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The effects of whole-body electromyostimulation exercise training on physical fitness in middle-aged sedentary females

By

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Submitted in fulfilment of the requirements for the degree

Master of Science (Sport Science)

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In the

Faculty of Health Sciences

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DECLARATION

I, the undersigned, declare that the dissertation hereby submitted to the University of Pretoria for the degree MSc (Sport Science) and the work contained therein is my own original work and has not previously, in its entirety or in part, been submitted to any university for a degree.

Signed……………………………this………………day of……………………………2019

DEDICATION

I would like to dedicate this dissertation to my grandmother, Elizabeth (Betty) May Koekemoer. Whom sadly passed away during the writing of this study. The sweetest and strongest woman I have ever known. She taught myself and everyone around her a great deal about goodness, simply through example.

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Last but by no means least, a massive thank you to all the ladies who took part in the study as participants. This would not have been possible without you and your time and effort is hugely appreciated.

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SYNOPSIS

Title	The effects of whole-body electromyostimulation on physical fitness in middle-aged sedentary females.
Candidate	Michael Burbidge
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Degree	MSc (Sport Science)

The purpose of this study was to determine the effects of whole-body electromyostimulation (WB-EMS) augmented calisthenic training on physique, maximum strength, balance and aerobic endurance and compare said effects to an active control only performing calisthenic exercise.

Electromyostimulation (EMS) also known as neuromuscular electrostimulation (NMES) produces a continuous muscle contraction via an electrode placed over a target muscle without any effort from the individual. EMS can be applied locally to a single muscle or in a WB-EMS fashion which allows for the stimulation of 16 different muscular regions simultaneously. Up to 2800 cm^2 of muscle mass. EMS has been observed to significantly increase maximum isometric and isokinetic strength. The effects of EMS on body composition and power parameters has varied between different research studies and styles of application. EMS training does not appear to positively affect aerobic fitness in healthy populations though it has in patient populations. The effects of EMS on balance have so far not been explored.

In the current study 39 sedentary females aged 35-55 years were allocated to either a control group performing 10-weeks of calisthenic training or an experimental group performing 10-weeks of WB-EMS augmented calisthenic training. Both groups completed a pre-testing (one week prior to the start of the 10-week training) and post-testing (one week following the conclusion of the 10-week training). The main outcomes were physique, determined by evaluating mass (kg), stature (cm) which were used to calculate Body Mass Index (kg/m^2), waist and hip girth (cm) which were

used to calculate the waist-hip ratio. Strength evaluated by measuring maximum handgrip and leg-and-back strength. Balance assessed by the functional reach (FR) test and aerobic endurance determined by measuring the distance covered with the Cooper-12-minute run/walk test and calculating maximal oxygen uptake (VO_2 max) with the use of a regression equation.

Following ten-weeks of exercise training significant increases were observed in mass and BMI (kg/m_2) in the WB-EMS group and high between-group effect sizes were observed. Significant decreases in waist girth and waist hip ratio were observed in the control with high between-group effect sizes observed for both. Handgrip strength did not change significantly in either group. While leg-and-back strength increased significantly in the WB-EMS group and did not change in the control group. A significant large between-group difference and effect size was also observed in leg-and-back strength. The reach distance achieved in the FR test increased significantly in the WB-EMS group and did not change in the control, however no between-group differences, but a large between-group effect size was observed. Distance covered in the Cooper-12-minute run/walk test and VO_2 max did not change significantly in the WB-EMS group but did significantly increase in the control group with medium effect sizes observed. No between group differences were observed with medium between group effect sizes.

Findings support that WB-EMS significantly increases strength. However, it is important to carefully place electrodes to stimulate target muscles and any strength increases will not translate to improvements in dynamic strength unless dynamic movements of the same kind are applied during the exercise training sessions. This can be observed in the significant increases in leg-and-back strength as many of the exercise completed during the training session simulated the test action. While neither right nor left handgrip strength changed significantly and none of the exercises performed simulated the test action. WB-EMS does not affect aerobic endurance as shown by the lack of increase in the distance covered and VO_2 max. WB-EMS also appears to significantly increase forward reach and dynamic balance, this is curious as no dynamic movements related to the test movement were applied during the exercise sessions. It may be that the primary muscles involved in the test movement

were strengthened during the training and this in turn improved the test distance achieved. As there is currently very little information on WB-EMS effect on balance this area should be researched more in the future and the precise mechanisms involved should be investigated.

Key words: Whole-body electromyostimulation, physique, strength, balance, aerobic endurance, VO_2 max, calisthenic, isometric, dynamic, mass, stature

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LIST OF ABBREVIATIONS

ACL	Anterior Cruciate Ligament
BMI	Body Mass Index
CK	Creatine Kinase
cm	centimetre
cm^2	centimetres squared
e.g.	exempli gratia
EMG	Electromyography
EMS	Electromyostimulation
FES	Functional Electrical Stimulation
Fmax	Force maximum
FR	Functional Reach
Hz	Hertz
i.e.	id est
ICU	Intensive Care Unit
kg	kilogram
km	kilometre
Ltd	Limited
m	metre
mA	milliampere
Min	Minutes
MVC	Maximum Voluntary Contraction
n	number
NMES	Neuromuscular Electrostimulation
OPT	Optimal Performance Training
PFST	Positional Feedback Stimulation Training
PNF	Proprioceptive Neuromuscular Facilitation
Pty	Proprietary
RM	Repetition Maximum
ROM	Range Of Motion
RPE	Rate of Perceived Exertion
SD	Standard Deviation
SMI	Skeletal Muscle Index
T12	Thoracic Vertebrae Number Twelve

T4	Thoracic Vertebrae Number Four
T7	Thoracic Vertebrae Number Seven
VO_2 max	Maximum Oxygen Consumption
VT1	Ventilatory Threshold One
VT2	Ventilatory Threshold Two
WB-EMS	Whole-Body Electromyostimulation
WHO	World Health Organization

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION AND MOTIVATION FOR THE STUDY

There are many different electro stimulators which produce currents in a variety of ways (monophasic, biphasic or pulsatile) (Prentice & Arnheim, 2013). Each different stimulator allows the adjustment of the parameters (amplitude, pulse duration and pulse frequency) (Douceta et al., 2012). The adjustment of these parameters will result in differing physiological effects (De Kroon et al., 2005). A low current will only cause a sensory reaction whereas a higher current should exceed the motor threshold and cause a muscular contraction, referred to as motor stimulation. Motor stimulation can be achieved via EMS, electromyography (EMG)-stimulation and positional feedback stimulation training (PFST) (De Kroon et al., 2005). Electromyostimulation also known as neuromuscular electrostimulation (NMES) produces a continuous muscle contraction without any effort from the individual. EMG-stimulation uses a volitionally generated EMG signal which exceeds the pre-set threshold. PFST is applied when a voluntary contraction exceeds a joint translation beyond the pre-set threshold (De Kroon et al., 2005).

De Kroon et al. (2005) state that the stimulation should be applied to the target muscles i.e. the muscles one wants to affect, this is referred to as local EMS application. Whole-body electromyostimulation (WB-EMS) equipment, as described by Kemmler et al. (2012: 241-242) *"enables the simultaneous activation of the muscles of 16 regions".*

Significant positive increases in strength have been observed following local (Babault et al., 2007; Jubeau et al., 2008; Billot et al., 2010; Bezerra et al., 2011; Lategan et al., 2014; Wirtz et al., 2015 and Wirtz et al., 2016) and WB-EMS application (Kemmler and von Stengel, 2012a; Kemmler and von Stengel, 2012b; Kemmler et al, 2013 and Kemmler et al, 2016a). In other factors such as power the effects have varied. In post-menopausal woman and elderly males (Kemmler and von Stengel, 2012a; Kemmler and von Stengel, 2012b) WB-EMS augmented training produced a significant increase. While in sporting populations Billot et al. (2010) found no significant increases. Babault et al. (2007) however, observed significant increases in some tests, such as squat jump and drop jump and none in others, such as counter movement jump, 15 repetitive counter movement jumps and 20 metre (m) and 50 m sprint tests. When looking at EMS effect on body composition, lean body mass has increased significantly (Kemmler et al., 2013; Kemmler et al., 2016a) and fat mass has been significantly reduced (Kemmler and von Stengel., 2012a; Kemmler and von Stengel.,2012b; Kemmler et al., 2016a). Muscle mass (Kemmler and von Stengel., 2012a; Kemmler and von Stengel., 2012b; Kemmler et al., 2013) and bone density (Arija-Blázquez et al., 2014; von Stengel et al., 2015), however appear to be unaffected by EMS application. The effects of EMS on aerobic fitness and balance is less well known and requires further investigation.

WB-EMS augmented training usually prescribes a low training frequency e.g. one session every five (5) days (Kemmler et al., 2013; Kemmler and von Stengel. 2012a; Kemmler and von Stengel. 2012b; Wirtz et al., 2016).

Despite the important role which exercise plays in maintaining physical functioning (Centers for Disease Control., 1996; Blair et al., 2004; World Health Organisation (WHO)., 2010; Buford et al., 2013) a lack of physical inactivity accounts for 6% of global deaths (http://www.who.int/dietphysicalactivity/pa/en/). Middle-aged populations report the lack of time as one of the main reasons for not exercising enough (Justine et al., 2013). During middle-age many women will also begin to experience menopause, usually in the late 40's to early 50's (Stojanovska et al., 2014). While the impact of exercise on the symptoms of menopause are inconclusive, woman who are physically active have lower stress and a better quality of life overall (Stojanovska et al., 2014).

1.2 RESEARCH QUESTION

The research question for this study is:

Does ten weeks of WB-EMS augmented calisthenic training result in a significant improvement in selected physical fitness components in middle-aged women, and if so, are said improvements significantly greater than in a control?

1.3 RESEARCH AIM AND OBJECTIVES

This study aimed to determine the effects of WB-EMS augmented calisthenic training on strength, aerobic endurance, and balance in sedentary middle-aged females in Pretoria, and to compare the effects on strength, aerobic endurance, and balance to those in a control group. This was determined by evaluating: maximum isometric strength, balance, and aerobic endurance capacity.

Additionally, the objectives of this study were to:

- Evaluate whether WB-EMS is effective at altering physique by measuring mass in kilograms (kg), stature (cm), body mass index (BMI) (kg/m_2), waist girth (cm), hip girth (cm) and waist hip ratio.
- Evaluate whether WB-EMS augmented calisthenic training is effective at improving maximum strength assessed by the isometric handgrip test and the isometric leg strength test.
- Evaluate whether WB-EMS augmented calisthenic training is effective at improving balance, assessed by the functional reach (FR) test.
- Evaluate whether WB-EMS augmented calisthenic training is effective at increasing aerobic endurance capacity assessed by the Cooper 12-minute (min) test.
- Compare any changes in the measured parameters in the experimental group with those in a control group.

If this study provides evidence that WB-EMS augmented calisthenic training is effective at improving strength, aerobic endurance, and balance it may be seen as an effective and time saving alternative to other exercise protocols.

1.4 RESEARCH APPROACH AND DESIGN

This study used a quantitative research approach with a longitudinal, experimental, pre-test post-test, control group design, with two randomized groups (one control and one experimental) (Hopkins, 2008).

1.5 RESEARCH PROCEDURE AND STRATEGY

The procedures and strategies laid out in Figure 1 were followed throughout the course of the study.

Identification of the research question

↓

Writing of the research proposal

↓

Research proposal was submitted to and approved by the MSc committee of the University of Pretoria (399/2017).

↓

Proposal was submitted to and approved by the ethical committee of the University of Pretoria (399/2017).

↓

Beginning of data collection

a. Volunteers recruited from the city of Pretoria. Through the distribution of flyers (Appendix A).
b. Volunteers sent self-report questionnaires (Appendix B) to determine whether they met the necessary inclusion criteria and were free of the exclusion criteria
c. Pre-testing of participants.
d. Intervention period 10-weeks.
e. Post-testing of Participants

→ Setting

a. Pre and post-testing took place at the University of Pretoria, L.C. de Villiers sport campus.
b. The training intervention took place at Garsfontein Pretoria, 0167.

↓

Data analysis

a. Data from the pre- and post-testing was captured by the researcher.
b. Data was analyzed at the Medical Research Council, Biostatistics Unit.

↓

Results were interpreted and discussed.

↓

Research conclusions formulated, report written, finding communicated.

Figure 1: Flow diagram of the testing procedure followed.

1.6 FLOW OF DISSERTATION

The literature review and the methodology utilized to carry out this study are presented in Chapters two and three respectively. Chapter Four will present the results of the statistical analysis. Chapter five will discuss the results, conclude this study, document the practical application of the study as well as highlight study limitations and any recommendations for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 HISTORY OF EMS

Electricity has been used to treat muscle paralysis for over 2000 years and was used in ancient Greece by the physician Aetius as a treatment for gout (Lategan et al., 2014). In 1790 Luigi Galvani observed motion in the severed leg muscles of a frog after applying electrical wires to said muscles ((Douceta et al., 2012)). In 1831 Michael Faraday observed that electrical currents could be used to stimulate nerves and induce motion (Douceta et al., 2012). During the 19th century Duchenne had begun using electrodes placed over nerve trunks and motor points to elicit muscular contractions and had discovered that electrical stimulation could also be used to stimulate spastic muscles (Lategan et al., 2014).

It was considered that EMS should be used for rehabilitation specifically in the early phase of rehabilitation when voluntary activity was not possible (Vanderthommen and Duchateau, 2007). However following claims by Yakov Kotts of strength gains of up to 40% following EMS training, interest began to grow in the use of EMS to increase strength and other physical fitness parameters (Vanderthommen and Duchateau., 2007; Lategan et al., 2014). Unfortunately, due to a lack of data it was not possible to fully reproduce the strength gains reported by Kotts (Vanderthommen and Duchateau., 2007; Filipovic et al., 2012). However, Lloyd et al. (1986) determined voluntary contractions to produce higher torque than electrically stimulated contractions. Lloyd et al. (1986) speculated that the lower torque produced may be due to an inadequate electrical stimulation as the optimal stimulation parameters had not yet been determined.

Despite this, EMS training has been used for healthy individuals and high-performance athletes to develop strength (Maffiuletti et al., 2000; Maffiuletti et al., 2002; Malatesta et al., 2003; Filipovic et al., 2012) and although EMS is still mainly used in rehabilitation (Maffiuletti et al., 2000) research and interest in the use of EMS as a training method has increased over the last two decades (Brocherie et al., 2005 EMS). This increase in research has allowed researchers to make better recommendations on training style (Filipovic et al., 2012; Amaro-Gahete., 2018a; Amaro-Gahete., 2018b) and the parameters affecting impulse intensity. In the last few years WB-EMS has increased in popularity as a training modality (Amaro-Gahete et al., 2018a; Amaro-Gahete et al., 2018b) and has significantly affected both body composition and strength (Teschler et al., 2016). WB-EMS is now used in leisure and high-performance level sport (Filipovic et al., 2012).

2.2 ADMINISTRATION

EMS can either be applied subcutaneously or via surface electrodes usually placed on the skin above the motor points of the targeted muscle or muscles. Up until recently EMS was applied locally to a single muscle or group of muscles, however over the last decade advances in WB-EMS technology have made simultaneous multiple muscular areas possible and popular. EMS devices allow for the adjustment of amplitude, pulse duration and pulse frequency (Douceta et al., 2012). Different application of these variables as well as different exercise styles will produce differing results. Many different EMS devices are available making inter-research comparisons difficult as different devices are used in various research studies (Filipovic et al., 2011). For local EMS application a “Compex” stimulator has been used in 37% of trials from 1994 onwards and before then an “Electrostim 180” was used in 28% of trials (Filipovic et al., 2011). Recently WB-EMS stimulators designed to stimulate large areas of muscle simultaneously, such as the “Bodytransformer” or the WB-EMS device produced by “miha bodytec®” (Filipovic et al., 2011) have also been included.

2.3 USES

Over the last 50 years, EMS has been used for both strength training and as a rehabilitation tool (Hansen, 2015). Over the years EMS has been used for many reasons including pain relief, treating musculoskeletal conditions, maintaining bone mineral density, preventing muscular atrophy, reducing oedema, promoting and accelerating wound healing, increasing muscle strength and for the enhancement of sport performance (Lategan et al., 2014).

