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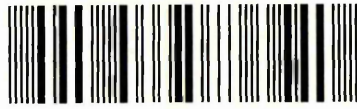
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THE BIOMECHANICS OF AND PHYSIOLOGICAL RESPONSES TO VERTICAL TREADMILL EXERCISE

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Abstract

The vertical treadmill is a novel exercise mode designed for the physical conditioning of athletes. It requires a running action in a recumbent posture on a vertically hung, non-motorised treadmill whilst the limbs are supported with overhanging resistance cables. To the author's knowledge, there has been no research on the vertical treadmill. Therefore, the aim of this thesis was to identify whether the vertical treadmill is an appropriate tool for physical conditioning. To achieve this aim there were four objectives: 1) identify the lower limb kinematics; 2) identify the neuromuscular recruitment patterns during vertical treadmill exercise in different postures and intensities; 3) identify the acute physiological responses to vertical treadmill exercise at varying intensities and 4) identify the adaptations to a training intervention on the vertical treadmill in a physically active population. The kinematic and neuromuscular recruitment patterns during vertical treadmill exercise revealed that irrespective of posture and intensity, the hamstrings and gastrocnemius muscles were active to draw the leg downwards against the resistance cables and the rectus femoris and tibialis anterior were active in the upward phase. The vastii muscles were not active. The 40° and 70° postures were similar and both differed from the supine posture. The physiological responses to submaximal and maximal vertical treadmill exercise in the 40° posture revealed a lower maximum heart rate and $\dot{V}O_{2peak}$ when compared with conventional treadmill running. The onset of blood lactate (2 mmol·L^{-1}) during very light vertical treadmill exercise and a high maximal lactate identified the vertical treadmill as a predominantly anaerobic exercise. In light of this, the effect of a 6-week sprint interval training (SIT) (4-6, 30 s all-out efforts with 4.5 min recovery, 3 times per week) on $\dot{V}O_{2max.}$, maximum anaerobic running power and responses to submaximal running on a conventional treadmill were compared with SIT performed over ground (20 m shuttle sprints) and control group. The key findings of this study were that over ground and vertical treadmill SIT increased the anaerobic running power by 4% each and that $\dot{V}O_{2max.}$ increased by 4% and 6%, respectively. No differences were found in submaximal running responses. This evidence indicates that vertical treadmill can be used as a low-impact conditioning tool without detriment to running performance. The physiological underpinnings for the improvement in running performance should be the focus of future research.

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Last, but by no means last, I would like to thank my family and friends for their invariable support, especially my mum and dad, Sue and Mike. I hope this thesis will make you proud.

Preface

The findings of this thesis have been peer-reviewed as follows:

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List of Symbols and Abbreviations

ACSM	American College of Sports Medicine
ADP	adenosine diphosphate
ANOVA	analysis of variance
ATP	adenosine triphosphate
BASES	British Association of Sport and Exercise Science
[BLa]	blood lactate concentration
bpm	beats per minute
Ca^{2+}	calcium ion
CI	confidence interval
COX	cytochrome c oxidase subunit
CO_2	carbon dioxide
CV	coefficient of variation
ES	effect size
EMG	electromyography
GLUT	glucose transporter
h	hour
H^+	hydrogen ions
H_2O	water
HIIT	high intensity interval training
HR	heart rate
$HR_{max.}$	maximum heart rate
ICC	Intra class correlation
kg	kilogram
kpm	kilopondmeter
L	litre
LOA	limits of agreement
m	metre

MAOD	maximal accumulated oxygen deficit
MART	maximal anaerobic running
MCT	monocarboxylate transporter
min	minute: unit of time
ml	millilitre
MLSS	maximum lactate steady-state
mmol	millimole
N	Newtons
n	number of samples
O_2	oxygen
OBLA	onset of blood lactate accumulation
PCO_2	partial pressure of CO_2
PCr	phosphocreatine
PO_2	partial pressure of O_2
RCP	respiratory compensation point
RER	respiratory exchange ratio
RPE	rate of perceived exertion
s	second: unit of time
SD	standard deviation
SEM	standard error measurement
sEMG	surface electromyography
SIT	sprint interval training
TEM	technical error measurement
TVent	ventilatory threshold
$\dot{V}CO_2$	rate of carbon dioxide production
$\dot{V}E$	minute ventilation
$\dot{V}O_2$	rate of O_2 consumption
$\dot{V}O_{2max.}$	maximum rate of O_2 consumption

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1.1.   Introduction

Exercise was eloquently described as the potential disruption of homeostasis brought about by exclusive, or combined, concentric, eccentric or isometric muscle activity (Winter and Fowler, 2009). The disruption of homeostasis by exercise alters the function, the physiologic responses and adaptations of body systems. The study of these changes in the body systems to acute and repeated bouts of exercise is 'exercise physiology'. Exercise physiology can be traced back to the fifth century B.C. when the Greek physician and athlete; Herodicus advocated exercise to improve physical performance (Wilmore and Costill, 1999). Until recently (20th Century) physiologic measures during exercise have been limited by the technology of measurement equipment. If required, modern technologies and methods allow the physiologic analysis of performance to a cellular level. Exercise physiologists use the physiologic information to optimise training programmes and subsequently optimise human performance or health.

The optimisation of the training-induced adaptations is dependent on many characteristics of the training programme including intensity, duration, recovery, frequency and exercise mode (Jones and Carter, 2000). The novel exercise mode of vertical treadmill exercise (Figure 1) has been developed with the aim of aiding rehabilitation and training programmes. A key characteristic of the vertical treadmill is that the user engages in "running like" exercise in a recumbent posture. During vertical treadmill exercise, the mass of the torso is supported by the bench, thus the loading forces on the joints and soft tissues of the lower limbs are reduced. A pilot study indicated that the loading force during

vertical treadmill exercise, as measured by tibial shock accelerometry, was 46% lower than conventional treadmill running. The low-impact nature of vertical treadmill exercise could enable individuals to exercise during injury rehabilitation without exacerbating injuries and also reduce the likelihood of overuse injuries associated with repeated impact loading during running over ground (Hreljac, 2004).
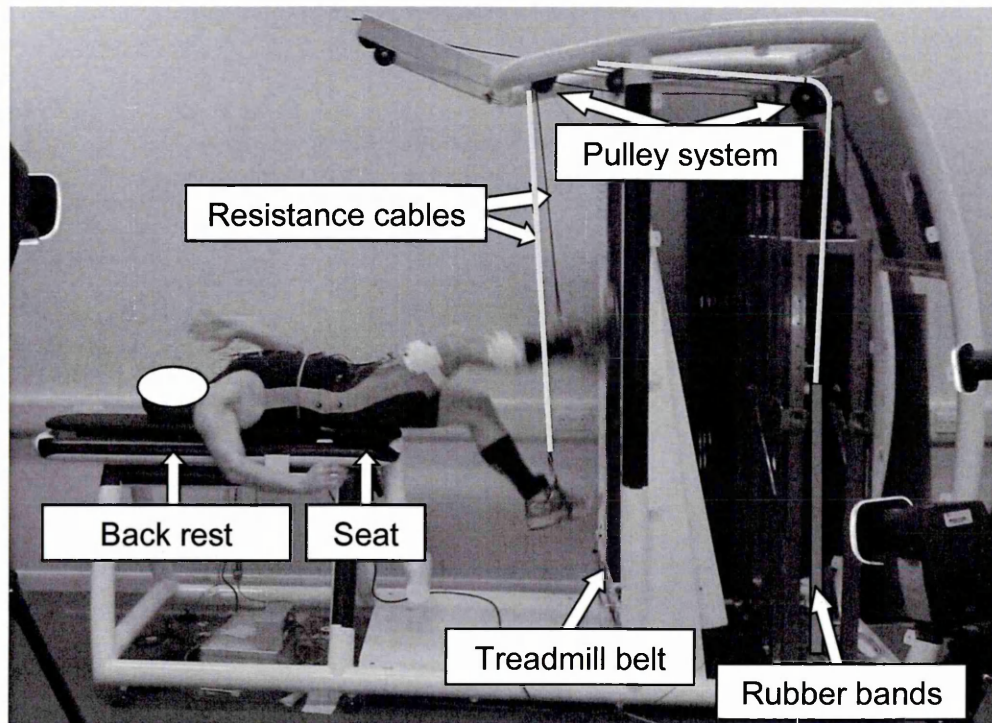
Figure 1. Vertical treadmill being used in the supine posture.

The vertical treadmill consists of a vertically hung non-motorised treadmill, an adjustable bench mechanism and overhanging resistance cables (Figure 1). The bench mechanism has an adjustable back rest that ranges from supine (0°) to 70° in 10° increments, a seat angle ranging from supine (0°) to 30° in 10° increments and a fore and aft setting that adjusts the distance of the user from the treadmill belt face. The fore and aft setting positions the seat 0.63 – 0.88 m from the treadmill surface at 0.025 m intervals. The treadmill belt is hinged at

the top of the treadmill so the treadmill belt can be angled from vertical (0°) to 30° in 10° increments. The treadmill belt was manufactured as a 'frictionless' treadmill mechanism so resistance to belt rotation is minimal. The overhanging resistance cables offer resistance to users as the leg progresses down the treadmill belt face. The resistance cables are attached to rubber bands that are anchored behind the treadmill belt through a pulley system. The resistance experienced by the vertical treadmill user was measured by the author at 20 N at the uptake of tension up to 70 N as the leg descends to the lowest portion of the treadmill. Therefore, the precise resistance and intensity of exercise is dependent on the leg length of the user and the range of motion exhibited during vertical treadmill exercise. The intensity of exercise on the vertical treadmill is also dependent on the speed of the treadmill belt which is a function of the step rate (cadence) and the distance the treadmill belt is rotated per step. Similar to normal exercise modes, exercise programmes can be constructed on the vertical treadmill by altering speed, stride frequency and the number and duration of repetitions and sets.

Another characteristic of the vertical treadmill is the ability to alter the posture of the user. It was reported that alterations in body position altered the relative geometry of body segments at rest and during exercise, thus compensatory movements brought about by changes in muscle recruitment could be demonstrated (Massion, 1992). Egana et al., (2010) also reported posture-related deviations in muscle recruitment, however, these were only evident during high intensity cycling rather than low intensity cycling (20 vs. 80% peak power output). Therefore, the adjustment of the bench mechanism and the intensity of exercise might alter the angles of the hip, knee and ankle,

which might alter the neuromuscular recruitment patterns and the physical demands of vertical treadmill exercise.

Anecdotally, the vertical treadmill has been shown to be a useful training mode to supplement strength and conditioning and rehabilitation programmes in many sports including football, middle distance running, boxing and triathlon. For example, an elite 800 m junior athlete (16 years of age) supplemented running training with vertical treadmill exercise 3 times per week for 6 months and his improved 800 m run time by 14.3 s and a 32 year-old female elite triathlete improved her sprint triathlon time (same triathlon event) by 7 minutes following 6 months of vertical treadmill exercise only. Consequently, the vertical treadmill exercise might provide an appropriate form of cross training for a variety of sports. This anecdotal evidence originated from the VertiRun company and to the author's knowledge, independent scientific investigations have not been performed to substantiate these purported improvements in performance. To inform the development of appropriate training programmes for strength and conditioning of individuals, the underpinning principles of vertical treadmill exercise need to be established.

1.2.   Statement of the problem

The vertical treadmill was designed as a low-impact exercise mode to prevent the loss of physical fitness during the injury rehabilitation process and reduce the likelihood of overuse injuries resulting from high volumes of impact loading on joints and muscles during prolonged periods of over ground running (Hreljac, 2004). Anecdotal evidence suggests that the vertical treadmill could have a role in training programmes, however, the anecdotal evidence has not

been substantiated with independent scientific research. To the author's knowledge, the fundamentals of vertical treadmill exercise such as the muscles recruited, the movement patterns and the acute physiological responses during have not been identified and could be used to inform the development of appropriate training and rehabilitation programmes.

1.3. Research question

Can the vertical treadmill be used for physical conditioning?

1.4. Aim and objectives

This thesis aims to determine the efficacy of the vertical treadmill as an exercise mode for physical conditioning in a physically active population. To achieve this aim, four major objectives are proposed:

1. Identify the lower limb kinematics during vertical treadmill exercise in different postures and intensities in a physically active population.

2. Identify the muscle recruitment patterns during vertical treadmill exercise in different postures and intensities in a physically active population.

3. Identify the acute responses of the cardiorespiratory system and metabolic demands of vertical treadmill exercise during varying intensities in a physically active population.

4. Identify the chronic adaptations of the cardiorespiratory, muscular and neuromuscular systems to a training intervention on the vertical treadmill in physically active population.

Chapter 2: **Review of literature**

2.1. Exercise modes

Exercise programmes incorporate aerobic and resistance components that aim to enhance cardiovascular fitness and musculoskeletal strength (Hass *et al.*, 2001). The magnitude of cardiovascular and muscular benefits is dependent on, among others, exercise mode. Many exercise modes exist that require an individual to exercise in an erect posture such as running over ground or on a treadmill. Running provides impact loading of skeletal system and soft tissues due to gravity, maintains bone strength and encourages adaptations brought about by repeated eccentric and concentric muscle contractions (Watenpaugh *et al.*, 2000), both of which would benefit human performance. Repeated or prolonged loading of the lower limbs has been implicated in the occurrence of overuse injuries sustained during training for sport (Hreljac, 2004). Nielsen and Yde, (1989), reported that of 123 soccer players of varying levels of competition, lower limb overuse injuries accounted for 34% of all injuries and half of these were observed in the national division competition. Similar results were found in Swedish national division female soccer players over a season. Fifty players were injured and 38% were reported to be as a result of overuse (Söderman *et al.*, 2001). In addition, Billinger *et al.*, (2008b) suggested that exercising in an erect posture is not always feasible for those with balance deficiencies, poor limb control and poor postural control as well as those who are injured or overweight in which impact loading of tissues is undesirable. Exercise in a recumbent position reduces the impact loading of the lower limbs by supporting the mass of the individual in a seat (Hass *et al.*, 2001 and Billinger *et al.*, 2008a,b).

Research into the effects of the recumbent position during exercise has mostly been performed using cycling ergometers and recumbent steppers, probably due to their popularity for performance and clinical testing and exercise prescription. Recumbent ergometry often offers an easy method of modifying intensity (Saitoh *et al.,* 2005) and in some cases such as the vertical treadmill, the degree of recumbency can be adjusted. For athletes who are already injured, recumbent exercise might enable the individual to continue exercising and prevent loss of physical fitness that is associated with disuse during rehabilitation (Perell *et al.,* 2002). Hass *et al.,* (2001) stated that there is a degree of transferability of physiological adaptations from recumbent exercise to performance in erect postures, thus recumbent exercise might provide an appropriate form of cross training for a variety of sports that involve running over ground. The physiological and biomechanical mechanisms for the purported improvements in erect posture performance from recumbent exercise are unclear. A reason for the uncertainty surrounding the effect of posture on exercise and training-induced adaptations is that the research articles are often difficult to compare due to differences in the methods used to gather data, the intensity of exercise, the exercise mode, participants with different pathologies, the athletic ability of participants and the varying degree of recumbency. All these variables make it difficult to determine the true effect of recumbent exercise for enhancing human athletic performance. To review the effect of posture on the physiology and biomechanics of exercise in an effective manner, the literature has been grouped into four postures: erect, upright, supine and recumbent. The 'erect' posture includes standing, running over ground or on a conventional treadmill. The 'upright' posture entails seated cycling (conventional cycle ergometer) where the torso is positioned upright and the legs are beneath

the torso in both situations. The supine posture infers exercise while lying down with the legs positioned around the level the torso. The recumbent posture entails exercise in a seated posture while the legs are positioned around the level of the hip (such as recumbent bicycling and recumbent stepping).

