as cross-talk (Serner *et al.*, 2014; Barton *et al.*, 2018; Cochrane *et al.*, 2019). Owing to the close proximity of the m. TFL and m. gluteus minimus to the mGmed, it is possible that these two muscles may contribute to the muscle activity recorded by the sEMG signal for the mGmed (Distefano *et al.*, 2009). The current study attempted to minimise this phenomenon by using standardised methods for electrode placement, securing the electrodes with adhesive tape to inhibit movement and by detecting the sEMG signal output before data collection. Future studies may, therefore, wish to utilise fine-wire electrodes to determine the muscle activity generated for each exercise (Selkowitz *et al.*, 2016; Barton *et al.*, 2018).

It is theorised that when a specific primary muscle responsible for a particular joint movement weakens, the synergistic muscle becomes the new primary muscle responsible for the movement (Boren *et al.*, 2011; Lee & Jo, 2016; Barton *et al.*, 2018). The m. TFL is a muscle that is synergistic with the mGmed and assists the mGmed during hip abduction (Barton *et al.*, 2018; Han *et al.*, 2018). The m. TFL is a hip abductor and internal rotator (Han *et al.*, 2018). Weakness of the mGmed can result in overuse of the m. TFL as a hip abductor, a phenomenon known as synergistic dominance (Han *et al.*, 2018). Due to the m. TFL connection to the ITB, a predominant m. TFL can also exert lateral force on the patella (Han *et al.*, 2018). Excessive hip internal rotation and lateral patellar displacement can lead to iliotibial band friction syndrome and patellofemoral pain syndrome (Han *et al.*, 2018). Therefore, if the mGmed is weak or weakens, the m. TFL will become the new primary hip abductor. Distefano *et al.* (2009) and Barton *et al.* (2018) stated that this theory has been supported by numerous studies that reported that individuals with a weak mGmed reveal signs of increased m. TFL activation and shortening. Relative hip internal rotation and valgus positioning of the knee are the biomechanical consequences of increased m. TFL activation relative to mGmed activation (Barton *et al.*, 2018). Han *et al.* (2018) stated that less m. TFL activity is required to reduce anterior pelvic tilting and to maintain a level pelvis during exercise. Future studies should consider the influence of the m. TFL as a synergistic muscle of the mGmed and determine the gluteal-to-tensor fascia latae muscle activation (GTA index) by comparing sEMG muscle activation of the mGmax, mGmed, and m. TFL in executing the four body weight rehabilitation exercises of the current study that are designed to target the mGmax and mGmed. Moreover, future investigators may wish to illustrate which exercises generate adequate activation levels of the mGmax and mGmed while preventing the m. TFL from producing increased activation.

Based on the hypothesis of previous studies that high levels of muscle activation will result in strength gains, future studies should implement these four body weight rehabilitation exercises into a strengthening programme and investigate whether it will result in muscle strength gains over time.

The findings of this study may have been influenced by the submaximal effort of the participants during execution of the manual muscle strength tests to determine MVIC. Standardised verbal encouragement, a proven technique to generate a maximal muscle contraction, was given to each participant in an attempt to control for this (Ayotte *et al.*, 2007; Boren *et al.*, 2011).

Also, varying pelvic postures may have influenced the results of the study given the level of difficulty to execute the exercises. The current study attempted to control for this by measuring specific joint angles and adjusting target bars accordingly. Furthermore, standardised corrective feedback typically used in the rehabilitation setting with verbal and physical cueing was given to each participant.

CHAPTER 7 – REFLECTION ON THE RESEARCH PROCESS

7.1 Introduction

This chapter provides a transparent journey of the research process. Research provides the unique opportunity to ask and answer a pertinent question, something that holds value to both the scholar and the practitioner. For practitioners, research provides the gateway to invaluable knowledge that can be implemented into their field of practice, ultimately to benefit those whom the practitioner serves. Research, furthermore, should be an ongoing (lifelong) engagement to ensure that practitioners equip themselves with the latest evidence-based findings.

7.2 Reflecting on the research process

The research process can best be summarised by the opening phrase of Charles Dickens' famous novel, *A Tale of Two Cities*: "It was the best of times, it was the worst of times". That being said, it also reminds me of the game of field hockey. In this game, to score a goal, you strike the ball forward, sometimes bypassing several players along the way. The ball moves swiftly from one side of the field to the next. The goal is scored and a grand celebration follows. Things, however, do not always proceed so smoothly on the field. On other occasions, the best way forward is to play the ball backwards – you literally take a step back, play it towards someone behind you and, after much patience, you strike the ball forward. The point, at any rate, is that things do not always go as planned: sometimes you need to take a few steps back to go forward; at other times, things proceed much quicker and you almost forget about the difficulties you experienced along the road. Such it is in field hockey, and such it is in research.

It is perhaps appropriate to briefly comment on the first phase of the research process. After completion of my Honours degree, I experienced an intense sense of relief that my studying days were done and dusted. However, after a conversation or two with my supervisor about the possibility of doing a Master's degree, I began to contemplate the matter seriously. At the same time, the reality of researching a Master's degree, coupled with the responsibility of full-time employment, became a sobering thought.

Finding a topic of interest that would add value to the field of Biokinetics was not challenging, given that I conducted my Honours degree on a subject closely related to the current one. After perusing the literature, I realised that there was a lack of research focusing on this topic in a high-performance population. Discovering that field hockey involves extensive recruitment of the mGmax and mGmed was at first a subjective assumption and then later confirmed after research was done. Furthermore, given that there exists such a great variety of gluteal exercises to choose from in the clinical setting, my programme prescription during my internship year was also based on subjective assumptions concerning the best gluteal exercise to prescribe. Therefore, I concluded that it would be of great scholarly and practical value to objectively determine the activation elicited by the mGmax and mGmed during various rehabilitation exercises. This, I contended, would enable the practitioner to prescribe an evidence-based strengthening programme for the target population without entertaining guesswork. Additionally, field hockey was a significant part of my life before I ended my playing days three years ago and it further spurred me on to conduct the research.

Having found a gap in the literature, this initially caused much celebration, almost like taking significant steps forward toward scoring a goal in field hockey, as described above. Then came the part where I had to realise that you sometimes have to take a few steps back to move forward in getting closer to scoring the goal. I subsequently received feedback on my proposal from the internal committee of the Department of Exercise and Sport Sciences. The feedback gave me much food for thought, which altogether helped me to improve the quality of the study. At this stage, I quickly came to realise the substantial effort that would be required to produce a quality academic product. At the same time, my admiration increased for those who had already completed the academic journey of writing a dissertation. As my experience in the world of research improved, I felt more confident about my thought progression, knowing that I was heading in the right direction. This was necessary for continued motivation in conducting the research.

The next phase of the research process turned on the difficulties and pleasures of data collection. Here, one of the first challenges related to gaining sufficient knowledge about the technical aspects of the sEMG system. With this in mind, I found some very informative sources on the internet, which simplified the somewhat technical aspects of sEMG testing.

Arranging and conducting the testing procedure for this study was one of the most challenging, frustrating and time-consuming parts of this research project. It took two weeks to obtain the necessary permission from the conditioning coach to test the players and to ensure everything is ready at the testing facility. In light of these challenges, my initial thought was that it probably was unwise to select a type of study that involves testing participants and that a systematic review would perhaps have been a more convenient option. Initially, I aimed to recruit and test 30 participants; however, I was very thankful that I managed to recruit and test 26. Current injuries or a recent history thereof prevented a few players from participating in the study. For various reasons, some participants did not come for the testing procedure as initially communicated by them. This implied that I had to rearrange a different time slot with a particular participant to accommodate her. In some instances, the "various reasons" cited above eventually resulted in the potential participant failing to communicate a new time slot. Ultimately, this led to the loss of possible participants. However, as the saying goes, beggars can't be choosers, especially when the researcher is wholly dependent on participants for data collection purposes. Moreover, the testing procedure entails that you arrange the schedule according to the comfort of the participants and not your own.

My husband (a capable researcher in an altogether different field from mine) has arguably been the best research partner. He made the research process easier for me by always being willing to assist me, to read each chapter as the study progressed and to give relevant recommendations.

The nationwide lockdown following from the emergence of COVID-19 (the 'Corona' virus) was a blessing in disguise. It gave me uninterrupted time to work on the last shift of the study. Similar to the game of field hockey, the research process was marked by various passes backwards and forwards. Still, ultimately I managed to press forward, reaching ever closer to shooting the proverbial goal.

7.3 Personal remarks

Commencing and completing this study was a hugely rewarding experience beyond simply investigating and answering the research question, such that I gained invaluable experience in conducting research and writing a research report. It was rewarding in yet another sense: the particular research question exposed me to a world of cutting-edge research by experts on sEMG and Biokinetics, and I thus could learn from the experts even though I was situated thousands of kilometres away. I thus became part of a network of experts researching an issue pertinent to exercise prescription. The research conducted for this study fostered in me a wonderful habit of being interested in research (hence, a lifelong learner), a habit that I intend to pursue in the future.

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APPENDICES

APPENDIX A – MEASUREMENT SPECIFICATIONS

1. TeleMyo DTS Specifications

According to Concordia University PERFORM Centre (2016), the following specifications of TeleMyo DTS should be adhered to:

Power Requirements

• Li-ion rechargeable battery that can operate for more than 8 hours after fully charged.

DTS Probe Output & Transmission Frequency

• A transmission range of 10m

• An output power of 4mV

EMG Sensor Data Acquisition System

• 16-bit resolution

• Sample rates 1,500 (for 16-channels)

• Selectable low-pass filter 500, 1000, 1500Hz

EMG Sensor Preamplifiers

• No notch (50/60Hz) filters are used

• Baseline noise <1µV RMS

• Input impedance >100Ohm • CMRR >100dB • Input range +/- 3.5mV

• Base gain 400V

• Snap-style or Pinch-style terminal electrode connections

• Rechargeable Lithium Polymer battery

Dimensions

• EMG Probes Dimensions: 3.4cm x 2.4cm x 1.4cm

• EMG Probes: Weight: Less than 14g

• DTS Belt Receiver Dimensions: 12.6cm L x 6.75cm W x 2.38cm H

• DTS Belt Receiver Weight: Less than 185g

2. Operation

Given that there are various TeleMyo DTS EMG Transmitters, each transmitter has a unique four character serial number which consists of digits numbered 0–9 and letters named A–F, to provide a simplified way to identify one sensor from another (Concordia University PERFORM Centre, 2016). Each serial number appears next to the TeleMyo DTS EMG Transmitter's charging contacts (Concordia University PERFORM Centre, 2016). The TeleMyo DTS EMG Transmitter has a green sensor 'STATUS' indicator that provides information regarding the system's operational state (Concordia University PERFORM Centre, 2016). The 'STATUS' indicator flashes at a low rate (i.e., once every second) if the sensor is in an idle state (Concordia University PERFORM Centre, 2016). The 'STATUS' indicator will flash noticeably faster when an EMG signal is actively measured by the sensor (Concordia University PERFORM Centre, 2016). When the 'STATUS' indicator does not flash at all, it indicates that the TeleMyo DTS EMG Transmitter's battery is depleted and must be recharged by placing it in the charging dock (Concordia University PERFORM Centre, 2016). The 'Charge' LED on a TeleMyo DTS EMG Transmitter remains orange while charging in the charging dock (Concordia University PERFORM Centre, 2016). When the TeleMyo DTS EMG Transmitter is fully charged, the orange LED will turn off (Concordia University PERFORM Centre, 2016).

To ensure that the TeleMyo DTS EMG Transmitter operates properly on the measurement site, the reference electrode pad should be on the bottom side and care should be taken that it makes direct contact with bare skin (Concordia University PERFORM Centre, 2016). Skin preparation applied on the reference electrode site may strengthen the EMG signal where a wandering baseline occurs (Concordia University PERFORM Centre, 2016). To secure the TeleMyo DTS EMG Transmitter in place, it is recommended that the researcher make use of double-sided adhesive tape or elastic straps supplied by Noraxon (Concordia University PERFORM Centre, 2016). Where the expectation holds that very dynamic movements will occur, the use of elastic straps are recommended (Concordia University PERFORM Centre, 2016).

The TeleMyo DTS EMG Transmitter has a lead connecter to connect interchangeable terminal lead wires that will be attached to the disposable surface electrodes (Concordia University PERFORM Centre, 2016). The one terminal lead wire is longer than the other – the amount of difference is equal to the standard 2cm spacing for EMG electrodes (Concordia

University PERFORM Centre, 2016). Insertion of the 2-pin lead wire connector into the TeleMyo DTS EMG Transmitter can occur in one of two ways to facilitate attachment to the surface electrodes (Concordia University PERFORM Centre). Currently, there are two lead lengths available – 10cm and 15cm (Concordia University PERFORM Centre, 2016).