2.4 EMS APPLICATOIN VARIABLES

Filipovic et al. (2012) make the recommendation that for increasing maximum strength, individuals should focus on isometric EMS training, whereas for maximal dynamic strength, EMS should incorporate dynamic movements into the EMS training sessions and be combined with dynamic strength training. To improve speed strength EMS should incorporate fast concentric dynamic movements within the training sessions (Filipovic et al., 2012). For EMS to improve jumping and sprinting ability, it should be done in combination with sprinting and plyometric jump training respectively (Filipovic et al., 2012). Amaro-Gahete et al. (2018a) state that for the training to be effective at improving aerobic fitness factors it must incorporate functional exercises and a periodization of the electrical parameters. This was done by splitting the training into four phases, namely “warm up”, “strength training”, “high intensity power interval training” and “high intensity interval training” (Amaro-Gahete et al., 2018a; Amaro-Gahete et al., 2018b). Each of the four phases applied by Amaro-Gahete et al. (2018a) and Amaro-Gahete et al. (2018b) applied a specific frequency in hertz (Hz), duration, rate of perceived exertion (RPE) and duty cycle (“on-off” ratio) of the electrical impulse. It should be noted that both studies conducted by Amaro-Gahete et al. (2018a) and Amaro-Gahete et al. (2018b) had small group sizes of only six individuals in both the experimental and control groups.

In terms of the electrical stimulation produced by the EMS device the important parameters as described by Lloyd et al. (1986) are pulse shape, charge, duration, frequency and intensity. A meta-analysis by Filipovic et al. (2011) determined impulse type, impulse form, impulse width, impulse frequency, impulse intensity, impulse on time and stimulation intensity to be the parameters which affected stimulation effectiveness.

The stimulation intensity appears to be the important factor in improving strength and it is affected by impulse intensity in milliampere (mA), stimulation frequency (Hz) and impulse width (microseconds) (Filipovic et al., 2011). Frequency relates to the amount of impulses applied for each second of stimulation (Douceta et al., 2012). EMS devices apply pulses in waveform and the impulse width describes the amount of time a single pulse lasts for (Douceta et al., 2012). Impulse intensity refers to the strength of the current being applied, and a stronger current will result in a higher impulse intensity (Douceta et al., 2012).

Stimulation intensity can be determined by the participant's interpretation of perceived exertion scales (von Stengel et al., 2015; Kemmler et al., 2016a) and individual pain threshold (Wirtz et al., 2016). Vanderthommen and Duchateau (2007) state that it is not possible to produce contractions which are equal to individual maximum voluntary torque due to the associated discomfort. It is also necessary to decrease the stimulation intensity if EMS training is done in conjunction with dynamic exercise to allow for free movement (Wirtz et al., 2015).

FIlipovic et al. (2011) state that a stimulation intensity of > 50% maximum voluntary contraction (MVC) is needed to produce strength gains. To produce a stimulation intensity of > 50% MVC, an impulse intensity of > 50 mA, stimulation frequency of 76.4 ± 20.9 Hz and an impulse width of 306.9 ± 105.1 microseconds is required (Filipovic et al., 2011). Vanderthommen and Duchateau (2007) state that a pulse rate of 50 - 100 Hz and an impulse width of 0.1 - 0.5 milliseconds which is equal to 100 - 500 microseconds is required to produce an optimal stimulation and Maffiuletti et al., 2000 state 80 - 100 Hz without mentioning microseconds. A biphasic current is preferable as individuals can tolerate the stimulation more easily than from a monophasic current, allowing for higher stimulation intensities resulting in higher strength gains (Filipovic et al., 2011; Vanderthommen and Duchateau, 2007). From 1994 onwards biphasic impulses have been utilised in 67% of research trials (Filipovic et al., 2011).

The positioning of the active electrode also plays a role as axonal branches nearer the electrode will be recruited before those further away (Vanderthommen and Duchateau, 2007; Maffiuletti 2000). An increase to the stimulation intensity will cause axonal branches further away from the electrode to be depolarized (Vanderthommen and Duchateau, 2007) while also increasing the intensity to the axonal branches which are closest to the active electrode. For example, electrodes placed onto the quadriceps muscles will stimulate the quadriceps muscles before stimulating the calf muscles and electrodes placed on the upper arms will stimulate the triceps and biceps before stimulating the forearm muscles. The preferential recruitment of the axonal branches nearest to the electrode is also one of the reasons EMS preferably stimulates Type llb fibers as the largest motor units are usually near to the surface of the muscle, large motor units also have a low threshold of excitability and are therefore more easily recruited (Maffiuletti., 2000).

In terms of training time, an overall training period of four to six weeks at a frequency of three sessions per week is sufficient to increase maximum strength and speed strength, as well as jumping and sprinting ability and maximum power (FIlipovic et al., 2011). Each of the individual EMS sessions should last 10-15 min and the stimulation ratio should be three to ten seconds on time with a 20-25% duty cycle (Filipovic et al., 2011). EMS is usually applied with intermittent stimulation i.e. the impulses are cycled on-and-off for a certain period of time (Douceta et al., 2012). This is referred to as the “duty cycle” and is done for the comfort of the participant and to help preserve force development (Douceta et al., 2012). The duty cycle is usually presented as a ratio or a percentage describing impulse on time in relation to overall on-and-off time together (Douceta et al., 2012).

EMS is suitable for trained and untrained individuals, however trained subjects increase their strength more than untrained subjects following EMS application (Filipovic et al., 2011). Filipovic et al. (2011) speculate that this may be due to athletes possessing better inter and intra-muscular coordination allowing them to more effectively transfer strength gains into test conditions and also allowing them to more easily coordinate the simultaneous electrical and mechanical stimulation during training sessions allowing for a better quality of training.

2.5 LOCAL VERSUS WB-EMS

EMS can be applied locally to focus on one muscle or group of muscles or in a WB-EMS fashion to stimulate multiple muscle groups simultaneously. Whole-body electromyostimulation involves the activation of up to 18 different muscle regions simultaneously (Kemmler et al., 2012; Kemmler et al., 2016; Amaro-Gahete., 2108a;

Amaro-Gahete., 2018b) via the use of a jacket fitted with several electrodes which stimulates the torso and a series of electrode belts used to stimulate the upper arms, upper legs and gluteal muscles.

Filipovic et al. (2012) state that strength increases following WB-EMS application are minor compared to strength increases observed following local application. However, Kemmler et al. (2018b) speculate that the disparity between strength increases following WB-EMS and local EMS application may be due to the optimal placement of electrodes during local application and the focus is on a single muscle region. Kemmler et al. (2018b) also state that when comparable stimulation parameters are applied the effects of WB-EMS application are comparable to the effects of local EMS application.

2.6 EMS EFFECTS

This section will focus on the effects of EMS application on various physiological and physical factors

2.6.1 STRENGTH

Muscular strength is described as: "*the ability of a muscle or group of muscles to apply force against resistance"* (Plowman and Smith, 2011: 551).

EMS exercise training significantly improves maximum strength when it has been applied both locally (Kacoglu and Kale, 2016; Avila et al., 2008; Maffiuletti et al., 2000; Maffiuletti et al., 2002; Brocherie et al., 2005; Babault et al., 2007; Jubeau et al., 2008; Billot et al., 2010; Bezerra et al., 2011; Lategan et al., 2014; Mignardot et al., 2015; Wirtz et al., 2015 and Wirtz et al., 2016) and in a WB-EMS fashion (Kemmler and von Stengel, 2012a; Kemmler and von Stengel, 2012b; Kemmler et al, 2013; Kemmler et al, 2016a; Kemmler et al, 2018b). Significant increases have been observed in both maximum isometric strength (Jubeau et al., 2008; Billot et al., 2010; Bezerra et al., 2011; Kemmler and von Stengel., 2012a; Kemmler and von Stengel., 2012b; Kemmler et al., 2013; Lategan et al., 2014; Wirtz et al., 2015 and Wirtz et al., 2016 and Kemmler et al., 2016a) and maximum isokinetic strength (Kacoglu and Kale, 2016 Avila et al., 2008; Maffiuletti et al., 2000; Brocherie et al., 2005;Babault et al., 2007; Billot et al., 2010). The increases in maximum strength following EMS training have been prevalent in a number of different age groups, as well as in athletic populations (Brocherie et al., 2005, Maffiuletti et al., 2000; Hussain et al., 2017; Babault et al., 2007; Billot et al., 2010;), and non-athletic populations (Avila et al., 2008; Kacoglu and Kale, 2016; Maffiuletti et al., 2002; Jubeau et al., 2008; Bezerra et al., 2011; Kemmler and von Stengel., 2012a; Kemmler and von Stengel., 2012b; Kemmler et al., 2013; Lategan et al., 2014; Wirtz et al., 2015; Wirtz et al., 2016 and Kemmler et al., 2016a). The effect of EMS training on middle-aged females is still lacking.

When compared to control groups, performing low intensity exercise routines WB-EMS training has shown significantly greater increases in maximum strength (Kemmler and von Stengel., 2012a; Kemmler and von Stengel., 2012b). Kacoglu and Kale (2016) compared a single session of low (30 Hz), high (100 Hz) and no (0 Hz) frequency EMS, observing significant increases to isokinetic knee flexion strength at 180° and 300° knee angle in both high and low frequency conditions compared to no frequency. Neither the high nor low frequency conditions showed significant difference in increases between one another and no significant increases were observed in knee extension at 60° 180° or 300° and flexion at 60° knee joint angle (Kacoglu and Kale, 2016). EMS training of the upper legs has significantly increased isometric MVC of the knee extensors following four ($p < 0.001$) and eight ($p < 0.001$) weeks of four per week training sessions (Gondin et al., 2005).

When comparing six weeks of twice per week squat resistance training combined with EMS of the calves, upper legs, gluteals, lower back and abdomen, to squat resistance training alone, comparable increases in isometric strength as well as in 10 repetition maximum (RM) squatting weight were observed (Wirtz et al., 2015; Wirtz et al., 2016). No changes in maximum isometric strength on either the leg press or leg curl were observed following eight weeks of two per week WB-EMS training (at an intensity of 70% maximum tolerable pain threshold) or traditional resistance training (at an intensity of > 16 on the Borg RPE scale) (Micke et al., 2018). Maximum isometric leg extension strength however, increased significantly only in the WB-EMS group (Micke et al., 2018). A recent review determined WB-EMS in healthy subjects to be no more affective at increasing strength compared to traditional resistance exercise training (Stöllberger and Finsterer. 2018). Whole-body electromyostimulation and jump training performed simultaneously has significantly increased ($p < 0.01$) 1 RM leg press following both seven and 14-weeks of training and no increases were observed in a control performing only jump training (Filipovic et al., 2016).

When EMS is combined with sport specific training, increases to both isokinetic and isometric strength are greater than sport specific training alone (Hussain et al., 2017; Brocherie et al., 2005; Babault et al., 2007; Billot et al., 2010).

The increases in maximum strength do not always lead to improvements in other strength-related parameters. For example, Billot et al. (2010) observed a significant increase in kicking speed with run up following three ($p < 0.05$) and five weeks ($p < 0.01$), of separate EMS and soccer training in soccer players, kicking speed with run up improved significantly only after five weeks ($p < 0.05$). No changes were observed in a control which only performed soccer training sessions (Billot et al., 2010).

Whole-body electromyostimulation training combined with separate soccer training has also significantly increased kicking velocity with run up ($p < 0.01$) and without run up ($p < 0.05$) following 14-weeks of training and no changes were observed in a control which only performed soccer trainings (Filipovic et al., 2016).

Hussain et al. (2017) observed significant increases in batting velocity in softball players but Babault et al. (2007) observed no improvement in scrummaging strength in rugby players following EMS training. It is recommended by Filipovic et al. (2012) that to produce increases in dynamic strength, dynamic movements should be incorporated into the EMS training sessions and/or combined with separate dynamic strength training sessions. This was done by Billot et al. (2010) by combining EMS training with separate soccer training sessions and by Hussain et al. (2017) by incorporating exercises usually used to increase batting velocity into the EMS sessions themselves. While Babault et al. (2007) combined EMS training with separate rugby training, the scrummaging test utilised to evaluate dynamic strength was performed by both backline and forward players and therefore differing technique may have played a role in the results.

A meta-analysis by Filipovic et al. (2012) found isometric, dynamic and isometric EMS in conjunction with conventional weight training to significantly increase isometric force max (Fmax) in trained and untrained subjects. In terms of local compared to WB-EMS application, local showed a greater increase in isometric Fmax (Filipovic et al, 2012). So far as isokinetic strength is involved both isometric and dynamic EMS application has resulted in similar significant increases (Filipovic et al, 2012).

2.6.2 POWER

Power is defined as the amount of work managed over a period of time (Powers and Howley, 2009).

A meta-analysis by Filipovic et al. (2012) determined WB-EMS to be affective at increasing Pmax (maximum power). Eight weeks of two per week WB-EMS training however has shown no significant changes in Pmax on leg curl, leg extension and leg press machines (Micke et al., 2018).

Babault et al. (2007) did not observe any significant changes in 20 m and 50 m sprint time following 12-weeks of local EMS training of the knee extensors, plantar flexors and gluteus maximus. Training was performed three times per week for the first six weeks and once per week for the following six weeks (Babault et al., 2007). Billot et al. (2010) also observed no significant changes in sprint time (10 m) following local EMS of the quadriceps at a frequency of three sessions per week for a total of five weeks. Eight weeks of twice per week WB-EMS training however, significantly decreased 30 m linear sprint time while no changes were observed following eight weeks of twice per week resistance training (Micke et al., 2018). Pendular sprints (3m x 10m) were unaffected in both the WB-EMS and resistance trained groups (Micke et al., 2018). Significant decreases to 5 m linear sprint were observed following seven weeks of dynamic WB-EMS training, however no significant changes were observed following 14-weeks and 10, 20 and 30m sprint time remained unchanged at both seven and 14-week measurements (Filipovic et al., 2016). Local EMS of the quadriceps applied three times per week for 12-min per session has significantly decreased 10 m skating time in ice hockey players but did not significantly affect 30 m skating time (Brocherie et al., 2005). A meta-analysis by Filipovic et al (2012) determined isometric EMS and combination (EMS training two times per week and plyometric training two times per week) training to significantly increase sprint performance. Interestingly the studies conducted by Babault et al. (2007), Billot et al. (2010) and Brocherie et al. (2005) all applied EMS isometrically and the participants in each study also performed sport specific (rugby, soccer and ice hockey) training in conjunction with the EMS.

Negative effects in drop jump, counter movement jump and squat jump have been observed, with all decreasing significantly following 3-weeks of EMS training (Brocherie et al., 2005). When investigating the effects of EMS, applied three times a week for a period of five weeks, on power, Billot et al. (2010) reported no changes to standing vertical jump, counter movement jump (with the arms kept close to the hips), or counter movement jump (with the arms free to move). Similarly, no changes to squat jump, counter movement jump, drop jump or standing long jump were observed following either eight weeks of twice per week WB-EMS or traditional resistance training (Micke et al., 2018). Malatesta et al. (2003) also observed no changes to squat jump and counter movement jump following 4-weeks of EMS training, however 10-days following the post-intervention both conditions showed significant increases. While Babault et al. (2007) observed a significant increase in standing vertical and drop jump conditions, and no increases to counter movement jump or 15 repetitive jumps following 12 weeks of training. When the training was split into two 6-week blocks, occurring three times a week for the first block and once per week during the second block (Babault et al., 2007).

However single sessions of low (30 Hz) and high (100 Hz) intensity EMS of the calves and upper legs have both produced significant increases in both squat and counter movement jump in comparison to control condition (0 Hz) (Kacoglu and Kale, 2016). In basketball players squat jump has also increased significantly, following four weeks of three times per week EMS training of the vastus lateralis and medialis (Maffiuletti et al., 2000). While counter movement jump showed a significant increase only after an additional four weeks post intervention at which time the increases to squat jump had been maintained (Maffiuletti et al., 2000).

Fourteen weeks of WB-EMS augmented training at a frequency of one session every five days for 20 min (Kemmler and von Stengel., 2012a) and 30 min (Kemmler and von Stengel., 2012b) has significantly improved counter movement jump, as has a single WB-EMS session per week for six weeks (Amaro-Gahete et al., 2018a; Amaro-Gahete et al., 2018b). A meta-analysis by Filipovic et al. (2012) determined that WB-EMS application did not significantly increase jumping ability, whereas local application produced significant increases when applied isometrically or dynamically, and mixed results were observed following combination EMS. However, a more recent study applying dynamic (jumping) exercise WB-EMS observed significant increases to squat jump ($p < 0.05$), counter movement ($p < 0.05$) jump and drop jump ($p < 0.05$) following 14-weeks of training while no changes were observed in an active control which performed the same jump training without simultaneous WB-EMS (Filipovic et al., 2016).

The varying effects observed may have to do with the populations tested as well as the frequency of training per week and the overall duration of training. Babault et al. (2007) and Billot et al. (2010) both looked at sportsmen, soccer and rugby players respectively, both sports that already have power components, so it is less likely to see a significant change. While Kemmler and von Stengel (2012a) used postmenopausal woman aged 65 ± 5 years and Kemmler and von Stengel (2012b) used elderly males aged 69 ± 3 years, neither of which have as high a need for power as sportsmen. This could lead to any increases in power being more prominent amongst the older populations.