2.2. Physiological effects of posture

Physiological differences between erect and recumbent postures have been reported at rest, during exercise and recovery from exercise (Smith and Mathias, 1995 and Jones et al., 2004). Coonan et al., (1983) suggested that alterations in posture will affect the gravitational gradient experienced by body systems, many of which depend on gravity to function.

2.2.1. Postural effects on cardiac function

The cardiovascular system is dependent on gravity for function. In the erect and upright postures, the longitudinal axis is parallel to the gravitational pull so blood is drawn from the upper body to the lower extremities (Coonan et al., 1983). In the recumbent posture and more so in the supine posture, the hydrostatic pressure across the body is more uniform than in the erect posture resulting in an increased venous return (Coonan et al., 1983). The increase in venous return associated with the recumbent and supine posture affects cardiac function by the Frank-Starling law. The Frank-Starling law is the mechanism by which an increased end-diastolic volume preloads the cardiac walls (Takahashi et al., 2000). In response to a greater preload, the contractility of the cardiac musculature increases (greater amplitude and velocity of contraction) resulting in a reduction in the end-systolic volume and an increase in stroke volume (Elstad et al., 2009). It was hypothesised that the heightened contractility might

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provide a sufficient stimulus for a conditioning of the heart (Mohrmen & Heller, 1997), however there is no evidence to support this. Stroke volume was reported to be 21-40% higher in the supine posture than the upright seated posture at rest (Poliner *et al.*, 1980 and Takahashi *et al.*, 2000). In response to a greater stroke volume, cardiac output (the product of stroke volume and heart rate (HR)) was reported to be 21% greater in the supine posture compared with the standing posture (Takahashi *et al.*, 2000). Bevegård *et al.*, (1963) reported that at the onset of exercise (800 kpm·min^{-1}) stroke volume increased by 9% in the supine posture, whereas stroke volume increased by 48% during upright cycling from resting. The greater proportional increase in stroke volume in upright cycling was due to a lower resting stroke volume. No further increases were observed as exercise intensity increased to 1600 kpm·min^{-1}, however, the difference in stroke volume between the postures reduced to 9 ml compared with 43 ml at rest (Bevegård *et al.,* 1963). This suggested that maximum stroke volume was achieved in both postures at low intensity exercise and that the maximum stroke volume was greater in the supine posture (Bevegård *et al.,* 1963). The larger contribution of stroke volume to the cardiac output means that the cardiac output can be maintained by a lower HR at rest (Poliner *et al.*, 1980).

McGregor *et al.*, (1961) reported that during work-matched steady-state exercise (500 kg-m·min^{-1}), HR was 7% lower during supine cycling than upright cycling (120.5 vs. 128.6 beats per minute (bpm)). In agreement, Poliner *et al.*, (1980) reported lower HR in the supine than upright while cycling at 300 kpm·min^{-1} (124 ± 5 vs. 152 ± 6 beats per minute (bpm) respectively), 600-750 kpm·min^{-1} (165 ± 4 vs. 169 ± 8 bpm respectively) and peak intensity cycling (1092 kpm·min^{-1} vs. 946 kpm·min^{-1}, 182 ± 2 vs. 206 ± 7 bpm respectively). In

agreement, Billinger *et al.,* (2008a) reported lower HR during recumbent stepping than upright cycling exercise at the same submaximal work rate in healthy individuals. During maximal aerobic exercise, Billinger *et al.,* (2008a) observed a 4% lower maximum HR during recumbent stepping than during upright cycling. When compared with the maximal treadmill running (Bruce protocol), the recumbent stepper exhibited a lower $HR_{max.}$ (188 ± 13 and 181 ± 13 bpm respectively) (Billinger *et al.,* 2008a). Billinger *et al.,* (2008a) suggested that a lower $HR_{max.}$ was a result of body weight being supported by the recumbent stepper thus the energy demand is reduced and the subsequent demand on the cardiovascular system to supply O_2 and nutrient rich blood is reduced.

2.2.2. Postural effects on blood pressure

The effects of posture on systolic and diastolic blood pressure are also a result of gravity-influenced blood redistribution. Buchheit *et al.,* (2009) stated that in the erect posture, blood from central venous system is shifted to the lower extremities, hence on standing the blood pressure in the feet can rise by 90 mm Hg (Levitzky, 2007). In response, sympathetic vasomotor activity increases to preserve blood pressure in the rest of the body and is co-triggered by the activation of postural musculature (Buchheit *et al.,* 2009). During exercise the muscle pump also assists the return of blood from the lower extremities to prevent blood pooling in the upright posture (Elstad *et al.,* 2009). While cycling in the supine posture, maximum systolic and diastolic blood pressure (182 ± 27 mm Hg and 88 ± 14 mm Hg respectively) was reported to be higher than in treadmill running (167 ± 27 mm Hg and 82 ± 10 mm Hg respectively), probably due to increased central blood volume (Badruddin *et*

al., 1999). Saitoh et al., (2005) found that systolic blood pressure was higher during low intensity cycling at 15-30 W in the upright posture (~130 mm Hg, ~140 mm Hg respectively) than in supine cycling (~120 mm Hg, ~125 mm Hg respectively), but this was not the case during moderate intensity cycling (50-70 W). Saitoh et al., (2005) did not present actual mean or standard deviation data, hence, values were approximated from graphs. Buchheit et al., (2009) inferred that the increased venous return observed while supine activates the baroreceptors to increase parasympathetic activity and inhibit sympathetic activity. As a result, vasodilation of the arteries and veins limits the increase in blood pressure associated with the supine posture. The research by Buchheit et al., (2009) refers to posture-related changes in blood pressure while recovering from submaximal exercise. Inferring exercise-induced blood pressure changes from post-exercise measures is flawed as the blood pressure could reduce between exercise cessation and the time of measurement, however, movement artefact during exercise reduces accuracy of blood pressure measures (Billinger et al., 2008b). Therefore, the blood pressure during exercise in different postures is unclear, as are the alterations in blood pressure during exercise in erect and recumbent posture.

2.2.3. Postural effects on pulmonary function

The pulmonary system is affected by posture, once again due to the differences in the gravitational gradient between postures. Gravity deforms the lung due to its own weight and alters the mechanics of lung function (Prisk et al., 2007). In the erect posture the diaphragm is assisted by gravity to draw air in to the lungs, thus the lung volume is increased. In the supine posture gravity does not assist the diaphragm. Instead, the abdominal contents impinge on the underside of the

diaphragm, thus altering the length-tension relationship of the diaphragm and impairing its function (Jones *et al.*, 2004). The impingement of the diaphragm also reduces lung volume, incurs airway closures and coupled with an increase in venous return and pressure in the thoracic cavity, the vital capacity in the supine posture was purported to be reduced (Coonan *et al.*, 1983). Coonan *et al.*, (1983) suggested that lung volume in the supine posture can be 800 ml less than in the erect posture. In response to a reduced lung volume the functional residual capacity of the lungs was reduced by approximately 25% (Grönkvist *et al.*, 2002), the expiratory reserve volume decreases and the inspiratory reserve volume increases when assuming the supine posture from a standing posture (Levitzky, 2007). In addition to changes in lung volumes, gravity-induced alterations in the ventilation and pulmonary perfusion rates occur between the regions of the lungs. The dependent region of the lung is the lowest portion of the lung in relation to the gravitational pull and in the erect posture it is characterised by a 2.5 times greater ventilation, 5 times greater perfusion and alveolar compliancy than the upper apical portion of the lung (Armour *et al.*, 1998). It is for these reasons that the absolute gas exchange is greatest in the dependent region (Armour *et al.*, 1998). As the degree of recumbency nears the supine posture, the gravity-influenced dependent region is redistributed to the posterior portion of the lung and the apical portion is repositioned anteriorly (Levitzky, 2007). Perfusion across the lung is more uniform and is the result of increased blood flow to the thoracic cavity (Coonan *et al.*, 1983). The ventilation is disrupted in the supine posture by the weight of the heart, lungs and blood compressing the dependent region and closing airways. As a consequence, the ventilation-perfusion ratio across the entire lung is reduced in the supine posture compared with the erect posture (Levitzky, 2007). Despite the reported

changes in the dependent and apical regions between postures, Armour *et al.*, (1998) reported that the ventilatory equivalent ratio (minute ventilation ($\dot{V}E$) / volume of carbon dioxide ($\dot{V}CO_2$)) and the rate of perceived breathlessness did not differ between postures during a maximum rate of O_2 consumption test ($\dot{V}O_{2max.}$ test). However, McGregor *et al.*, (1961) reported that $\dot{V}E$ (a component of ventilatory equivalent ratio) during intensity-matched steady-state exercise was 6.29 L·min^{-1} greater during cycling in the upright posture than in the supine posture at 50 W and 80 W and this was attributed to a higher respiratory frequency (27 and 22% respectively). The stimulus for the higher respiratory frequency in the erect and upright posture was a higher partial pressure of CO_2 (PCO_2), brought about by a lower cardiac output while the rate of O_2 consumption ($\dot{V}O_2$) remained similar between postures. A possible reason for the disagreement between these studies is the exercise intensity. Saitoh *et al.*, (2005) found that low intensity cycling (15W and 30W) in the upright posture exhibited a greater $\dot{V}E$ and $\dot{V}CO_2$ than in supine cycling whereas differences were not observed during moderate intensity cycling (50W and 70W). Therefore it could be postulated that the respiratory system is mechanically altered by posture, however the ability of the lungs to oxygenate the blood is mediated by exercise intensity.

2.2.4. Postural effects on oxygen uptake

The physiology of bodily systems responsible for the delivery of O_2 tended to differ between postures, however, the effect on $\dot{V}O_2$ between postures is unclear. At rest, Jones *et al.*, (2004) found a reduced $\dot{V}O_2$ in the supine posture compared with the upright seated posture. The reduced $\dot{V}O_2$ in the supine

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posture was attributed to a reduced myocardial O_2 demand since the rate pressure product was also reduced in the supine posture and the arterial saturation was indifferent between postures (Jones *et al.*, 2004). With regards to exercise in different postures, the degree of recumbency appears to affect $\dot{V}O_2$ demand. Hughson *et al.*, (1991) found that during work-matched submaximal cycling (<105 W), $\dot{V}O_2$ during upright cycling was higher than in supine cycling. When compared with work-matched submaximal cycling (65% of the maximum oxygen uptake ($\dot{V}O_{2max.}$)) in the recumbent posture, upright cycling demonstrated similar $\dot{V}O_2$ (Ferrone *et al.*, 2001). Research comparing $\dot{V}O_2$ during recumbent exercise with supine exercise would be beneficial to provide a comprehensive understanding of the effect of a range of postures on $\dot{V}O_2$ during exercise. Until such time it could be postulated that $\dot{V}O_2$ is greater during recumbent exercise than in supine since the $\dot{V}O_2$ during the upright and recumbent exercise are similar, and upright cycling $\dot{V}O_2$ is greater than supine cycling. A possible reason for higher $\dot{V}O_2$ during upright cycling and potentially recumbent cycling compared with supine cycling is that the myocardial O_2 demand is greater as observed during rest (Jones *et al.*, 2004).

During high intensity exercise, the $\dot{V}O_{2max.}$ was reported to be higher during upright cycling than supine posture (Hughson *et al.*, (1991). Billinger *et al.*, (2008a) reported a higher treadmill running $\dot{V}O_{2max.}$ (3.67 ± 1.07 L·min^{-1}) than recumbent stepping $\dot{V}O_{2max.}$ (3.13 ± 0.80 L·min^{-1}). The reduced $\dot{V}O_{2max.}$ during recumbent stepping was attributed to body weight being supported and a relatively reduced muscle mass being utilised. A reduced muscle mass and unaccustomed exercise were reported to lead to early localised fatigue as a result of an increased anaerobic metabolism to meet the demand of the

exercise (Hass *et al.*, 2001 and Billinger *et al.*, 2008a). This might be reflected in a lower onset of anaerobic metabolism (anaerobic threshold) exhibited during supine cycling compared with upright cycling (Armour *et al.*, 1998). The participants in the study by Armour *et al.*, (1998) were symptomatic with heart failure and the effect of posture on anaerobic threshold in healthy participants is unknown.

2.3. Biomechanics and posture

It has been suggested that differences in the physiology of exercise in different postures will influence the performance of the neuromuscular and musculoskeletal systems (Jones *et al.*, 2004), thus the biomechanical profile will also be altered. The literature comparing the biomechanical profiles of exercise in different postures is limited. Alterations in body position were reported to alter the relative position of body segments, thus compensatory movements brought about by changes in muscle recruitment are to be expected (Massion, 1992). For example, the rectus femoris crosses the hip and knee joint, hence its length varies with respect to position of hip and knee (Maffiuletti and Lepers, 2003). During cycling in an upright posture, the rectus femoris length was shorter than cycling in a supine posture (Maffiuletti and Lepers, 2003). Although mediated by contraction type and contraction velocity, the consensus is that greater neural activation has been reported when muscle length is shorter (Babault *et al.*, 2003 and Maffiuletti and Lepers, 2003). It was hypothesised that motor neuron firing rate of the quadriceps might be mediated by strain receptors in the knee ligaments and joint capsule. In a shortened position (35° knee angle), the torque around the knee joint is reduced and consequently strain is reduced, thus less of an inhibition of motor neuron firing rates might be observed when compared

with longer quadriceps muscle lengths (55° and 75° knee angle) and greater torque (Babault *et al.*, 2003 and Maffiuletti and Lepers, 2003).

Altered neuromuscular recruitment and musculoskeletal performance resulting from postural differences will induce different training stimuli and adaptations to physiology. Egana *et al.*, (2010) also reported posture-related deviations in muscle recruitment during cycling, however, these were only evident during high intensity cycling rather than low intensity cycling (20 vs. 80% peak power output). Consequently, in addition to posture, neuromuscular recruitment is also influenced by exercise intensity during each posture.

Stoloff *et al.*, (2007) investigated the neural activity and kinematics during recumbent stepping and walking (stance phase and swing phase of walking compared with extension and flexion during recumbent stepping). The amplitude of the neuromuscular activity in the upper extremities and knee extensors was higher during recumbent stepping than walking. The amplitude of tibialis anterior and medial gastrocnemius recruitment was lower during the stance/extension phase of recumbent stepping than in walking. The lateral gastrocnemius and soleus activity was greater in the swing/flexion phase. In addition, the kinematics exhibited during recumbent stepping compared with walking was found to differ. The range of motion of the hip, elbow and shoulder were greater in recumbent stepping than walking. These kinematic differences may have been expected due to the different natures of the exercise mode. Despite these kinematic differences, Stoloff *et al.*, (2007), suggested that recumbent stepping utilises similar neuromuscular activation patterns to walking. An important characteristic of exercise and rehabilitation machines is to activate neuromuscular pathways similar to that of the task they are designed to

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replicate, consequently Stoloff *et al.*, (2007) recommended the recumbent stepper for gait retraining.