3. MyoResearch XP Master Edition

3.1 Main screen elements

The pre-eminent level in the MyoResearch XP database hierarchy is 'Project' (Concordia University PERFORM Centre, 2016). Different projects or users working simultaneously in a version can be separated by using this level (Concordia University PERFORM Centre, 2016). In any given version, several projects are available, with the pull-down button allowing the user to open a list of pre-existing projects and to switch to a different Project Directory (Concordia University PERFORM Centre, 2016).

To create a new project, click 'New' in the top left corner of the 'Project' section (Concordia University PERFORM Centre, 2016). A dialogue box will open where the name of the project can be entered. After completion of this task, click 'OK' (Concordia University PERFORM Centre, 2016).

Every operation required to manage a Project Directory (Edit, Copy, Delete) is included (Concordia University PERFORM Centre, 2016). In the MyoResearch XP Database System, participants constitute the second level (Concordia University PERFORM Centre, 2016). All records of each participant (third level) are stored and listed here (Concordia University PERFORM Centre, 2016). A new participant can be added by clicking 'New' in the 'Subject' section (Concordia University PERFORM Centre, 2016). A dialogue box will open where all of the subject's information can be inserted. Once all the information necessary for the study has been filled out, click on 'OK' (Concordia University PERFORM Centre, 2016).

To start the EMG recording, click on 'Measure' on the bottom left corner of the window (Concordia University PERFORM Centre, 2016).

3.2 Measurement Setup screen elements

The Measurement Setup consists of different panes which are crucial for users, namely 'Muscle/Device Maps', 'Channels' and 'Application/Configuration' (Concordia University

PERFORM Centre, 2016). The 'Muscle/Device Maps' appears in the left pane, where the recommended EMG placement sites for muscles are displayed (Concordia University PERFORM Centre, 2016).

The 'Channels' pane is displayed in the centre of the screen where the user can select which channel should be recorded, which side of the body should be recorded (which will change depending on muscle selection), the name of the channel (which will also vary depending on selection), the type of recording (default is EMG), the amplitude (default is 500), the units (default is μV) and whether or not this channel will be recorded (default is set to record) (Concordia University PERFORM Centre, 2016). These selections are all set up by default to record EMG (Concordia University PERFORM Centre, 2016). The information will only change if users have different interfacing peripherals (Concordia University PERFORM Centre, 2016).

The right pane consists of the 'Application', 'Configuration' and 'Measurement Options' icons (Concordia University PERFORM Centre, 2016). The 'Application' window serves the purpose of displaying the icons which represent the 'Application Group' that are currently in use. 'Measurement Configurations' are arranged by their applications, e.g., 'Gait' will be the location of gait configurations and 'Feedback Training' for clinical feedback protocols. (Concordia University PERFORM Centre, 2016). By grouping each, the arrangement and management of the numerous 'Measurement Configurations' are easier (Concordia University PERFORM Centre). The MyoResearch XP comes with different predefined Application Groups, all of which allows the researcher to cover a diverse range of EMG applications (Concordia University PERFORM Centre, 2016). However, the user may desire using, modifying or creating specific 'Application Groups' and 'Measurement Configurations' (Concordia University PERFORM Centre, 2016). There are several options in the 'Measurement Options' window which can be adapted for collection, real-time processing, display of biofeedback and synchronised video (Concordia University PERFORM Centre, 2016).

After selection of the desired channels' muscles and data collection trial, click on the 'Start' button at the bottom left of the window (Concordia University PERFORM Centre, 2016). The 'Measurement Monitor' will display a live trace of the EMG channel (Concordia University PERFORM Centre, 2016). Click on 'Zero Offset' to ensure that the baseline of the trace has been zeroed before beginning with the recording (Concordia University PERFORM Centre, 2016). Once the end of the recording is reached, click ‘Stop’ (Concordia University PERFORM Centre, 2016).

Upon completion of all the data acquisition of a selected muscle, click ‘Database’ to return to the ‘Subject Database’ menu (Concordia University PERFORM Centre, 2016). The newly obtained data can be highlighted and the data processing can commence (Concordia University PERFORM Centre).

3.3 Data Processing

From the subject’s ‘Database’ window, highlight the desired trials for processing and then click ‘View/Analyse’ (Concordia University PERFORM Centre, 2016). A trace of the EMG will appear in the ‘Signal’ window, together with any proceedings that were entered during acquisition by using the ‘Mark’ function (Concordia University PERFORM Centre). Discrete samples of the EMG can be displayed in the centre pane’s bar graph to manually inspect elements of the EMG signal (Concordia University PERFORM Centre, 2016).

Processing of the EMG can commence by clicking the ‘Record Option’ on the right-hand side (Concordia University PERFORM Centre, 2016). By clicking on the ‘Marker’ menu, several options for manually adding markers, automatically adding markers by threshold, Max/Min, will display (Concordia University PERFORM Centre, 2016). Markers are mainly set to define analysis periods of the trace (Concordia University PERFORM Centre).

The ‘Record Option’ also has a ‘Signal Processing’ tool (Concordia University PERFORM Centre, 2016). This is where the raw signal begins to take shape, depending on the analysis protocol used (Concordia University PERFORM Centre, 2016). The stored EMG data are processed by various signal processing methods, such as rectification, smoothing and normalisation, before an analysis is started, except frequency-based analysis types (Concordia University PERFORM Centre, 2016).

3.4 Available Operations

<u>Rectification:</u> This processing method takes the absolute value of all amplitude values and makes all negative values positive (Concordia University PERFORM Centre, 2016). The purpose of this operation is geared towards achieving positive amplitude curves which put the

user in the position to calculate parameters such as the mean amplitude, area under the curve, etc. (Concordia University PERFORM Centre, 2016).

Smoothing: In order to calculate and analyse the amplitude, the raw EMG is smoothed by digital filters, RMS or moving average algorithms to eliminate non-reproducible EMG spikes (Concordia University PERFORM Centre, 2016). Another advantage is that the EMG patterns can be read easier, which is valuable for clinical tests, biofeedback oriented treatments or training (Concordia University PERFORM Centre, 2016). The interference pattern of EMG is random in nature given that it is marked by constant changes within the diameter of available motor units and the arbitrary way the motor unit action potentials superpose (Konrad, 2006). Therefore, a raw EMG burst cannot be reproduced twice by its precise shape (Konrad, 2006). One way to overcome this concern is to decrease the non-reproducible part of the signal through the application of digital smoothing algorithms which outline the mean trend of signal development (Konrad, 2006). To this end, a cutting away from the steep amplitude spikes occurs, with the signal receiving a "linear envelope" (Konrad, 2006).

The following smoothing algorithms are supported:

1. RMS: Root-Mean-Square
2. Mean: the moving average
3. Mean absolute: the moving average with combined rectification.

The preferred recommendation for the process of smoothing is RMS. The RMS reveals the mean power of the signal (also called RMS EMG) based on calculation of the square root. Considering the moving average, the sliding window technique is used to get an average for a circumscribed quantity of data based on the temporal window defined by a user. When it is applied to rectified signals, it is also known as the Average Rectified Value and operates as an "estimator of the amplitude behavior" (Konrad, 2006).

Window: allows the user to define the millisecond-based window for each algorithm (Concordia University PERFORM Centre, 2016).

Amplitude Normalisation: One main disadvantage is that the amplitude (microvolt scaled) data have a strong influence on any EMG analysis by the given detection condition, such as significant variation between electrode sites, subjects as well as day to day measures of the same muscle site (Konrad, 2006). To bridge the "uncertain" nature of microvolt scaled parameters, it is required that these parameters be normalised to a reference value, e.g., the maximal voluntary isometric contraction (MVIC) value of a reference contraction is an absolute necessity (Konrad, 2006). Basically, "calibration of the microvolts value to a unique calibration unit with physiological relevance", the "percentage of maximum innervation capacity", should be performed (Konrad, 2006). The outcome of every normalisation method is the elimination of the influence on the given detection condition and ensuring that the microvolts are rescaled to the percentage of the selected reference value (Konrad, 2006). MVIC normalised data facilitates comprehension of the performance capacity level of muscles, how well a given training exercise "reached" the muscles or how ergonomically demanding a work task is for a worker (Konrad, 2006). While the shape of EMG curves is not changed by amplitude normalisation, the Y-axis scaling is changed (Konrad, 2006). There are five normalisation routines available in the pull-down list:

1. <u>Manual value:</u> Here, the normalisation value can be entered manually per channel (Concordia University PERFORM Centre, 2016).

2. <u>Peak value:</u> The EMG peak value is only significant in the case of averaged curves, since significant variability also exists for smoothed rectified EMG traces (Konrad, 2006). The use of an average peak calculation can be a reasonable alteration of the single peak calculation by which the first ten highest peak values of an analysis period are averaged to the average peak (Konrad, 2006). Furthermore, the peak value represents the primary method of finding MVIC (Maximal Voluntary Isometric Contraction) values within MVIC recordings (Concordia University PERFORM Centre, 2016). The entry window defines a window for the MVIC value calculation, namely the mean value which is taken as the MVIC value (Concordia University PERFORM Centre, 2016). An automatic algorithm separately calculates each selected channel (Concordia University PERFORM Centre, 2016). The highest mean window is located in the channel and indicates the signal portion with a green colour (Concordia University PERFORM Centre, 2016). When completed, a prompt appears that requests the user to update the MVIC stack (Concordia University PERFORM Centre, 2016). The MVIC stack is an internal memory that saves these MVIC values, given that it is filled by the next peak value normalisation operation (Concordia

University PERFORM Centre, 2016). By clicking 'Yes', it confirms that these MVIC values are available for the next normalisation routine: MVIC Stack (Concordia University PERFORM Centre, 2016). The functions 'Restrict calculation to...' and 'Pick' are useful if the user wants to mark a signal portion in the record – in this case, the MVIC calculations will only be performed in this marked area (Concordia University PERFORM Centre, 2016). Measurements designed where an MVIC recording period is part of a given record (e.g., at its very beginning) can benefit from this function (Concordia University PERFORM Centre, 2016).

3. <u>Mean value:</u> The most important EMG calculation is the amplitude mean value of a particular analysis interval, due to a reduced sensitivity to duration differences of analysis intervals (Konrad, 2006). The mean EMG value provides an excellent description of the gross innervation input of a specific muscle for a particular task and operates the best for comparative analysis (Konrad, 2006). The amplitude mean value is calculated for each channel and taken as a reference value for the normalisation (Concordia University PERFORM Centre, 2016). Typically, this type of normalisation is used in gait analysis where time normalised EMG patterns are amplitude normalised again, each to its mean value (Concordia University PERFORM Centre, 2016).

4. <u>MVIC stack:</u> A method that loads the current MVIC values from the stack which can be repeated as often as required (e.g., normalised records and trials completed after the MVIC record of a subject) (Concordia University PERFORM Centre, 2016). Although the computer might be shut down, the MVIC values will remain in the stack (Concordia University PERFORM Centre, 2016). To summarise, normalisation to peak value creates MVIC values, normalisation to MVIC stack loads MVIC values, which result in the normalisation of other records (of the same subject). A significant benefit of MVIC normalisation is the rescaling to a unique percentage of a reference value and standardisation for all subjects within a study (Konrad, 2006). With this, any changing influence of local signal detection conditions is eliminated, which allows that EMG findings could be directly and quantitatively compared between subjects (Konrad, 2006). Another benefit is the development of group statistics and normative data which can be statistically verified (Konrad, 2006).

5. Values from other records: A method that accesses normalisation values found from this ‘other’ record; however, it only lists records of the same participant, as normalisation to another subject's muscle activation would not make sense (Concordia University PERFORM Centre, 2016). Usually, this is the MVIC trial of one participant that is used to calculate the MVIC values within the maximal contraction series (Concordia University PERFORM Centre, 2016).

The inter-electrode bipolar sEMG electrodes (comprising an inter-electrode distance of 20mm) will be applied with the goal of avoiding unstable recordings that often result from tendon and motor endplate effects (SENIAM, 2019). Placing the electrodes with extreme care and consistency is of the utmost importance, and for two reasons: one, cross-talk of adjacent muscles will be reduced; and two, different studies will be comparable using the same EMG protocol (Campanini *et al.*, 2007).