The type of application may also be a mitigating factor, with WB-EMS applications producing significant increases (Kemmler and von Stengel, 2012a; Kemmler and von Stengel, 2012b) while local application did not (Babault et al., 2007; Billot et al., 2010). Similarly, the length of the training period and the number and length of training sessions within the training period may explain discrepancies in the comparison of results from different EMS studies. With the longer duration studies (Babault et al., 2007; Kemmler and von Stengel, 2012a; Kemmler and von Stengel, 2012b) showing significant increases in some power tests when compared to the shorter duration utilised by Billot et al. (2010). Brocherie et al., 2005 state that longer and more specific training sessions are required to improve the neuromuscular performance required for specific movements such as a vertical jump. While Filipovic et al. (2012) state that for EMS to improve jumping and sprinting ability, it should be done in combination with sprinting and plyometric jump training respectively.

2.6.3 AEROBIC FITNESS

Aerobic activity involves the break-down of fuel (carbohydrates, fats and proteins) via oxidative processes to produce energy (Baechle and Earle, 2008).

Deley and Babault (2014) reported increases in both maximum oxygen consumption (VO_2 max) (4.5%) and VO_2 at the ventilatory threshold (11.5%) in a case study on a 33-year-old male. Local EMS application has produced significant increases in VO_2 max and VO_2 at the anaerobic threshold, in patients who suffered from chronic heart failure (Soska et al., 2014). The increases in VO_2 max and VO_2 at the anaerobic threshold, however, were comparable to increases observed in two control groups that performed aerobic training and aerobic training augmented with EMS respectively (Soska et al., 2014).

Due to the small sample sizes and conflicting results observed in patients suffering from chronic heart failure a meta-analysis was conducted by Sbruzzi et al. (2010) in which functional EMS was observed to produce comparable increases to 6-min walk test, distance but a smaller gain in VO_2 max compared to conventional aerobic training.

Whole-body electromyostimulation augmented training has produced significant increases in VO_2 max in untrained elderly males suffering from the metabolic syndrome with the increases being significantly higher than those observed in a control group performing low intensity exercise on vibration plates (Kemmler and von Stengel., 2012b). Whole-body electromyostimulation training has also significantly increased VO_2 max as well as ventilatory threshold 1 (VT1), ventilatory threshold 2 (VT2) and running economy in male recreational runners (Amaro-Gahete et al., 2018a).

Amaro-Gahete et al. (2018a) also state that for the training to be effective at improving the aerobic fitness factors of VO_2 max, VT1, VT2 and running economy, it must incorporate functional exercises and a periodization of the electrical parameters. This was explored by Amaro-Gahete et al. (2018b) by comparing periodized and functional running training WB-EMS to traditional WB-EMS and observing significantly greater improvements in VO_2 max, VT1 and running economy in the periodized and functional running training group. The traditional WB-EMS consisted of 10 dynamic exercises, performed during a duty cycle of 4s: 4s, with a frequency of 85 Hz, impulse width of 350 µs and an impulse intensity of 60 mA and the total duration increasing from 12-min at the first training session to 20-min at the sixth training session (Amaro-Gahete et al., 2018b). The periodized and functional running WB-EMS split the training session into four separate phases all of which had a different total time, frequency (Hz), RPE and duty cycle (Amaro-Gahete et al., 2018b).

2.6.4 PHYSIQUE AND BODY COMPOSITION

Physique can be defined as the structure of the body (Dorland, Dzul and Zimenkovskyi, 2003) and body composition can be defined as separating total body mass into fat mass and fat free mass (Plowman and Smith, 2011).

When evaluating the studies on the effect of EMS on fat free mass WB-EMS augmented training done three times per two weeks significantly increases lean body mass in elderly females aged >70 at risk of sarcopenia (Kemmler et al., 2013) as well as in males aged 30-50 years (Kemmler et al., 2016a), although muscle mass

(Kemmler and von Stengel., 2012a; Kemmler and von Stengel., 2012b; Kemmler et al., 2013) and bone mineral density (Arija-Blázquez et al., 2014; von Stengel et al., 2015) appear to be unaffected. Arija-Blázquez et al. (2014) and Baldi et al. (1998) both observed significant increases in muscle mass following EMS application, however this was in patients who had suffered complete motor post-traumatic spinal cord injuries. Baldi et al. (1998) compared three groups, one control which performed no EMS training and two experimental groups, one which performed isometric EMS training, and one which had EMS applied whilst cycling on a cycle ergometer. A significant increase in lean body mass was observed in the EMS and cycling group whilst changes in the isometric group were not significant (Baldi et al., 1998). This is in contrast to Arija-Blázquez et al. (2014) who observed significant increases following isometric EMS application of the rectus femoris, vastus lateralis and vastus medialis, however the participants' knee angle was changed throughout the training.

In healthy males aged 23.5 ± 5.0 years significant increases to the anatomical cross-sectional area of the upper legs, determined with B-mode ultrasonography, has been observed following four ($p < 0.001$) and eight weeks ($p < 0.001$) of local EMS application of the upper legs (Gondin et al., 2005). No changes were observed in an inactive control (Gondin et al., 2005). Additionally, a meta-analysis by Kemmler et al. (2018b) states WB-EMS to be effective at improving muscle mass in untrained individuals. However, a meta-analysis by Maffiuletti et al. (2013) observed inconsistent changes in muscle mass following EMS application in intensive care unit (ICU) patients. The sarcopenic Z score has been shown to decrease significantly following both WB-EMS training and WB-EMS training combined with protein supplementation in woman (Kemmler et al., 2016b) and men (Kemmler et al., 2017a) older than 70 years suffering from sarcopenic obesity. This was attributed to an increase in skeletal muscle index (SMI) (Kemmler et al., 2016b).

When examining studies on the effect of WB-EMS on total fat mass, significant decreases have been observed in well trained postmenopausal woman (Kemmler and von Stengel 2012a), males aged 65-75 years suffering from the metabolic syndrome (Kemmler and von Stengel.,2012b) both of which trained every five days for 14-weeks as well as in sedentary males aged 30-50 years (Kemmler et al., 2016a) who trained three times per two weeks for a total of 16-weeks and in older men (aged > 70 years) suffering from sarcopenic obesity (Kemmler et al., 2018a). No significant changes, however, were observed in older females (aged >70 years) at risk of sarcopenia (Kemmler et al., 2013). Abdominal fat mass has also decreased significantly (Kemmler and von Stengel, 2012b) as has waist circumference (Kemmler and von Stengel, 2012a; Kemmler and von Stengel, 2012b; Wittman et al., 2016). A meta-analysis by Kemmler et al. (2018b) concluded that EMS training was effective at reducing both total and abdominal fat mass. EMS training applied in conjunction with aerobic training reduces fat mass more than aerobic training done on its own (Pano-Rodriguez et al., 2019).

A recent review by Stöllberger and Finsterer (2018) observed WB-EMS to be no more effective at improving body composition parameters than traditional resistance exercise training in healthy individuals. Another review has determined there to be no statistically conclusive changes in anthropometry following WB-EMS training due to the small effect size, large standard deviation (SD) and the low number of significant changes which were observed in the reviewed studies (Pano-Rodriguez et al., 2019).

2.6.5 METABOLISM

Metabolism refers to all energy transformations, anabolic and catabolic, that occur in the human body (Plowman and Smith, 2011). This section focuses on EMS effect on energy expenditure and the various hormonal responses.

As EMS is augmenting motor unit involvement during exercise, energy expenditure will be higher during acute exercise, it is unsurprising that energy expenditure increases when adjuvant EMS is applied in conjunction with other exercise, when compared to the same exercise done without EMS application (Kemmler et al, 2012; Jubeau et al, 2008). Total energy expenditure is significantly increased for up to 72 h, and resting metabolic rate for up to 48 h, following WB-EMS training (Teschler et al., 2017).

Similarly, again unsurprisingly, acute hormonal changes occur. Serum growth hormone, lactate and creatine kinase (CK) concentrations have increased significantly more following EMS augmented training in comparison to the same training done without EMS application (Jubeau et al., 2008). Following WB-EMS application in conjunction with jump training of 14-weeks, significant increases to CK levels were observed 24 hours after the first training session ($p < 0.01$) and 24 hours after training at week seven ($p < 0.05$) (Filipovic et al., 2016). CK levels were unchanged 24 hours after training following 14 weeks of WB-EMS training (Filipovic et al., 2016) The increase in CK levels can be four times higher than levels following completion of a marathon, mainly due to the large amount of muscle which is stimulated during EMS sessions (Teschler et al., 2016.).

There is evidence for a repeated bout effect as Wirtz et al. (2015), Teschler et al. (2016) and Filipovic et al. (2016) observed the post-training increases in CK to lessen over time. As there was a significantly lower increase in CK following 10-weeks, 12-weeks and 14-weeks of EMS augmented training respectively, when compared to increases observed after 1-week (Filipovic et al., 2016; Wirtz et al., 2015; Teschler et al., 2016.). Post-training lactate concentrations on the other hand are significantly higher following 12 weeks of EMS training, while no effects were observed to cortisol, growth hormone and testosterone levels after 12 weeks but did increase over time during each session (Wirtz et al., 2015; Kemmler et al., 2016a)

2.6.6 BLOOD FLOW

EMS application appears to increase blood flow to the area of application. EMS of the gluteal muscles has significantly increased blood flow to the gluteal muscles in both healthy participants ($p < 0.05$) and participants suffering from spinal cord injury ($p = 0.12$) at or above thoracic vertebrae number 7 (T7) (Levine et al., 1990). Menendez et al. (2016) compared the effects of both combined EMS of the gastrocnemius and whole-body vibration as well as whole-body vibration and EMS in isolation, on blood flow to the lower legs. Mean and peak blood flow increased significantly in each condition but was highest in the combined whole-body vibration and EMS, however it is not stated whether there was any significant difference between the test conditions (Menendez et al., 2016).

2.6.7 RANGE OF MOTION

EMS in conjunction with proprioceptive neuromuscular facilitation (PNF) stretching has increased ROM (range of motion) to a greater extent than either EMS or PNF stretching done in isolation (Hansen, 2015). PNF stretching in conjunction with EMS is done by applying EMS to a single muscle group e.g. the quadriceps and when the electrical impulse is switched off, the participant will lengthen the antagonist, in the case of this example, the hamstrings (Hansen, 2015).

2.6.8 BALANCE

Mignardot et al. (2015) explored the effects of four-weeks of NMES training of the plantar flexors, at a frequency of three sessions per week, on limit of stability and musculotendinous stiffness and compared these effects to a control group who maintained their habitual lifestyle. The NMES group consisted of nine pre-frail females aged 82.2 ± 4.4 years, who had a significantly (p = 0.001) lower limit of stability and musculotendinous stiffness (p = 0.003) compared to the control group, which consisted of seven non-frail females aged 74 ± 4.6 years at the pre-testing (Mignardot et al., 2015). At the post-testing the NMES group had improved and the differences to limit of stability (p= 0.051) and musculotendinous stiffness (p = 0.978) were no longer significant (Mignardot et al., 2015). It is stated that the improvements to biomechanical and muscular properties were directly transferable to a functional context which improved limit of stability and musculotendinous stiffness (Mignardot et al., 2015). A recent meta-analysis states that to improve dynamic and static balance the exercises performed during training should be specialised towards that goal although the studies which this statement is based upon are not cited (Kemmler et al., 2018b).

2.6.9 REHABILITATION

EMS has been used as a rehabilitation tool, mainly for patients that cannot perform voluntary contractions and should be implemented in the early phases of rehabilitation when voluntary contraction is still not possible (Vanderthommen and Duchateau, 2007). The effects of EMS on patients recovering from total knee replacement, anterior cruciate reconstruction, meniscal injuries, knee osteoarthritis and stroke have been studied (Lategan et al., 2014), as well as EMS effects on patients who suffer from chronic heart failure, chronic obstructive pulmonary disease or those who are critically ill (Veldman et al., 2016). EMS has been used therapeutically as a treatment for hemiplegic shoulder pain, cardiovascular conditioning, spasticity, retarding muscular atrophy, osteoporosis and deep venous thrombosis (Sheffler & Chae. 2007). In clinical settings, electrical stimulation can be used for improving or maintaining muscle strength (Burke et al., 2016; Douceta et al., 2012) as well as increasing ROM, reducing oedema, healing tissue, and decreasing pain (Douceta. et al., 2012).

Handgrip strength has been observed to increase non-significantly following 12-weeks of WB-EMS training and nutritional supplementation in patients suffering from advanced solid tumors (stage three and four) (Schink et al., 2018). Significant increases to distance during the 6-min walk test were observed by Schink et al. (2018), with a WB-EMS and nutritional support group improving distance during the 6-min walk test significantly more than a control which only received nutritional support. Schink et al. (2018) also observed functional performance (evaluated via the Karnofsky Index) to increase significantly more in the WB-EMS and nutritional support group compared to the nutrition only control group.

Although EMS does not appear to significantly increase muscle mass in healthy populations as discussed in section 2.6.4 there is evidence of increases in muscle mass observed in participants in rehabilitation settings. In patients who had suffered complete motor post-traumatic spinal cord injuries between thoracic vertebrae number 4 (T4) and thoracic vertebrae number 12 (T12) (Arija-Blázquez et al., 2014) a significant increase to the cross-sectional area of the thigh was observed. A meta-analysis by Thomaz et al. (2019) on six studies, observed EMS to be effective at increasing muscle volume but had no effect on spasticity in patients suffering from both complete and incomplete spinal cord injury. Patients undergoing rehabilitation for anterior cruciate ligament (ACL) injuries, whose rehabilitation incorporated adjuvant EMS from the 2nd post-operative day until 4 weeks after the surgery, presented an increase in rectus femoris, vastus lateralis, vastus medialis and calf muscle thickness whereas those only performing ACL rehabilitation without EMS showed a significant reduction in muscle thickness (Hasegawa et al., 2011). A systematic review by

Maffiuletti et al. (2013) observed EMS to significantly increase muscle strength in patients in the ICU however changes in muscle mass were inconsistent. While Adams et al. (2018) state that EMS training positively affects muscle mass and function. So far as decreasing muscle atrophy following injury is concerned it is important to begin the EMS stimulation as soon as possible following said injury (Baldi et al., 1998) as if EMS is applied following extended disuse it becomes ineffective.

A meta-analysis by Sbruzzi et al. (2010) stated that functional electrical simulation (FES) could be used as an alternative to conventional aerobic training in patients suffering from chronic heart failure and Veldman et al. (2016) observed low frequency EMS to be most effective for increasing VO_2 max, however no information regarding frequency or duration of training was presented. Whole-body electromyostimulation training has also been observed to decrease lower back pain (Kemmler et al., 2017b; Kemmler et al., 2018b). FES has also been observed to increase muscle strength, ROM, circulation and blood flow (Douceta et al., 2012). Reductions to spasticity, pain and muscular atrophy have also been observed as well as the healing of tissue (Douceta et al., 2012).

EMS can also be used as an aid to active recovery methods, by applying low-intensity impulses to large muscle groups which increases the circulatory effect of active recovery while also dilating blood vessels which will increase blood flow and nutrient transport (Hansen, 2015). EMS should always be used as an aid to active recovery rather than replacing it as EMS is not as effective full body aerobic recovery work (Hansen, 2015).

2.7 ADVANTAGES AND DISADVANTAGES OF EMS APPLICATION

The main reported advantage to WB-EMS application is time saving, with the frequency of exercise described as *'rather low'* by Kemmler et al. (2012a) and Kemmler et al. (2012b). As well as a low frequency of exercise the duration of a single EMS training session is also quite low compared to traditional exercise (Seyri and Maffiuletti, 2011). Kemmler et al. (2013) described WB-EMS training as a time saving alternative for those individuals unwilling or unable to take part in traditional exercise programs.

EMS can also be used as a bridge for more conventional or complex exercise training (Adams et al., 2018). Seyri and Maffiuletti (2011) state that EMS should be considered as a supplement to traditional training even for elite athletes.

For patients suffering from chronic heart failure, or other illnesses which prevent exercise, FES can be used as an alternative to aerobic exercise (Sbruzzi et al., 2010; Veldman et al., 2016).

The main disadvantage would appear to be the high costs involved (Kemmler at al., 2013; Kemmler et al., 2016a). There is also the risk of rhabdomyolysis due to significantly higher CK (Filipovic et al., 2011) levels which is due to the simultaneous activation of up to 2800 cm^2 of muscle mass, however this will only occur if an inappropriately high stimulation intensity is applied (Kemmler et al., 2018b). Even when CK levels have become high enough to signify rhabdomyolysis, following EMS application, the expected health implications were not observed (Teschler et al., 2016).