2.4. Exercise programmes and posture

The literature reviewed thus far suggests that the acute responses on assuming a recumbent or supine posture will reduce oxygen uptake at the lungs and stress the cardiovascular system which may, or may not, provide a beneficial conditioning mechanism and alter the muscle recruitment when compared with the erect posture. There have been few reports on the long-term adaptations to recumbent exercise programme. Loy *et al.*, (1994) compared the effects of 9 weeks of work-matched high-intensity treadmill running and cycle ergometry on treadmill $\dot{V}O_{2max.}$, cycling $\dot{V}O_{2peak}$, 1-mile running time trial and submaximal $\dot{V}O_2$, HR and blood lactate concentration ([BLa]) in healthy young men. Training intensity began at 75-80% maximum heart rate ($HR_{max.}$) for 4 days a week and from week 3-9 the intensity increased to 80-85% $HR_{max.}$ with two additional sessions per week of interval training at 90-95% $HR_{max.}$, totalling 40-45 minutes of exercise per session. Both groups improved 1-mile running time trial, $\dot{V}O_{2max.}$ and cycling peak $\dot{V}O_2$, however, greater improvements were observed in the treadmill $\dot{V}O_{2max.}$ and 1-mile time trial for the running group. Loy *et al.*, (1994) concluded that cycle training might be a substitute for running with relatively similar increases in aerobic running and cycling power.

Hass *et al.*, (2001) exercised sedentary participants for 12 weeks on a recumbent stepper, 3 times per week at 50% HR reserve (difference between $HR_{max.}$ or the measured HR and resting HR) for 20 minutes, followed by 75% HR reserve for 40 minutes. The programme resulted in an increased lean mass

(1.3 kg), a reduction in body fat (6.3%), an increase in $\dot{V}O_{2max.}$ (11%), an increased strength as measured by leg press, chest press seated row by 1 repetition maximum (10.8, 3 and 5.2% respectively) and strength endurance as measured by repeated lifts to exhaustion at 60% of the baseline 1 repetition maximum (55.7, 30.1 and 38.8% respectively). The same protocol performed on a conventional treadmill resulted in similar anthropometric and performance improvements to that of recumbent stepping (Hass *et al.*, 2001), thus supporting the claim that a recumbent exercise programme has the potential to improve conventional treadmill running performance and at least to a similar standard as conventional treadmill or over ground training.

2.5. Energy provision for exercise

During exercise, the catabolism of adenosine triphosphate (ATP) to adenosine diphosphate (ADP) and inorganic phosphate releases energy to form actin-myosin cross-bridges, thus contracting the muscle for movement (Gollnick and King, 1969, and Sahlin, 1992). The ATP-derived energy also drives the release and uptake of Ca^{2+} from the sarcoplasmic reticulum, thus facilitating cross-bridge formation (Hargreaves, 2000).

There is a limited concentration of intra-muscular ATP (5-6 mmol·kg^{-1} wet mass) that can sustain maximal activity for a few seconds of maximal exercise (Hargreaves, 2000). If exercise is to continue beyond a few seconds, more ATP has to be resynthesised at a sufficient rate to meet the demand of the contracting muscles. There are 3 main metabolic pathways that provide the energy for the resynthesis of ATP: the phosphocreatine system (PCr), anaerobic glycolysis and aerobic glycolysis (Gastin, 2001). The contribution of

each energy system to the energy demand is dependent on the intensity, duration of the exercise and the fitness of the exerciser (Gastin, 2001). Physical training can improve the rate of ATP resynthesis and contribution of each metabolic pathway.

2.5.1. Phosphocreatine

In the presence of the enzyme creatine kinase, anaerobic catabolism of PCr in the cytoplasm releases an inorganic phosphate and energy (Hargreaves, 2000). The energy released is used to resynthesise ATP by binding the inorganic phosphate with ADP. PCr is an immediate energy source and was reported to peak within the first 5 s of sprint exercise (Smith and Hill, 1991). The power of PCr to resynthesise ATP means that the potential muscular power output is high (Gastin, 2001), hence, PCr availability is a major determinant of sprint performance (Maughan and Gleeson, 2004). In a single 30 s cycle sprint, the PCr was reduced by 80.3 (1.2)% from resting values and PCr accounted for 25-30% of the total energy supply (Bogdanis et al., 1995). Similarly, Smith and Hill (1991) reported a 28% contribution of PCr to the total energy expenditure during a 30 s cycle sprint. During a 400 m sprint, PCr decreased by 47% at 100 m and 89% at 400 m and running speed decreased as PCr began availability reduced (Hirvonen et al., 1992). When sprint efforts were repeated, a strong correlation (r=0.71-0.86, $p<0.05$) was found between the percentage PCr replenishment and the percentage restoration of the peak power output (Bogdanis et al., 1995), thus highlighting the importance of recovery between sprints to replenish PCr for subsequent sprints. PCr was reported to be 65% of replenished after 90 s, rising to 85% at 6 minutes (Bogdanis et al., 1995).

In sprints of shorter duration (6 s), PCr reduced by 57% (Gaitanos *et al.*, 1993) which was less of a reduction when compared with 30 s, indicating that exercise duration affected the degree of PCr degradation. When a single 6 s cycle sprint was performed, the PCr was 55% recovered by 10 s, 69% by 30 s and 90% of resting values after 3 minutes of recovery. When short sprints were repeated (5 x 6 s), the PCr recovered 27%, 45% and 84% at 10 s, 30 s and 3 minutes respectively. Therefore, greater depletion of PCr is achieved by increasing repetitions or duration of the sprint bout and this prolongs the PCr recovery.

PCr is a finite resource and is an inefficient method to resynthesise ATP because 1 mol. PCr only yields 1 mol. ATP, hence sprint type activity can only be sustained for up to 10 s after which PCr rapidly declines (Sahlin *et al.*, 1998). When PCr stores are near depletion, the exercise intensity has to be reduced as more efficient but timely methods of ATP resysnthesis are employed (Hargreaves, 2000). In addition to the depletion of PCr, other mechanisms of fatigue have been suggested. In a review by Westerblad *et al.*, (2002) the accumulation of creatine was reported to have little effect on muscle contractility. There were, however, several mechanisms where the inorganic phosphate might depress muscle contractility. These included a decrease in the cross-bridge force production and myofibrillar Ca^{2+} sensitivity, inhibition of the ATP-driven uptake of Ca^{2+} (potentially resulting in an inorganic phosphate-induced loss of Ca^{2+} from the muscle cell) and inhibition of the release of Ca^{2+} from the sarcoplasmic reticulum. Fryer *et al.*, (1995) inferred the inhibition of the Ca^{2+} release by an accumulation of Ca^{2+} in the sarcoplasmic reticulum from skinned muscle fibres of the rat. Furthermore, Kabarra and Allen, (2001) reported that in skinned cane toad muscles the Ca^{2+} availability was reduced in

fatigued states. To the author's knowledge there is no empirical evidence to support the inhibition of muscle contractility and force in the human muscle due to an accumulation of inorganic phosphates.

2.5.2. Anaerobic glycolysis

Anaerobic glycolysis is the degradation of carbohydrate (glucose) stored in the muscle and liver (glycogen) to pyruvic acid via many enzymatic processes. In the absence of oxygen the pyruvic acid is converted to lactic acid which, in turn, dissociates H^+ ions to form lactate (Hargreaves, 2000). The net energy yield from anaerobic glycolysis resynthesises 2 ATP from 1 mol. of glucose.

Anaerobic glycolysis was reported to be a key factor for fatigue during high-intensity exercise (Bishop, 2012). In response to sprint exercise, the anaerobic glycolysis begins immediately at the onset of exercise as evidenced by an immediate accumulation of lactate (Boobis, 1987). The rate of anaerobic glycolysis was reported to peak at 15 s in to a sprint (Smith and Hill, 1991), however anaerobic glycolysis can sustain a few minutes of high intensity exercise depending on an individual's fitness. The accumulation of H^+ reduces cellular pH resulting in metabolic acidosis. Acidosis has been implemented in the inhibition of enzyme activity which is essential for energy production and consequently limits human physical performance (Sahlin, 1969).

The majority of H^+ is transported away from the muscle by haemoglobin in the blood. Extra cellular chemical buffering by bicarbonate (forming carbonic acid), phosphates and protein molecules accept the excess H^+ in an attempt to normalise pH and maintain homeostasis. At the lung carbonic acid is broken down into CO_2 and H_2O with the former being expelled by the lung by an

increased ventilation or excreted by the kidney. In contrast, the review of mechanisms for muscular fatigue by Westerblad et al., (2002) concluded that metabolic acidosis had little effect on force production during isometric activity, maximum shortening velocity and the rate of glycolysis. This conclusion was based on the work by Pate et al., (1995) who found that in skinned rabbit psoas muscle fibre the muscle force during a state of metabolic acidosis (pH 6.2 – 7.0) was reduced at 10°C, but the effect of metabolic acidosis on force production at 30°C was insignificant ($p>0.05$). Westerblad et al., (1997) compared states of metabolic acidosis (~pH 6.9) with non-acidic conditions (pH 7.4) and the shortening velocity of the intact mouse muscle fibres was reduced by ~20% at 12°C, however, there was no difference in shortening velocity at 32°C ($p>0.05$). Therefore, the inhibition of actin-myosin cross-bridges in mammalian muscle appeared to be affected by temperature rather than metabolic acidosis (Westerblad et al., 1997). Bangsbo et al., (1996) investigated the rate of anaerobic glycolysis in the vastus lateralis during exhaustive knee extensor exercise (61.4 ± 3.7 W at 60 revolutions per minute) with preceding arm ergometry consisting of 4 x 1 minute bouts at 137 ± 3 W separated by 30 s rest (arm ergometry group) and without preceding arm ergometry (control group). The arm ergometry group exhausted earlier than the control (3.46 ± 0.28 vs. 4.67 ± 0.55 minutes respectively), however, at exhaustion the [BLa] was similar between groups (26.5 ± 2.7 vs. 25.4 ± 2.4 mmol·L^{-1}) indicating the same total amount of anaerobic glycolysis. The rate of glycolysis was indifferent between the arm ergometry group and control group (8.1 ± 1.2 vs. 8.2 ± 1.0 mmol·kg^{-1}(wet mass)·min^{-1} respectively) despite a greater muscle acidity in the arm ergometry group (pH 6.65) than the control group (pH 6.82). An accumulation of potassium was also observed with fatigue and was greater

in the arm ergometer group (7.0 ± 0.9 vs. 5.4 ± 1.3 mmol·L^{-1}). The physiological rationale for the fatiguing effect of an accumulation of potassium was unclear. In conclusion, metabolic acidosis is not the only mechanism for fatigue during intense exercise. An accumulation of potassium and inorganic phosphate have been identified as likely mechanisms for fatigue in high intensity exercise (Bangsbo *et al.*, 1996 and Westerblad *et al.*, 2002).

The contribution of anaerobic glycolysis to the exercise is affected by the duration of high intensity exercise. Over 400 m sprint, Hirvonen *et al.*, (1992) reported a considerable lactate accumulation in the vastus lateralis (17.3 ± 0.9 mmol·kg^{-1}), indicating a high rate of anaerobic glycolysis. Hill, (1999) reported that the mean anaerobic energy contributions (inclusive of PCr) for females performing the 400 m, 800 m and 1500 m was 62%, 33% and 17%, respectively. In males, the mean anaerobic contribution was 63%, 39% and 20% respectively, indicating a gender difference, an inhibition of anaerobic glycolysis over time due to H$^+$ accumulation and the increased contribution from other energy systems (Hill, 1999).

In the first of 10 x 6 s sprints, approximately 40% of the energy was supplied by anaerobic glycolysis (Gaitanos *et al.*, 1993). By the tenth sprint, anaerobic glycolysis contribution fell to 16.1% of the total contribution and no further increases in [BLa] between pre and post-sprint suggested an inhibition of anaerobic glycolysis (Gaitanos *et al.*, 1993). The mean power output of the final sprint only fell by 27%, therefore, it was concluded that PCr and aerobic metabolism compensated for the inhibition of anaerobic glycolysis to meet the ATP demand in the latter stages of repeated sprint exercise (Gaitanos *et al.*, 1993). Following a sprint bout, lactate is oxidised further and H$^+$ is buffered.

The longer the recovery periods between sprints, the greater the reduction of acidosis and thus energy production is unhindered and power output in the subsequent exercise can be maintained (Bogdanis, 1995). Therefore the contribution of the anaerobic glycolysis is dependent on the intensity of exercise, the duration and recovery periods between exercise bouts. The resynthesis of ATP for exercise beyond a few minutes of intense exercise or repeated sprints with insufficient recovery requires a more efficient energy system.

2.5.3. Aerobic glycolysis

Aerobic glycolysis begins with anaerobic glycolysis however the presence of oxygen prevents the transformation of pyruvate to lactic acid. Instead, pyruvate is converted to acetyl-Coenzyme A and is subject to oxidative phosphorylation in the Kreb's cycle and the electron transport chain within the mitochondria (Hargreaves, 2000). The net yield of ATP from 1 mol. glucose is 38 mol. ATP, thus aerobic glycolysis is a relatively efficient energy system, but the rate of ATP resynthesis is relatively poor.

Aerobic metabolism of lipids has a much greater ATP resynthesis potential. Lipolysis catabolises triglycerides to free-fatty acids and Beta oxidation of free-fatty acids in the mitochondria produce acetyl-Coenzyme A for oxidative phosphorylation. The net yield of ATP varies depending on the length of free-fatty acid chains. As an example, palitic acid (16-carbon chain) produces 106 mol. ATP, however, more oxygen is required for lipid metabolism (23 mol. O_2 for 1 mol. palmitic acid compared with 6 mol. for 1 mol. glucose) which limits aerobic metabolism of lipids (Hargreaves, 2000).

Energy production from aerobic metabolism takes approximately 2-4 minutes with PCr and anaerobic glycolysis supplying the energy in the meantime (Hargreaves, 2000). In contrast, Gastin, (2001) reported that aerobic metabolism was able to match anaerobic contributions to maximal exercise in 1-2 minutes, most probably in 75 s, which was significantly less time than previously thought. The delay in aerobic ATP resynthesis was due to a delay in O_2 uptake at the lung, delivery to the working muscles by the cardiovascular system and a delay in the substrate supply and subsequent metabolism in the mitochondria (Hargreaves, 2000). Therefore, the aerobic system is the primary energy system for endurance events which are characterised by prolonged, submaximal exercise (Carter and Jones, 2000). During simulated races over 200, 400, 800 and 1500 m, Spencer and Gastin, (2001) reported the contribution from aerobic metabolism to 29 (4), 43 (1), 66 (2), and 84 (1)% respectively. Therefore, as the duration of exercise increased, the contribution of aerobic glycolysis increased. This was a result of PCr depletion and inhibition of anaerobic glycolysis, thus the aerobic system was the predominant energy system by 15-30 s over the 400, 800 and 1500 m (Spencer and Gastin, 2001). During an intense cycling protocol designed to exhaust participants in 3 minutes, high aerobic contributions of 40% were reported at 30 s and it continued to increase to 50% at 1 minute and 65% at 2 minutes (Medbo and Tabata, 1989). In contrast, Kavanagh and Jacobs, (1988) and Smith and Hill, (1991) found that over a 30 s cycle sprint, the aerobic contribution was 9-19% and 16% respectively, thus aerobic energy system is a contributor but not the main contributor to such exercise. Differences might be attributed to the method of estimating aerobic contribution in such intense exercise (Smith and Hill, 1991) or the trained status of the participant (Granier et al., 1995).