4. Designing an EMG test: the requirement of standardisation

The outline below represents the factors that influence a test position or movement. Standardisation or control over these factors is one of the paramount strategies in meaningfully analysing and interpreting an EMG test (Konrad, 2006). The interpretation of EMG data is almost impossible without an understanding of and control over the movement characteristics (Konrad, 2006). An overall scientific requirement is the ability to replicate a test (Konrad, 2006). With this in mind, Konrad (2006) identified the following factors as the most important ones to consider and standardise:

Factor	*Comments*	*Strategies*
Angle or position (in static tests)	The angle and muscle length directly influence the EMG amplitude due to the migration of the active muscle below the electrodes and muscle mechanics change with different sarcomere distance (besides other biomechanical aspects).	• Belts should be used to arrange a proper fixation of body segments. • Goniometers should be used to monitor the range of motion (ROM) in free functional movements. • A ‘grid mirror’ should be used for free

		functional movements in order to standardise the range of motion (ROM).
Range of motion (in dynamic tests)	Analogous to the previous factor, the appropriate standardisation is necessary because as the ROM varies significantly, the variability of findings increases.	• Belts should be used to arrange a proper fixation of body segments. • Goniometers should be used to monitor the ROM in free functional movements. • A 'grid mirror' should be used for free functional movements with the goal of standardising the ROM.
Movement velocity (in dynamic tests)	Constant acceleration and braking are the meaning of any repetition cycle; an increase in velocity implies an increase in acceleration and more motor unit recruitment per time that results in variability of the overall contraction times and innervation levels as an outcome.	• A metronome should be used for standardisation of the contraction velocity.
Load or resistance	Where understanding of a particular load condition or repeatable resistance is absent, performing, e.g., test-retest designs or fatigue studies or any other EMG test to test comparisons, will not be possible.	• The whole body or body segments should be used as a static resistance. • External weights should be used for standardisation of load. • Force load/torque cells

		should be used to vary force output.
Duration or repetitions (in static or dynamic tests)	Beyond 30%MVIC innervation intensity, one must consider the duration of static contraction or amount of dynamic repetitions as a strong determining factor of influence (e.g., fatigue) is necessary.	• Fixed contraction intervals should be used. • Count repetitions. • Repetitions at high intensities should be limited.
Preliminary status (e.g., fatigue)	Consideration should be given to factors of uncontrolled variability, notably metabolic and central nervous conditions as well as the time of day.	• Time of day should remain the same. • A non-fatigued condition should be selected and participants provided with a warm-up period. • The room temperature should be constant.

5. Considerations in inspecting the raw EMG-baseline quality

It is of the utmost importance to visually inspect the raw EMG baseline. This cannot and should not be replicated by any other method, e.g., an automatic impedance check (Konrad, 2006). The signal which the amplifier picks up should not exceed a few millions of a volt (microvolt) in size, given that this sensitive signal is highly susceptible to external sources or artifacts, if treated incorrectly (Konrad, 2006). The latter problem can be remedied if proper skin preparation and electrode position are controlled for (Konrad, 2006). Once the electrodes are connected to the amplifier, the researcher should engage the PC-signal monitor, subsequently zooming into the raw EMG trace of every channel with the goal of ensuring a detailed inspection (Konrad, 2006). The subject should relax completely by laying down on a plinth (Konrad, 2006). According to Konrad (2006), three major factors become the subject of focus when conducting the EMG baseline inspection:

1) Baseline noise: It is not possible to obtain a noise-free recording: small amplitude spikes of random nature may appear, but this should not be in excess of 10-15 microvolts. “The average noise level (calculate the EMG mean amplitude of the raw rectified EMG for 5 seconds) should be detected at 1 (excellent) to 3.5 microvolts.”

2) Baseline offset: An automatic offset correction is usually part and parcel of the majority of amplifiers. At times, however, it is possible that the EMG baseline might shift away from the true zero line (test: mean value of the raw EMG ≠ zero), for example, if the subject did not relax at the measurement start. In such cases, identification and correction are required. Where the latter does not take place, all the amplitude-based calculations of that recording will be invalid.

3) Baseline shifts: Before or after contractions, the researcher needs to ensure that the baseline constantly remains at the zero line. Any regular EMG burst will return to zero within the span of a few milliseconds (ms), while the EMG rest-line will constantly stay at zero. An artifact will be signalled by any visible shift. An artifact is signalled by a visible shift of >5ms. This usually occurs if the cables shake too much or where there are changes in the volume distance between the muscle belly and electrode site owing to poor cable fixation or local pressure. However, these factors can be eliminated if care is taken to properly fasten the electrode or cable and with proper skin preparation.

6. EMG action list, according to Konrad (2006):

Action	*Comment*
1. The subject should wear appropriate clothes.	Access to muscles that may be covered by pants etc. will be required. Tight clothes on the electrodes might hamper the EMG signal, producing artifacts.
2. Decide on a 'navigation' technique with the goal of identifying the location of the electrodes and the landmark regions.	Make use of a pen in order to mark the landmarks and a flexible measuring tape for measuring distances. SENIAM guidelines should be followed.
3. The skin should be cleaned with either abrasive or conductive fluid.	This method is the easiest and quickest. Alternatively, apply excellent alcohol cleaning.
4. The smallest available electrodes should be used. Attach the electrodes parallel to the muscle fibres orientation – 2cm electrode distance.	Avoid motor endplates, if possible. Select the middle belly portions for increased selectivity and decreased risk of muscle belly dislocation.
5. A minimum waiting period of 3 minutes should be upheld. Stretch, warm-up and prepare the subject during this time.	To ensure that the electrode to skin contact obtains a stable electrical (impedance) condition, time is required.
6. Cables should be connected and secured.	Secure all cables for dynamic movements while allowing sufficient room to prevent lever forces on the electrodes.
7. The participant should be requested to lie down on the plinth and relax.	This is the best position in order to proceed with the testing.
8. Do baseline checks by starting the signal monitor and check if the EMG trace is working correctly.	Check the noise levels and zero offset to detect if there are any shifts within joint movements.
9. Check the EMG activity burst to see if an EMG appears.	Checking the general appearance of EMG bursts should be done by using manual muscle strength tests.

7. EMG Signal origin

7.1 The Motor Unit

A motor unit (Fig. 10) comprises of the smallest functional unit that describes “the neural control of the muscular contraction process” (Konrad, 2006). Konrad (2006) defines it as “the cell body and dendrites of a motor neuron, the multiple branches of its axon, and the muscle fibres that innervates it.” On its part, ‘units’ refer to the behaviour that all muscle fibres of a particular motor unit act “as one” within the innervation process (Konrad, 2006).

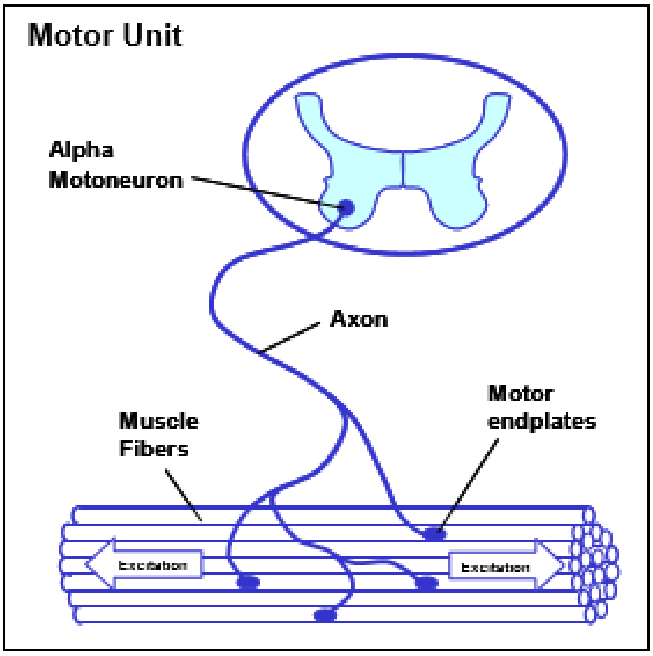


Figure 10: Motor unit (Konrad, 2006)

7.2 Provoking the excitability of muscle membranes

One of the most important factors in muscle physiology is the excitability of muscle fibres through neural control (Konrad, 2006). An explanation of this phenomenon can be presented by a model of a semi-permeable membrane that provides a description of the sarcolemma’s electrical properties (Konrad, 2006). The resting potential at a muscle fibre membrane (more or less -80mV to -90mV when not contracted) is formed by “an ionic difference between the inner and outer spaces of a muscle cell” (Konrad, 2006). Physiological processes (ion pump) maintain this difference in potential, resulting in a negative intracellular charge in comparison to the external surface (Konrad, 2006). An alpha-motor anterior horn cell (brought forth by the central nervous system or reflex) is activated, which has the result of transmitting the excitation along the motor nerve (Konrad, 2006). As transmitter substances are released at the motor endplates, the formation of endplate potential at the muscle fibre that innervated this motor unit follows (Konrad, 2006). The muscle fibre membrane's diffusion characteristics are momentarily altered for Na+ ions to flow in (Konrad, 2006). As a result, the membrane depolarises, which is followed by immediate restoration by the backward exchange of ions within the active ion pump mechanism, namely repolarisation, as illustrated below:

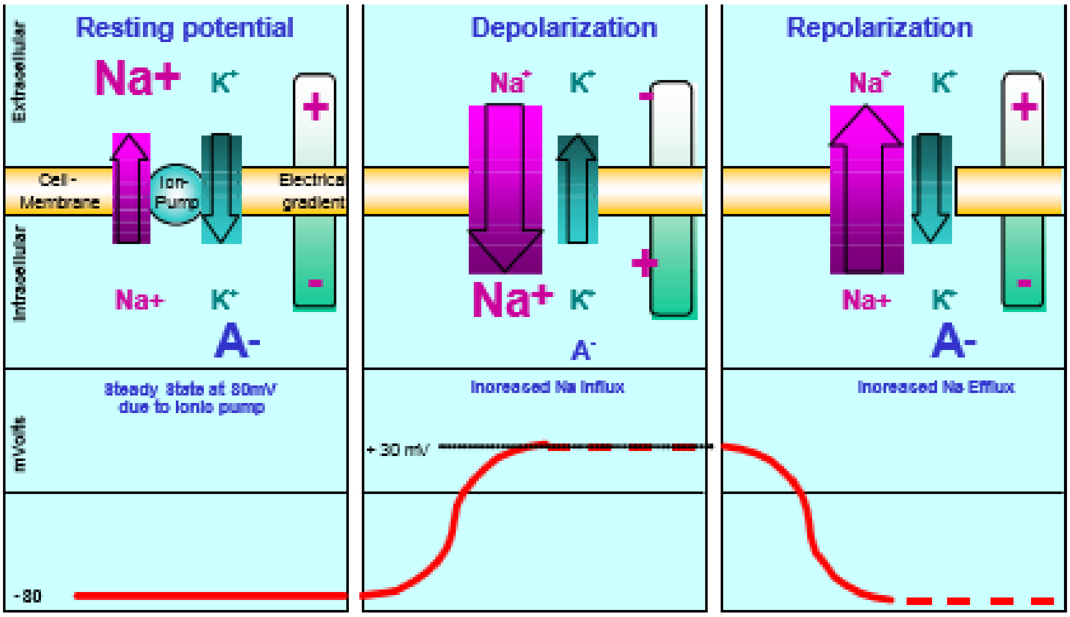


Figure 11: Schematic illustration of depolarisation/repolarisation cycle within excitable membranes (Konrad, 2006)

8. The Generation of the EMG signal

8.1 The Action Potential

The depolarisation of the membrane results in an action potential to rapidly change from 80mV up to + 30mV (Fig. 12) when a particular threshold level within the Na+ influx is exceeded (Konrad, 2006).

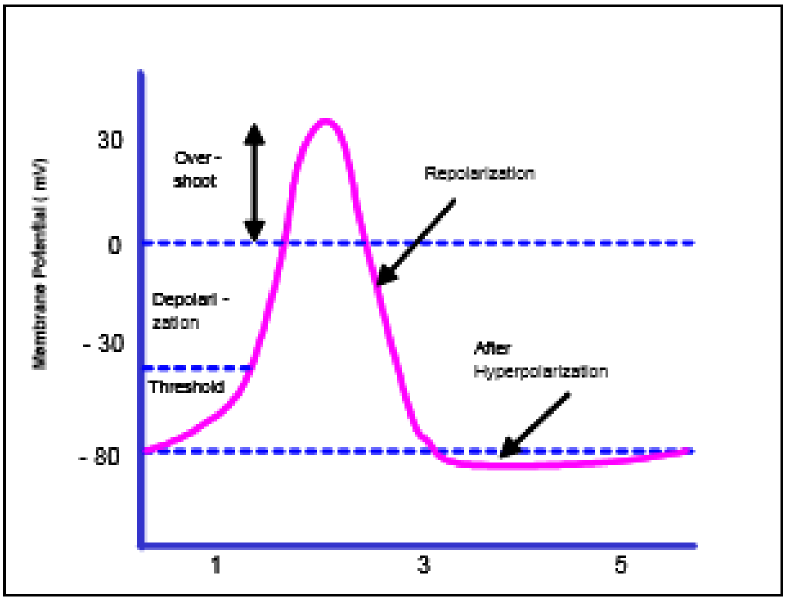


Figure 12: The action potential (Konrad, 2006)

The repolarisation phase restores a monopolar electrical burst, with this followed by an after hyperpolarisation period of the membrane (Konrad, 2006). The action potential starts at the motor end plates and spreads bidirectional along with the muscle fibre and inside the muscle fibre by way of a tubular system (Konrad, 2006). Calcium ions are released in the intracellular space due to this excitation (Konrad, 2006). Finally, linked chemical processes (electro-mechanical coupling) affect a shortening of the contractile elements of the muscle cell (Konrad, 2006). A highly correlated relationship is represented by this linking excitation model and contraction; however, weak excitations can exist, which will not result in contraction (Konrad, 2006). Practically, it can be hypothesised that “in a healthy muscle any form of muscle contraction is accompanied by the described mechanisms” (Konrad, 2006).