EMS is becoming more popular as a means to impact muscle mass and function (Adams et al., 2018).

CHAPTER 3: METHODOLOGY

In this chapter, the methods and procedures used for the testing of participants and data collection and analysis will be discussed.

3.1 RESEARCH APPROACH AND STUDY DESIGN

This was a longitudinal, experimental, quantitative, pre-test post-test, randomized, control group design, with two groups (one control and one experimental) (Hopkins, 2008). Quantitative research designs, as the name implies, are used for the measurement of quantities, i.e. amounts which can be expressed numerically (Kothari, 2004). The experimental condition involved 18 WB-EMS augmented calisthenic exercise training sessions over a 10-week period, while the control condition involved 18 calisthenic exercise training sessions over a 10-week period. All participants (control and experimental groups) were required to complete at least 15 of the 18 prescribed exercise sessions during the 10-week intervention period for their data to be included in the study. Changes in physical fitness scores observed in the control group were compared to the changes observed in the experimental group in order to isolate the effect of the augmented WB-EMS application.

3.2 ETHICAL APPROVAL AND CONSIDERATIONS

The research proposal was submitted to the MSc Committee and the Research Ethics Committee of the Faculty of Health Sciences, University of Pretoria (protocol number 399/2017). Participant recruitment and subsequent data collection commenced once both of these committees provided written approval. The researcher conducted the research according to the University of Pretoria's code of ethics for research (Appendix C).

Individuals who met the inclusion criteria listed in section 3.4.1 were emailed an information form and an informed consent form (Appendix D and E) describing the procedures, methods, aims and possible risks and benefits of participating in the study. The informed consent form also explained the voluntary nature of the study and that participants were free to withdraw at any time without facing any penalty. If any participant withdrew from the study before completing the minimum of 15 out of the 18 prescribed exercise training sessions, their data was destroyed and not included in the analysis. Participant personal details were kept confidential at all times and were only known to the researcher and supervisors. Participant data was numerically coded rather recorded by name to ensure that all collected data was analysed anonymously. The intervention involved in this study was considered to confer minimal risk to the participants, and the researcher had two years' experience in administering this type of exercise programme. All exercise sessions forming part of this study were provided to all participants free of charge. Additionally, on conclusion of the 10-week training prescription, participants in the control group were offered the option of completing 18 WB-EMS sessions at no charge, provided they had completed a minimum of 15 exercise sessions. All data collected during this study will be stored in original format for 15 years in the Division of Biokinetics and Sport Science, Department of Physiology. The information will only be available on request from the researcher, supervisors or statistician involved in this study.

3.3 SETTING

Pre- and post-intervention testing sessions were completed at the High Performance Centre of the University of Pretoria (Burnett Street, Hatfield, Pretoria, 0186), the site depicted in Figure 3.1 and 3.2. The intervention (10 weeks of exercise training in the control or experimental condition) took place at the Bodytec® Faerie Glen studio (649 Vercueil Street, Garsfontein, Pretoria, 0167), the site depicted in Figure 3.3 and Figure 3.4.

Figure 3.1: University of Pretoria, High Performance Centre

Figure 3.2: University of Pretoria, High Performance Centre exam room

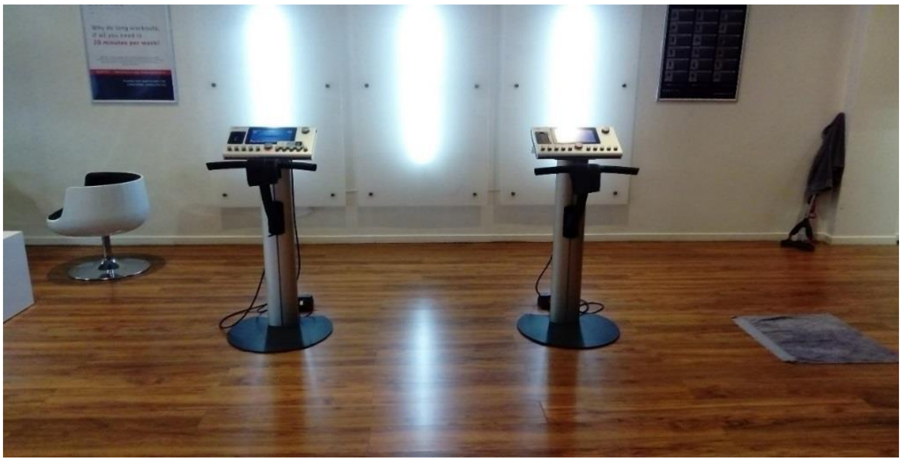

Figure 3.3: Bodytec® Faerie Glen studio

Figure 3.4: Bodytec® Faerie Glen Studio

3.4 PARTICIPANT RECRUITMENT AND RANDOMIZATION

Participants for this study were recruited via advertisements in the form of flyers (Appendix A) which were distributed at businesses close to the Bodytec® Faerie Glen studio where the intervention period took place. Digital copies of the flyers were also emailed, initially to clients of the Bodytec® Faerie Glen Studio who were asked to spread the flyers to colleagues, family and friends. Existing clients of the Bodytec® Faerie Glen Studio were informed that they could not take part themselves. Volunteers were then contacted directly by the researcher either via email or telephone. The flyers were designed to target sedentary females aged between 35 and 55 years. The inclusion and exclusion criteria used for this study are outlined under sections 3.4.1 and 3.4.2 respectively. A self-report questionnaire (Appendix B) was used to determine whether volunteers qualified to participate in the study, by determining whether they met the necessary inclusion criteria and were free of the exclusion criteria. Overall 68 individuals volunteered and 14 were excluded due to not meeting the inclusion criteria. Thus, a total of 54 volunteers met the inclusion criteria and were included in the study.

3.4.1 INCLUSION CRITERIA

Volunteers were required to meet the following inclusion criteria in order to participate in the study:

- Female
- Aged between 35 and 55 years
- Activity level: sedentary i.e. accumulating less than 60 min of exercise per week (Bennett et al., 2006)
- Agreed to comply with experimental procedures by reading the information sheet and completing and signing an informed consent form (Appendix E).

3.4.2 EXCLUSION CRITERIA

Volunteers were excluded from participating in the study if they presented with, or developed during the course of the study, any one or more of the following exclusion criteria, which closely follow recommendations made by commercial electromyostimulation (EMS) providers (BODYTEC® Your Time Your Fitness (cc), Cape Town, South Africa). The criteria were listed on the self-report questionnaire (Appendix B).

- Neurological disorder (e.g. epilepsy)
- Circulatory disorder (e.g. stroke, stent, thrombosis and cardiovascular disease.
- Pregnant, or within eight weeks post-partum
- Hernia (e.g. inguinal, abdominal)
- Acute surgery within eight weeks prior to the study
- Bleeding disorder (e.g. haemophilia)
- Chronic disease (e.g. arthritis, cancer)
- Acute infection (e.g. bacterial, viral infection). If a volunteer had an infection upon completion of the self-report questionnaire but was free from all other exclusion criteria, they were asked to wait until they had recovered and then complete the self-report questionnaire again. Participants that developed infections during the intervention period were advised not to exercise until they had recovered from said infection.
- Accumulating more than a total of 60 min of exercise per week.

Fourteen volunteers were excluded; for already exercising more than 60 min per week (7), illnesses preventing participation (5), age (2) and inability to commit to 10weeks of continuous exercise (2). One volunteer was both too young and exercised too much and one other volunteer exercised too much and couldn't commit to 10 consecutive weeks of training. Prior, recent or current participation in EMS-style exercise was not considered as an included as exclusion criterion. One participant mentioned they had tried EMS training once before. Besides that, none of the other participants mentioned ever experiencing EMS-style exercise.

3.4.3 GROUP RANDOMIZATION

Participants were assigned numbers as they were recruited, i.e. the first participant which was recruited was assigned the number one and the last participant to be recruited was assigned the number 54. To divide the sample and reduce bias a simple random sampling method known as the 'fishbowl technique' was used (Brink et al., 2012). Individual pieces of paper where marked with numbers from one to 54 and then placed into a bowl. Half (27) of these pieces of paper were then randomly removed from the bowl. Those numbers which were removed from the bowl formed the experimental group and those remaining in the bowl formed the control group.

3.5 PRE- AND POST-INTERVENTION MEASUREMENT

Measures of selected physical fitness attributes were collected from the study participants twice: once at the pre-intervention assessment which took place two weeks prior to the start of the intervention, and once at the post-intervention assessment which took place one week after completion of the 10-week intervention period. Specific procedures involved in each assessment are provided below.

3.5.1 PHYSIQUE

Body mass was measured using a Seca 703 electronic scale (Delta Surgical S A (Pty) Ltd, Johannesburg, South Africa). After the researcher ensured the scale was correctly reading zero, the participant stood on the centre of the scale with their weight distributed evenly between both feet, and body mass was recorded to the nearest 0.1 kg (International Society for the Advancement of Kinanthropometry, 2001).

Stature was measured using a Seca 217 Leicester Height Measure (Seca Limited (Pty) Ltd, Birmingham, UK). The researcher raised the stadiometer head piece allowing the participant to stand below it with their feet pointing slightly outward and their heels, buttocks, shoulder blades and the back of their head all in contact with the stadiometer's backboard. Once the researcher ensured the horizontal line between the ear canal and lower border of the orbit of the eye was parallel to the ground and perpendicular to the stadiometer's backboard, the stadiometer head piece was lowered to slightly compress the participants hair after which the participant took a deep breath and stature was recorded to the nearest 0.1 cm (National Health and Nutrition Examination Survey, 2007).

Body mass index was determined by dividing body mass in kg by stature in m, squared (Esmat, 2016).

The circumference around both the waist and the hip were measured using a measuring tape (Cescorf Equipamentos Para Esporte Ltda Me, Porto Alegre, Brazil). Once the researcher ensured the participant was standing on a flat stable surface with their feet close together and their arms hanging at their sides, waist circumference was measured approximately at the midpoint between the lower margin of the last palpable rib and the top of the iliac crest and hip circumference was measured at the maximum protuberance of the buttocks, while the measuring tape was kept level and parallel to the ground (WHO, 2008).

The researcher calculated waist-hip ratio by dividing waist circumference by hip circumference (WHO, 2008).

3.5.2 STRENGTH

Maximum isometric handgrip strength was measured using a T.K.K. 5401 Grip D (Takei Scientific Instruments Co., (Pty) Ltd, Niigata, Japan) dynamometer. The participant sat in a chair with back support and fixed arm supports, resting their forearms on the arms of the chair with their wrists hanging over the edge and their hands in a neutral position (thumbs facing up). Once the researcher had ensured the dynamometer was correctly reading zero the participant performed three attempts with each hand, squeezing the dynamometer as hard as possible for three to five seconds, after which the value (kg) was recorded (Roberts et al., 2011).

Maximum isometric leg-and-back strength was measured using a T.K.K. 5401 Back D (Takei Scientific Instruments Co., (Pty) Ltd, Niigata, Japan) dynamometer. Once the researcher had ensured the dynamometer was correctly reading zero, the participant stood on the dynamometer platform, bent their knees to about 110° (measured with a goniometer) and leant forward to grip the dynamometer handle with their arms and back straight, palms facing toward their bodies and their head kept upright and looking forward. The participant then performed three attempts, pulling as hard as possible for three to five seconds without bending their arms or back, and the value (kg) was recorded (Blackburn, 2000).

3.5.3 BALANCE

A FR test was used to evaluate dynamic balance (Duncan et al., 1990). The participant stood with their right side adjacent to a wall, their feet shoulder width apart and the arm closest to the wall lifted to 90° (i.e. shoulder flexed so that the arm is parallel to the ground) and hand closed in a fist. The researcher marked the wall with a pencil at the participant's third metacarpophalangeal joint. Then using the pencil mark as the starting point, the participant leant forward, for three attempts, as far as possible without taking a step or losing their balance, and their furthest reach was measured to the nearest 0.1 cm again at the third metacarpophalangeal joint. The distance between the first pencil mark on the wall and the three test reaches was then measured (Duncan et al., 1990).

3.5.4 AEROBIC ENDURANCE

Aerobic endurance was assessed using the Cooper 12-min run test. Once the researcher had ensured the Sanji 5000 model stopwatch (Casio Computer co., Ltd. Tokyo, Japan) was set to zero the participant was timed for 12 min as they ran, or walked if they were too tired to run, as far as possible around a 400 m grass athletics track. The distance covered by the participant was then recorded to the nearest meter (Bandyopadhyay, 2015). This distance was then used to estimate maximum oxygen consumption (VO_2 max) by applying the equation: VO_2 max (mL/kg/min) = (22.351 x distance covered in kilometres [km]) – 11.288 (Cooper, 1968).

3.5.5 WB-EMS FEEDBACK QUESTIONNAIRE

At the post-testing, those participants who were in the experimental group also completed a post intervention questionnaire (Appendix F) which was focused on their personal experience of the WB-EMS augmented calisthenic training. The questionnaire consisted of 5 questions on a Likert scale with options from 1 (very poor) to 5 (exceptional) for the participant to choose from. The questionnaire also contained a section for any general comments the participant may have had regarding the WB-EMS augmented calisthenic training.

3.6 WB-EMS INTERVENTION PROGRAMME

The intervention period began two weeks after the pre-test had been completed.

3.6.1 FAMILIARIZATION

One week prior to the onset of training, the WB-EMS group underwent a familiarization session which took 10 min to complete. Participants were appropriately fitted with the WB-EMS jacket and associated electrode belts with the help of the researcher, and the sizes of the jackets and pads worn by each participant were recorded so that the sizes would not have to be re-established at each subsequent training session.

During the first 5 min of familiarization, the EMS impulse strength for the different muscle areas (upper legs, gluteals, abdominals, latissimus dorsi, upper back, chest and upper arms) was determined. The participant was shown the Borg CR-10 scale (Borg, 1998) and the various levels on the scale were described to the participant. It was then explained that the electric impulse applied to each muscular area would be slowly increased, causing the muscles to contract. The WB-EMS equipment of miha bodytec® (miha bodytec (Pty) Ltd, Augsburg, Germany) uses a numerical scale, ranging from 0-99 to regulate the impulse intensity to each muscular area. As the impulse intensity of the device was increased, the intensity of the muscular contractions would also increase. Participants were instructed to aim for a contraction intensity of 6 out of 10 on the Borg CR-10 scale (Borg, 1998). The impulse intensities for each muscular area, in the 0-99 range, were then recorded and used as baseline values for the subsequent training sessions. Furthermore, at each subsequent exercise training session after the familiarization, participants were asked if the intensities in any specific muscular area needed to be adjusted in order to maintain an RPE score of 6 out of 10 for the entirety of the 10-week training prescription. The Borg CR-10 scale (Borg, 1998) is a subjective rating scale. Similar subjective scales have been used previously in EMS studies (Kemmler and von Stengel, 2012a; Kemmler and von Stengel, 2012b; von Stengel et al., 2015; Wirtz et al., 2015; Wirtz et al., 2016). Subjective rating scales are used rather than simply applying maximum intensity to allow for movement when superimposed EMS is applied in conjunction with dynamic exercise, as described by Wirtz et al. (2015). The intensity of the impulse to each muscle area was increased individually until the participant felt they had reached an RPE of 6 out of 10, a classification of 'hard' on the Borg CR-10 scale (Borg, 1998) as done previously by Kemmler et al. (2016).

The second 5 min of the familiarization session were used to allow the participants to experience the 4-s on-and-off cycling of the EMS impulse, and for initial explanation and practice of the calisthenic exercises that were to be done during the prescribed exercise sessions of the intervention period. Establishing the baseline intensities and the initial practicing of the exercises were done under the supervision and instruction of the researcher.

Participants in the control group also undertook a familiarization session one week prior to the onset of the intervention. The participants were dressed into the jacket and various pads with the help of the researcher, and the sizes of the pads worn by each participant were recorded so that the sizes would not have to be re-established at each subsequent training session. As the participants in the control group trained without any electrical impulse, they did not have to establish baseline intensities for each muscle area and simply spent 5 min practicing the different calisthenic exercises, and getting used to the 4-s on-and-off cycling of the exercise repetitions, under the supervision and instruction of the researcher.

3.6.2 EXPERIMENTAL GROUP

Participants in the experimental group were prescribed eighteen 20-min exercise training sessions for a period of 10 weeks, making use of the miha bodytec® (miha bodytec (Pty) Ltd, Augsburg, Germany) training device, jacket and belts. For the first five weeks of the intervention, training was completed on three occasions within a fortnight with 3 or 4 days between sessions to allow sufficient time for recovery. During the second five weeks, two sessions were completed per week with 2-3 days between sessions, for a total of 18 prescribed exercise training sessions over the 10 weeks. The EMS impulse was cycled on for 4 s and off for 4 s for the entirety of the 20 min exercise session. During the 4 s when impulse was delivered, participants were instructed to perform bodyweight (calisthenic) exercises without the use of any additional weights or equipment. The exercises which were performed are listed in Table 3.1. The impulse intensity was regulated for each participant individually during each session to maintain an RPE of 6 out of 10 for the entirety of the session.