Aerobic glycolysis also plays a large role in supplying energy for repeated sprints. Bogdanis *et al.*, (1996) reported that in the second of 2 x 30 s aerobic glycolysis compensated for a 41% reduction in anaerobic glycolysis as indicated by an increased $\dot{V}O_2$ (0.49 L·min^{-1}). Aerobic metabolism was estimated to provide approximately 49% of the energy in the second sprint (Bogdanis *et al.*, 1996). Glaister, (2005) reported a small contribution of aerobic metabolism in a 6 s sprint (<10%) and when repeated (10 x 6 s) Gaitanos *et al.*, (1993) inferred that the aerobic contribution increased to meet the energy requirement in the latter sprints. Therefore, the contribution of aerobic system to the total energy demand is greater in repeated sprints than in single short sprints. No aerobic contribution data was presented by Gaitanos *et al.*, (1993), an increased aerobic contribution was concluded from significant reduction in anaerobic glycolysis (reduced to 16% of the first sprint) and only a small reduction in power output (27%).

Following a sprint bout, the aerobic system is essential to the restoration of muscle homeostasis by replenishing ATP and PCr in the initial stages as indicated by elevated oxygen consumption (Glaister, 2005). A review of literature by Tomlin and Wenger, (2001) found that an individual's aerobic fitness the aerobic system to speedily resynthesise ATP and PCr in the recovery phase affects the repeated sprint performance, thus emphasising the importance and contribution of the aerobic system to repeated sprints. Therefore, the contribution of the aerobic system to sprint performance is dependent on the intensity of exercise, duration of sprints, the number of sprints and the length of recovery.

2.6. Training programmes

Training is an organised programme of exercise bouts which aim to improve and optimise physiological state of an individual, with a view to improving athletic performance (Whyte, 2006). During training, the disruption of homeostasis brought about by exercise alters the function, the physiologic responses and the adaptations of body systems to minimise the disturbance in future training (Whyte, 2006). The type and magnitude of the adaptations is dependent on the intensity, duration, frequency of training sessions and the recovery periods (Jones and Carter, 2000). Other factors that influence the design of training programmes are the specificity of the training type and exercise mode. Different combinations of these exercise components induce specific acute responses, termed the 'training stimulus', and eventually specific chronic training-induced adaptations (Hawley, 2002). Therefore the selection of an appropriate training programme is essential to obtain the desired outcomes.

An appropriate training stimulus can improve the maximum aerobic power ($\dot{V}O_{2max.}$) which was described as the maximal O_2 consumption per minute during severe exercise (Bassett and Howley, 2000) and aerobic capacity which is the time to exhaustion at submaximal workloads (Blomqvist and Saltin, 1983). An increase in $\dot{V}O_{2max.}$ is indicative of a greater ability to aerobically resynthesise ATP at a higher exercise intensity and has been shown to be an important aspect of fitness for a variety of sports (Tanaka et al., 1986 and Helgerud et al., 2007). For example, Helgerud et al., (2001) reported that endurance training improved $\dot{V}O_{2max.}$ (58.1 ± 4.5 to 64.3 ± 3.9 ml·kg^{-1}·min^{-1}) and reported soccer performance related parameters such as the distance covered, frequency of sprints and mean work intensity in first and second half and in a

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match. Tanaka *et al.*, (1986) reported that $\dot{V}O_{2max.}$ was strongly correlated with 10,000 m (r=−0.60 to −0.85) running performance along with $\dot{V}O_2$ at anaerobic threshold (r=−0.69 to −0.92).

A higher oxidative potential will also increase anaerobic threshold which was described as the intensity of exercise (work rate or $\dot{V}O_2$) at which anaerobic metabolism is occurs (Beaver *et al.*, 1986), hence, anaerobic threshold is indicative of the level of exercise that can be maintained for prolonged periods of time without deleterious effects of metabolites from anaerobic glycolysis (H^+, inorganic phosphate and potassium) (Kumagai *et al.*, 1982). Anaerobic threshold can be identified by the exponential increase in lactate from anaerobic glycolysis (lactate threshold), changes in ventilatory parameters brought about by anaerobic metabolism (ventilatory threshold) or cellular pH and has a strong correlation with athletic performance (5 km time trial, r=−0.945) (Kumagai *et al.*, 1982).

Many athletes undertake sprint type activity with periods of low intensity exercise, such as soccer and rugby players and therefore require a degree of anaerobic power to maintain a high power output during sprints in addition to aerobic power to recover between sprint exercise (Coutts *et al.*, 2003 and Bangsbo *et al.*, 2006). Anaerobic power can be described as the total amount of energy produced by the anaerobic energy systems hence anaerobic power is moderately correlated with sprint performance (r=0.53) (Tharp *et al.*, 1985). Only a moderate correlation was observed, probably because anaerobic power is mediated by the ability of the neuromuscular system to recruit the musculature appropriately during high intensity exercise. In contrast, Cometti *et al.*, (2001) described anaerobic power as the ability of the neuromuscular

system to give the largest impulse in a given, thus the neuromuscular system is the main determinant of anaerobic power. It could be concluded that the neuromuscular and anaerobic energy systems are both influential in anaerobic power to recruit and supply the energy for recruitment. Sinnet *et al.*, (2001) reported that in trained distance runners traditional anaerobic performance tests including vertical jump, 50 m, 300 m and plyometric leap distance were highly correlated with 10 km run time with the latter two variables accounting for 77.9% of the run time variance. Sinnet *et al.*, (2001) concluded that endurance athletes also need to supplement aerobic training with anaerobic-based exercise to optimise endurance performance as well as those engaging in sprint type activity (Bravo *et al.*, 2008).

2.6.1. Endurance training

Traditionally, endurance training is used to improve the aerobic performance and is characterised by prolonged single bouts of exercise lasting 5-240 minutes at 65-100% $\dot{V}O_{2max.}$ and is performed a few times per week (Jones and Carter, 2000). Adaptations to endurance training concern the delivery and utilisation of O_2 and include improvements in the cardiovascular, pulmonary and metabolic systems. Examples of aerobic adaptations to endurance training include cardiac hypertrophy and increased left ventricular dimension resulting in increased stroke volume, thus indicating a systemic adaptation to improve blood the blood supply (Landry *et al.*, 1985). Daussin *et al.*, (2008) found a 40 (3)% increase in capillary density in the recruited muscle, thus improving the localised delivery of O_2 for aerobic metabolism. Saltin *et al.*, (1976) suggested that aerobic training increased the percentage of type I muscle fibres and mitochondrial density within the working muscles, thus

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increasing oxidative potential. In addition, increases in the concentration and activity of key oxidative enzymes such as a 25% increase in citrate synthase have been reported (Gorostiaga *et al.*, 1991). After 8 weeks of endurance training (cycling initially 20 min, increasing by 5 minutes per week at 61% of peak cycling power, 3 times per week), Daussin *et al.*, (2008) reported a 9% increase in $\dot{V}O_{2max.}$. Burgomaster *et al.*, (2008) also found a 9% increase in $\dot{V}O_{2max.}$ in a 6-week endurance programme (cycling for 1hr at 65% $\dot{V}O_{2max.}$ for 5 days per week). The increased $\dot{V}O_{2max.}$ in a shorter programme duration could be attributed to a larger training stimulus for aerobic adaptation brought about by increasing the duration of the exercise sessions and a higher session frequency per week. Gaesser and Rich, (1984) compared an 18-week low intensity endurance programme (50 minutes at 45% $\dot{V}O_{2max.}$, 3 times per week) with an 18-week high intensity endurance programme (25 minutes at 80-85% $\dot{V}O_{2max.}$, 3 times per week) and found that the $\dot{V}O_{2max.}$ increased significantly in both groups (8.5 ml·kg^{-1}·min^{-1} in the high intensity group and 6.5 ml·kg-^{1}·min^{-1} in the low intensity group), however there was no difference between groups. Therefore, shorter bouts of higher intensity exercise can elicit similar aerobic performance enhancements without having to engage in prolonged bouts of exercise.

Tabata *et al.*, (1996) reported that stressing of the aerobic energy system in endurance training (1 hour a day, 5 days per week) improved only aerobic performance (9% increase in $\dot{V}O_{2max.}$). Anaerobic performance which is key to many sporting activities including endurance sports was not increased, thus endurance training has limited adaptations and should be supplemented with more intense training to elicit anaerobic adaptations. In agreement, Bravo *et*

al., (2008) concluded that training should target both aerobic fitness and anaerobic-based repeated to improve the performance of athletes engaging in repeated sprint-type sports such as soccer.

2.6.2. High intensity interval training

There is a growing body of evidence suggesting that similar aerobic performance benefits to endurance training can be achieved by performing relatively brief, intermittent periods of exercise at an intensity that is close to or at $\dot{V}O_{2max}$ and is termed high intensity interval training (HIIT) (Gibala, 2009 and Buchheit and Laursen, 2013). HIIT has been used for decades, predominantly for endurance athletes (Christensen *et al.,* 1960; Wenger and Macnab, 1975 and Cunningham *et al.,* 1979). In elite endurance performers, Hawley *et al.,* (2002) reported a 'ceiling effect' whereby further increases in training volume do not incur further improvements in aerobic performance. HIIT performed at or near $\dot{V}O_{2max}$ induces a large training stimulus to overload O_2 transport and utilisation systems to further aerobic adaptations and improve endurance performance (Laursen and Jenkins, 2002). Buchheit and Laursen (2013) suggested that nine variables can be manipulated to tailor the training stimulus and the aerobic and anaerobic adaptations. These were the duration and intensity of exercise, duration and intensity of recovery periods, exercise mode, number of repetitions and sets and the duration and intensity of between-sets recovery periods. For example, Helgerud *et al.,* (2007) compared 2, 8-week HIIT protocols in junior soccer players. The protocols consisted of treadmill running (inclined 5.3%) at 95% of HR_{max} for 4 x 4 minutes with 3 minutes of active recovery (~70% HR_{max}) and 47 x 15 s of treadmill running (inclined 5.3%) at 95% of HR_{max} with 15 s of active recovery (~70% HR_{max}) for

3 times per week each. The $\dot{V}O_{2max}$. increased by 7.2% in the 4 x 4 minute group and by 5.5% in the 15 x 15 s group. Stroke volume increased by 12.5% in the 4 x 4 minutes group and by 10% in the 15 x 15 s group. Therefore, similar central adaptations were observed in shorter duration HIIT and these were, in part, attributed to the increased aerobic power. Buchheit and Laursen, (2013) reported that longer exercise bouts tended to elicit greater central adaptations such as the cardiac hypertrophy and resultant increased stroke volume. Helgerud *et al.*, (2007) contradicted this claim since there was no difference between stroke volume in between the 4 x 4 minute and 15 x 15 s groups. The 15 x 15 s protocol maintained a high cardiovascular stress (93% HR_{max}.) due to insufficient recovery between bouts, resulting in cardiovascular adaptations to the 4 x 4 minutes protocol.

Bravo *et al.*, (2008) also exercised academy soccer players for 4 x 4 minutes at 90-95% HR_{max}. interspersed with 3 minutes of recovery (~70% HR_{max}.), twice a week for 7 weeks. This protocol was compared with 3 x 6, 40 m all-out sprints interspersed with 20 s passive recovery between repetitions and 3 minutes between the 3 sets, twice a week for 7 weeks. Both groups improved $\dot{V}O_{2max}$. (5.9%) and anaerobic threshold (3.8%) following the interventions. The increased aerobic power and anaerobic threshold were attributed to an increased performance in a soccer-specific fitness test (YoYo Intermittent Recovery Test) by 12.5% in the 4 x 4 group and by 28% in the 40 m sprint group (Bravo *et al.*, 2008). Anaerobic performance was also improved as evidenced by a 2.1% improvement in repeated sprint ability in the 40 m sprint group. Such anaerobic performance improvement was not observed in the 4 x 4 minutes group. The improvement in anaerobic performance would have facilitated the performance in the YoYo Intermittent Recovery test as it requires

a high anaerobic contribution (Krustrup *et al.*, 2003). Therefore short bouts of maximal intensity exercise provided a sufficient training stimulus to improve aerobic performance and improved anaerobic performance when compared with submaximal HIIT.

2.6.3. Sprint interval training

Sprint interval training (SIT) is characterised by repeated sprints of 'all-out' effort interspersed with recovery periods (Bayati *et al.*, 2011). Repeated bouts of 'all-out effort' have been used by practitioners on the vertical treadmill with a variety of athletes such as footballers, boxers and triathletes (from personal contact) where aerobic and anaerobic performance are crucial to performance (Bangsbo *et al.*, 2006; Smith, 2006 and Bernard *et al.*, 2009). SIT is associated with peripheral metabolic and morphological adaptations in the muscle that have elicited similar performance benefits to endurance training, despite different training stimuli (Burgomaster *et al.*, 2008). The stress and contribution of the aerobic system during repeated sprints to resynthesise ATP and PCr during the sprint and during the recovery was reported to be high (41% contribution to 30 s sprint (Bogdanis *et al.*, 1996) and 65% contribution to repeated 20 s sprints inclusive of 140 s recovery periods (Zagatto *et al.*, 2011)), hence aerobic energy improvements were observed following SIT (Buchheit and Laursen, 2013). In addition, the high anaerobic and neuromuscular demands during SIT incur adaptations in the anaerobic performance (Dawson *et al.*, 1998; MacDougall *et al.* 1998 and Ørtenblad *et al.*, 2000). There are numerous SIT protocols with varying exercise modes, duration of sprint bouts, intensity and duration of the recovery periods and frequency of training sessions.

The repetition of short duration sprints (<10 s) interspersed with relatively short bouts of recovery of <60 s have been reported in the literature (Dawson *et al.,* 1998; Bravo *et al.,* 2008 and Ørtenblad *et al.,* 2000). Short sprints of <10 s were demonstrated to stress the PCr and anaerobic glycolysis system, whereas the aerobic system was stressed in the latter stages of repeated 6 s sprints (Gaitanos *et al.,* 1993). More common in the literature are longer duration sprints of 30 s all-out cycling interspersed with 4 minutes (Burgomaster *et al.,* 2005; 2006; 2007; Gibala *et al.,* 2006, Babraj *et al.,* 2009 and Bayati *et al.,* 2011) or 4.5 minutes of passive or very light active recovery (Burgomaster *et al.,* 2008; Whyte *et al.,* 2010). Repetitions of 30 s, all-out cycling was shown to nearly deplete PCr stores (19.7 ± 1.2% of resting value) and have a high glycolytic (69.9 ± 1%) (Bogdanis, *et al.,* 1995) and aerobic (41 ± 2%) contribution (Bogdanis, *et al.,* 1996), thus providing a training stimulus for both aerobic and anaerobic adaptations. The selection of 4-4.5 minute rest has been used previously as it was reported by Hultman (1967) that the total restoration of PCr and ATP can take between 3 to 5 minutes following a 30 s sprint. This estimation is debatable since it was found that following an initial rapid restoration of PCr (65.0 ± 2.8% of the resting value at 1.5 minutes) (Bogdanis *et al.,* 1995) the rate of PCr slowed to 78.7 ± 3.3% of the resting value at 3.8 minutes (Bogdanis *et al.,* 1996) and 85.5 ± 3.5% of the resting value at 6 minutes (Bogdanis *et al.,* 1995). Therefore, near-full restoration of PCr was achieved in the SIT literature employing 30 s sprints interceded with 4-4.5 minutes of recovery.