As described above, the EMG signal is established from action potentials at the muscle fibre membrane, which results from the processes of depolarisation and repolarisation (Konrad, 2006). According to the literature, the extent of this depolarisation zone (Fig. 13) is approximately 1-3mm² (Konrad, 2006). Following initial excitation, this zone makes its way along the muscle fibre at a velocity of 2-6ms to pass through the electrode site:

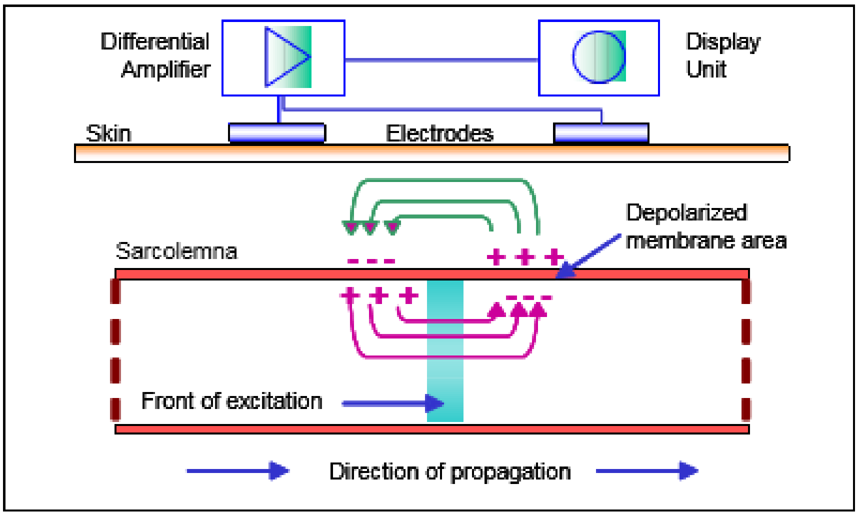


Figure 13: The depolarisation zone on muscle fibre membranes (Konrad, 2006)

9. Signal Propagation and Detection

9.1 An electrical model for the motor action potential

A depolarisation wave or electrical dipole results from the depolarisation-repolarisation cycle that subsequently makes its way along the surface of a muscle fibre (Konrad, 2006). For simplicity, the following scheme represents an illustration of the detection of a single muscle fibre (Konrad, 2006). The spatial distance between electrode 1 and 2 will determine if the dipole forms a potential difference between the electrodes (Konrad, 2006).

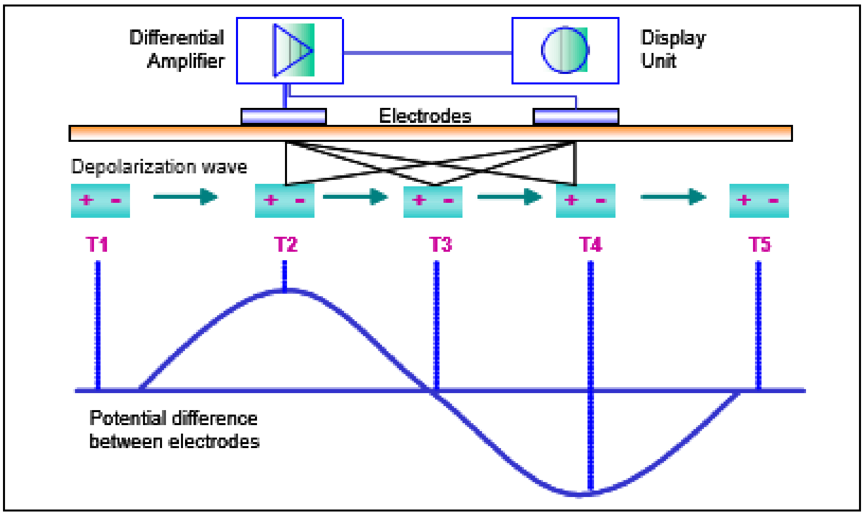


Figure 14: The model of a wandering electrical dipole on muscle fibre membranes (Konrad, 2006)

As illustrated in the example above, T1 represents the generation of the action potential which travels towards the electrode pair. The potential difference which is measured between the electrodes is increasing and is the highest at position T2. The dipole should reach an equal distance between the electrodes for the potential difference to pass the zero line in order to become the highest at position T4, practically implying the shortest distance to electrode 2. This model explains why the monopolar action potential creates a bipolar signal within the differential amplification process. A motor unit comprises of many muscle fibres, which enables the electrode pair to "see" the magnitude of all innervated fibres within this motor unit (although it depends on their spatial distance and resolution). Typically, they constitute a triphasic motor unit action potential ("MUAP"). The form and size of the MUAP's will depend on the geometrical fibre orientation in ratio to the electrode site (Fig. 15).

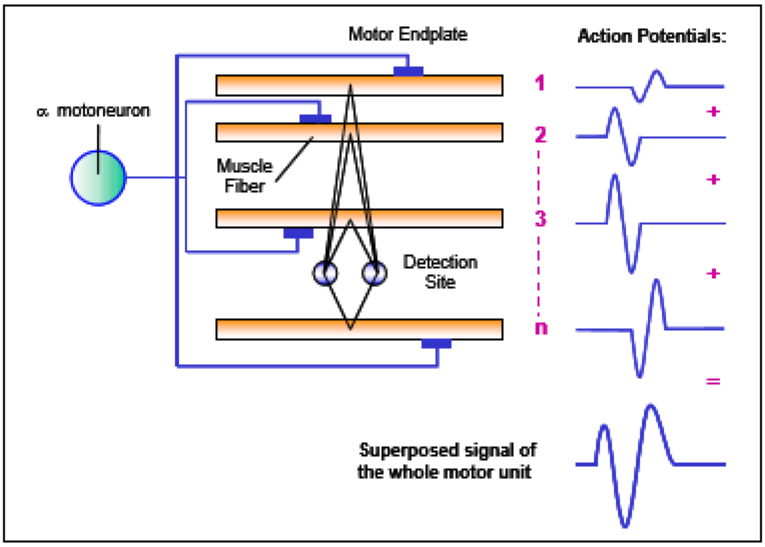


Figure 15: Generation of the action potential from the triphasic motor unit (Konrad, 2006)

9.3 EMG Signal Compositions

9.3.1 MUAP's and their superposition

In studies regarding kinesiology, the MUAP's of every active motor unit that is detectable beneath the electrode site is electrically superposed (Fig. 16). The researcher will observe it as a bipolar signal, symmetrically distributed in positive and negative amplitudes (mean value equal to zero), namely an interference pattern (Konrad, 2006).

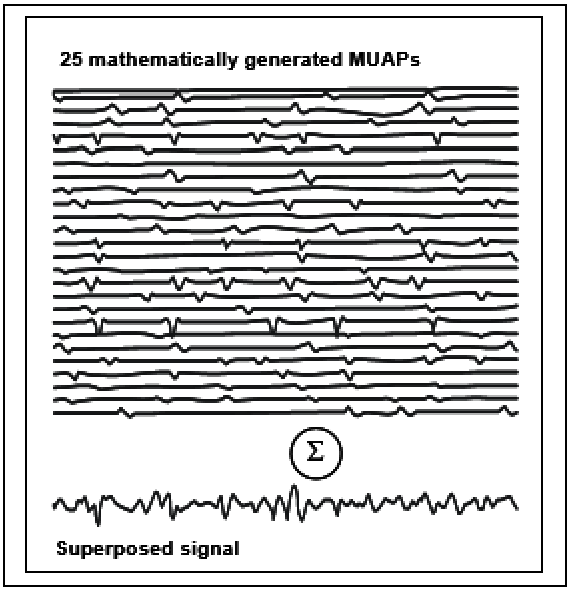


Figure 16: MUAP's superposition as found on an EMG (Konrad, 2006)

9.3.2 The frequency of recruitment and firing

Two principal mechanisms influence the magnitude and density of the observed signal, namely, the frequency of recruiting the MUAP's and their firing frequency (Konrad, 2006). The latter ones are the major control strategies for adjusting and modulating the process of contraction and force output of the involved muscle (Konrad, 2006). Furthermore, Konrad (2006) stated that the EMG signal directly displays the detected motor units recruited as well as the firing characteristic of the measured muscle (Fig. 17).

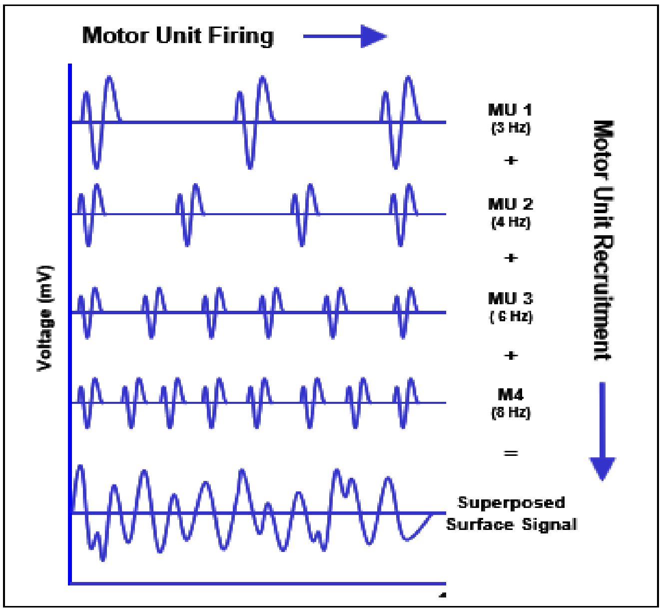


Figure 17: The frequency of motor units recruitment and firing alter force output which reflects in the superposed EMG signal (Konrad, 2006)

10. SENIAM (2019) recommendations regarding sensors and the placement procedures for sensors

An EMG sensor comprises the ensemble of electrodes, electrode construction and the integrated preamplifier. Regarding bipolar sensors, the development of recommendations was undertaken for electrode shape and size, inter-electrode distance, electrode material and sensor construction. The "Standards for reporting EMG Data", written by Roberto Merletti (2015), also recommend that the reports on recording surface EMG should include the following:

10.1 The shape and size of the electrode

The electrode shape refers to "the shape of the conductive area of EMG electrodes", e.g., circular (SENIAM, 2019). SENIAM (2019) indicated no criteria that clearly and objectively provide recommendations for electrode shape. Literature reports that both rectangular (square) and circle (oval) can be utilised for EMG recordings. Considering only the differences in shape, no significant difference can be expected in the performance and pick-up area (SENIAM, 2019). Both electrodes should have the same total surface area for the skin impedance to be equal (SENIAM, 2019). The European inventory demonstrated that electrodes that are circular with a 10mm diameter should preferably be used (SENIAM, 2019).

The electrode size refers to "the size of the conductive area of an EMG electrode". The size of the EMG electrodes influences the recorded EMG (SENIAM, 2019). Increasing the electrode size in the direction of the muscle fibres will result in an integrative effect on the EMG signal, which increases the detected amplitude that subsequently decreases the high-frequency contents (SENIAM, 2019). The size of the electrodes in the direction of the muscle fibres should not be more than 10mm (SENIAM, 2019). Both electrodes should have a similar total surface area in order to ensure equal skin impedance and noise. When increasing the size of the EMG electrode perpendicular to the muscle fibres, a decrease in impedance will be observed (SENIAM, 2019).

10.2 Inter-electrode distance

The inter-electrode distance comprises the centre-to-centre distance across the conductive areas of two bipolar electrodes (SENIAM, 2019). The bipolar EMG electrodes should be applied at the suggested sensor location with a 20mm inter-electrode distance (SENIAM, 2019). The application of bipolar electrodes on relatively small muscles should have an inter-electrode distance of not more than one-quarter of the muscle fibre length (SENIAM, 2019). This will result in the avoidance of unstable recordings attributed to tendon and motor endplate effects (SENIAM, 2019). Deeper motor units present relatively better in the EMG signals than superficial ones if the inter-electrode distance is 40mm (Roeleveld *et al.*, 1997).

10.3 Electrode material

The electrode material forms the contact layer with the skin. It requires proper electrode-skin contact, low electrode-skin impedance and stable behaviour in time related to the impedance and chemical reactions at the skin interface (SENIAM, 2019). Pre-gelled Ag/AgCl electrodes should be used, given that they provide a stable transition with relatively low noise and are commercially available (SENIAM, 2019). To reduce the electrode-skin impedance, use electrode gel and paste (SENIAM, 2019).