3.6.3 WHOLE-BODY ELECTROMYOSTIMULATION (WB-EMS)

The EMS impulses were delivered via the use of the miha bodytec® (miha bodytec (Pty) Ltd, Augsburg, Germany) training device (Figure 3.5) which was plugged into a jacket (Figure 3.6) containing electrodes and electrode belts (Figure 3.7). The device delivers an electrical impulse of 85 Hz (Kemmler et al., 2014; Kemmler et al., 2016; Kemmler and von Stengel, 2012a; Kemmler and von Stengel, 2012b) through the electrodes superficially to the body surface adjacent to the underlying skeletal musculature, which causes the muscles to contract. There are 10 electrodes within the jacket which were positioned to stimulate the muscles of the chest, abdominal wall, latissimus dorsi and the lower and upper back. Five electrode belts were used to stimulate the muscles of the upper legs and arms, and the buttocks. The leg and arm belts were placed midway along the upper legs and the upper arms respectively. The buttocks belt, with its two electrodes, was placed over the buttocks and was fastened in front of the pelvis. The EMS impulse intensity for each muscular area (upper legs, buttocks, lower back, upper back, latissimus dorsi, abdominals, chest and upper arms) can be individually and independently adjusted through switches on the training device which correspond to the different areas. Added to this is a switch (overall) which corresponds to all the muscular areas and can be used to adjust them simultaneously.

Figure 3.5: miha bodytec® (miha bodytec (Pty) Ltd, Augsburg, Germany) training device. www.careersinfitnessltd.co.uk

Figure 3.6: miha bodytec® (miha bodytec (Pty) Ltd, Augsburg, Germany) electrode jacket. www.advertise.ie

Figure 3.7: miha bodytec® (miha bodytec (Pty) Ltd, Augsburg, Germany) electrode pads. www.cyprus24.net

3.7 CONTROL GROUP

The control group performed the same prescribed exercises as the experimental group for 10 weeks and worked to the same rhythm (4 s of exercise, 4 s of rest) and frequency (number of sessions per week) of training as the WB-EMS group. The control group also wore the same jacket (Figure 3.4) and electrode belts (Figure 3.5) as those participants in the WB-EMS group, but no electrical stimulation was applied. This isolated the effect of the WB-EMS and ensured that any observed changes could be attributed only to the WB-EMS.

3.8 EXERCISE PRESCRIPTION

All participants completed the same set of exercises in the same order. The exercises prescribed are listed in Table 3.1 and described thereafter. There were 13 different exercises: 10 exercises were completed for 8 repetitions each and 3 exercises were completed for 16 repetitions each. Exercises were done at a rhythm of 2-s concentric, 2-s isometric, and 1-s eccentric, i.e. when the 4-s impulse was activated, the movement was done for 2-s, then held for 2-s after which the impulse cycled off for 4-s, and the participant returned to their starting position. The entire exercise set was completed in 20 min. For the first 90-s of the training session participants assumed a position standing with the feet shoulder width apart, knees slightly bent and toes facing forward. The hands were clasped with the upper arms parallel to the ground and the elbow joint bent at 90°. This position was assumed to allow for the initial increase of the electrical impulse, which began with no impulse, i.e. an RPE of 0 on the Borg CR-10 scale (Borg, 1998) and was slowly turned up for each muscular area until the participant was at an intensity of 6 out of 10 on the Borg CR-10 scale (Borg, 1998). After this initial 90-s, period once the participants confirmed an intensity of 6 out of 10 on the Borg CR-10 scale, they began performing the exercises listed in table 3.1. This position was also assumed between each exercise set to allow the researcher time to explain and demonstrate the next exercise. Exercises were selected using the studies by Kemmler et al. (2012) and Kemmler et al. (2016a) as guides.

Table 3.1. Calisthenic (bodyweight) exercises completed during training sessions

Exercise	Repetitions
Squat (down), latissimus pull down	8
Squat (up), upward rowing	8
Squat (down), chest press	8
Squat (up), shoulder press	8
Half squat, crunch	8
Lunges	16 (8 on each side)
Squat (down) bicep curl	8
Half squat, Russian twist	16 (8 on each side)
Squat (up), reverse fly	8
Squat (down), front fly	8
Squat (down), shoulder front raise	8
Squat (up), triceps extension	8
Side crunch	16 (8 on each side)

Exercises adopted from Kemmler et al. (2012) and Kemmler et al. (2016a)

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Table 3.2. Description and pictures of calisthenic exercises completed during training sessions

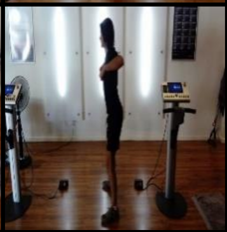
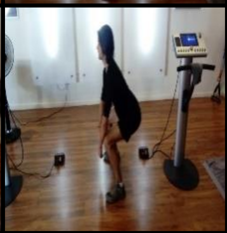
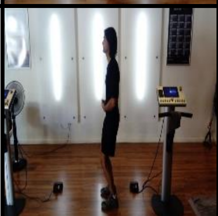
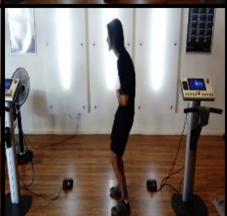
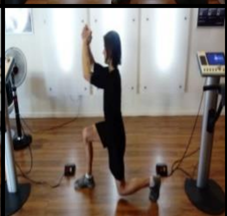
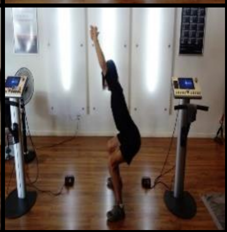
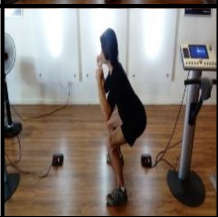
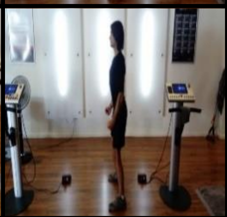
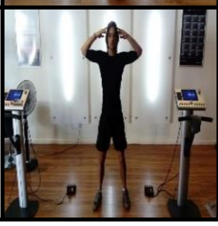
Exercise name	Starting Position	Movement	Exercise description
Squat (down), Latissimus pull down			Starting position – Standing with the knees bent at 90°, the feet shoulder width apart and the arms extended in front of the body. Movement – Extend the knees to 180° to lift the body. At the same time, the elbows are flexed to 90° pulling the arms upward.
Squat (up), Upward rowing			Starting position – Standing upright with the feet shoulder width apart, and the shoulders abducted with the elbow joint flexed at 90° and the upper arms facing forward. Movement – Bend the knees to 90° to lower the body. At the same time extend the elbows to 180° touching the hands together.
Squat (down), chest press			Starting position – Standing with the knees bent at 90°, the feet shoulder width and the shoulders abducted, with the elbows flexed at 90° and the lower arms facing upward. Movement – Extend the knees to 180° to lift the body. At the same time extend the elbows to 180° straightening the arms.
Squat (up), shoulder press			Starting position – Standing with the knees slightly bent, the feet shoulder width apart and the hands clasped in front of the naval. Movement – Flex the trunk, to lower the upper body towards the knees.
Half squat, crunch			Starting position – Standing upright with the legs split one in front of the other and the hands clasped in front of the body with the elbows flexed to 90°. Movement – Bend the knees to 90° to lower the body.
Lunges			Starting position – Standing upright with the feet shoulder width apart and the arms extended at the sides. Movement – Bend the knees to 90° to lower the body. At the same time flex the elbow to 90°.
Squat (down) bicep curl			Starting position – Standing with the knees slightly bent, the feet shoulder width apart and the hands clasped in front of the body with the elbows flexed to 90°. Movement – Rotate the trunk to one side as far as possible without moving the lower body.

Table 3.2 (cont.). Description and pictures of calisthenic exercises completed during training sessions

Exercise name	Starting Position	Movement	Exercise description
Half squat, Russian twist			Starting position – Standing with the knees bent to 90°, the feet shoulder width apart and the shoulders and elbows flexed to 90°. Movement – Extend the knees to 180° to lift the body. At the same time abduct the shoulders horizontally.
Squat (up), reverse fly			Starting position – Standing upright with the feet shoulder width apart and the shoulders horizontally abducted with the elbows bent to 90°. Movement – Bend the knees to 90° to lower the body. At the same time horizontally adduct the shoulders to bring the arms together.
Squat (down), front fly			Starting position – Standing upright with the feet shoulder width apart and the hands clasped in front of the body with the elbows extended. Starting position – Standing upright with the feet shoulder width apart and the hands clasped in front of the body with the elbows extended.
Squat (down), shoulder front raise			Starting position – Standing upright with the feet shoulder width apart and the hands clasped in front of the body with the elbows extended. Movement – Bend the knees to 90° to lower the body. At the same time flex the shoulders to 180° to lift the arms over the head.
Squat (up), triceps extension			Starting position – Standing with the knees bent to 90°, the feet shoulder width apart, and the elbows flexed to 90°. Movement – Extend the knees to 180° to lift the body. At the same time extend the elbows to 180° to straighten the arms.
Side crunch			Starting position – Standing upright with the feet shoulder width apart and the hands placed palm down on the back of the head. Movement – Flex the trunk laterally as far as possible to one side.

3.9 DATA ANALYSIS

The data from this research was captured manually by the researcher and converted into a digital format before detailed analysis. All data was recorded and transferred to a Microsoft Excel (Microsoft Corporation, Redmond, USA) spreadsheet. The continuous variables are reported using mean and SD. The categorical variables obtained from questionnaires are described using frequencies and proportions (percentages). Alpha level was set at 0.05. Repeated measures analysis of variance (ANOVA) was used to test for the significance of differences between the experimental and control groups, and where appropriate, t-tests were used to compare the experimental and control groups. Cohen's d was calculated to indicate the effect size of the differences observed between groups for each outcome variable. The analysis was completed using STATA 14 software (StataCorp LP, College Station, USA).

CHAPTER 4: RESULTS

4.1 INTRODUCTION

Of the entire cohort of volunteers (n = 54; mean ± SD age: 43.2 ± 5.9 years), 20 participants in the control group (mean age: 42.6 ± 6.2 years) and 19 in the WB-EMS group (mean age: 43.9 ± 5.7 years) completed the pre-test, 10-week intervention period, and post-test. This chapter will provide the descriptive results and analytical findings of the main research questions based on the participants who completed the trial and adhered to the procedures. Attendance to the sessions was high in both the WB-EMS group, at 89%, and in the control group at 86%. Five participants withdrew immediately following the pre-test and their data was therefore destroyed. Over the course of the study another 10 participants (control group, n = 4; WB-EMS group: n = 6) discontinued participation for various reasons. Five participants withdrew due to being unable to attend the training sessions. Injuries unrelated to the WB-EMS augmented calisthenic training, but which hindered participants' ability to take part in training caused the withdrawal of three participants. Two participants did not complete the minimum number of training sessions stipulated for inclusion in the study (15 out of a total of 18, or 83.3%), and therefore their data was destroyed.

The between-group differences and within-group changes for the physique variables are presented in Table 4.1. Results for maximum leg-and-back and handgrip strength are detailed in Table 4.2, and aerobic endurance in Table 4.3. Figure 4.1 details the results of the FR test and Figure 4.2 summarizes the results of the post-intervention questionnaire.

4.2 PHYSIQUE

None of the physique variables showed any significant between-group differences in 10-week responses (Table 4.1). Within-group analysis showed that mass increased significantly in the WB-EMS group by 1.6% ($p = 0.014$), as did BMI by 1.5% ($p = 0.021$). In the control group, waist girth and waist-hip ratio both showed significant decreases of 3.6% ($p = 0.011$; d = 0.63) and 3.8% ($p = 0.007$; d = 0.67) respectively.

Table 4.1. Between-group differences and within-group changes in physique

Variable	Control group				WB-EMS group				Difference between within-group changes (mean)	Between-group difference (*p* value)	Cohen's d
	Pre (mean ± SD)	Post (mean ± SD)	Within-group change (*p* value)	Cohen's d	Pre (mean ± SD)	Post (mean ± SD)	Within-group change (*p* value)	Cohen's d			
Mass (kg)	79.97 ± 12.44	80.68 ± 12.56	0.055	-0.46	77.37 ± 17.32	78.61 ± 18.01	0.014*	-0.62	0.52	0.482	0.92
Stature (cm)	165.98 ± 5.90	166.01 ± 5.97	0.720	-0.82	165.04 ± 4.85	165.11 ± 4.88	0.170	-0.33	-0.04	0.329	0.76
BMI (kg/m_2)	29.07 ± 4.67	29.32 ± 4.68	0.052	-0.46	28.48 ± 6.74	28.91 ± 6.97	0.021*	-0.58	0.18	0.474	0.91
Waist girth (cm)	90.49 ± 11.23	87.27 ± 9.99	0.011*	0.63	87.59 ± 13.64	86.06 ± 16.21	0.207	0.30	-1.69	0.347	0.96
Hip girth (cm)	110.97 ± 10.10	111.20 ± 10.02	0.720	-0.81	110.60 ± 13.63	110.44 ± 12.48	0.773	0.07	-0.39	0.800	0.48
Waist-hip ratio	0.82 ± 0.08	0.78 ± 0.06	0.007*	0.67	0.79 ± 0.05	0.77 ± 0.06	0.186	0.32	-0.01	0.480	0.94

* Significant change ($p<0.05$), Abbreviations: WB-EMS, whole-body electromyostimulation; SD, standard deviation; BMI, body mass index

4.3 MAXIMUM STRENGTH

The WB-EMS group had a significant within-group increase and a large effect size in maximum leg-and-back strength (p = 0.001; d = 0.87). Leg-and-back strength also increased significantly (p = 0.043; d = 1.46) more in the WB-EMS group (17.4%) compared to the control group (2.2%). Neither right (p = 0.912; d = 0.03; p = 0.922; d = 0.03) nor left (p = 0.110; d = 0.37; p = 1.000; d = 0.03) handgrip strength demonstrated any significant change in either the control or WB-EMS groups respectively. There was no significant difference in right or left handgrip strength (p = 0.844; p = 0.103) in the responses to the intervention between the two groups although medium (d = 0.62) and large (d = 1.07) effect sizes were observed respectively (Table 4.2).

4.4 FUNCTIONAL REACH

Functional reach distance increased in the WB-EMS group by 12.1%, representing a significant (p < 0.001; d = 0.96) within-group difference, while the control group only increased by 1.3% (p = 0.662; d = 0.09). The between group difference was not significant but a large effect size was observed (p = 0.06; d = 1.39) (Figure 4.1).

4.5 AEROBIC ENDURANCE

Three participants in the control group and one participant in the WB-EMS group did not complete the aerobic endurance post-test due to illness (three) and injury (one) which prevented participation in the Cooper 12-min run test. After 10-weeks no significant difference in distance covered or estimated VO_2 max was observed between the WB-EMS and control groups (p = 0.488; d = 0.48). Only the control group displayed significant increases in total distance completed (p = 0.023) and estimated VO_2 max (p = 0.023) a medium effect size was observed (d = 0.48) (Table 4.3).

4.6 POST INTERVENTION QUESTIONNAIRE

The post-intervention questionnaire was only completed by the participants in the WB-EMS group, with 78.9% reporting the equipment was comfortable to wear, 89.5% reporting they enjoyed the WB-EMS augmented calisthenic training, and 94.7% reporting a positive general perception of WB-EMS augmented calisthenic training.

Only 52.6% found the electrical stimulation comfortable, while 47.4% gave a neutral response. When asked if they would like to continue with WB-EMS augmented calisthenic training 63.2% of participants reported they would, 15.8% said they would not, and 21.1% gave a neutral response.

Of the 19 participants in the WB-EMS group, ten (10) filled out the comments section of the post intervention questionnaire. Three participants stated they enjoyed the training and another three stated that continuing with WB-EMS training, following the free sessions which were provided in this study, would probably not be possible as commercial WB-EMS training would likely be too expensive. One participant felt the exercise had positive effects on strength but not on fitness or weight loss, and another believed adding in aerobic endurance fitness training would be more effective. The only negative comment was to do with the exercises performed during the session: one participant felt that doing the same exercises at every session became a bit boring.