The rest periods in previous research were passive or at a very low cadence without resistance to assist the H^+ buffering, prevent venous pooling and the associated feelings of light-headedness and nausea (Burgomaster *et*

al., 2008). In these studies the number of sprints per session was four, initially, and in accordance with the over load principle the number of repetitions rose to 6 (Burgomaster *et al.*, 2008; Gibala *et al.*, 2006 and Babraj *et al.*, 2009) and 7 (Burgomater *et al.*, 2005) over the duration of the SIT programme (2-7 weeks). Each training session was repeated 3 times per week thus allowing 1-2 days for the recovery of the energy systems and for repair and adaptation of the tissues.

2.6.3.1.   Aerobic performance and SIT

Dawson *et al.*, (1998) used <10 s SIT consisting of 20-40 x 30-80 m sprints interspersed with <60 s recovery, 3 times per week for 6 weeks. $\dot{V}O_{2max}$ increased by 6% and this was despite a reduction in % type I fibres which are high oxidative fibres and 36% reduction in citrate synthase activity. Citrate synthase catalyses the oxidation of acetyl-Coenzyme A to citrate in the Kreb's cycle (Wiegand and Remington, 1986), thus it is a marker of oxidative potential. It was concluded that the participant fitness prior to the SIT protocol and that citrate synthase might not be a limiting factors of $\dot{V}O_{2max}$ might have been responsible for these findings. The 30 s SIT programme (30 s : 4-4.5 minutes) has also been shown to improve aerobic performance. Burgomaster *et al.*, (2008) reported a 6.8% increase in $\dot{V}O_{2max}$ after 6 weeks. Bayati *et al.*, (2011) observed a greater increase in $\dot{V}O_{2max}$ of 9.6% after just 4 weeks and an increased power output at $\dot{V}O_{2max}$ (12.8%). In contrast, Creer *et al.*, (2004) did not find any increase in $\dot{V}O_{2max}$ in trained cyclists following 30 s SIT concurrently with endurance training, however this was probably due to SIT being performed twice a week therefore the training stimulus was reduced. In response to 30 s SIT, Burgomaster *et al.*, (2005) reported a 100% improvement in aerobic capacity (cycling at 80% $\dot{V}O_{2max}$ to exhaustion) in 2 weeks and

Bayati *et al.*, (2011) reported a 48.4% increase in aerobic capacity (cycling at $\dot{V}O_{2max.}$) after 4 weeks of 30 s SIT.

There are many other adaptations that are attributable to the improved aerobic performance that begin within a week of engaging in 30 s SIT. Burgomaster *et al.*, (2007) monitored alterations in metabolite transport proteins over a 6-week 30 s SIT programme and 6 weeks post-SIT. After 1 week, the muscle content of glucose transporter 4 (GLUT 4), cytochrome c oxidase subunit 4 (COX4) and monocarboxylate transporter 4 (MCT4) increased above baseline by ~20%, ~35% and ~45% respectively. GLUT4 facilitates glucose uptake hence resting muscle glycogen is increased (Burgomaster *et al.*, 2007). COX4 catalyses the transfer of electrons from the electron transport chain to oxygen to form water and is a regulator of oxidative phosphorylation (Li *et al.*, 2006) and MCT4 transports glycolytic-induced lactic acid out of the muscle cell to maintain homeostasis (Fox *et al.*, 2000). Therefore, SIT increased the substrate stores, increased the capacity for oxidative phosphorylation and improved the regulation of [BLa] to delay metabolic acidosis and prolong high intensity exercise after 3 sessions.

After 2 weeks of 30 s SIT, Burgomaster *et al.*, (2005) reported 100% increase in the cycle endurance capacity at ~80% $\dot{V}O_{2max.}$. In contrast to the research by Dawson *et al.*, (1998) in which shorter sprint bouts of <10 s were used, 30 s sprint SIT increased citrate synthase activity by 38%, indicating an increased oxidative potential and was attributed to the 100% increase in cycle endurance capacity (Burgomaster *et al.*, 2005). Burgomaster *et al.*, (2006) reported changes in glycogenolysis and lactate accumulation after 2 weeks of SIT and a greater availability of substrate for aerobic metabolism as evidenced

by a 50% increase in muscle glycogen stores. Pyruvate dehydrogenase, which catalyses pyruvate to acetyl-Coenzyme A in preparation for oxidation in the Kreb's cycle in the mitochondria, increased thus enhancing the capacity for aerobic metabolism (Burgomaster et al., 2006). This was reflected in the lower [BLa] during submaximal intensity cycling indicating a reduced contribution from anaerobic glycolysis following SIT (Burgomaster et al., 2006).

After 6 weeks of 30 s SIT, monocarboxylate transporter 1 (MCT1) was found to improve by ~35% thus improving the regulation of lactic acid further (Burgomaster et al., 2007). Also, pyruvate dehydrogenase concentration was found to increase (Burgomaster et al., 2005). Therefore 30 s sprints elicited greater oxidative enzyme activity than shorter sprints, possibly due to a greater aerobic demand in longer sprint bouts (Bogdanis et al., 1996). Substrate utilisation was also reported to be altered as a result of 6 weeks of SIT. The 3-hydroxyacyl-Coenzyme A dehydrogenase, which catalyses the oxidation of fatty acids, increased following 6 weeks of SIT resulting in an increase lipid oxidation during exercise (Burgomaster et al., 2008). An increased lipid oxidation reduced the utilisation of glycogen and PCr as reported by Burgomaster et al., (2008) and if coupled with an increased resting muscle glycogen of 26-50% after 2 weeks (Gibala et al., 2006 and Burgomaster et al., 2005) the capacity for aerobic metabolism and exercise is increased. MCT1 and MCT4 declined back to baseline measures after 6 weeks of detraining, whereas GLUT4 and COX4 adaptations were maintained (Burgomaster et al., 2007), thus demonstrating the reversibility of such adaptations.

The aerobic power and capacity can be improved by <10 s and 30 s SIT, however greater improvements have been demonstrated in the 30 s and there

is a greater volume of research regarding this protocol. The aerobic performance improvements were comparable to those of endurance training despite a significant reduction in training volume (Burgomaster et al., 2008). The aerobic adaptations to SIT appeared to be focused on muscle metabolism rather than central adaptations observed in the longer and less intense training programmes of HIIT and endurance training (Buchheit and Laursen, 2013).

2.6.3.2. Anaerobic performance and SIT

Under the specificity principle, adaptations and improvements in anaerobic performance measures might be expected given the high intensity exercise and very high/exhaustive demand on the anaerobic system. In response to <10 s SIT, Dawson et al., (1998) reported anaerobic performance improvements of a 2% decrease in 40 m sprint time (5.50 ± 0.05 s to 5.37 ± 0.08 s) and 6 x 40 m repeated sprint performance (35.66 ± 0.65 s to 34.88 ± 0.49 s). The anaerobic performance improvement was attributed to 9.6% increase in type II muscle fibres which have a strong correlation with anaerobic power as measured by 10 m (r=-0.93) and 40 m sprint (r=-0.82) which were strengthened post SIT (40 m r=-0.97) (Dawson et al., 1998). Intra-muscular ATP and PCr stores did not change, however, phosophorylase activity increased suggesting a greater supply of glucose for anaerobic glycolysis in the type II fibres (Dawson et al., 1998).

Neural adaptations to SIT were demonstrated following <10 s SIT by Ørtenblad et al., (2000). A 5-week SIT programme of 20 x 10 s all-out efforts on a cycle ergometer, separated by 50 s of recovery, repeated 3 times per week elicited a 12% improvement in the mean power output during a repeated sprint

ability test (10 x 8 s sprints). This was attributed to an increase in the sarcoplasmic reticulum volume and peak Ca^{2+} release following SIT. The role of Ca^{2+} is to bind with tropomyosin complexes resulting in an opening of the actin binding sites for muscle contraction to occur. An increased Ca^{2+} availability reduces the likelihood of neural fatigue being a limiting factor on performance. Ørtenblad et al., (2000) inferred that the increased Ca^{2+} activity could be due to an increased proportion of type II muscle fibres following SIT. Neural adaptations were also observed in the 30 s cycling SIT devised by Creer et al., (2004). The root mean square of the vastus lateralis neural activity increased by 28% indicating an improved motor unit activation following a 4-week 30 s SIT programme.

Anaerobic performance improvements were also observed after 30 s SIT. After 2 weeks, Burgomaster et al., (2006) and Whyte et al., (2010) reported increases in the peak power in a Wingate anaerobic cycle test of 5.4% and 8% respectively. Burgomaster et al., (2006) reported that after 2 weeks the muscle glycogen stores increased by 50% thus greater substrate availability for anaerobic glycolysis was evident. Such improvements in anaerobic performance parameters have not always observed. For example, Parra et al., (2000) found that there was no change in anaerobic capacity after 2 weeks of SIT. Burgomaster et al., (2005) suggested this might be due to programme-induced fatigue, which highlights the importance of a sufficient recovery between SIT sessions.

After 4 weeks of 30 s SIT performed 3 times a week, Bayati et al., (2011) reported a 10.3% increase in power output and a 17.1% increase in mean power output in a Wingate anaerobic cycle test. Creer et al., (2004) reported a

6% increase in peak power output, mean power output and total work performed during an aerobic cycling test (4 Wingate anaerobic tests separated by 4 minutes of recovery) after 4 weeks of 30 s SIT performed twice a week in conjunction with endurance training. The increases in power and work coincided with a 15.5% increased [BLa] (15.5%, Bayati *et al.*, 2011), indicating an increased contribution from in anaerobic glycolysis (Creer *et al.*, 2004, Bayati *et al.* 2011). An increased [BLa] suggests that the associated H$^+$ accumulation was being buffered, thus resisting the disruption to homeostasis and muscle function. Gibala *et al.*, (2006) inferred from pH measurements that buffering capacity improved by 7.6% after 2 weeks of SIT (6 sessions) which reduced a 50 and 750kJ time trial performance. A greater buffering capacity increases the intensity of exercise that can be sustained before the accumulation of H$^+$ induces metabolic acidosis and fatigue. The exact reasons for increased buffering capacity, whether it was increased bicarbonate, phosphate and/or plasma protein concentration was not mentioned by Gibala *et al.*, (2006). The improvement in buffering capacity of musculature following SIT was not observed following endurance training (Sharp *et al.*, 1986).

Both <10 s and 30 s SIT have been shown to demonstrate some neural, metabolic and morphological adaptations that might facilitate anaerobic performance. Adaptations occurred in a relatively short time frame (within 4 weeks of SIT) and such anaerobic performance measures have not been demonstrated in endurance training (Sharp *et al.*, 1986 and Tabata *et al.*, 1996).

2.7. Measures of physiological function

The assessment of physiological function can be used to quantify the fitness of an individual and to demonstrate the efficacy of a training intervention. Also, physiological function could be used to describe the demands of a particular exercise and inform the prescription of training programmes (ACSM, 2000). There are many measures and tests of physiological function available.

2.7.1. Heart rate

As exercise intensity increases, the blood flow to the active muscles increases to deliver O_2, nutrients and remove metabolites. The required blood flow (cardiac output) is dependent on the stroke volume and HR (Saltin et al., 1998). Therefore, HR is an indicator of the cardiovascular stress brought about by metabolic changes during exercise (Kilpatrick et al., 2009). HR is highly correlated with exercise intensity (Karvonen and Vuorimaa, 1988) and so it is often used to prescribe exercise intensity when expressed as a percentage of an individual's maximum HR ($HR_{max.}$) (Tanaka et al., 2001). A strong linear relationship (r=0.99) was reported between HR and exercise intensity ($\dot{V}O_2$), however, linear relationship was only evident in submaximal exercise of 120-170 bpm (Hale, 2008). A non-linear, asymptotic HR response was found at maximum exercise intensity (Kinfu et al., 2011) thus limiting the use of heart rate as a measure of intensity during maximum intensity exercise.

The age-predicted maximum (220-age) was first cited in 1970's (Fox et al., 1971), however it was not based on original research but data from published and unpublished research therefore it is not and has been highly debated. Several prediction equation of $HR_{max.}$ have been proposed for various

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age groups. For example, Tanaka et al., (2001) developed an age-predicted equation based on the mean $HR_{max.}$ from 351 research articles of various populations (208 − 0.7 x age) and cross-validated the equation with laboratory-based $HR_{max.}$ determined from 514 healthy participants (209 − 0.7 x age) and found a strong correlation between the $HR_{max.}$ measures (r= -0.9). In contrast, a review of age-predicted $HR_{max.}$ by Robergs and Landwehr (2002) concluded that the majority of age-predicted $HR_{max.}$ equations exhibited large prediction errors (<10 bpm) and should be used cautiously.

HR can be measured by electrocardiogram (ECG) which is a noninvasive method that measures the neural impulses of cardiac muscle (Blackburn et al., 1960). Yu et al., (2006) reported that heart rate can be reliably determined from the waveforms of ECG using automatic detection algorithms (92% agreement) when compared with HR determined by expert ECG researchers. Telemetric HR monitors and corresponding watches can also be used to monitor HR out in the field. A review by Laukkanen and Virtanen, (1998) concluded looked at many commercially available HR monitors and concluded that HR monitors can correlate well with ECG (correlation coefficient of 0.97 - 0.99) and therefore provide are an accurate and valid method of monitoring and recording HR in the field. Furthermore, time-domain variability of Polar heart rate monitors using a T31 was reported to be very good (ICC 0.74 − 0.98) (Guijt et al., 2007).

2.7.2. Lactate accumulation

As exercise intensity increases, the contribution from anaerobic glycolysis increases. Anaerobic glycolysis produces lactate and therefore the

measurement of lactate is an indicator of the anaerobic stress at a given exercise intensity (Pyne et al., 2000). Lactate accumulation can be measured by muscle biopsy or by blood sample (Goodwin et al., 2007). Muscle biopsy technique is complex and requires a local anesthetic, the removal of muscle tissue by a suitably qualified person, the sample is frozen in liquid nitrogen and subject to chemical analysis (Sahlin, et al., 1976). It is important that this procedure is performed as quickly as possible because the lactate might be oxidised or converted to glucose between sampling and analysis. The validity of determining the anaerobic activity from the muscle biopsy technique is questionable because the active muscles during the exercise have to be identified it does not account for the lactate that has been released into the blood, thus underestimating the anaerobic activity.