10.4 Sensor construction

The sensor construction consists of the use of mechanical construction for the integration of the electrodes, the cables, and, if necessary, the preamplifier (SENIAM, 2019). Use a construction with a fixed inter-electrode distance, made from a lightweight material (SENIAM, 2019). After marking the location for the sensor, the researcher can place and fix the electrodes around this marked location (SENIAM, 2019). The sensor is connected to the body in a particular way that refers to 'fixation'. Fixation enables a good and stable electrode-skin contact, minimise the risk of movement of the sensor on the skin and limits the pulling of cables. Poor fixation will influence the EMG recordings, which will result in the following disturbances: noise, common-mode voltages, and movement artifacts (Baten, Frericks & Hermens, 1997). Therefore, the cables should be fixated with (double-sided) tape or elastic bands in a certain way to avoid pulling artifacts (SENIAM, 2019). During quick, dynamic contractions, the sensor constructions produce significant movement artifacts – SENIAM (2019) recommends eliminating this effect by fixing the inter-electrode distance through the use of double-sided taping or rings. The SENIAM (2019) recommendations for EMG sensors are restricted to bipolar sensors that comprise two surface electrodes.

Securing of the suitable cable and preamplifier on the skin may not be of importance in studies that examine motions that are static or slow. However, studies examining dynamic motions should pay attention to this point to prevent cable movement artifacts and to reduce the risk of electrodes being separated from the skin (Konrad, 2006). Use regular tape, elastic straps, or net bandages to secure each electrode lead, though too much tension must be avoided (Konrad, 2006). To maintain a constant application pressure for each electrode, avoid direct taping over the electrodes (Konrad, 2006).

Another relevant aspect is that the EMG signal characteristics will be affected when the application is in such a way that it causes variation in the inter-electrode distance while the muscle contracts. Specific attention is required when using EMG to examine the low back muscles when dynamic contractions are involved in the full ROM. However, the muscles of the thigh are less affected (Hermens *et al.*, 2000).

10.5 Sensor location and orientation on the muscle

After positioning the participant in the suggested starting posture, marking of the location of the EMG sensor can proceed (SENIAM, 2019). The sensor location is described as the central position of two bipolar electrodes on the muscle, while orientation refers to "the direction of the muscle fibres" (SENIAM, 2019). The sensor should be located on a part where proper and stable EMG recordings can be produced (SENIAM, 2019). The following factors influence the recording of an adequate and stable EMG signal: the occurrence of motor units and muscle tendons, and the occurrence of additional active muscles closely located to the EMG sensor (cross-talk) (SENIAM, 2019). Always ensure that the orientation is parallel to the direction of the muscle fibres. Previous research conducted by Zedka, Kumar and Narayan (1997) and Ng, Kippers and Richardson (1998) noted that alignment of the electrodes over the muscle fibre orientation should be parallel to the underlying muscle to result in optimal detection of EMG signals.

Hence, knowing the approximate location of the innervation zone, the placement of the EMG sensor can be done "far away" from the innervation zone and the end zone of the muscle, if possible in the centre of this region (Merletti, 2015). Usually, the distal part of the muscle will be the most appropriate location for this application. Placement of the sensor in the proximal region may effortlessly produce shifting of one electrode beneath the endplate zone during muscle contraction (Blok & Stegeman, 1997; Merletti, 2015).

Furthermore, geometrical changes across the muscle belly and electrode site are of paramount importance (Konrad, 2006). There will be alterations in the EMG reading due to the alterations in the distance across the signal origin and detection site (Konrad, 2006). This is a common inherent problem in studies examining dynamic movement and can also be triggered by external pressure (Konrad, 2006).

10.6 Biological and technical factors

From the muscle fibre towards the electrodes, numerous internal (biological) and external (technical) factors can affect the EMG signal that causes an alteration in its shape and characteristics or influence the reliability and validity when using EMG as the measurement procedure (Ng *et al.*, 1998).

10.7 Physiological variability

All humans have physiological variability that may significantly influence the magnitude of the EMG signal amplitude (Burden, 2010; Cho *et al.*, 2018; Tabard-Fougère *et al.*, 2018). In general population samples, studies have discovered that normal participants have a particular degree of physiological variability concerning muscle activity asymmetry (Ferrario *et al.*, 1993; Abekura *et al.*, 1995) and postural position (Gross *et al.*, 1999; Suvinen *et al.*, 2003). Mohl (1993) stated that the existence of variability across individuals, in addition to the presence of extensive overlap between these so-called "normal" and "abnormal" groups, results in difficulty to ascertain any diagnostic conclusions irrespective of the particular patient concerned. Movement patterns or repetition cycles that are highly standardised, for instance, gait or isokinetic knee extension/flexion, display a considerable signal difference in the smoothed rectified EMG between repetitions that can be detected visually (Konrad, 2006). The principal reason for this is the typical coordinative variability that exists in human locomotion (Konrad, 2006). Participants cannot present as robots; therefore, it is highly unlikely for normal participants to replicate the same movement a second time – variety exists among every biomechanical data curve (Konrad, 2006). Averaged EMG curves have typically higher standard deviation ranges than the angle or force curves (Konrad, 2006). To provide a description of the "typical" movement characteristics and neuromuscular input, analysing more than one repetition (>6 until 30; subject to the complexity and fatigue factor) should be investigated (Konrad, 2006). Thereafter, these repetitions should be averaged to the "ensemble average" curve (Konrad, 2006).

10.7.1 Age

In studies with healthy populations, the recording of EMG activity during isometric contraction decreases as age increases, most likely attributed to gradual muscle atrophy and increases in the infiltration of adipose tissue (Visser *et al.*, 1994). The latter may be the result of a decrease in the number of motor units activated in this voluntary contraction (Visser *et al.*, 1994; Jensen, 1999).

10.7.2 Gender

Differences in EMG recordings occur due to differences across males and females. Visser *et al.* (1994) and Jensen (1999) informed that the outcome in samples involving a general population would be increased masticatory EMG levels in male participants compared to female participants during MVIC.

10.7.3 Skin thickness and weight

A human's body is poised to be a good electrical conductor; however, variability in tissue type, the thickness of skin, changes in physiological composition and temperature account for differences in the electrical conductivity (Konrad, 2006). All the latter conditions can significantly vary from individual to individual, and within an individual, and can prohibit a quantification comparison of EMG amplitude parameters directly calculated on the unprocessed EMG signal (Konrad, 2006). Therefore, the EMG activity of the underlying muscles that is measured is greatly influenced by the thickness of the overlying soft tissues (Konrad, 2006; Cho *et al.*, 2018). De la Barrera and Milner (1994) and Cho *et al.* (2018)

explained the mechanism of this phenomenon as a process attenuating the electrical signals that result in low-pass-filtering as they pass through muscle tissue and subcutaneous adipose tissue. Furthermore, they reported that increasing the conduction distance would increase filtering and attenuation. For this reason, EMG signals cannot be interpreted with the same method for all individuals. The selectivity of EMG measurements will increase as the thickness of the subcutaneous adipose layer interposes between the skin, resulting in a decreased muscle surface. Compared to males, it was discovered that the skinfold of females is considerably thicker; hence, more significant attenuation of the EMG signal presents in females. Variation in the thickness of particular muscles (counting for different areas within the same muscle) results in a reduced signal (Van der Glas *et al.*, 1996). Consequently, every measurement test that utilises EMG must be defined and adjusted for the thickness of the soft tissues that overlie the muscles under investigation.

10.7.4 Surface Electrode Placement

Once the area of investigation has been properly prepared, the electrodes and EMG TeleMyo DTS transmitter can be placed on the allocated landmarks. According to the Concordia University PERFORM Centre (2016), the following guidelines for electrode placements are recommended:

1. Wet-gel electrodes provide the best skin impedance values;
2. Small electrodes should be used for increasing the selectivity of the measurements to avoid cross-talk;
3. The recommended distance for the inter-electrode is 20mm;
4. Electrodes should be applied in accordance with the direction of the muscle fibre;
5. Apply the electrode on the dominant central portion of the muscle belly for the finest selectivity; and
6. Ensure that the participant does not sit on or apply too much pressure to the electrode or transmitter.

APPENDIX B – INFORMATION DOCUMENT

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

Skool vir Aanvullende Gesondheidsberoepe (SAGB)/School for Allied Health Professions (SAHP)
Posbus/PO Box 339, Bloemfontein 9300, Republiek van Suid-Afrika/Republic of South Africa
Department of Exercise and Sport Sciences / Departement Oefen- en Sportwetenskappe

INFORMATION DOCUMENT

STUDY TITLE: ***RANDOMISED CROSS-SECTIONAL STUDY OF m. GLUTEUS MAXIMUS AND m. GLUTEUS MEDIUS ACTIVATION DURING REHABILITATION EXERCISES IN FEMALE HOCKEY PLAYERS***

Dear participant

I, Daretha Maartens (a Master's degree student in Biokinetics at the University of the Free State), am researching which rehabilitation exercises recruit the highest percentage activation of two specific buttock muscles, the m. gluteus maximus and m. gluteus medius.

Due to the numerous utilisation of gluteal specific activation exercises in practice, this study aims to test which exercises are the best to activate the m. gluteus maximus and m. gluteus medius in high-performance female field hockey players. Adequate strength and activation of the buttock muscles can ensure a decrease in risk of injury to the lower extremities as well as to the pelvic and lower back regions.

These findings will be utilised to provide which exercise elicits the highest activation of the m. gluteus maximus and m. gluteus medius to improve decisions regarding programme prescription for practitioners in the interprofessional team during prehabilitation and the later stages of rehabilitation in female field hockey players. This will assist in forming the basis for a graded rehabilitation program.

I am inviting you to participate in this research study, which will be done on voluntary high-performance female field hockey players from the UFS.

The expected outcomes will not be revealed to you (the participant) until after the project has been completed. However, any possible risks, such as muscle stiffness/discomfort following the exercise testing and, possible though unlikely, skin reaction to electrode adhesive, will be explained to you. You will also sign a waiver of indemnity and liability in the case of any adverse event or injury during the exercise testing. Upon arrival at the Exercise and Sport Sciences Centre of the UFS, the researcher will explain the purpose and procedure of the study to you.

If you volunteer to participate in this study, the researcher would ask you to do the following:

Pre-participation screening: You will fill in a pre-participation screening form, which will assist the researcher to collect essential data. Importantly, this data will be kept confidential. This data will be useful in helping describe the study population and help identify important aspects, such as leg dominance.

Testing: Consists of one session of Surface electromyography (sEMG) testing during four exercise positions. The sEMG implies the application of electrode stickers (electrode stickers are used to record signals from muscle activity) on the skin surface over the underlying buttock muscles of your dominant side. During this exercise testing procedure, you will undergo the following: Height and weight measurements will be taken after completion of the informed consent and health screening form. The exercise testing will commence after the height and weight measurements which will start with a 5-minute warm-up on a stationary bike. During your warm-up period, the researcher will demonstrate the four exercises that you will execute during the testing. After the warm-up, you will be requested to lie on a bed on your stomach and the researcher will ask you to slightly reposition your pants to display the buttock of your dominant side. The researcher will start to determine the landmarks for the placement of the electrodes and mark it on your skin with a black eyeliner pencil. The researcher will prepare the skin for testing by using an isopropyl alcohol swipe to remove any oils on the area where the electrode stickers will be applied. The researcher will apply the electrode stickers. Four stickers will be applied on the skin – two over the m. gluteus maximus muscle and two over the m. gluteus medius muscle. To secure the electrodes stay in place, hypoallergenic tape or Velcro strapping will be used. After application, the researcher will request you to cover the area of investigation by repositioning your pants. Hence, your buttock area will not be visible during the execution of the exercises. The researcher will demonstrate the first exercise to you and will ensure that you are in the correct position. You will execute four exercises in total and eight repetitions of each. After each exercise, you will receive a two-minute rest period. During this period, the researcher will demonstrate the next exercise to you. After completion of all the exercises, you will again be asked to reposition your pants on your dominant side for the researcher to remove the electrode stickers. Upon removal of the electrodes, the skin will be wiped with isopropyl alcohol to remove any signal conductance gel. Water will be used to clean the area to minimise skin irritation and dryness. You may depart directly after completion of the exercise testing.

Confidentiality: Efforts will be made to keep personal information confidential. Absolute confidentiality cannot be guaranteed. Personal information may be disclosed if required by law. Organisations that may inspect or copy your research records for quality assurance and data analysis include groups such as the Health Sciences Research Ethics Committee and the Medicines Control Council (where appropriate). If results are published, this may lead to individual/cohort identification.

Thank you for your interest in the study.

If you have any questions or concerns regarding how the tests will be conducted, you may contact the Secretariat of the HSREC, UFS, Mrs M. Marais on (051) 401 7795.

Please contact me with any questions: 076 087 4577 or darethamaartens@gmail.com

Kind regards

Researcher — Head of Department

Miss D. Maartens — Prof. F.F. Coetzee

APPENDIX C – INFORMED CONSENT

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

Skool vir Aanvullende Gesondheidsberoepe (SAGB)/School for Allied Health Professions (SAHP)
Posbus/PO Box 339, Bloemfontein 9300, Republiek van Suid-Afrika/Republic of South Africa
Department of Exercise and Sport Sciences / Departement Oefen- en Sportwetenskappe

INFORMED CONSENT FOR PARTICIPANTS

***STUDY TITLE:* RANDOMISED CROSSOVER TRAIL OF m. GLUTEUS MAXIMUS AND m. GLUTEUS MEDIUS ACTIVATION DURING REHABILITATION EXERCISES IN FEMALE HOCKEY PLAYERS**

You are asked to take part in a research study conducted by Daretha Maartens, from the Department of Exercise and Sports Sciences, University of the Free State, as part of a dissertation for a Master's Degree. You were selected as a possible participant in this study because you are of appropriate age and injury status for the study.