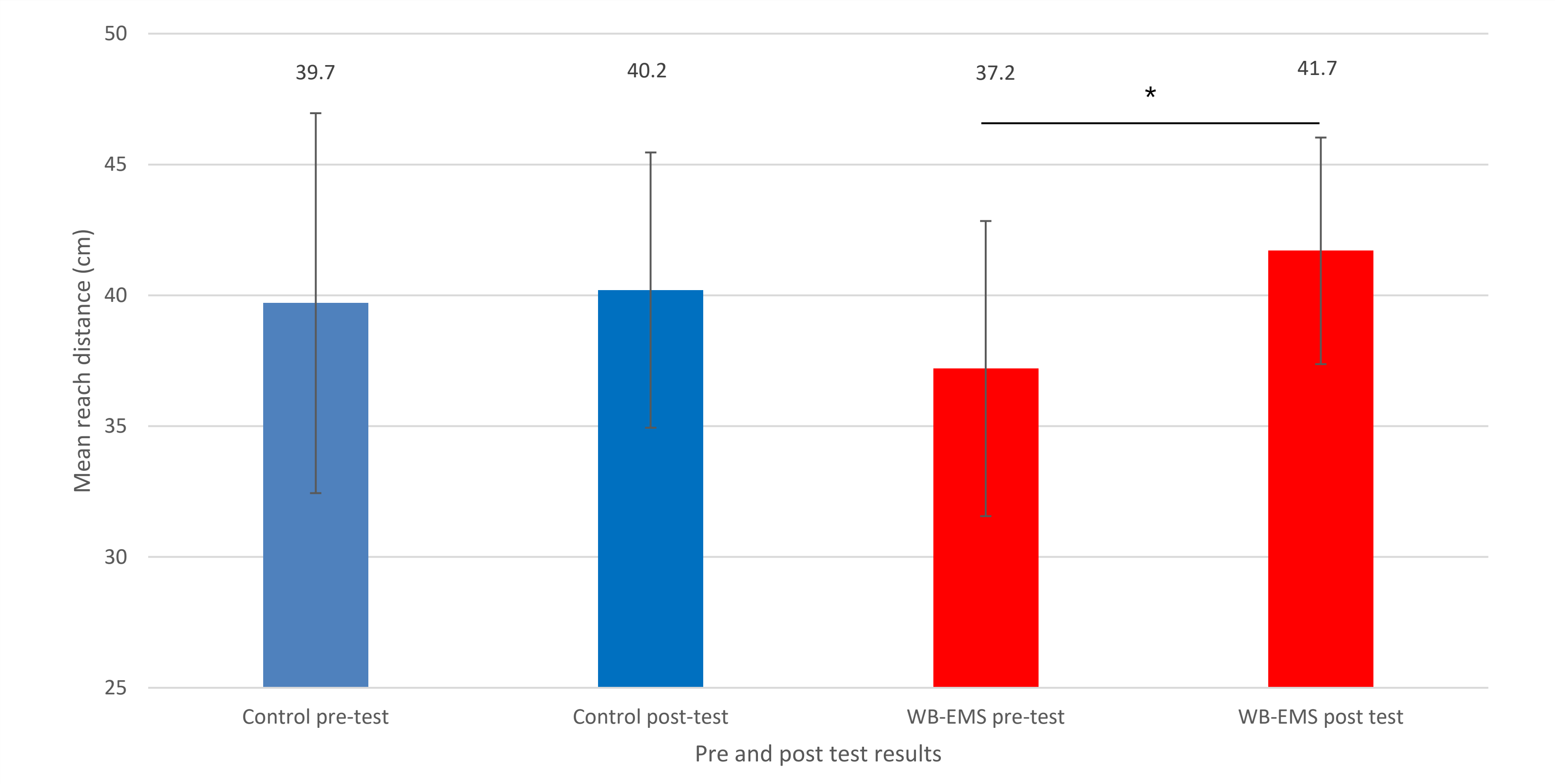
4.7 SUMMARY

In terms of physique WB-EMS training increases mass and therefore BMI but does not affect waist and hip girth or the waits-hip ratio either negatively or positively. The results of this study show that WB-EMS training significantly increases leg-and-back strength without increasing or decreasing handgrip strength. The significant increase in reach distance achieved during the FR test shows an improvement in forward limit of motion and potentially balance. Aerobic endurance is not affected as the WB-EMS group did not increase the distance covered during the Cooper 12-min run test and therefore did not improve their VO_2 max.

Table 4.2. Between-group differences and within-group changes in maximum leg-and-back strength and handgrip strength.

Variable	**Control group**			**Cohen's d**	**WB-EMS group**				**Difference between within group changes (mean)**	**Between group differences (*p* value)**	**Cohen's d**
	Pre (mean ± SD)	**Post (mean ± SD)**	**Within group change (*p* value)**		**Pre (mean ± SD)**	**Post (mean ± SD)**	**Within group change (*p* value)**	**Cohen's d**			
Leg-and-back strength (kg)	68.78 ± 17.04	70.33 ± 16.58	0.550	-0.14	66.21 ± 16.98	77.68 ± 18.04	0.001*	-0.87	9.92	0.043*	1.46
Right handgrip strength (kg)	26.52 ± 6.10	26.63 ± 5.64	0.912	-0.03	26.621 ± 3.913	26.71 ± 4.96	0.922	-0.03	- 0.02	0.844	0.62
Left handgrip strength (kg)	26.47 ± 5.64	24.94 ± 5.90	0.110	0.37	25.23 ± 4.50	25.32 ± 4.79	1.000	-0.03	-1.62	0.103	1.07

* Significant change ($p < 0.05$), Abbreviations: WB-EMS, Whole-body electromyostimulation; SD, standard deviation



* Significant change ($p < 0.05$); Abbreviations: WB-EMS, whole-body electromyostimulation

Figure 4.1: Average reach distance achieved at pre and post-test in the FR test for the control and WB-EMS groups.

Table 4.3. Between-group differences and within-group changes in aerobic endurance.

Variable	Control group				WB-EMS group				Difference between within group changes (mean)	Between group differences (*p* value)	Cohen's d
	Pre (mean ± SD)	Post (mean ± SD)	Within group change (*p* value)	Cohen's d	Pre (mean ± SD)	Post (mean ± SD)	Within group change (*p* value)	Cohen's d			
Distance (m)	1337.99 ± 212.51	1464.73 ± 272.60	0.023*	-0.61	1458.14 ± 202.63	1527.67 ± 217.80	0.103	-0.41	31.81	0.488	0.48
Estimated VO_2 max (mL/kg/min)	18.62 ± 4.75	21.45 ± 6.09	0.023*	-0.61	21.30 ± 4.53	22.86 ± 4.87	0.103	-0.41	0.71	0.488	0.48

* Significant change, ($p < 0.05$), Abbreviations: WB-EMS, whole-body electromyostimulation; SD, standard deviation VO_2 max, maximum oxygen uptake

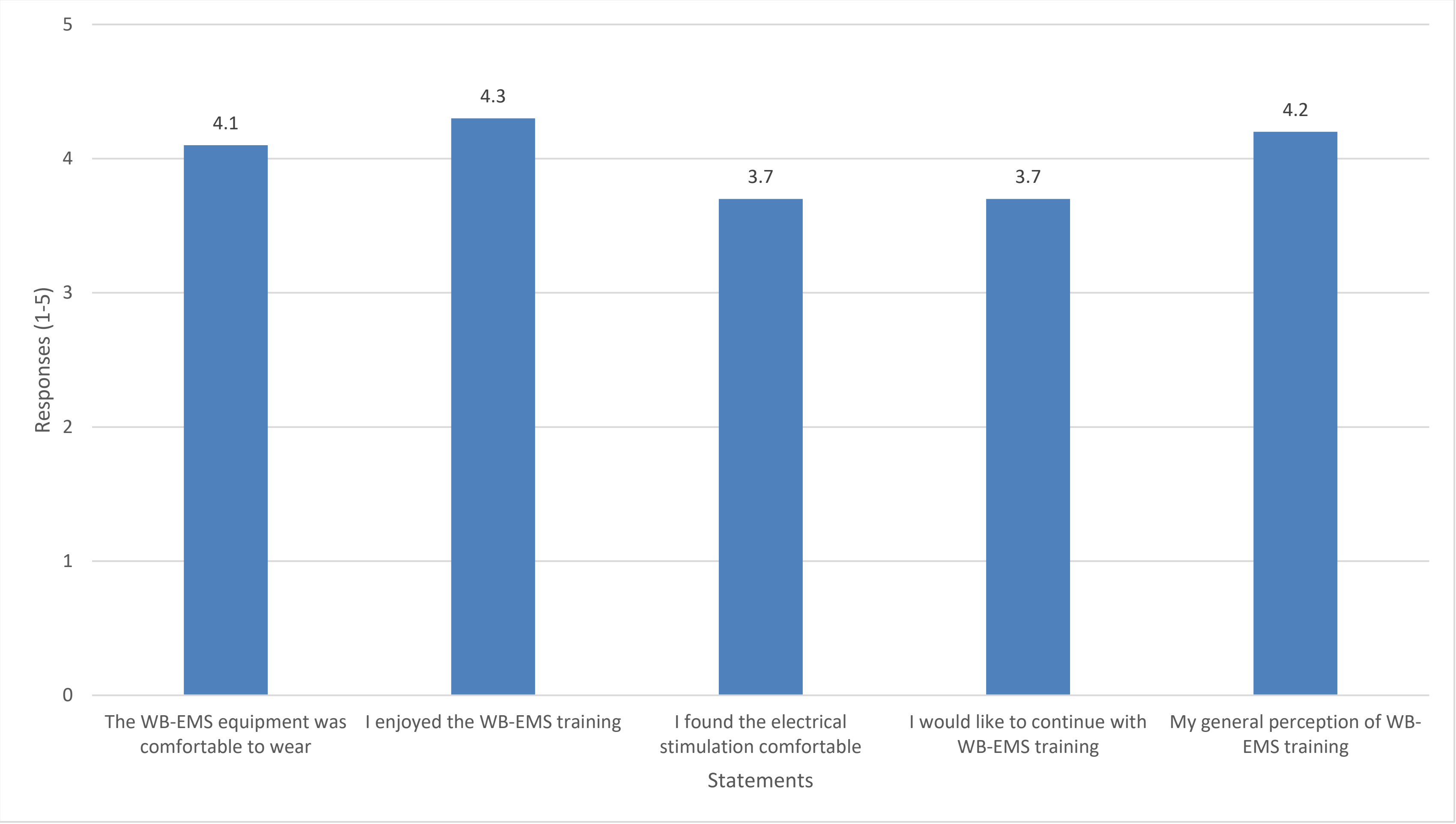


Figure 4.2: Mean scores for the post-intervention questionnaire completed by the WB-EMS group (n = 19).

CHAPTER 5: DISCUSSION

5.1 INTRODUCTION

This study aimed to determine the effect of ten-weeks of WB-EMS augmented calisthenic training on physique, strength, aerobic endurance, and balance in sedentary females aged 35-55 years in Pretoria. As well as to compare the effects to those in an active control group. This was determined by evaluating body mass, stature, BMI and waist-hip ratio as well as maximum isometric strength, balance and aerobic endurance. Maximum isometric strength was assessed by the isometric handgrip test and the isometric leg strength test, balance was assessed by the FR test and aerobic endurance capacity was assessed by the Cooper 12-min run test.

Additionally, the objectives of this study were to:

- Evaluate whether WB-EMS is effective at improving physique;
- Evaluate whether WB-EMS augmented calisthenic training is effective at improving maximum isometric strength;
- Evaluate whether WB-EMS augmented calisthenic training is effective at improving balance;
- Evaluate whether WB-EMS augmented calisthenic training is effective at increasing aerobic endurance capacity.

5.2 PHYSIQUE

Both mass and BMI significantly increased in the WB-EMS group and did not change significantly in the control group. However, the control group significantly decreased waist circumference and the waist-hip ratio in contrast to the WB-EMS group which did not change.

The increase in BMI in the WB-EMS group is due to the significant increase in mass. It is not possible to say what the composition of the increased mass in the WB-EMS group is, as no specific tests for body fat or muscle mass were administered in the current study. The known effects of WB-EMS on muscle mass and fat percentage have been explored, previously in other research studies (Kemmler and von Stengel. 2012a; Kemmler and von Stengel. 2012b; Kemmler et al., 2016a; Kemmler et al., 2016b; Kemmler et al., 2017a; Kemmler et al., 2018a; Kemmler et al., 2018b).

Body fat percentage does correlate with waist circumference (r = 0.804, 20-39 years; r = 0.768, 40-59 years) as well as BMI (r = 0.839, 20-39 years; 0.798 40-59 years) in women (Flegal et al., 2008). The BMI of women shows a significantly higher correlation with fat percentage than it does with men (Flegal et al., 2008). Thus, an increase in BMI may signal an increase in body fat percentage within the WB-EMS group. However, it has also been argued that BMI does not correlate well with fat percentage, as BMI calculations do not differentiate between lean body mass and fat mass, and important variables such as sex, ethnicity, leg length and age are not taken into account (Nuttall, 2015). Consequently, the increase in mass observed in the current study could also signify an increase in lean body mass.

Significant decreases in BMI and body mass have been observed following once per week WB-EMS training in conjunction with once per week running training (Amaro-Gahete et al., 2018a). The effect of WB-EMS in BMI does not appear to be reliant on additional non-EMS exercise training. As Amaro-Gahete et al. (2018b) observed significant decreases following both traditional resistance-based WB-EMS training as well as periodized and functional training WB-EMS and no significant difference was observed between the groups. However, the participants studied were all younger males ranging between 25.8 ± 7.4 years and 27.0 ± 7.5 years compared to the current middle-aged female cohort aged 42.6 ± 6.2 years in the control group and 43.9 ± 6.2 years in the WB-EMS group (Amaro-Gahete, 2018a, Amaro-Gahete et al., 2018b). Additionally, both studies utilised small group sizes (n=6) (Amaro-Gahete et al., 2018a; and Amaro-Gahete et al., 2018b).

Whole-body electromyostimulation training has also been observed to significantly decrease total fat mass (Kemmler and von Stengel, 2012a; Kemmler and von Stengel, 2012b; Kemmler et al., 2016a; Kemmler et al., 2018a; Kemmler et al., 2018b) and abdominal fat mass (Kemmler and von Stengel, 2012b; Kemmler et al., 2018b).

Significant decreases in fat mass have been observed following WB-EMS sessions which were split into two separate parts of equal time (Kemmler and von Stengel, 2012a; Kemmler and von Stengel, 2012b). The first part applied intermittent 4-s on-and-off cycling of the electric impulse at 85 Hz for 10 and 15 min respectively and the second part consisted of a continuously applied impulse at 7 Hz for 10 and 15 min respectively equalling a total of 20 and 30 min respectively (Kemmler and von Stengel, 2012a; Kemmler and von Stengel, 2012b). The current study only applied intermittent on-and-off cycling of the impulse. During the 15 min of continuous impulse participants trained on a cross trainer at a heart rate of 70-85% of maximum heart rate (Kemmler and von Stengel, 2012b). Significant decreases in fat mass have also been observed following WB-EMS sessions which only applied an on-and-off cycling of the impulse, at an intensity of "hard" to "very hard" on the Borg CR-10 scale (Kemmler et al., 2016a; Kemmler et al., 2018a), similar to the intensity of the current study which was set at 6 out of 10 or "hard" on the Borg CR-10 scale. However, Kemmler et al. (2016a) applied a 6-s and 4-s intermittent on-and-off cycle while Kemmler et al. (2018a) applied a 4-s on-and-off cycle and also prescribed protein supplementation of 1.7-1.8 g/kg/body/mass/day. The studies by Kemmler et al. (2016a) and Kemmler et al. (2018a) were also both conducted on males, aged between 30 and 50 years and over 70 years respectively in contrast to the current study which had a female cohort.

An increase in muscle mass could also explain an increase in mass. However, currently consensus on the effects of WB-EMS on muscle mass is not strong. Kemmler and von Stengel (2012a); Kemmler and von Stengel (2012b) and Kemmler et al. (2013) did not observe any significant changes in muscle mass following WB-EMS training- in females aged 65 ± 5 years, males aged 69 ± 3 years, and females aged 75 ± 4 years. Lean body mass on the other hand has been shown to increase significantly (Kemmler et al., 2013; Kemmler et al., 2016a). Women and men aged >70 years suffering from sarcopenic obesity have been shown to decrease their sarcopenic z-score by increasing their SMI (Kemmler et al., 2016b; Kemmler et al., 2017a). Kemmler et al. (2018b) also produced a recent meta-analysis of 23 research articles and theses, most of which focused on participants aged >60 years. The meta-analysis conducted by Kemmler et al. (2018b) determined WB-EMS to be effective at increasing muscle mass in untrained individuals and as WB-EMS training appears to be effective at decreasing fat percentage it is unlikely the significant increase in mass observed in the WB-EMS group is due to an increase in fat percentage. However, as this was not directly measured in the current study, more research needs to be conducted to establish the effects of WB-EMS training on body composition and physique.