Another method requires the sampling of blood (~25 µl) by finger pricking at the end of each stage of exercise an incremental exercise test. The blood can be subject to enzymatic spectrophotometer, lactate dehydrogenase or lactate oxidase electrode analysis. All methods have been shown to provide measures of [BLa] with very high instrument and intra-investigator reliability (r = 0.99) (White et al., 2009). Although highly reliable measures have been demonstrated the validity of [BLa] measures is questionable. After intense or exhaustive exercise, lactate in the muscle was reported to be 2-3 times higher than [BLa] (Sahlin, et al., 1976). This could be a result of a time-delay exists between the production of lactic acid at the muscle and the detection of lactate in the blood due to non-readily diffusible lactate across muscle fibre membranes. The diffusion of lactate into surrounding tissues reached equilibrium between 3-8 minutes post-exercise, thus the timing of sampling is critical to the observed [BLa] (Goodwin et al., 2007). Goodwin et al., (2007) also

reported that the oxidisation of lactate by other tissues with high oxidative potential such as the heart or the regeneration of the lactate to glycogen at the liver means that the [BLa] sampled is not necessarily that produced during the exercise. Therefore, [BLa] sampling is merely an estimate of anaerobic metabolism during incremental exercise.

Lactate accumulation has been used to monitor glycolytic activity, assess exercise performance (Gollnick *et al.*, 1986 and Pyne *et al.*, 2000) and identify lactate threshold which has strong correlation with athletic performance (Pyne *et al.*, 2000). The mathematical or visual analysis of the [BLa]-intensity relationship during the steady-state incremental exercise test can be used to determine the inflection point whereby lactate increases exponentially, thus indicating lactate threshold. In exercisers who are free from metabolic disorders, lactate threshold coincides with anaerobic threshold (Wasserman, 1987). Visual examination of the [BLa]-intensity relationship is subjective and the inflection point indicating lactate threshold might not be obvious since some researchers suggested that the relationship is smooth monotonically increasing function (Hughson *et al.*, 1987). An objective measure of lactate threshold is the use of Lactate-E software advocated by Newell *et al.*, (2007) which uses linear splines and the 'broken stick' regression model to determine the intensity at which lactate threshold occurred.

Another method of assessing the glycolytic changes is the determination of the intensity of exercise at which the onset of blood lactate accumulation (OBLA) occurs. Tokmakidis *et al.*, (1998) reported that consistent use of arbitrary points on the [BLa]-intensity relationship curve can be used as a performance index for glycolytic activity. Fixed arbitrary [BLa] values for OBLA

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of 2 and 4 mmol·L^{-1} are often used to standardise comparisons of [BLa] (Heck *et al.*, 1985). Aunola and Rusko, (1984) reported that an OBLA of 2 mmol·L^{-1} was indicative of an initial [BLa] elevation (lactate threshold). Heck *et al.*, (1985) and Chicharro *et al.*, (1999) reported that an OBLA of 4 mmol·L^{-1} is indicative of maximum lactate steady-state (MLSS). MLSS was described as the highest steady-state exercise where there were no further increases [BLa] i.e. lactate production and lactate elimination are in equilibrium (Beneke and Von Duvillard, 1996 and Dekerle *et al.*, 2003), therefore, 4 mmol·L^{-1} is a good indicator of endurance performance (Chicharro *et al.*, 1999). Visual inspection of the intensities at which the OBLA 2 and 4 mmol·L^{-1} occurred can be performed but objective measures can be achieved using the Lactate-E software that uses inverse predictions of [BLa] to calculate the work rate that corresponds to the specified fixed [BLa] (Newell *et al.*, 2007).

2.7.3. Pulmonary gas exchange

The analysis of pulmonary gases and ventilatory changes in response to exercise is a non-invasive method of estimating aerobic and anaerobic parameters during exercise.

2.7.3.1. Measurement of aerobic power

Indirect estimates of aerobic power ($\dot{V}O_{2max.}$) exist, many of which are used to estimate $\dot{V}O_{2max.}$ with simple equipment and can be performed out in the field rather than in a laboratory. Indirect measures apply generic equations to performance measures (Safrit and Wood, 1986) such as the extrapolation of submaximal heart rate to estimate $\dot{V}O_{2max.}$ in the Astrand-Rhyming test

(Astrand, 2003). The accuracy of such measures is questionable because the equations or nomograms are based on general populations, not the individual and their response to submaximal exercise (Safrit and Wood, 1986). Hence, Sady et al., (1988) reported the Astrand overestimated $\dot{V}O_{2max.}$ by 9.0 (19.4%) whereas Gonzalez & Carrasco, (1989) reported a 20.3 (7.2)% underestimation of $\dot{V}O_{2max.}$.

A more accurate measure of $\dot{V}O_{2max.}$ is to analyse inspired and expired air for the O_2 and CO_2 composition while exercise intensity is increased gradually until volitional fatigue (Poole et al., 2008). The Douglas bag method is the 'gold standard' in which expired air is collected for an allotted time and the $\dot{V}O_2$ is calculated from the composition of gases in the sample (Archer and Coulson, 2009). The Douglas bag method has been used to assess the accuracy of modern online systems (Lucia et al., 2008 and McLaughlin et al., 2001). Online systems analyse $\dot{V}O_2$, among other respiratory markers, on a continuous breath-by-breath basis and can provide valid and reliable measures when compared with the Douglas bag method ($p<0.05$) (McLaughlin et al., 2001 and Lucia et al., 2008).

The advent of breath-by-breath online gas analysers has allowed $\dot{V}O_{2max.}$ to be determined from continuous incremental exercise protocols, rather than discontinuous series of constant work rate bouts that preceded them (Yoon et al., 2007 and Poole et al., 2008). Cooper et al., (2009) compared the reliability of 6 commercially available breath-by-breath online systems on a test-retest basis and reported unsatisfactory reliability (coefficient of variation of 4.8-10.9%). The poor reliability of the online systems contradicts the good reliability reported by McLaughlin et al., (2001) and Lucia et al., (2008) when compared

with Douglas bag method and could be a result of considerable biological variance and specific to the research environment and facility.

Continuous incremental protocols typically increase the work rate as a function of time until volitional fatigue (Poole *et al.*, 2008). Astorino *et al.*, (2004) reported that optimal $\dot{V}O_{2max.}$ scores from continuous protocols were achieved when volitional fatigue was reached within 7-10 minutes and also reported that longer protocols >13 minutes significantly reduce $\dot{V}O_{2max.}$ and $HR_{max.}$ measures. A review of $\dot{V}O_{2max.}$ measures by Millet *et al.*, (2009) found that the direct $\dot{V}O_{2max.}$ measurement is specific to the exercise mode being used since runners tended to achieve higher $\dot{V}O_{2max.}$ on a treadmill than on a cycle ergometer. It is recommended that the exercise mode in a $\dot{V}O_{2max.}$ test should allow rhythmic exercise and involve large muscle groups to increase the number of active mitochondria, thus maximising $\dot{V}O_{2max.}$. The $\dot{V}O_{2max.}$ tests that do not utilise large muscle groups are subject to localised muscular fatigue and early cessation of exercise prior to maximal cardiorespiratory and oxidative stress (Billinger *et al.*, 2008a).

Increments in exercise intensity of running can be achieved through increasing in the speed or gradient of a treadmill. St Clair-Gibson *et al.*, (1999) did not demonstrate any difference in the $\dot{V}O_{2peak}$ between an incremental speed protocol (1 $km \cdot h^{-1}$) and incremental inclination protocol ($1° \cdot min^{-1}$), however, $HR_{max.}$ was lower in the inclination protocol indicating that the cardiovascular stress was not maximal in this protocol and therefore increments in speed are preferred.

Midgley et al., (2007) reported considerable variation in the literature regarding the criteria for establishing for $\dot{V}O_{2max.}$, many of which are not reported (62% from 4 prominent sport science and applied physiology between 2005 and 2006), thus invalidating comparisons across research articles and highlighting the requirement for a standardised criteria for establishing true $\dot{V}O_{2max.}$. The British Association of Sport and Exercise Sciences (BASES) published criteria for the establishment of $\dot{V}O_{2max.}$. The BASES (1997) criteria include a plateau in the $\dot{V}O_2$-intensity relationship, HR within 10 bpm of the age-predicted $HR_{max.}$ (220-age), a respiratory exchange ratio of 1.15 and volitional fatigue was achieved as indicated by an RPE of 19-20. It was stated previously that the previously stated, the appropriateness of $HR_{max.}$ (220-age) was questionable and the potential errors associated with respiratory exchange ratio and rate of perceived exertion will be discussed later. The plateau has been defined as a reduced or no increase in the $\dot{V}O_2$-intensity relationship (BASES, 1997). A reduction in the $\dot{V}O_2$-intensity relationship suggests that the rate of $\dot{V}O_2$ has slowed, not necessarily that the maximum was reached (Midgley et al., 2007). Therefore the cessation of exercise might be related to volitional fatigue or effort from the participants. The achievement of a true $\dot{V}O_2$-intensity relationship is seldom the case. St Clair-Gibson et al., (1999) reported that only 50% of the participants exhibited a true plateau. If a plateau is not observed, $\dot{V}O_{2peak}$ is established, however, the terms have been used as synonyms incorrectly (Midgley et al., 2007).

Midgley et al., (2007) advocated the employment of a verification bout in which participants undertake a supramaximal constant speed run to exhaustion performed after the incremental $\dot{V}O_{2max.}$ test. If the of $\dot{V}O_2$ exhibited in the

verification bout was within the tolerance of measurement error (~2%), of $\dot{V}O_{2max.}$ was observed. Despite the concerns over aspects of the criteria for the determination of $\dot{V}O_{2max.}$ the criteria are still used in laboratories (although under reported in the literature) and until the criteria has been fully debated and a standardised criteria is established the BASES (1997) criteria will suffice.

2.7.3.2. Ventilatory threshold

Ventilatory threshold (TVent) can be indicative of anaerobic threshold in those free from metabolic disorders (Wasserman et al., 1973). TVent is indicated by an abrupt increase in pulmonary ventilation ($\dot{V}E$) as metabolic acidosis from anaerobic metabolism stimulates the carotid chemoreceptors and consequently the CO_2 is 'blown off' (Powers et al., 1983 and Carey et al., 2005). Beaver et al., (1986) suggested that the $\dot{V}E$ increase might not be a result of metabolic acidosis. Other reasons for an increased $\dot{V}E$ include changes in posture (McGregor et al., 1961 and Saitoh et al., 2005) and biochemical activity such as changes in epinephrine and norepinephrine (Whelan and Young, 1953), therefore using $\dot{V}E$ alone to determine TVent is questionable. Also the reliability of the $\dot{V}E$ method was the lowest of available methods of determining TVent (r= 0.732) (Carey et al., 2005).

More common methods of determining TVent include the excess $\dot{V}CO_2$, ventilatory equivalent and V-slope method. Excess $\dot{V}CO_2$ method measures the $\dot{V}CO_2$ that is 'blown off'. The exercise intensity at which $\dot{V}CO_2$ continues to rise above steady-state signifies TVent (Gaskill et al., 2001). The ventilatory equivalents method of determining TVent requires the ventilatory equivalents for oxygen ($\dot{V}E / \dot{V}O_2$) and carbon dioxide ($\dot{V}E / \dot{V}CO_2$) to be plotted against

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exercise intensity. The exercise intensity at which $\dot{V}E / \dot{V}O_2$ increases and is unparalleled by $\dot{V}E / \dot{V}CO_2$ represents anaerobic threshold (Gaskill *et al.*, 2001). The $\dot{V}E / \dot{V}O_2$ ratio increases as a result of the increased $\dot{V}E$ without any discernible increase in the $\dot{V}O_2$ demand at that exercise intensity. The $\dot{V}E / \dot{V}CO_2$ ratio is unchanged at anaerobic threshold because both $\dot{V}E$ and $\dot{V}CO_2$ are increasing simultaneously (Beaver *et al.*, 1986). Although the ventilatory equivalents method also relies on metabolic acidosis being the driving force behind the increased $\dot{V}E$ (Beaver *et al.*, 1986), it was reported to be reliable at estimating anaerobic threshold (r= 0.933) (Carey *et al.*, 2005).

In contrast to Carey *et al.*, (2005), Shimizu et al., (1991) advocated the V-slope method as the most was reliable method of identifying TVent. The V-slope method was developed as it identifies TVent without using $\dot{V}E$. In the V-slope method, the $\dot{V}CO_2$ is plotted against $\dot{V}O_2$ and the exercise intensity a breakpoint in the relationship is observed denotes TVent. Beaver *et al.*, (1986) devised a computerised regressional analysis algorithm which expresses the $\dot{V}CO_2$ as a fraction of $\dot{V}O_2$ and detects a transition in the $\dot{V}CO_2/\dot{V}O_2$ relationship. The exercise intensity at which the transition occurs is indicative of the TVent (Beaver *et al.*, 1986). At times, the identification of the TVent cannot be made solely based on one method due to erratic or unclear alterations in the respiratory data (Gaskill *et al.*, 2001). In the majority of cases this can be resolved by combining the 3 methods to determine TVent. When the methods were combined, the reliability of identifying TVent was reported to have an ICC of 0.85 (Shimizu *et al.*, 1991).

2.7.3.3. Respiratory compensation point

Respiratory compensation point (RCP) is the second inflection point in the $\dot{V}E / \dot{V}O_2$ relationship. Meyer *et al.*, (2004) reported that the physiological meaning of RCP was unclear, but it was associated with the exercise intensity above TVent at which the buffering systems become unable to buffer H^+, as well as muscle sensory afferents. Increases in exercise intensity above TVent induce a steeper increase in the $\dot{V}E / \dot{V}O_2$ relationship. This results in a hyperventilation-induced reduction in the PCO_2 in the expired gases to limit the metabolic acidosis during high intensity exercise. Therefore, the $\dot{V}O_2$ at which $\dot{V}E / \dot{V}O_2$ increases and end tidal PCO_2 plateaus and then decreases is indicative of the respiratory compensation point (Takano, 2000). The plateau in PCO_2 observed between TVent and respiratory compensation point demonstrates isocapnic buffering. Therefore, RCP represents the highest exercise intensity in which the respiratory system can maintain a physiological steady-state (Wasserman *et al.*, 1973).

2.7.3.4. Respiratory exchange ratio

Respiratory exchange ratio is the ratio of $\dot{V}CO_2 / \dot{V}O_2$ and gives an indication of the whole body substrate utilisation during steady-state exercise (Ramos-Jimenez *et al.*, 2008). The quantity of O_2 required to metabolise substrates is proportional to the number of carbon-chains in the substrate. Glucose is a 6-carbon chain and therefore requires 6 mol. O_2 to be fully metabolised, hence the RER value is 1.0. Free fatty acids have more carbon-chains than carbohydrate and therefore more O_2 is required to metabolise lipids, consequently, the RER for lipid metabolism can be lowered to 0.7. An

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RER of above 1.0 is indicative of anaerobic metabolism as the $\dot{V}CO_2$ from anaerobic metabolism increases. During submaximal exercise, there was large inter-individual variability in RER measures reported by Ramos-Jimenez *et al.*, (2008) (RER 0.718–0.927). Many factors have been reported to affect the RER. Trained endurance athletes exhibited a lower RER (~10%) during exercise above lactate threshold, at lactate threshold and below lactate threshold than untrained males. The difference was attributed to a greater oxidative potential of the trained group (Ramos-Jimenez *et al.*, 2008). The consumption of high fat foods or carbohydrate-rich foods affected the availability and metabolism of substrates, thus affecting the RER (Bergman and Brooks, 1999). Goedecke *et al.*, (2000) also reported that major determinants of RER were muscle glycogen content, proportion of type I muscle fibres and substrate availability (adjusted r^2=0.59, P<0.001). It was also found that determinants of RER differed with respect to exercise intensity. At 25% peak cycling power, blood substrates were the major determinant of RER. At 50% peak power output, muscle substrate and glycolytic enzyme activities were the major determinant of RER and at 70% peak power lactate accumulation was the determining factor (Goedecke *et al.*, (2000). Therefore the measurement of RER from pulmonary ventilatory data is useful but can be subject to large variability (Ramos-Jimenez *et al.*, 2008).