1. PURPOSE OF THE STUDY

The purpose of the research study is to test the top rehabilitation exercises from previous studies of two buttock muscles (m. gluteus maximus and m. gluteus medius) to determine the level of muscle activation of these two muscles. Surface electromyography (sEMG) will be utilised as the measuring instrument. Surface electromyography implies the application of electrode stickers on the skin surface over the underlying muscles. These electrode stickers will record signals from muscle activity and will be applied onto two buttock muscles of the dominant side of the participant.

Adequate strength and activation of the buttock muscles can ensure a decrease in risk of injury to the lower extremities as well as to the pelvic and lower back regions; therefore, this research could be useful in the future to assist practitioners in making informed decisions regarding selecting the most effective exercise in programme prescription for strengthening of these two buttock muscles during prehabilitation and the later stages of rehabilitation.

2. PROCEDURES

The expected outcomes of the study will not be revealed to you (the participant) until after the project has been completed. However, any possible risks, such as muscle stiffness/discomfort following the exercise testing and, possible though unlikely, skin reaction to electrode adhesive, will be explained to you. Upon arrival at the Exercise and Sport Sciences Centre of the UFS, the researcher will explain the purpose and procedure of the study to you.

If you volunteer to participate in this study, the researcher would ask you to do the following:

Pre-participation screening: You will fill in a pre-participation screening form, which will assist the researcher to collect essential data. Importantly, this data will be kept confidential. This data will be useful in helping describe the study population and help identify important aspects, such as limb dominance.

Testing: Consists of one session of Surface electromyography (sEMG) testing during four exercise positions. The sEMG implies the application of electrode stickers (electrode stickers are used to record signals from muscle activity) on the skin surface over the underlying buttock muscles of your dominant side. During this exercise testing procedure, you will undergo the following: Height and weight measurements will be taken after completion of the informed consent and health screening form. The exercise testing will commence after the height and weight measurements which will start with a 5-minute warm-up on a stationary bike. During your warm-up period, the researcher will demonstrate the four exercises that you will execute during the testing. After the warm-up, you will be requested to lie on a bed on your stomach and the researcher will ask you to slightly reposition your pants to display the buttock of your dominant side. The researcher will start to determine the landmarks for the placement of the electrodes and mark it on your skin with a black eyeliner pencil. The researcher will prepare the skin for testing by using an isopropyl alcohol swipe to remove any oils on the area where the electrode stickers will be applied. The researcher will apply the electrode stickers. Four stickers will be applied on the skin – two over the m. gluteus maximus muscle and two over the m. gluteus medius muscle. To secure the electrodes stay in place, hypoallergenic tape or Velcro strapping will be used. After application, the researcher will request you to cover the area of investigation by repositioning your pants. Hence, your buttock area will not be visible during the execution of the exercises. The researcher will demonstrate the first exercise to you and will ensure that you are in the correct position. You will execute four exercises in total and eight repetitions of each. After each exercise, you will receive a two-minute rest period. During this period, the researcher will demonstrate the next exercise to you. After completion of all the exercises, you will again be asked to reposition your pants on your dominant side for the researcher to remove the electrode stickers. Upon removal of the electrodes, the skin will be wiped with isopropyl alcohol to remove any signal conductance gel. Water will be used to clean the area to minimise skin irritation and dryness. You may depart directly after completion of the exercise testing.

3. POTENTIAL RISKS AND DISCOMFORTS

The possible risks are muscle soreness/discomfort following exercise sessions and, possible though unlikely, skin reaction (redness or irritation) to electrode adhesive. Skin irritation may result from cleaning the skin with alcohol or through the application of surface electromyographic (sEMG) recording electrodes with electrolyte gel. In the case of skin irritation, the following safety procedures will be followed: The sEMG will be discontinued on that area. The skin will be wiped with water to wash the electrolyte gel from the skin surface. The participant will receive unscented skin lotion that can be applied to minimise the irritation. First aid will be administered as necessary by a qualified Biokineticicst who completed a level two first aid course.

This study, furthermore, will require time from you to complete the questionnaire and execute the exercises.

4. POTENTIAL BENEFITS TO SUBJECTS AND/OR SOCIETY

The possible benefits of participation in the research are a better understanding of the gluteal muscles' function and improved exercise technique.

The study can also contribute to the clinical field when it comes to determining which gluteal activation exercise to prescribe during rehabilitation. The research could make a valuable contribution to the academic field in the understanding of gluteal muscle recruitment. This research could also act as a stepping stone for further research into the understanding and management of injury prevention, rehabilitation prescription for gluteal muscle activation and numerous lower extremity injuries.

5. PAYMENT FOR PARTICIPATION

You will receive no payment for participation in this study. A report on the outcomes of your tests and the findings of the study will be made available to you upon request. The outcomes of the testing will be made accessible to you after completion of the study upon request, particularly if the results of the study show particular benefits to you. A debriefing will be held following the completion of the study during which all results will be discussed and any questions you may have will be answered.

6. CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by assigning codes to the data. All results of the tests will be stored under a code with a list linking the names and the codes kept separate and only available to the researcher. All results of the tests will only be made available to the study supervisor at the Department of Exercise and Sport Sciences of the University of the Free State (at this point no names will be linked to the data).

7. PARTICIPATION AND WITHDRAWAL

Participation in this study is voluntary. If you volunteer to take part in this study, you may withdraw at any time without consequences. You may also refuse to answer any questions you do not want to answer and remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so. These circumstances include: injury, sickness, and failure to adhere to exercise intervention. Non-participation in the study will not influence the player’s position in the UFS field hockey squad.

If you have any questions or concerns about the research, please feel free to contact Daretha Maartens 076 087 4577 or Prof. Derik Coetzee 051 401 2944 – Department of Exercise and Sports Sciences, University of the Free State.

8. RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and end your participation without penalty. You are not wavering any legal claims or rights because you are participating in this research study. For questions regarding your rights as a research subject, contact:

The Chair: Health Sciences Research Ethics Committee Dr S.M. Le Grange for attention: Mrs M. Marais, Block D, Room 104, Francois Retief Building, Po Box 339 (G40), Nelson Mandela Drive, Faculty of Health Sciences, University of the Free State, Bloemfontein, 9300. Mrs M Marais Head: Administration Mrs J du Plessis Administration (051) 401 7795; (051) 401 7794.

SIGNATURE OF RESEARCH PARTICIPANT

The information above was described to me, ____, by Daretha Maartens in *English/Afrikaans* and I am proficient in this language. I was given the opportunity to ask questions and these questions were answered to my satisfaction.

I hereby consent to participate in this study voluntarily. I have been given a copy of this form.

____

Name of Participant

_______________________________________ ________

Signature of Participant Date

SIGNATURE OF RESEARCHER

I declare that I explained the information given in this document to ______________________________

and she was encouraged and given ample time to ask me any questions. This conversation was conducted in *English/Afrikaans* and *no translator* was used.

______________________________ _________

Signature of researcher Date

APPENDIX D – HEALTH SCREENING FORM

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

Skool vir Aanvullende Gesondheidsberoepe (SAGB)/School for Allied Health Professions (SAHP)
Posbus/PO Box 339, Bloemfontein 9300, Republiek van Suid-Afrika/Republic of South Africa
Department of Exercise and Sport Sciences / Departement Oefen- en Sportwetenskappe

PARTICIPANT HEALTH SCREENING FORM:

Screening Code:______

This form is to be used to gather important information relevant to the study.

The questions must be answered with accuracy and care to ensure optimal study conditions and parameters.

Many thanks for your willingness to partake in the study as your involvement will help make a valuable contribution to the field of Biokinetics.

1	Date of birth?	DD MM YYYY ------/------/---------			
2	Weight (kg)? (Researcher will take the measurement and document it in this space)				
3	Height (in cm)? (Researcher will take the measurement and document it in this space)				
2	Which is your dominant leg? (i.e., which leg would you most likely use to kick a ball – choose one)	Left		Right	
3	How many hours per week are you engaged in physical activity? The American College of Sports Medicine (2017) defines physical activity as any bodily movement	0–2	3–4	5–6	≥7

	produced by the contraction of skeletal muscles that result in a substantial increase in caloric requirements over resting energy expenditure? (circle applicable)				
4	If you gym, please circle all applicable objectives.	Toning	Muscle building	Plyometric/ Power	Cardiovascular exercise
5	Are you currently living with any back pain or have you injured your back in the last 12 months?	Yes		No	
		If yes, describe:			
6	Are you currently living with any lower extremity injury or have you had an injury to the lower extremities in the last 12months?	Yes		No	
		If yes, describe:			
7	Are you currently living with a muscle injury or have you injured a muscle in the last 12 months?	Yes		No	
		If yes, describe:			
8	Are you aware of any reason why you should not participate in the study? (if yes, please specify in the space provided)	Yes	No		
9	Are you allergic to adhesives such as tape?	Yes	No		

APPENDIX E – PERMISSION LETTER TO HEAD OF EXERCISE AND SPORT SCIENCES CENTRE

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

Skool vir Aanvullende Gesondheidsberoepe (SAGB)/School for Allied Health Professions (SAHP)
Posbus/PO Box 339, Bloemfontein 9300, Republiek van Suid-Afrika/Republic of South Africa
Department of Exercise and Sport Sciences / Departement Oefen- en Sportwetenskappe

September 2019

Ms Karabelo Mpeko
Head of Exercise and Sport Sciences Centre
University of the Free State
BLOEMFONTEIN
9301

STUDY TITLE: ***RANDOMISED CROSSOVER TRAIL OF m. GLUTEUS MAXIMUS AND m. GLUTEUS MEDIUS ACTIVATION DURING REHABILITATION EXERCISES IN FEMALE HOCKEY PLAYERS***

With this letter, Miss Daretha Maartens (a Master's degree student in Biokinetics), would like to request permission to use the Exercise and Sport Sciences Centre as a facility for a research study conducted by the Department of Exercise and Sport Sciences, University of the Free State. I am requesting access to all registered gym members as well as free entrance to all participants not registered as a member at the gym.

Due to the numerous utilisation of gluteal specific activation exercises in practice, this study aims to test which body weight rehabilitation exercise simultaneously produce the highest activation of the m. gluteus maximus and m. gluteus medius in female field hockey players. Adequate strength and activation of the buttock muscles can ensure a decrease in risk of injury to the lower extremities as well as to the pelvic and lower back regions.

These findings will be utilised to assist in improving decisions regarding programme prescription for practitioners in the multi-professional team during prehabilitation and the different stages of rehabilitation in high-performance female field hockey players. The data will also assist in forming the basis for a graded rehabilitation program.

The research study will be done on voluntary high-performance female field hockey players from the UFS.

The expected outcomes will not be revealed to the participant until after the project has been completed. However, any possible risks will be truthfully explained to the participant.

The researcher will arrange an information session with the women's hockey squad before one of their training sessions at the UFS astroturf. During this session, the squad will be informed regarding the purpose of the intended study and the testing procedures to be administered. Emphasis will also be placed on the voluntary nature of the study. Refusal to participate will involve no penalty or loss of benefits to which the participant is otherwise entitled. Non-participation in the study will in no way influence the players' position in the UFS hockey squad.

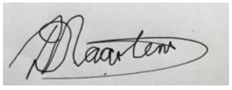
The recruited cohort of high-performance female hockey players will report at the Exercise and Sport Sciences Centre in the selected time slot. The researcher will test each participant who met the inclusion criteria of this study with the assistance of a registered Biokineticist. The testing will be conducted in a private evaluation room to ensure the confidentiality and privacy of the participants. The researcher will receive each participant upon their arrival at the UFS Exercise and Sport Sciences Centre and indicate the room where commencement of the testing will proceed. The researcher will briefly explain the procedures of the study and the content of documents that each participant has to sign. The required documents consist of an informed consent form and a health screening document. After the participant signed the informed consent form and completed the health screening document, the researcher will conduct the height and weight measurements of the participant according to the guidelines of the World Health Organisation (2017). Importantly, this data will be kept confidential. Hereafter, exercise testing of the four body weight rehabilitation exercises will proceed. During this exercise testing procedure, the participant will undergo the following: The participant will start with a 5-minute warm-up on a stationary bike. The participant will execute eight repetitions of each exercise with a two-minute rest period after each exercise.

This data will provide a valuable contribution to the clinical field and will enable Biokineticists in practice to select and prescribe the exercises that activate the m. gluteus maximus and m. gluteus medius most effectively. If you have any questions or concerns regarding how the tests will be conducted, you may contact the Secretariat of the HSREC, UFS, Mrs M. Marais on (051) 401 7795.