5.3 STRENGTH

No significant changes in handgrip strength were observed in either the WB-EMS group or the control group. Leg-and-back strength however, increased significantly in the WB-EMS group and not in the control group, with the difference between the groups also being significant and a high effect size (d = 1.46) observed.

Whole-body electromyostimulation has been established as a strength training modality and increases in maximum strength have been observed in several studies (Kemmler and von Stengel, 2012a; Kemmler and von Stengel, 2012b; Kemmler et al., 2013; Kemmler et al., 2016a; Kemmler et al., 2018b). Increases in maximum isometric strength following WB-EMS training are also significantly higher than increases in control groups performing light exercise (Kemmler and von Stengel, 2012a; Kemmler and von Stengel, 2012b; Kemmler et al., 2013). However, when WB-EMS is compared to higher intensity forms of exercise, the increases in maximum strength appear to be similar. In males aged between 30- and 50-years Kemmler et al. (2016a) compared WB-EMS training to high-intensity resistance training and observed both to significantly increase maximum isometric leg and back extensor strength without observing significant differences between the two training conditions. While in younger males aged between 18 and 30 years Micke et al. (2018) observed similar results in maximum isometric strength tests on leg-press and leg-curl machines, when comparing WB-EMS at an intensity of 70% of maximum pain threshold to matched-intensity resistance training. The only significant difference between the groups was on a leg extensor machine where the WB-EMS group increased significantly more than the control (Micke et al., 2018).

The leg-and-back strength test used in the current study emulated a deadlift action, but in an isometric test. Each exercise session had a total of 13 exercises, nine of which emulated a squatting or deadlift action and none of which focused specifically on either forearm or grip strength. The effects of this can be seen in the results as a significant strength increase was only observed in the test which most closely resembled the exercises performed in the training sessions

Information on the effects of WB-EMS training specifically in handgrip strength is scarce, similarly to the current study Biyilki (2018) observed no changes in handgrip strength following a longer 20-week WB-EMS intervention and OPT (optimal performance training) model exercise. While Kemmler et al. (2017a) observed significant increases in handgrip strength in males aged >70 years suffering from sarcopenic obesity after 16-weeks of WB-EMS training at an intensity of 6-7 on the Borg CR-10 scale, in conjunction with protein supplementation. The study by Kemmler et al. (2017a) applied very similar methods to the current study. The main differences were the duration of 16-weeks (maximum of 24 sessions) applied by Kemmler et al. (2017a) compared to 10-weeks (maximum of 18 sessions) in the current study. As well as the protein supplementation of 1.7-1.8 g/kg/day (Kemmler et al., 2017a).

Some investigators (Wirtz et al., 2015 and Wirtz et al., 2016) have combined EMS with resistance training, by applying EMS to the calf muscles, thigh muscles, gluteal muscles, lower back muscles and abdominal muscles while participants completed back squats. Increases in maximum strength were not significantly different to participants who completed back squats without additional stimulation (Wirtz et al., 2015; Wirtz et al., 2016). The reason for the differences in the effect in maximum strength observed in the current study could be due to the specific exercises used during the training sessions. Filipovic et al. (2012) recommend that for maximum increases in dynamic strength, dynamic movements should be incorporated into the training sessions.

This has been observed in a number of athletic populations, Husain et al. (2017) observed significant increases to 1 RM bench press, squat, rotational strength and batting velocity following EMS training which incorporated exercises usually used to increase both strength and batting velocity. Billot et al. (2010) did not utilise dynamic movements in their EMS training sessions but instead combined stationary EMS training with sport-specific soccer training done separately. This resulted in significant increases in maximum strength as well as in kicking speed (Billot et al., 2010). Babault et al. (2007) applied a similar method by combining stationary EMS training of the quadriceps with rugby training and observed significant increases in maximum leg strength but not in scrummaging strength. The scrummaging strength test was performed by both backline and forward position players and differences in technique may have influenced the transfer of significant isokinetic strength increases in the quadriceps, in scrummaging strength (Babault et al., 2007).

Another factor affecting the differences in change in maximum strength could be the positioning and placement of the electrodes. As both Maffiuletti et al. (2000) and Vanderthommen and Duchateau (2007) have stated that EMS will preferentially recruit the axonal branches which are closest to the electrodes. This means the electrodes which are placed on the upper arms for example will stimulate the muscles of the upper arm before stimulating the muscles of the forearm. The intensity of the stimulation needs to be increased in order to stimulate the axonal branches which are further away (Vanderthommen and Duchateau, 2007). During dynamic EMS, however, the intensity of the impulse needs to be downgraded in order to allow motion (Wirtz et al., 2015) and to prevent discomfort (Vanderthommen and Duchateau, 2007). Thus, if one were to increase the impulse intensity to the upper arms by enough to significantly influence forearm strength one may overstimulate the upper arms and prevent dynamic movement.

Therefore, when WB-EMS training is used specifically to stimulate strength increases, it is important to specify the exercises done during the WB-EMS training session, to focus on the goals of the individual who is training. An alternative would be to perform goal-specific exercises in additional training sessions which do not utilise WB-EMS stimulation. Finally, it is important to place the electrodes of the WB-EMS device specifically to stimulate the muscles which one would like to strengthen.

5.4 BALANCE

The FR test is a measure of balance and more specifically measures forward reach ability from a bilateral stance position (Duncan et al., 1990). The FR test is also used as a fall predictor in elderly populations, with a reach score lower than 15.2 cm (6 inches) representing a significant fall risk and a score between 15.2 cm and 25.4 cm (10 inches) representing a moderate fall risk. As the participants of this study were not elderly (≥65 years) it is not surprising that none of the participants had scores below 15.2 cm and only one had a score below 25.4 cm at the time of pre-test. Normative scores for females in the FR test are 37.0 ± 5.6 cm in the 20-40-year age group and 35.0 cm ± 5.6 cm in the 41-69-year age group. As the population for this study was aged 35-55 years, the researcher considered both the 20-40 year and 41-69-year age ranges. Both the control and WB-EMS groups achieved mean scores within the normative range for both the 20-40 year and 41-69-year age ranges at pre-test.

Notwithstanding normal pre-test values the WB-EMS group significantly increased their reach distance ($p < 0.001$; d = 0.96) while no change was observed in the control group ($p = 0.662$; d = 0.09). Despite the significant increase observed in the WB-EMS group no significant difference between the groups was observed ($p = 0.06$), however a large effect size (d = 1.39) was observed.

Currently no other studies have directly evaluated the effects of EMS training on balance (Chapter 2). A meta-analysis states that to improve dynamic and static balance the exercises performed during training should be specialised towards that goal, however no citations were provided for this statement (Kemmler et al., 2018b). The exercise set applied in this study was not specialised towards improving balance and no additional exercise focused specifically on balance were performed by the participants. Instead, the exercise set focused mainly on squatting and deadlift movements, as explained in section 5.2. Despite this the WB-EMS group still significantly increased their FR distance without a significant difference between the WB-EMS and control groups. Thus, as a significant increase was only observed in the WB-EMS group, WB-EMS training does appear to have a positive effect on balance.

However, more research, specifically on balance is needed to determine and understand the possible influence of WB-EMS on balance.

In this study the placement of the electrodes may help explain the significant increase in balance. The muscles involved in the FR test are the tibialis anterior, rectus femoris, rectus abdominus, sternocleidomastoid, hamstrings, soleus and L-4 level erector spinae (Maranesi et al., 2016). Of these muscles the tibialis anterior, soleus and sternocleidomastoid were the only muscles not directly activated by electrodes, however the sternocleidomastoid originates at the manubrium of the sternum and clavicle and therefore may be stimulated by the electrodes placed over the chest.

Fall risk increases with age and WB-EMS training has been advocated as an exercise option for the elderly and for individuals with low time availability (Kemmler et al., 2016b; Kemmler et al., 2017a; Kemmler et al., 2018b). WB-EMS is advocated mainly due to its positive effects on musculoskeletal factors such as sarcopenia and obesity (Kemmler et al., 2017a) as well as WB-EMS ability to improve health-related parameters in both moderately and untrained middle-aged and older populations (Kemmler et al., 2018b). If WB-EMS is effective at improving balance this could be seen as another positive and valuable effect for elderly populations.

5.5 AEROBIC ENDURANCE

Only the control group significantly increased their distance covered (m) in the Cooper 12-min run test and therefore also their estimated VO_2 max, while no significant changes were observed in the WB-EMS group a small effect size (d = 0.41) was observed. A significant within-group difference was observed in the control group and a medium effect size (d = 0.61), though no between-group differences were observed. A small to medium between group effect size of d = 0.48 shows a small difference in training response between the groups.

Significant increases in VO_2 max have been observed following local EMS application. However, the populations in which this was observed suffered from chronic heart failure (Soska et al., 2014). Following local EMS application, the increase in VO_2 max is less so than with conventional aerobic training (Sbruzzi et al., 2010). Healthy populations have been observed to significantly increase VO_2 max following WB-EMS application by Kemmler and von Stengel (2012b); Biyilki (2018); Amaro-Gahete et al. (2018a) and Amaro-Gahete et al. (2018b). Kemmler and von Stengel (2012b) and Amaro-Gahete et al. (2018b) adjusted the WB-EMS sessions in order to focus on aerobic endurance fitness. Kemmler and von Stengel (2012b) split the WB-EMS session into two phases namely endurance and resistance which lasted 15 min each. The endurance training involved participants exercising on a cross-trainer (elliptical walker) at 70-85% of maximum heart rate while an electrical impulse of 85 Hz was continuously applied, during the resistance training the electrical impulse was turned on and off every 4-s and while the impulse was on, slight movements for all main muscle groups were completed (Kemmler and von Stengel, 2012b). Amaro-Gahete et al. (2018b) split the 20-min session into four phases each lasting five min, namely warm up (A), strength training (B), high intensity interval power training (C) and high intensity interval training (D). Each phase had a different frequency (Hz), duration (min) and on-off cycle (s) of the impulse. The current study applied the same frequency, duration and on-off cycle for the entire exercise session. Instead of adjusting the EMS exercise sessions Amaro-Gahete et al. (2018a) and Biyilki (2018) did the WB-EMS in conjunction with other exercise, running training and OPT model respectively. Amaro-Gahete et al. (2018b) were the only researchers to compare traditional resistance-based WB-EMS (similar to that applied in the current study) to an aerobic specified group which performed running training and similarly to the current study, observed no changes in VO_2 max in the traditional WB-EMS group.

Amaro-Gahete et al. (2018a) compared WB-EMS training in conjunction with running training to only running training and observed a significant increase in VO_2 max in the WB-EMS and running group but not in the running only group; the difference between the groups was also significant. Kemmler and von Stengel (2012b) compared the WB-EMS training to a control performing 18 min of light training on vibration plates, observing VO_2 max to significantly increase in the WB-EMS group but not in the control. The studies by Kemmler and von Stengel (2012b), Amaro-Gahete et al. (2018a) and Amaro-Gahete.et al. (2018b) were all conducted in male cohorts aged 69

± 3 years and between 20 and 30 years respectively. While the cohort observed by Biyilki (2018) was similar in age (37.75 ± 11.97 years in the OPT and WB-EMS group, and 35.24 ± 10.98 years in the personal training group) to the current study's cohort (43.2 ± 5.9 years), the gender of the participants was not reported.

As observed by Amaro-Gahete et al. (2018b) and in the current study traditional resistance-based WB-EMS training done alone does not significantly increase aerobic endurance fitness. However, WB-EMS training has been adapted in several ways which have been observed to significantly increase aerobic endurance (Kemmler and von Stengel. 2012b; Biyilki 2018; Amaro-Gahete et al., 2018a and Amaro-Gahete et al., 2018b). The adaptations either involve adapting the WB-EMS exercise sessions themselves (Kemmler and von Stengel, 2012b; Amaro-Gahete et al., 2018b) or prescribing separate non-EMS aerobic endurance exercise sessions (Amaro-Gahete et al., 2018a; Biyilki 2018). Therefore, in order to increase aerobic endurance, it is necessary to either adapt the WB-EMS training to focus on improving aerobic fitness (Kemmler and von Stengel, 2012b; Amaro-Gahete et al., 2018b) or to complete additional endurance training sessions along with the WB-EMS training as done by Amaro-Gahete et al. (2018a) and Biyilki (2018).

5.6 ADHERENCE AND POST-INTERVENTION QUESTIONNAIRE

In terms of the attractiveness of the WB-EMS training, attendance to the sessions, which had a maximum of 18, was high in both the WB-EMS group, at 89%, and in the control group at 86%. Study compliance appears to be similar in WB-EMS studies of similar duration with attendance rates ranging between 88%-98% in studies ranging between 14-26 weeks.

Other WB-EMS studies have also observed high attendance rates to WB-EMS sessions of 98% over a 14-week duration (Kemmler and von Stengel, 2012a), 93% and 91% over a 16-week duration (Kemmler et al., 2016a; Kemmler et al., 2017a) and, 88% over a 26-week duration (Kemmler et al., 2016b). A meta-analysis of five WB-EMS studies observed an average attendance rate of 92% (Kemmler et al., 2017b).

However, a lower attendance rate of 76% has been observed in a much longer 52-week intervention WB-EMS study (Kemmler et al., 2013).

It is assumed that compliance to exercise is positively affected by an individual's perceived enjoyment of the activity. The majority (95%) of the participants in the current study reported to have had a positive general perception of WB-EMS training with 63% of participants stating that they would like to continue with the training while only 16% stated they would not like to continue training and 21% gave a neutral answer. An even higher amount was observed by Kemmler and von Stengel (2012a) when 93% of participants stated they would like to continue with WB-EMS training. The WB-EMS training applied by Kemmler and von Stengel (2012a) was somewhat different than in the current study, by being split into two parts of 10-min each, one which applied 4-s on-and-off cycling of the impulse and one with a continuously applied impulse. The participants in the current study were sedentary (Bennett et al., 2006) while the participants in the study by Kemmler and von Stengel. (2012b) were active (exercising twice per week for 60 min) and therefore may have been more open to continuing with exercise. It has been stated that the attractiveness of the training may be due to the assistance, supervision and interactions between the participant and the individual conducting the training session (Kemmler et al., 2018b).

In terms of the comfort of electrical stimulation only 53% found the stimulation comfortable, however none of the participants reported discomfort related to the electrical stimulation as 47% gave a neutral response regarding the comfort of the electrical stimulation. It is important to note that no participants dropped out due discomfort related to the electrical stimulation. Three participants dropped out of the study by Kemmler et al. (2013), only one of which reported discomfort related to the electrical impulse as the reason. Two participants dropped out of the study by Kemmler et al. (2016a), again only one reported discomfort as the reason.

In the current study the same exercise set was used for both the WB-EMS and control groups at each session. The exercise set consisted of five sets of squats in conjunction with upper body movements i.e. latissimus pull down, chest press, bicep curl, front fly and shoulder front raise; four sets of deadlifts in conjunction with upper body movements i.e. upward rowing, shoulder press, reverse fly and triceps extension; two sets of lunges, one set of crunches, two sets of side crunches and two sets of Russian twist with each set consisting of eight repetitions. One participant did state that it became boring doing the same exercise set at each session. This may be of interest to commercial EMS providers, as clients who become bored may not want to continue with the training for a prolonged period. By changing the exercises utilized in a session, commercial providers can perhaps maintain a client's interest and enjoyment in the training for a longer period of time. The researcher felt it was necessary to utilize the same exercise set for both the control and WB-EMS groups and in each training session in order to match the two training groups and participants as closely as possible and to isolate the effect of the WB-EMS application.

5.7 CONCLUSION

In summary, the results of this study show that resistance-based WB-EMS training was only effective in improving leg-and-back strength and balance components of physical fitness in middle-aged sedentary females. Physical fitness attributes that WB-EMS did not improve include physique, maximum strength, balance and aerobic endurance.

Mass increased significantly in the WB-EMS group which also yielded a significant increase in BMI. Due to the measurements made in the current study it cannot be determined what the composition (e.g. fat, muscle) of the increased mass was. However, significant fat reduction following WB-EMS training has been observed (Kemmler and von Stengel, 2012a; Kemmler and von Stengel, 2012b; Kemmler et al., 2016a; Kemmler et al., 2018a; Kemmler et al., 2018b). Thus, the increase in mass (kg) may be due to increases in muscle mass.

Maximum leg-and-back strength significantly improved in the WB-EMS group and significantly more than in the control, but handgrip strength showed no change in either group. This is likely due to the specific exercise set utilised during the WB-EMS training which did not focus on improving hand grip strength but did include nine exercises which simulated a squatting or deadlift action. In order to improve dynamic strength both local and WB-EMS training sessions must incorporate dynamic movements (Filipovic et al., 2012) either within the EMS training session or during separate training sessions (Billot et al., 2010; Hussain et al., 2017), and target the muscles for which strength gains are required.