2.7.4. Measurement of anaerobic power

An athlete's anaerobic power is the total amount of energy produced by the anaerobic energy systems. Anaerobic power is influenced by many factors including metabolic pathways to resynthesise ATP, muscle fibre type, metabolic pathways, buffering capacity and the ability of the neuromuscular system to

recruit musculature appropriately during such high intensity exercise (Rusko and Nummela, 1996). Measurement of an individual's anaerobic power can be achieved directly and indirectly. The direct measure of anaerobic power requires a muscle biopsy to be taken pre and post high-intensity exercise. Changes in the concentration of ATP, PCr and lactate between the biopsies can be used to quantify anaerobic activity during the high intensity exercise (Goodwin *et al.*, 2007). Winter and McLaren, (2009) identified limitations of the muscle biopsy technique. Firstly, the removal of muscle tissue during a biopsy might leave the participants with bruising and pain. Also, speed is required when taking and freezing the biopsy in liquid nitrogen as the resynthesis of ATP, PCr and an elimination of lactate might occur in the meantime. The measure of anaerobic power via muscle biopsy is specific to the site of the biopsy and is not representative of anaerobic power of the working muscle group or body as a whole. Finally, the muscle biopsy technique only considers the concentration of lactate in the biopsy and does not account for the preceding release of lactate into the blood, thus the anaerobic power might be underestimated (Winter and McLaren, 2009).

Indirect measures offer estimations of anaerobic power exist that attempt to maximally stress all the determinants of anaerobic power. It is for this reason that a plethora of anaerobic tests exist such as Margaria stair sprint test, Wingate anaerobic test, vertical jump and long jump. None of these tests stress all the determinants of anaerobic power and lack specificity to athletes competing in sports where over ground running is the main mode of exercise.

2.7.4.1.   Maximal accumulated oxygen deficit (MAOD)

Anaerobic running power is commonly measured by Maximal Accumulated Oxygen Deficit (MAOD) (Bosquet *et al.*, 2008). In the MAOD, the oxygen deficit of high-intensity exercise is predicted from the extrapolation of the linear $\dot{V}O_{2max.}$-intensity relationship. The assumption that the $\dot{V}O_2$-intensity relationship is linear is debatable since the $\dot{V}O_2$ consumption does not accurately reflect the oxygen demand of the exercise during high intensity exercise (Hill and Vingren, 2011). Instead it was reported that the $\dot{V}O_2$-intensity relationship is curvilinear during running, therefore anaerobic power might be underestimated using the MAOD method (Hill and Vingren, 2011). In addition, Noordhof *et al.*, (2010) reported that the $\dot{V}O_2$-intensity relationship appears to be dependent on the number, duration and intensity of the submaximal exercise bouts, thus the MAOD scores can varying depending on the selected submaximal exercise protocol. Despite these reservations the reliability of the MAOD in terms of CV% and ICC (6.8% and 0.91, respectively) deemed the MAOD as reliable, however large 95% limits of agreement (0 ± 15.1 ml O_2) indicated large variability and deemed the MAOD as unreliable (Doherty *et al.*, 2000). Therefore the reliability of the MAOD is questionable and so the MAOD is not a fully defensible method to determine anaerobic power (Noordhof *et al.*, 2010).

2.7.4.2.   Maximal anaerobic running test (MART)

A maximal anaerobic running test (MART) has been devised which was purported to give a comprehensive description of the metabolic and neuromuscular demands of anaerobic power (Nummela *et al.*, 1996). In essence, the MART consists of 20 s runs on a conventional treadmill (with an

additional 3 s acceleration phase) with a 100 s passive recovery between runs. Maximum running power is determined by calculating the O_2 equivalents. Similar to MAOD calculation, the MART also assumes a linear $\dot{V}O_2$-intensity relationship, however, the MART was reported to correlate well with anaerobic performance measures such as the 400 m run time (r=0.90, p<0.001) (Rusko *et al.*, 1993). Also Nummela *et al.*, (1996) reported that the reliability of the maximal running power during the MART was high (r=0.92, p<0.001).

As a measure of anaerobic running performance, the energy supply for the MART must be from the anaerobic energy systems if the test is to be a valid test. Nummela *et al.*, (1996) reported that the anaerobic contribution was high with a mean anaerobic contribution of 68%, ranging from 64% to 72% during the 20 s exercise intervals. Zagatto *et al.*, (2011) reported that during the 20 s exercise intervals the ATP-PCr energy system was the main energy system (73.5 ± 1.0%). During the entire MART (inclusive of the recovery periods) the aerobic glycolysis system, anaerobic glycolysis system and ATP-PCr system contributed 65.4 ± 1.1%, 29.5 ± 1.1% and 5.1 ± 0.5%, respectively (Zagatto *et al.*, 2011).

There are discrepancies in the MART protocols reported in the literature regarding the inclination of the treadmill and the running speeds. In the interest of specificity, a treadmill inclination of 1% should probably be used in athletes engaging in sport where over ground running is prominent as it most accurately represents the physiological demands of over ground running (Jones and Doust, 1996). However, treadmill running above 1° inclination, more specifically, 4° and 7° has been shown to elicit a greater maximum running power as indicated by higher MART scores (Nummela *et al.*, 1996). Also, Nummela *et*

al., (1996) reported that [BLa] was higher in the MART at 4° and 7° inclination of the treadmill than 1° inclination which suggests that the lactic acid capacity was not stressed to its potential in the lower inclinations. The higher [BLa] and maximum running power indicate that the anaerobic metabolism is higher during 4° and 7° inclined running and probably accounts for the lower maximum velocities exhibited compared with running at 1° inclination. Lower maximum running velocities in the 4° and 7° present less of an injury risk and therefore MART protocols utilising inclined running above 1° are preferred.

The incline of the treadmill might also influence the prescribed initial running speed and the increments in speeds between each 20 s bout of a MART protocol. The initial running speed in the MART protocol described by Maxwell and Nimmo (1996) was 14.3 $km·h^{-1}$ and increased by 1.2 $km·h^{-1}$ per bout while the treadmill inclination was 10.5%. While developing a track version of the MART, Nummela *et al.,* (2007) employed an initial running speed of 17.1 $km·h^{-1}$ for male athletes and 14.18 $km·h^{-1}$ for female athletes on the treadmill. Regardless of gender, the treadmill inclination was 5.2% and the speed increments were 1.48 $km·h^{-1}$. Sprint times on the track were slower in the females, possibly due to a lower trained status and this was reflected in the lower initial speed compared with the males (3.94 $m·s^{-1}$ vs. 4.75 $m·s^{-1}$). The faster running speeds and greater speed increments performed by male athletes in the Nummela *et al.,* (2007) study might compensate for the lower treadmill inclination than Maxwell and Nimmo (1996), thus ensuring that the exercise intensity is great enough to predominantly stress the anaerobic systems. Therefore, the initial speed and increments in speed for a MART protocol must take into consideration the effect of the treadmill inclination and the trained status of the participants.

Some MART protocols have employed counter-movement jumps between each 20 s run to assess the muscular force capacity and fatigue of the neuromuscular system between bouts. The inclusion of counter-movement jumps between bouts was reported to affect the development of fatigue and maximal running power (Nummela et al., 1996). Also, the retest correlation of the difference in counter-movement jump heights between each 20 s bout was reported to be poor (Rusko and Nummela, 1996). Rusko and Nummela (1996) suggested that the time taken to perform countermovement jumps after volitional fatigue (15-35 s) allows for substantial recovery of the neuromuscular system and thus does not provide an accurate measure of neuromuscular fatigue or muscular force capacity. Therefore it was suggested that the MART protocol may include countermovement jumps, however, they are of questionable reliability and should only be performed pre and post MART as a measure of the neuromuscular performance.

2.7.5. Rate of perceived exertion

The rate of perceived exertion (RPE) is a subjective estimate of exercise intensity that integrates many of the signals of the body during exercise (Chen et al., 2013). Exercisers are required to assign a number ranging from 6-20 on the Borg RPE scale (Appendix 6) that represents the sensation of the amount of work being undertaken (Morgan, 1973). It is widely accepted as a means of assessing and regulating exercise intensity in different populations and situations (Eston and Conolly, 1996). The subjective nature of the RPE scale was suggested to be affected by psychological factors such as anxiety (Morgan, 1973), however, RPE has been shown to be reliable and have a strong correlation with other objective measures of exercise intensity. During

submaximal cycling, a strong correlation between RPE (RPE 9, 13, 15, 17), heart rate, and work rate (r=0.96 - 0.99) was found (Eston and Thompson, 1997). During stationary running in water at different cadences, relationships between RPE and HR (r=0.65; $p<0.001$), %HRmax. (r=0.65; $p<0.001$), $\dot{V}O2$ (r=0.60; $p=0.001$), $\dot{V}O_{2max.}$ (r=0.71; $p<0.001$) and VE (r=0.77; $p<0.001$). No relationships were found between RPE and neuromuscular recruitment therefore it was concluded that RPE shared an association with cardiorespiratory responses (Alberton *et al.*, 2011). Eston and Williams (1988) reported that the reliability of RPE measures is between exercise perceived as 'very light' and 'somewhat hard' exercise (RPE 9 and 13 respectively) was good (r=0.83 and r=0.94 respectively) but higher reliability was exhibited during harder exercise (RPE 17) (r>0.92) indicating that participants need to be accustomed to using the RPE at lower intensity exercise.

2.8. Biomechanical measures

2.8.1. Measurement of kinematic variables

2.8.1.1. Videography

A common method of determining kinematic variables is the digitisation of 2-dimensional (2-D) video data. Digitisation is the conversion of individual images to digital data to identify coordinate (x and y) positions of anatomical landmarks and joint centres from which body segment position, velocity or 3-point joint angles can be determined (Wilson *et al.*, 1999). In 2-D video digitisation, the accuracy of experienced researchers can be as low as ± 1° during frame-by-frame manual digitisation (Wilson *et al.*, 1999), however it is

time-consuming (Davis *et al.*, 1991). Some digitisation software offer automatic marker tracking that can speed up the digitisation process but at the expense of accuracy. Accuracy is reduced when analysing rapid movements that are too quick for the hardware to capture effectively and when markers are obscured by limbs (Wilson *et al.*, 1999). Common sources of error in videography include subjective identification of joint centres, movement of high contrast markers on the skin during exercise, perspective error (apparent change in the length of an object due to changes in the perpendicular distance of objects to the camera), parallax error (apparent shift in objects position due to a change in the angle of the observation) and misalignment of the superimposed crosshair with the markers during the digitisation process (Grimshaw *et al.*, 2007). Multiple video cameras can be used to obtain 3-D kinematic data, however, the sources of error can be multiplied (Bartlett *et al.*, 2006).

2.8.1.2.   3-D optical motion analysis

Three-dimensional optical motion analysis is another common method for determining kinematic variables. 3-D optical motion analysis utilises multiple infra-red cameras to track the 3-D coordinates (x, y and z) of passive retro-reflective markers adhered to the performer at sample rates of <1000 Hz (Davis *et al.*, 1991). 3-D optical motion analysis does not suffer from some of the sources of error associated with video digitisation since markers are automatically tracked and the analysis is less labour intensive (Davis *et al.*, 1991). The current recommendation is to use 6-8 cameras (Davis *et al.*, 1991 and Ferber *et al.*, 2002) to improve the tracking of the markers and to enable more markers to be tracked, thus a more comprehensive kinematic analysis can be achieved with less marker 'drop-out'. Similar to video

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digitisation, anatomical marker placement is important for reliability. In 3-D analysis, small changes in the marker positions can introduce cross-talk across the planes of motion or offset shift in the data (Ferber *et al.*, 2002). A met-analysis of 3-D optical motion analysis system performed by McGinley *et al.*, (2009) revealed moderate to good reliability in the sagittal and frontal plane kinematic variables during human locomotion. The majority of the articles reviewed expressed estimates of error of <5° in these planes (McGinley *et al.*, 2009). In partial agreement Doma *et al.*, (2012) reported moderate to high reliability for lower limb sagittal plane kinematics during running as measured by ICC (0.76 – 0.97), bias ratio */+ 95% ratio LOA (spread of 95% of observed ratios within the ratio LOA% of the mean bias, perfect agreement= 1) (1.03 */+ 1.09) and CV (2.0 – 6.0%). Lower reliability was observed in frontal plane (ICC 0.33 - 0.92, LOA 1.07 */+ 1.39 and CV 5.3 - 18.6%) and transverse plane (ICC 0.73 - 0.96, LOA 1.07 */+ 1.38 and CV 3.9 - 16.6%). Ferber *et al.*, (2002) also found more reliable sagittal plane measures than other planes and also found more reliable within-day kinematics (ICC 0.92-0.98 for sagittal peak angles) when compared with between-day reliability (ICC 0.85-0.93 for sagittal peak angles). The within-day variability was attributed to skin-related movement, measurement error and physiological variability during human locomotion whereas between-day variability include these and marker reapplication (Ferber *et al.*, 2002). Kadaba *et al.*, (1990), and Hamill and Selbie, (2004) also reported that poor reliability and validity measures were evident in the rotation of body segments around the longitudinal axis.

2.8.1.2.1.   3-D optical motion analysis calibration

The 3-D optical motion analysis system requires calibration of the movement volume. The calibration methods are specific to the manufacturer. Often, a

reference frame with retroreflective markers positioned at a known distance is used to calibrate the system (x, y and z). More recent techniques in the calibration of 3-D optical motion analysis systems require a dynamic calibration in which a 'wand' with retroreflective markers positioned at a known distance to be moved through the entire movement volume and was suggested to reduce measurement error (McGinley *et al.*, 2009). Kertis *et al.*, (2010) found that the accuracy of dynamic calibration ranged from 94.82 - 99.77% and in absolute terms the range was 0.09 ± 0.26 to 0.61 ± 0.31 mm.

2.8.1.2.2. Marker configuration

There are several marker models available and the selection of the model is dependent on the application. The markers aim to define the segment (pelvis, thigh, shank and foot) length (proximal to distal distance) and width (medial to lateral distance). Markers can be adhered to the skin overlying joint centres during data collection trials, however, this configuration is subject to skin-related movement during data collection trials (Ferber *et al.*, 2002 and Hamill and Selbie, 2004).

Some marker configurations utilise a 'wand markers' that protrude laterally aligned with the longitudinal axis of the segment in addition to the markers overlying the joint centres (Kadaba *et al.*, 1990). The movement of the wand is used to calculate the rotation of the segment relative to the position of the wand in a standing position recorded prior to the data collection trials (static segment model). Wren *et al.*, (2008) reported that wand markers were susceptible to oscillations, inertial effects as well as skin-related movements. These might account for the poor accuracy associated with measures of the hip rotation. Wren *et al.*, (2008) also found that the wand markers positioned at the

distal and proximal ends of the thigh underestimated hip rotation range of motion by 54% and 35% respectively when compared with actual hip rotation in static controlled tests of range of motion.