Your assistance in this matter will be much appreciated.

Please contact me with any questions or suggestions: 076 087 4577 or darethamaartens@gmail.com

Kind regards



Researcher Head of Department

Miss D. Maartens Prof. F.F. Coetzee

I hereby give permission that the centre may be used as testing facility for this research project.

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Signature Date

APPENDIX F – PERMISSION LETTER TO DIRECTOR OF KOVSIE SPORT

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

Skool vir Aanvullende Gesondheidsberoepe (SAGB)/School for Allied Health Professions (SAHP)
Posbus/PO Box 339, Bloemfontein 9300, Republiek van Suid-Afrika/Republic of South Africa
Department of Exercise and Sport Sciences / Departement Oefen- en Sportwetenskappe

September 2019

Mr DB Prinsloo
Director of Kovsie Sport
University of the Free State
BLOEMFONTEIN
9301

STUDY TITLE: ***RANDOMISED CROSSOVER TRAIL OF m. GLUTEUS MAXIMUS AND m. GLUTEUS MEDIUS ACTIVATION DURING REHABILITATION EXERCISES IN FEMALE HOCKEY PLAYERS***

With this letter, Miss Daretha Maartens (a Master's degree student in Biokinetics), would like to request permission to test all the high-performance female hockey players of the University of the Free State as part of a research study. The testing will be conducted by the Department of Exercise and Sport Sciences, University of the Free State. The researcher has requested permission from Mrs Karabelo Mpeko to use the Exercise and Sport Sciences Centre as a facility for the research as well as access to participants who are registered gym members and free entrance to all participants who are not registered as a member at the gym.

Due to the numerous utilisation of gluteal specific activation exercises in practice, this study aims to test which body weight rehabilitation exercise simultaneously produce the highest activation of the m. gluteus maximus and m. gluteus medius in female field hockey players. Adequate strength and activation of these buttock muscles can ensure a decrease in risk of injury to the lower extremities as well as to the pelvic and lower back regions.

The findings of the study will be utilised to assist in improving decisions regarding programme prescription for practitioners in the multi-professional team during prehabilitation

and the different stages of rehabilitation in high-performance female field hockey players. This data will also assist in forming the basis for a graded rehabilitation program.

The research study will be done on voluntary high-performance female hockey players from the UFS.

The expected outcomes will not be revealed to the participant until after the project has been completed. However, any possible risks will be truthfully explained to the participant.

The researcher will arrange an information session with the women's hockey squad before one of their training sessions at the UFS astroturf. During this session, the squad will be informed regarding the purpose of the intended study and the testing procedures to be administered. Emphasis will also be placed on the voluntary nature of the study. Refusal to participate will involve no penalty or loss of benefits to which the subject is otherwise entitled. Non-participation in the study will in no way influence the players' position in the UFS hockey squad.

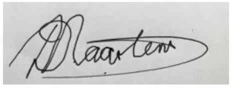
The recruited cohort of high-performance female hockey players will report at the Exercise and Sport Sciences Centre in the selected time slot. The researcher will test each participant who met the inclusion criteria of this study with the assistance of a registered Biokineticist. The testing will be conducted in a private evaluation room to ensure the confidentiality and privacy of the participants. The researcher will receive each participant upon their arrival at the UFS Exercise and Sport Sciences Centre and indicate the room where commencement of the testing will proceed. The researcher will briefly explain the procedures of the study and the content of documents that each participant has to sign. The required documents consist of an informed consent form and a health screening document. After the participant signed the informed consent form and completed the health screening document, the researcher will conduct the height and weight measurements of the participant according to the guidelines of the World Health Organisation (2017). Importantly, this data will be kept confidential. Hereafter, exercise testing of the four body weight rehabilitation exercises will proceed. During this exercise testing procedure, the participant will undergo the following: The participant will start with a 5-minute warm-up on a stationary bike. The participant will execute eight repetitions of each exercise with a two-minute rest period after each exercise.

If you have any questions or concerns regarding how the tests will be conducted, you may contact the Secretariat of the HSREC, UFS, Mrs M. Marais on (051) 401 7795.

Your assistance in this matter will be much appreciated.

Please contact me with any questions or suggestions: 076 087 4577 or darethamaartens@gmail.com

Kind regards



Researcher

Miss. D. Maartens

Head of Department

Prof. F.F. Coetzee

I hereby give permission that all the high-performance female hockey players may be tested with their consent.

------------------------- ---------------------

Signature Date

APPENDIX G – PERMISSION LETTER TO THE DEAN OF STUDENT AFFAIRS

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

Skool vir Aanvullende Gesondheidsberoepe (SAGB)/School for Allied Health Professions (SAHP)
Posbus/PO Box 339, Bloemfontein 9300, Republiek van Suid-Afrika/Republic of South Africa
Department of Exercise and Sport Sciences / Departement Oefen- en Sportwetenskappe

September 2019

Mr Pura Mgolombane
Dean of Student Affairs
University of the Free State
BLOEMFONTEIN
9301

STUDY TITLE: ***RANDOMISED CROSSOVER TRAIL OF m. GLUTEUS MAXIMUS AND m. GLUTEUS MEDIUS ACTIVATION DURING REHABILITATION EXERCISES IN FEMALE HOCKEY PLAYERS***

With this letter, Daretha Maartens (a Master's degree student in Biokinetics), would like to request permission to test all the high-performance female hockey players of the University of the Free State as part of a research study. The testing will be conducted by the University of the Free State, Exercise and Sport Sciences Department. The researcher has requested permission from Mrs Karabelo Mpeko to use the Exercise and Sport Sciences Centre as a facility for the research as well as access to participants who are registered gym members and free entrance to all participants who are not registered as a member at the gym.

Due to the numerous utilisation of gluteal specific activation exercises in practice, this study aims to test which body weight rehabilitation exercise simultaneously produce the highest activation of the m. gluteus maximus and m. gluteus medius in female field hockey players. Adequate strength and activation of the buttock muscles can ensure a decrease in risk of injury to the lower extremities as well as to the pelvic and lower back regions.

The findings of the study will be utilised to assist in improving decisions regarding programme prescription for practitioners in the multi-professional team during prehabilitation

and the different stages of rehabilitation in high-performance female field hockey players. The data will also assist in forming the basis for a graded rehabilitation program.

The research study will be done on voluntary high-performance female hockey players from the UFS.

The expected outcomes will not be revealed to the participant until after the project has been completed. However, any possible risks will be truthfully explained to the participant.

The researcher will arrange an information session with the women's hockey squad before one of their training sessions at the UFS astroturf. During this session, the squad will be informed regarding the purpose of the intended study and the testing procedures to be administered. Emphasis will also be placed on the voluntary nature of the study. Refusal to participate will involve no penalty or loss of benefits to which the subject is otherwise entitled. Non-participation in the study will in no way influence the players' position in the UFS hockey squad.

The recruited cohort of high-performance female hockey players will report at the Exercise and Sport Sciences Centre in the selected time slot. The researcher will test each participant who met the inclusion criteria of this study with the assistance of a registered Biokineticist. The testing will be conducted in a private evaluation room to ensure the confidentiality and privacy of the participants. The researcher will receive each participant upon their arrival at the UFS Exercise and Sport Sciences Centre and indicate the room where commencement of the testing will proceed. The researcher will briefly explain the procedures of the study and the content of documents that each participant has to sign. The required documents consist of an informed consent form and a health screening document. After the participant signed the informed consent form and completed the health screening document, the researcher will conduct the height and weight measurements of the participant according to the guidelines of the World Health Organisation (2017). Importantly, this data will be kept confidential. Hereafter, exercise testing of the four body weight rehabilitation exercises will proceed. During this exercise testing procedure, the participant will undergo the following: The participant will start with a 5-minute warm-up on a stationary bike. The participant will execute eight repetitions of each exercise with a two-minute rest period after each exercise.

If you have any questions or concerns regarding how the tests will be conducted, you may contact the Secretariat of the HSREC, UFS, Mrs M. Marais on (051) 401 7795.

Your assistance in this matter will be much appreciated. Please contact me with any questions or suggestions: 076 087 4577 or darethamaartens@gmail.com

Kind regards

Researcher — Head of Department

Miss. D. Maartens — Prof. F.F. Coetzee

I hereby give permission that all the high-performance female hockey players may be tested with their consent.

-------------------------- ----------------------

Signature Date

APPENDIX H – PERMISSION LETTER TO VICE-RECTOR: RESEARCH

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

Skool vir Aanvullende Gesondheidsberoepe (SAGB)/School for Allied Health Professions (SAHP)
Posbus/PO Box 339, Bloemfontein 9300, Republiek van Suid-Afrika/Republic of South Africa
Department of Exercise and Sport Sciences / Departement Oefen- en Sportwetenskappe

September 2019

Prof. Corli Witthuhn
Vice-Rector: Research
University of the Free State
BLOEMFONTEIN
9301

<u>STUDY TITLE:</u> RANDOMISED CROSSOVER TRAIL OF m. GLUTEUS MAXIMUS AND m. GLUTEUS MEDIUS ACTIVATION DURING REHABILITATION EXERCISES IN FEMALE HOCKEY PLAYERS

With this letter, Daretha Maartens (a Master's degree student in Biokinetics), would like to request permission to test all the high-performance female hockey players of the University of the Free State as part of a research study. The testing will be conducted by the Department of Exercise and Sport Sciences, University of the Free State. The researcher has requested permission from Mrs Karabelo Mpeko to use the Exercise and Sport Sciences Centre as a facility for the research as well as access to participants who are registered gym members and free entrance to all participants who are not registered as a member at the gym.

Due to the numerous utilisation of gluteal specific activation exercises in practice, this study aims to test which body weight rehabilitation exercise simultaneously produce the highest activation of the m. gluteus maximus and m. gluteus medius in female field hockey players. Adequate strength and activation of the buttock muscles can ensure a decrease in risk of injury to the lower extremities as well as to the pelvic and lower back regions.

The findings of the study will be utilised to assist in improving decisions regarding programme prescription for practitioners in the multi-professional team during prehabilitation

and the later stages of rehabilitation in high-performance female field hockey players. The data will also assist in forming the basis for a graded rehabilitation program.

The research study will be done on voluntary high-performance female hockey players from the UFS.

The expected outcomes will not be revealed to the participant until after the project has been completed. However, any possible risks will be truthfully explained to the participant.

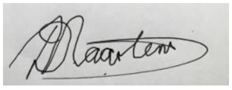
The researcher will arrange an information session with the women's hockey squad before one of their training sessions at the UFS astroturf. During this session, the squad will be informed regarding the purpose of the intended study and the testing procedures to be administered. Emphasis will also be placed on the voluntary nature of the study. Refusal to participate will involve no penalty or loss of benefits to which the subject is otherwise entitled. Non-participation in the study will in no way influence the players' position in the UFS hockey squad.

The recruited cohort of high-performance female hockey players will report at the Exercise and Sport Sciences Centre in the selected time slot. The researcher will test each participant who met the inclusion criteria of this study with the assistance of a registered Biokineticist. The testing will be conducted in a private evaluation room to ensure the confidentiality and privacy of the participants. The researcher will receive each participant upon their arrival at the UFS Exercise and Sport Sciences Centre and indicate the room where commencement of the testing will proceed. The researcher will briefly explain the procedures of the study and the content of documents that each participant has to sign. The required documents consist of an informed consent form and a health screening document. After the participant signed the informed consent form and completed the health screening document, the researcher will conduct the height and weight measurements of the participant according to the guidelines of the World Health Organisation (2017). Importantly, this data will be kept confidential. Hereafter, exercise testing of the four body weight rehabilitation exercises will proceed. During this exercise testing procedure, the participant will undergo the following: The participant will start with a 5-minute warm-up on a stationary bike. The participant will execute eight repetitions of each exercise with a two-minute rest period after each exercise.

If you have any questions or concerns regarding how the tests will be conducted, you may contact the Secretariat of the HSREC, UFS, Mrs M. Marais on (051) 401 7795.

Your assistance in this matter will be much appreciated. Please contact me with any questions or suggestions: 076 087 4577 or darethamaartens@gmail.com

Kind regards



Researcher
Miss. D. Maartens

Head of Department
Prof. F.F. Coetzee

I hereby give permission that all the high-performance female hockey players may be tested with their consent.

--------------------------   ----------------------

Signature   Date

APPENDIX I – ETHICS APPROVAL LETTER

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

Health Sciences Research Ethics Committee

19-Sep-2019

Dear Miss **Daretha Maartens**

Ethics Clearance: **Randomised cross over trial of m. gluteus maximus and m. gluteus medius activation during rehabilitation exercises in female hockey players**

Principal Investigator: Miss **Daretha Maartens**

Department: **Exercise and Sport Sciences Department (Bloemfontein Campus)**

CONDITIONALLY APPROVED

With reference to your application for ethical clearance with the Faculty of Health Sciences, this letter is to inform you on behalf of the Health Sciences Research Ethics Committee that ethical clearance will be granted for your research, pending clarifications/submission of the following:

UFS Authorities Approval

Please note: You have 60 calendar days from date of issuance to respond to this letter. If no response has been received by HSREC Administration within this time, this application will be withdrawn from further consideration and you will have to reapply.