Despite the lack of exercises specifically focused on balance in the current study, the WB-EMS group did significantly improve balance ($p < 0.001$; d = 0.96) whilst the control did not ($p = 0.662$; d = 0.09). The muscles involved in the FR test are the tibialis anterior, rectus femoris, rectus abdominus, sternocleidomastoid, hamstrings, soleus and L-4 level erector spinae (Maranesi et al., 2016). Of these muscles the rectus femoris, rectus abdominus, hamstrings and L-4 erector spinae were all directly stimulated by electrodes. An increase in strength to these muscles may help explain the significant improvement in balance. Future research on EMS effects on balance should look to directly stimulate all the muscles which are involved in the specific balance tests which are applied, and to incorporate dynamic movements specific towards improving balance, within the EMS training sessions.

This leads to another factor which may have affected the discrepancy in results between the leg-and-back and handgrip strength tests, i.e. the specific placement of the electrodes. The specific and optimal placement of electrodes during local EMS has been speculated to be the reason for local EMS increasing strength slightly more than WB-EMS in athletes (Kemmler et al., 2018b). Maffiuletti et al. (2000) and Vanderthommen and Duchateau (2007) have stated that the axonal branches closest to the electrode will be preferentially recruited before those which are further away. This may help to explain the lack of increase in grip strength as the forearm muscles did not have electrodes placed directly onto them, instead the closest electrodes were placed on the upper arms.

Finally, distance covered and estimated VO_2 max in the Cooper 12-min run test did not significantly change in the WB-EMS group. Again, the specific exercises done during the EMS training appear to be extremely important. Researchers that have observed increases in VO_2 max incorporated aerobic endurance training into the EMS sessions (Kemmler and von Stengel. 2012b; Amaro-Gahete et al., 2018b) or applied EMS training in conjunction with aerobic endurance training done separately (Biyilki 2018; Amar-Gahete et al., 2018a). The device variables i.e. frequency, overall duration and time of on-off cycle of the impulse can all be adjusted. Amaro-Gahete et al. (2018b) split their sessions into four phases, each of which had a specific and dedicated frequency duration and on-off cycle of the impulse. It appears that in order increase aerobic endurance with WB-EMS training the WB-EMS session must be highly modified and specified, usually by adjusting frequency, total session duration and the on-off cycle of the impulse. Another option is to perform aerobic endurance training separately from the WB-EMS exercise sessions.

Therefore, when conducting EMS training, whether it be local or WB-EMS, several factors are important to consider. The sessions should incorporate dynamic actions specific for a training goal or additional exercise sessions which incorporate actions specific to a training goal should be prescribed. Then it is also important to place the electrodes specifically and carefully to stimulate muscles that are targeted. Finally, the various device variables i.e. frequency, impulse intensity and impulse width, as well as overall session duration and on-off cycle of the impulse must be adjusted specifically towards the training goal.

5.8 STRENGTHS, LIMITATIONS AND RECOMMENDATIONS

The study has numerous strengths. The main strength in the current study was the matching of the exercise set between the WB-EMS and control groups. Both groups performed the same exercises, exercised for the same amount of time per exercise session and were required to complete the same minimum amount of exercise sessions. Matching the two groups in this way isolated the effect of the WB-EMS application and has only been done in three other studies (Wirtz et al., 2015; Wirtz et al., 2016; Micke et al., 2018). Furthermore, although the sample size was relatively small it is still of similar or larger size than previously published studies (Kemmler and von Stengel. 2012a; Kemmler and von Stengel. 2012b; Kemmler et al., 2016a; Amaro-Gahete et al., 2018a; Amaro-Gahete et al., 2018b; Micke et al., 2018; Wirtz et al., 2015; Wirtz et al., 2016). Finally, this study is one of the first to investigate the role of WB-EMS training in middle-aged females with good study compliance (Kemmler and von Stengel. 2012a; Kemmler and von Stengel. 2012b; Kemmler et al., 2016a; Kemmler et al., 2016b; Kemmler et al., 2017a; Kemmler et al., 2018a Amaro-Gahete et al., 2018a; Amaro-Gahete et al., 2018b; Micke et al., 2018; Wirtz et al., 2015; Wirtz et al., 2016).

Although steps were taken to minimise limitations in the study they should be acknowledged. Firstly, the current study evaluated physique but not body composition variables. Mass was recorded but body composition (i.e. fat mass versus fat-free mass), was not determined. Future research should explore physique and body composition variables in greater detail to determine WB-EMS effects on both fat mass and lean body mass. Ideally a more accurate determiner of lean body and fat mass such as dual X-ray absorptiometry or an InBody Body Composition Analyser (body impedance measurement) should be utilized.

Secondly, the strength tests applied were isometric in nature (even though the leg-and-back strength test simulates a deadlift motion) and further studies should aim to evaluate dynamic strength and 1-RM. Future studies should also aim to compare WB-EMS to exercise styles which are already known to improve strength. The effects of different dynamic motions within the WB-EMS training sessions should also be analysed to provide better recommendations for the use and application of WB-EMS training.

Thirdly, balance was tested by use of the FR test which evaluates forward limit of stability, and more specific balance tests could yield far more valuable information on this variable. Added to this the exercise set applied in the current study was not specifically designed to affect balance and future studies should adjust the training in both experimental and control groups to focus on this variable and isolate the effect of WB-EMS therein. Finally, as resistance-based WB-EMS training has been observed to not affect aerobic endurance while specifically adapted WB-EMS sessions (Kemmler and von Stengel. 2012b; Amaro-Gahete., 2018a; Amaro-Gahete., 2018b) have positively affected aerobic endurance in some instances. Future studies should continue to explore ways to adjust the WB-EMS training in order to focus on affecting aerobic endurance, in order to determine the optimal parameters and to provide better practical advice. Comparisons should also be made between the effects of 'adjusted' aerobic WB-EMS exercise and exercise training which is already known to positively increase aerobic endurance.

5.9 PRACTICAL APPLICATIONS

In untrained sedentary individuals' resistance-based WB-EMS training does appear to increase muscle mass and can be used as a training modality to do so, however in trained individuals the effects are less well known, and more research is required before practical recommendations can be made. To reduce fat mass WB-EMS should be done at a high intensity of "hard" to "very hard" on the Borg CR-10 scale as done by Kemmler et al. (2016a) and Kemmler et al. (2018a). Otherwise sessions should be split into two parts, one with continuously applied electrical impulse and one with intermittently applied impulse as done by Kemmler and von Stengel (2012a) and Kemmler and von Stengel (2012b).

Maximum strength can be significantly increased with WB-EMS exercise training and it can be used as an alternative to traditional resistance exercise training. However, the training goals of the trainee must be taken into account, as with all exercise. To increase dynamic strength, dynamic movements should be done during the WB-EMS session in unison with the 'on' phase of the electrical impulse (Filipovic et al., 2012). Conversely separate training sessions as done by Babault et al. (2007) and Billot et al. (2010) can be conducted. The separate training sessions should be designed specifically to improve dynamic actions as this will aid in the translation of strength gains from the WB-EMS training to more specific dynamic strength gains. It is also important to place the electrodes specifically to stimulate muscles which one would like to strengthen, as the muscles further away from the electrodes are stimulated to a lesser degree than the muscles which are closer (Maffiuletti et al., 2000; Vanderthommen and Duchateau (2007).

As far as affecting balance is concerned, the effects of WB-EMS are not well known. However, as observed in this study WB-EMS does appear to have some positive effect. Similarly, to the recommendations made for strength it is important to perform dynamic movements within the WB-EMS exercise sessions (Kemmler et al., 2018b). As well as to stimulate the muscles which are involved in the act of balance. More research is needed before better recommendations can be made.

Aerobic endurance does not appear to be affected by WB-EMS training unless the training session is highly adapted and specified as done by Amaro-Gahete et al. (2018b) and Kemmler and von Stengel (2012b), however specific guidelines on these adaptions are not available. Conversely aerobic exercise training can be conducted separately to the WB-EMS training sessions as done by Amaro-Gahete et al. (2018a) and Biyilki (2018). If the individual’s goal is to improve aerobic endurance and no other fitness parameters (e.g. strength), simply performing aerobic exercise training would be preferable.

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APPENDICES

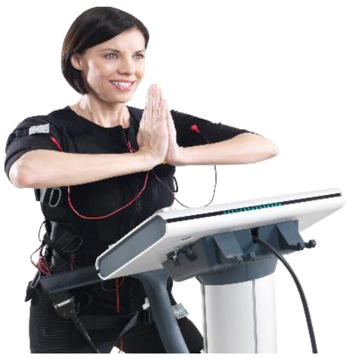
APPENDIX A: FLYER

Faculty of Health Sciences
Department of Physiology

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Want to exercise but can't find the time?

If so, then we need you!



A master's research study at the University of Pretoria aims to determine the effect of Whole-Body electromyostimulation on strength, endurance and flexibility. The study is being conducted by Michael Burbidge, an MSc (Sport Science) student, under the supervision of Prof. PS Wood and Mr James Clark, Department of Physiology, Faculty of Health Sciences.

All participants will be granted the opportunity to complete 10 weeks of **FREE Whole-Body electromyostimulation.** With only two training sessions per week (**18 session total**) you have the chance to improve your strength and muscle tone. Training sessions will be held at BODYTEC Faerie Glen, 649 Vercueil Street, Cnr of Solomon Mahlangu and Jaqueline Drive, Faerie Glen, Pretoria.

You qualify as a participant if you:

- Are female
- Aged 35 – 55 years
- Currently exercise for less than 60 minutes per week

If you would like more information please contact the researcher Michael Burbidge or his supervisor(s) Prof PS Wood and Mr JR Clark at:

burbidgemichael8@gmail.com (078 457 4239)
paola.wood@up.ac.za jimmy.Clark@up.ac.za

APPENDIX B: – SELF REPORT QUESTIONNAIRE

1. What is your sex?	Male	Female
2. Date of birth		
3. Do you currently exercise for less than 60 minutes per week?	Yes	No
4. Do you have any neurological disorders such as epilepsy?	Yes	No
5. Do you have any heart conditions such as heart attack or thrombosis?	Yes	No
6. Do you have any inguinal or abdominal hernias?	Yes	No
7. Have you had an acute operation in the last 8 weeks?	Yes	No
8. Do you have diabetes mellitus?	Yes	No
9. Do you have a pacemaker or internal implant?	Yes	No
10. Are you currently pregnant or within the first 8 weeks post-partum?	Yes	No
11. Do you suffer from a bleeding disorder such as haemophilia?	Yes	No
12. Do you suffer from a chronic illness or cancer or arthritis?	Yes	No
13. Are you currently suffering from a bacterial or viral infection	Yes	No

APPENDIX C: – LETTER OF ETHICAL APPROVAL

The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.
- FWA 00002567, Approved dd 22 May 2002 and Expires 03/20/2022.
- IRB 0000 2235 IORG0001762 Approved dd 22/04/2014 and Expires 03/14/2020.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences Research Ethics Committee

28/09/2017

Approval Certificate
New Application

Ethics Reference No: 399/2017

Title: The effects of whole-body electromyostimulation exercise training on physical fitness in middle-aged sedentary females

Dear Michael Burbidge

The **New Application** as supported by documents specified in your cover letter dated 31/08/2017 for your research received on the 31/08/2017, was approved by the Faculty of Health Sciences Research Ethics Committee on its quorate meeting of 27/09/2017.

Please note the following about your ethics approval:
- Ethics Approval is valid for 3 years
- Please remember to use your protocol number (**399/2017**) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, or monitor the conduct of your research.

Ethics approval is subject to the following:
- The ethics approval is conditional on the receipt of **6 monthly written Progress Reports**, and
- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

Dr R Sommers; MBChB; MMed (Int); MPharMed,PhD
Deputy Chairperson of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2015 (Department of Health).

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APPENDIX D: – INFORMATION FORM

Participant Information Sheet

NOTE: Please take the time to read all information carefully and ask questions if any of the information is not clear. It is important for you to understand the need for your participation, what will be required of you if you participate, and the relevance of our study.

Study title:

The effect of whole-body electromyostimulation exercise training on physical fitness in middle-aged sedentary females.

What is the purpose of the study:

The purpose of this study is to evaluate the effect of a 10-week whole-body electromyostimulation training programme on strength, balance and endurance fitness. The practical value of this study is that improvements in physical fitness are important elements of improving health and well-being.

Why have I been invited to participate:

You have been invited to volunteer as a participant in this study as you represent a portion of the female population aged between 35 and 55 years and who are not engaging in exercise regularly.

Do I have to take part?

Participation in this study is entirely voluntary. Should you choose to take part, you are free to withdraw at any time. Should you withdraw, any information that has been received from you will still be kept confidential, and will not be included in the findings and in the reporting of this study.

What do I have to do if I take part?

You will be required to complete 10 weeks of exercise training involving a total of 18 exercise sessions. You will either be placed into an exercise whole-body electromyostimulation group or in the active control group. If you are placed in the exercise whole-body electromyostimulation group you will be completing the exercise programme with whole-body electromyostimulation being applied simultaneously. If you are placed in the active control group, then you will be completing the exercise programme with no whole-body electromyostimulation being applied. At the conclusion of the 10-

week training period participants in the active control group, who have completed a minimum of 15 session, will be given the option to complete a maximum of 18 whole-body electromyostimulation sessions over a 10-week period.

You will be required to:

- *Have your height and weight measured.*
- *Have the circumferences of your waist and hips measured.*
- *Perform handgrip and leg-and-back strength testing.*
- *Perform a 12-minute run/walk test.*
- *Perform a balance/flexibility test.*

Note: these tests will be done on two occasions (two weeks prior to the beginning of exercise training and one week after the conclusion of exercise training). All of these tests and exercise sessions will be offered free of charge.

<u>What are the benefits of participating?</u>

The benefits of participating could include an improvement in strength, balance and endurance fitness. Improvements to these factors may also lead to improvements in general health and well-being. All participants in the control group, who have completed a minimum of 15 session, will be given the option to complete a maximum of 18 WB-EMS sessions over a 10-week period free of charge. All sessions will be provided to all participants at no charge.

<u>What are the risks of participating?</u>

Risks in this study are no higher than traditional exercise. Although, as with any testing and exercise of this nature, the risks involved include muscle soreness and stiffness. Participants training with EMS may initially experience superficial sensory sensation. However, measures will be taken to ensure that these risks are minimized and to make you feel as comfortable and at ease as possible. These measures include a standard warm–up and familiarization procedure and you will be allowed to stop the test/ exercise at any stage, should you feel the need to.

<u>Will my information be confidential?</u>

All information gathered will remain confidential. The only individuals with access to personal details will be the researcher noted at the end of this form, and the supervisors of this study, Prof. Wood and Mr. James Clark.

What should I do if I want to take part?

Should you wish to participate in this study, please complete the informed consent form AFTER reading this participation information sheet and asking any questions that you may have.

What will happen to the results of the research study?

The information obtained in the research study will be published for the general public and may be used by future researchers. HOWEVER, your personal information will remain confidential to the researchers and the research supervisors. The research findings will be made available to you following completion of the project.

What if I have questions about this study?

Should you have any questions, please contact any of the following researchers:

Michael Burbidge: burbidgemichael8@gmail.com

Prof. P.S. Wood: paola.wood@up.ac.za

James Clark: jimmy.Clark@up.ac.za

Thank you for taking time to read this important explanation regarding our study and the relevance of your participation.

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APPENDIX E: – INFORMED CONSENT FORM

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Informed Consent Form

(Form for research subject's permission)

Please read and complete the following form in order to acknowledge understanding of this research project and to grant consent for participation in the research study.

1. Title of research project:
   'The effect of whole-body electromyostimulation exercise training on physical fitness in middle-aged sedentary females'

2. I,*Name:*…………………………………………*Surname:*………………………………
   Hereby voluntarily grant my permission for participation in the project as explained to me by Michael Burbidge (Researcher).

3. The nature, objective, possible safety and health implications of this study have been explained to me and I understand them.

4. I understand my right to choose whether to participate in the project and that the information collected will be handled confidentially. I am aware that the results of the investigation may be used for the purposes of publication and will be stored in the Division of Biokinetics and Sport Science for a period of 15 years.

Signed: ____________________________ Date: ________________

Witness: ____________________________ Date: ________________

Researcher: ____________________________ Date: ________________

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APPENDIX F: – POST INTERVENTION QUESTIONNAIRE

Question	1-Very poor	2-Poor	3-Average	4-Good	5-Exceptional
The WB-EMS equipment was comfortable to wear.					
I enjoyed the WB-EMS training.					
I found the electrical stimulation comfortable.					
I would like to continue with WB-EMS training.					
My general perception of WB-EMS training.					
Additional comments:					