Your ethical clearance number will be issued as soon as the HSREC has reviewed and approved your response to the above mentioned stipulations. For the time being, please use the following RIMS reference number in all correspondence:**UFS-HSD2019/1349**

For any questions or concerns, please feel free to contact HSREC Administration: 051-4017794/5 or email EthicsFHS@ufs.ac.za.

Thank you for submitting this proposal for ethical clearance. We look forward to receiving your response.

Yours Sincerely

Dr. SM Le Grange
Chair : Health Sciences Research Ethics Committee

Health Sciences Research Ethics Committee
Office of the Dean: Health Sciences
T: +27 (0)51 401 7795/7794 | E: ethicsfhs@ufs.ac.za
IRB 00006240; REC 230408-011; IORG0005187; FWA00012784
Block D, Dean's Division, Room D104 | P.O. Box/Posbus 339 (Internal Post Box G40) | Bloemfontein 9300 | South Africa
www.ufs.ac.za

APPENDIX J – EVALUATION COMMITTEE REPORT

SCHOOL FOR ALLIED HEALTH PROFESSIONS

TEL: (051) 401-3319

FAX: (051) 401-3641

AlliedhealthFHS@ufs.ac.za

EVALUATION COMMITTEE REPORT - MASTER'S RESEARCH

Notice to supervisors and members of the Evaluation Committee

The evaluation committee must be appointed & approved by the research committee of the SAHP before a date is set. Committee members must receive the protocol at least ten (10) working days before the set date of the meeting**.**

DATE: 22 May 2019

VENUE: Committee Room, Department of Exercise and Sport Sciences

MASTER'S DISSERTATION: Dissertation....... Article format .... Master's: Full:…X… Modular:..... Article format ....

CANDIDATE:

D Maartens

STUDENT NUMBER:

2013099532

DEPARTMENT:

Exercise and Sport Sciences

CURRENT TITLE:

Randomised crossover trial of Gluteus Maximus and Gluteus Medius activation during rehabilitation exercises in female hockey players

MEMBERS OF THE COMMITTEE:

Chairperson: Dr Roline Barnes

Member of Executive Committee:

Expert: Dr Marlene Opperman

Expert: Dr Gerhard Jansen

Expert: Miss Cherezanne Marais

Biostatistician: Prof Robert Schall

Supervisor: Prof Derik Coetzee

Co-supervisor: Miss Colleen Sinclair

PROCEDURE

Word of Welcome

All members and the candidate are welcomed by the chairperson.

1. **Agreement on handling of session and process in SAHP**

   The chairperson explains the procedure of discussing the protocol page/section by section.

- Editorial corrections, as indicated by the members of the committee, will be given to the supervisor to be corrected under their supervision.
- The title will be discussed at the end of the session. **(*No title registration and appointment of examiners may take place before ethical approval has been granted).***
- Any member of the evaluation committee may request to review the protocol again after the recommended corrections have been done. After the reassessment of the corrected version of the protocol, these members have

to inform the chairperson in writing (by email) of their approval of the revised protocol.

- **Only** after all the approvals have been received by the chairperson will the report be signed off by the chairperson and **only then** may the protocol be submitted to the HS Research Ethics Committee. The chairperson will inform HSREC and supervisor of the final approval.
- The student will be excused after the discussion of the protocol.
- Members will be requested to hand in their copy of the protocol to the supervisor.
- All title registrations must be submitted to the office of the SAHP **electronically** on the correct form, for approval at the relevant committees.

2. Candidate has been informed of the procedure: (✓/×) √

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3. Presentation – if applicable: (✓/×)___

4. Summary of the most important recommendations on the protocol:

Grammatical changes and minor changes need to be made by the student.

5. Topic represents a major area that warrants research? (✓/×) √

Comments:

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1.1 Can be justified within the parameters of the discipline? (✓/×) √

1.2

Comments:

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1.3 Title page, Concept clarification & abbreviations: (✓/×) √

The title is a concise reflection of the content of the proposal:

Captures the keywords which enable other researchers to retrieve the research:

(✓/×) √

Comments:

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1.4 The statement of the problem:

(is of practical/scientific significance and thus could lead to knowledge creation; sets out different points of view in an unbiased manner; is in line with the purpose of the study)

Comments:

The first sentence must be deleted. Move the rationale for utilising elite hockey players to the literature review. The aim of the study must be adapted to align with the objective stated.

1.5 Research objective:

(Follows naturally from problem statement; is formulated unambiguously and is limited to the issues at stake)

Comments:

Clear research objectives stated.

1.6 Literature review:

Contains a clear statement; demonstrating the focus of the study; is sufficient regarding the protocol; provides a personal, justified point of view; attends to theory relevant to the study).

Comments:

Good literature review. The aim of the study must be consistent throughout the protocol. A suggestion from the committee is that the last column of Table 1 must be split into two sections please.

1.7 Methodology:

- Design/
  Appropriate for the research problem and question (✓/×)√__revision/ ____

  Comments:

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- Study population:

  Described in detail (✓/×) _√_revision/_____

  Comments:

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- Inclusion/exclusion criteria (✓/×)__revision/ _√__

Comments:

Please indicate that it is apparently healthy females. Delete bullets two, three and four as they are no longer indicated for the study.

- Measurement:

  In alignment with the research question and the literature (✓/×)___revision/ _√__

Comments:

Add one sentence to describe exactly what you are going to measure under 3.6
The recruitment procedure must be described in full.

- Data collection, administration and analysis (✓/×)__revision/ _√__

Comments:

The recruitment procedure must be described in detail please.
Clearly state in the data collection session who, when, why and how in each instance starting with reminding the participants when to attend sessions.

- Measurement errors (internal and external validity; reliability; triangulation)/

Comments:

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1.8 Pilot study:

Aim (✓/×)___revision_√__

Comments:

You need to state what participants you are going to use for the pilot study. The committee indicates that you only need to include four participants for the pilot study.

1.9 Data analysis: (✓/×) _revision/ ____

6. Ethics: (✓/×)___revision_√__

Comments:

More detail should be provided regarding ethical considerations. What are the exact procedures in the case of an adverse event or an injury? All the stakeholders need to be indicated from whom you need permission. These include consent from Kovsie Sport, Vice-Rector student affairs etc.

7. Time Schedule:

Realistic for execution (✓/×)___revision_√__

Comments:

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8. Budget:

Funds available and realistic? (✓/×)___revision_√__

Comments:

Please indicate that the equipment and area you are going to utilise for the study is free of charge.

9. Appendices:

- Letters of permission?/ (✓/×)___revision____√

Comments:

Editorial changes need to be made. Make sure that you do not copy and paste letters as this leads to mistakes. Please provide a definition for physical activity to clarify the concept for participants. Add the emergency protocol of the centre to Appendix H.

- Informed consent (✓/×)___revision_√__

Comments:

Editorial changes need to be made. Make sure that you do not copy and paste letters as this leads to mistakes. Please provide a definition for physical activity to clarify the concept for participants.

- Examples of measurement tools (if applicable(✓/×) _√_revision____

Comments:

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10. Language, style and layout: (✓/×)____revision √___

Comments:

Editorial and grammatical changes needed.

11. Discussion of the protocol with reference to:

- Feasibility of the study? (✓/×) √__

- Does the study adhere to the level descriptors (NQF) of a Master's degree? (✓/×) √____

- Will the candidate be able to complete the study? (✓/×) √__

- If not - reasons?

- Is the title correct? (✓/×) X__

- If not – recommend new title:
- Randomised crossover trial of m. Gluteus Maximus and m. Gluteus Medius activation during rehabilitation exercises in female hockey players

12. RECOMMENDATIONS:

To be re-assessed: (✓/×)_____ By whom:

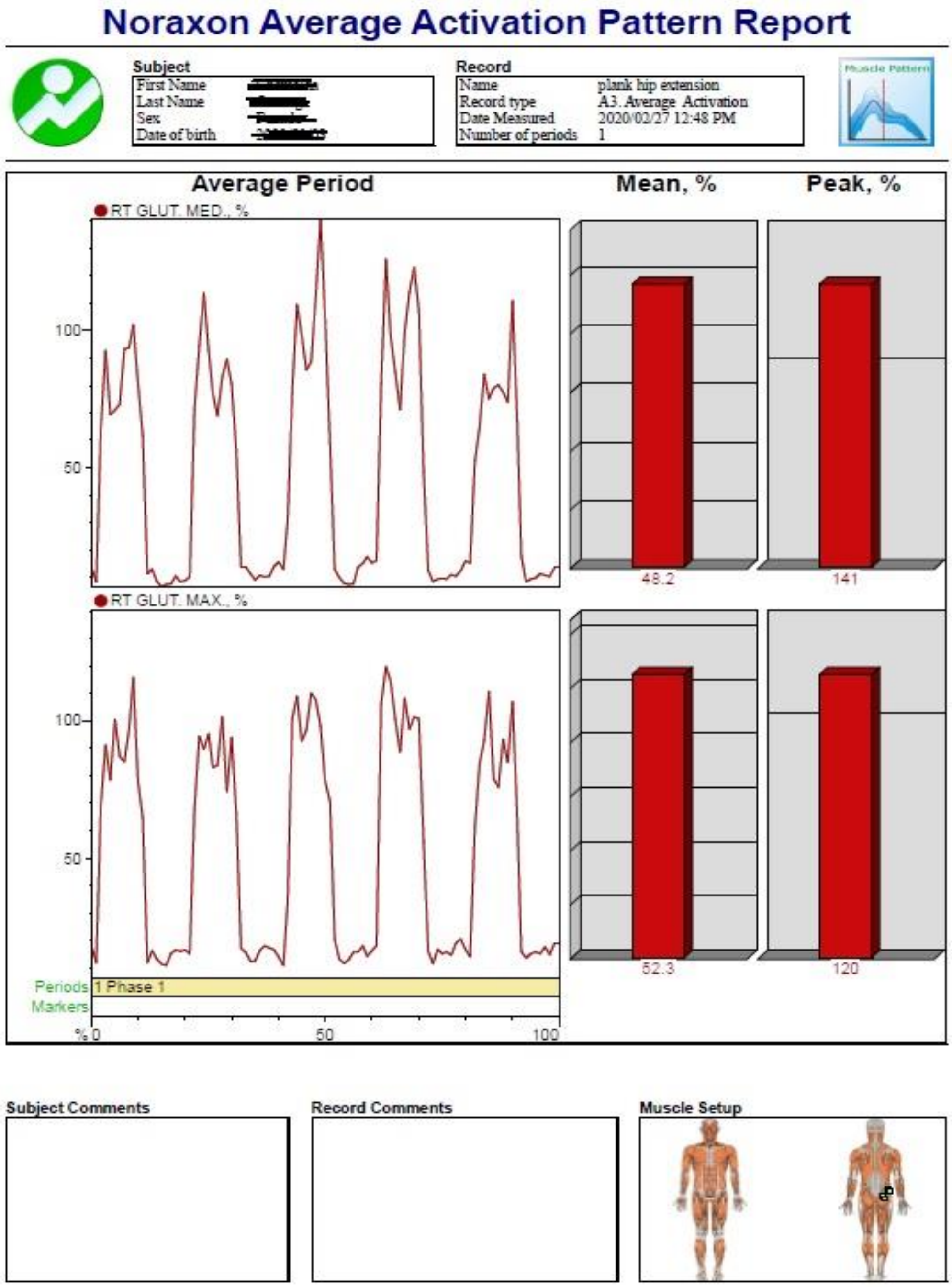
To be done under supervision of the supervisor: (✓/×) √

13. FINAL SIGN-OFF AFTER REASSESSMENT AND APPROVAL TO BE SUBMITTED TO THE RESEARCH ETHICS COMMITTEE:

.. 23/05/2019

CHAIRPERSON COMMITTEE **DATE**

APPENDIX K – NORAXON SURFACE EMG DATA REPORT



APPENDIX L – TURNITIN REPORT

ORIGINALITY REPORT

9%	2%	3%	8%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	lib.dr.iastate.edu Internet Source	1%
2	Andreas Serner, Markus Due Jakobsen, Lars Louis Andersen, Per Hölmich, Emil Sundstrup, Kristian Thorborg. "EMG evaluation of hip adduction exercises for soccer players: implications for exercise selection in prevention and treatment of groin injuries", British Journal of Sports Medicine, 2014 Publication	1%
3	Submitted to University of Bedfordshire Student Paper	1%
4	Submitted to Postgraduate Institute of Medicine Student Paper	1%
5	Submitted to Universiti Pendidikan Sultan Idris Student Paper	1%
6	Submitted to Australian Catholic University Student Paper	1%
7	Submitted to University of Birmingham	