A commonly used marker configuration utilises markers overlying the joint centres relative to 4 markers mounted on rigid plates (cluster markers) that are bound to each body segment (Hamill and Selbie, 2004). The movement of the body segment is calculated relative to the position of the cluster markers in a static segment model in a standing position to be recorded prior to the data collection trials. The benefits of this method are that the body segments are tracked independently based on the rigid 4-marker cluster-plates and therefore during the data collection trials, only the cluster need remain on the participant. Therefore markers overlying joint centres and some anatomical landmarks can be removed so they do not pose limiting factor on the movement analysis. Also, the rigid plates are less susceptible to skin-related movement than skin mounted markers overlying joint centres (Hamill and Selbie, 2004).

2.8.1.2.3.   Data processing

The raw data from each tracked marker has to be processed to remove erroneous data (noise) from sources such as system electrical interference and skin movement (Winter, 2005), especially if the data was to be used to calculate first and second derivatives (velocity and acceleration, respectively) as the error will be multiplied. Therefore, it is important to select an appropriate processing procedure to remove or minimise the noise while minimising the impact on the data.

Modern motion analysis software identifies markers automatically, however, they have to be checked to ensure switching of actual markers or

switching with 'ghost' markers has not occurred. In addition, portions where the data might be corrupted or missing can also be identified. Ideally, data collection trials with missing or corrupted portions of data should be performed again with the cameras in different positions and recalibrated accordingly. Alternatively and sometimes controversially, the data can be interpolated to predict the trajectory of the marker when the actual data is missing (Derrick, 2004 and Milner, 2008). Simple interpolation techniques such as a linear (straight trajectory between data points either side of missing data) and cosine (smooth trajectory between data points) are not appropriate for kinematic data given the nature of the movement in markers being complex, not linear or smooth. Splining is a popular method of interpolating in biomechanics in which a series of localised low-order polynomials are fitted to the data (Derrick, 2004). Therefore, the predicted trajectory of the marker is based on the trajectory in the 3-5 (cubic or quintic, respectively) frames preceding and following the missing data. Interpolation of data was deemed appropriate for a maximum of 5 frames by Milner, (2008) and providing the interpolation does not overlap with a critical point in the motion such as peak or minimum angles and change in direction (Milner, 2008).

Coordinate data can be filtered to distinguish the true data from noise. The majority of noise in coordinate data (skin movement) is of low amplitude and observed in the higher frequency domain (12+ Hz) and above the frequency of interest (Kaiser and Reed, 1977; Winter, 2005; Milner, 2008). A low-pass filter, such as a Butterworth filter, is a common processing technique that attenuates the higher frequencies (Hamill and Selbie, 2004). The selection of the cut-off frequency for the low-pass filter is important as if it is set too high, the data will not be altered sufficiently to remove the noise and if it is set too

high, the filtering process will alter the true data and ultimately alter the conclusions from the data (Winter 2005; Fellin et al., 2010). Winter (2005) suggested that the cut-off frequency should be based on the residual analysis of the difference between filtered and unfiltered over a range of cut-off frequencies (Winter, 2005). The 3-D coordinate data is normally filtered between 4-8 Hz and the exact cut-off is dependent on the signal frequency at which 90% of the raw signal is retained after the filtering process (Ferber et al., 2002). The rationale for 90% retention of the data after processing rather than more or less stringent criteria is unclear. Alternatively, the cut-off frequency can be determined by trial and error and visually inspecting the effect on the data (Milner, 2008). Winter (2005) and Milner (2008) suggested that an appropriate cut-off frequency for walking is approximately 6 Hz, however for running analysis higher cut-off frequencies of 8 to 12 Hz are often used (Ferber et al., 2003; Milner, 2008; Fellin et al., 2010; Ferber et al., 2010).

Processing techniques to smooth digital data are available. The Hanning algorithm is a weighted moving average algorithm to smooth the data. The averaging window of 'n' frames can be assigned and can be applied many times over to further smooth the data. Hanning algorithm is an easy smoothing technique but it is incapable of distinguishing signals from the noise and as such it was described as inflexible (Grimshaw et al., 2007). A more 'flexible' method of smoothing data which can be used for more complex smoothing as required by biomechanical data is a Butterworth second order algorithm (Derrick 2004). Derrick (2004) suggested that the Butterworth algorithm smoothed the data while maintaining the amplitudes of the frequencies in the pass-band, thus it is a desirable smoothing technique. A side-effect of applying the Butterworth algorithm is a forward time-shift in the data, which is detrimental

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to kinematic analysis where timing is essential, especially when synchronised with other biomechanical measures such as force plates and electromyography systems. It is for this reason that the Butterworth algorithm is applied twice (normal and then in reverse) to negate the time-shift and is termed a Butterworth fourth order algorithm (Grimshaw *et al.*, 2007). Another popular smoothing technique is splining. The series of low-order polynomials that are applied to the data to interpolate the missing data can also be used as a smoothing technique to remove erroneous data. The localised polynomials means that splining can be used to effectively smooth in complex data as seen in biomechanics and is used in many motion analysis software (Milner, 2008).

2.8.2. Measurement of neuromuscular recruitment

A method of measuring the amplitude and the timing of muscle activity can be achieved through electromyography (EMG). EMG is the measurement of electrical potential brought about by the depolarisation of the muscle fibre membranes (Marshall and Elliot, 1992). The EMG signal is commonly derived from the difference in the voltage detected by a pair of bipolar electrodes positioned in or overlying muscles of interest (Hermens *et al.*, 2000). Reservations toward EMG data were due to the erratic appearance and poor reproducibility of the signal (Hof, 1984). Also, the EMG signal was reported to be a poor indicator of muscle force and only had use as an indicator of timing of muscle activity (Hof, 1984). Regardless of these reservations EMG is still widely used in exercise biomechanics research (Wank *et al.*, 1998), rehabilitation, and clinical settings (Reaz *et al.*, 2006).

The interpretation of the EMG signal in terms of muscle activity is straightforward, however, the interpretation of EMG amplitude has to be approached cautiously (Marshall and Elliot, 1992). The amplitude of an EMG signal is not a direct measure of muscular force because the amplitude and the frequency of EMG signal are influenced by many in vivo factors such as blood flow, surrounding tissue impedance, fibre arrangement, and fibre type, fibre diameter, parallel elastic component, conduction velocity, muscle contraction velocity and muscle fibre length (Marshall and Elliot, 1992; Kamen, 2004; Winter, 2005; Gleeson, 2008). The combination of these factors complicates the EMG signal and complicates the comparisons of the EMG amplitude within or between muscles.

2.8.2.1.   Hardware configuration

The configuration of hardware and methods used to acquire the EMG signal varies in the literature and therefore requires review. Factors to improve the signal quality of the EMG data include the type of electrodes, electrode positioning, skin preparation, data processing, for example.

2.8.2.1.1.   Fine wire electrodes

Electrodes detect the electrical impulses in the motor units in the vicinity of the electrode. Fine wire electrodes are sterile electrodes inserted deep into the muscle via a hypodermic needle. The benefit of these electrodes is the ability to record the EMG of deep-lying musculature or target small muscles involved in fine motor movements (Winter, 2005). The tips of the fine wires are the sensors for recording the EMG signal. Larger recording surface area can be achieved by stripping the wire insulation from the tip (<1 mm) to capture activity of more

motor units (Kamen, 2004). Komi and Buskirk (1970) reported reasonable test re-test reliability of fine wire electrodes (r=0.62). The invasive nature of the method means there is the potential for the participants to experience pain or discomfort from the hypodermic needle. A specialism is required by the researcher to insert the fine wires into the intended muscle and into an appropriate position within the muscle.

2.8.2.1.2. Surface electrodes

Surface electrodes are adhered to the skin of the individual and detect the EMG signal of the underlying muscles. Depending on the size of the surface EMG electrode (sEMG), the EMG of thousands of muscle fibres stimulated by many motor units can be assessed simultaneously (Marshall and Elliot, 1992). The mounting of the electrodes on the skin predisposes the EMG signal to sources of error. The tissues between the muscle of interest and the sEMG (for example, muscle sheath, subcutaneous fat and skin) can impede the EMG signal. Also many EMG hardware units are hardwired, therefore the signal can be subject to low frequency noise brought about by the movement in the wires during dynamic activity (Grimshaw et al., 2007). Active sEMG electrodes have an insulated power supply to each electrode to power preamplifiers which reduced the noise (Kamen, 2004) and the impedance between the skin and sEMG electrode when compared with passive sEMG (Gleeson, 2008). Active sEMG reduce the impedance to such an extent that skin preparation procedures are not required (Gleeson, 2008). Skin preparations for passive electrodes is required to reduce the noise in the signal (Kamen, 2004) and include shaving, cleansing with alcohol swab, light abrasion of the skin and conductivity gel, which can subject the individual to considerable discomfort (Burden, 2008).

The reliability of sEMG has been reported to be high. Spector (1979) reported correlation coefficients of sEMG of 0.73 to 0.97 recorded from the paraspinal muscles. When compared with fine wire, greater within-day reliability was observed in sEMG (correlation coefficients of 0.62 vs. 0.88 respectively) (Komi and Buskirk, 1970). In addition to more reliable data, the relative ease of sEMG compared to the fine wire method makes it an attractive option for determining the neuromuscular recruitment of superficial musculature.

2.8.2.1.3.   Electrode positioning

The positioning of sEMG electrodes is important to ensure that the acquired signal is that of the muscle of interest and prevent cross-talk from active muscles in close proximity. To this point, the 'Surface EMG for Non-Invasive Assessment of Muscles' (SENIAM) was a project to standardise the methods for sEMG including the positioning. The results of the project were published by Hermens *et al.*, (2000). SENIAM recommended that the longitudinal position of the sEMG should be midway between the most distal motor endplate and the distal tendon (parallel with muscle fibre orientation) as erratic signals are evident in these regions (Rainoldi *et al.*, 2000; 2004). The transverse location should be away from the muscle edge whilst maximising the distance from other sEMG electrodes (Hermens *et al.*, 2000). In accordance with SENIAM recommendations, bipolar sEMG electrodes for the tibialis anterior should be positioned at 33% on the line between the tip of the fibula and the medial malleolus. The SENIAM recommendation for the gastrocnemius is to position the sEMG electrodes over the 'belly' of the muscle, which could predispose the gastrocnemius EMG measures to capturing over the motor endplate thus introducing error in to the signal (Rainoldi *et al.*, 2000; 2004). Sacco *et al.*, (2009) investigated the SENIAM recommendations on sEMG electrode

positioning for the peroneus longus, vastus lateralis, tibialis anterior and gastrocnemius in terms of raw signal density, motor end point and the shift in innervations zone during dynamic contraction and linear envelopes. Comparisons were made with the EMG signals from those positioned 25 mm distally and proximally to the SENIAM recommended position. Sacco *et al.*, (2009) agreed with the positioning of the vastus lateralis and peroneus longus, however, the optimal position for the tibialis was 47.5% and the gastrocnemius position was at 38% of its length (previously undetermined).

The inter-electrode distance between bipolar electrodes is also an important factor in EMG data collection. The computation of EMG (difference between pair of bipolar electrodes) will be altered if sampling from different portions of the muscle (Farina *et al.*, 2002). Beck *et al.*, (2005) investigated inter-electrode distances of 20 mm, 40 mm and 60 mm overlying the biceps brachii during isometric and isokinetic contractions. The inter-electrode distance between 20 mm and 60 mm did not affect the absolute EMG amplitude or the mean power frequency during the isometric or isokinetic contractions. The effect of inter-electrode distance was further reduced once the data had been normalised (discussed later in the chapter) (Beck *et al.*, 2005). Farina *et al.*, (2002) suggested that reducing the inter-electrode below 20 mm (5 mm up to 20 mm) led to a decrease in other EMG descriptors (average rectified EMG, root mean square and median power spectral frequency and EMG slope over time) in the trapezius muscle. Further increases in inter-electrode distance (up to 35 mm) did not reduce the EMG descriptors further (Farina *et al.*, 2002). Therefore an inter-electrode distance of 20 mm was recommended for the trapezius and agrees with the inter-electrode distance for the whole body recommendation of 20 mm by Hermens *et al.*, (2000).

2.8.2.1.4.   Amplification

The signal detected by the sEMG electrodes was suggested to be in the region of 5-9 mV which is too low for standard recording equipment to detect and therefore the signal requires amplification (Gleeson, 2008). Amplifiers increase the gain (ratio of the output to input voltage) of the signal by 100 to 10,000 times (Winter, 2005; Gleeson, 2008). There are a few factors that need to be considered in the amplification process.

Firstly, the amplifier must be able to amplify the signal linearly across the entire frequency spectrum so that the signal is not distorted. The frequency bandwidth that the amplifier can handle should be adequate to amplify the signal without attenuating the signal (Winter, 2005). For sEMG the amplifier bandwidth of 10 to 1000 Hz was deemed adequate since the expected frequency spectrum is between 20 and 1000 Hz for human locomotion (Winter, 2005).

At such low-voltage the signal can contain ambient noise from electrostatic and electromagnetic sources (electrical mains or radio signals), hence it is crucial that the ambient noise is minimised prior to amplification. To reduce the ambient noise, the amplification process must be performed as close as possible to the participant during the data collection so that the system is less exposed to sources of ambient noise prior to amplification (Gleeson, 2008), thus providing a rationale for active sEMG electrodes that have in-built pre-amplifiers and insulated wiring (Kamen, 2004). Differential amplifiers can be used to remove ambient noise by using a 'reference' electrode positioned on a bony landmark where only this ambient noise is detected. The ambient signal can then be subtracted from the EMG signal before amplification (Winter, 2005).

The required amplification gain is dependent on the equipment and application (Winter, 2005). In many cases where passive electrodes were believed to have been used, an amplifier gain of 1000 was used (Rainoldi *et al.*, 2000; Beck *et al.*, 2005; Mathur *et al.*, 2005). Lariviere *et al.*, (2002) reported an amplification gain of 1000 while using active electrodes, however the pre-amplification at the sEMG electrode was undisclosed. Sacco *et al.*, (2009) reported a 20 times pre-amplification of the EMG signal at the sEMG electrode with an overall differential amplified gain of 1000.

2.8.2.1.5. Signal processing

Once the signal is digitised it can be processed in numerous ways. Winter (2005) suggested that among others; signal rectification, root mean square and linear envelope were common processing techniques for EMG data. These techniques dominate the literature because of their appropriateness for the estimation of EMG amplitude (Clancy *et al.*, 2002).

As previously discussed, low frequency noise can be introduced to a signal through movement in the system wires. Also, any cross-talk from distant musculature can introduce low frequency noise (Burden, 2008). In addition, amplifiers often process the signal prior to amplification by applying a band-pass filter (combination of low and high pass filters) to the incoming signal. Signal noise outside of this band-pass is attenuated, therefore the band-pass filter must suite the range of the EMG signal as not to distort the true signal. Grimshaw *et al.*, (2007) suggested that an amplifier bandwidth of 20 to 500 Hz is appropriate; however, Kamen (2004) reported a lower expected range of sEMG data of approximately 10 to 400 Hz. The SENIAM project incorporated both estimates and recommended a bandwidth of 10 to 500 Hz

which has also been used by other sEMG studies (10 - 500 Hz (Farina *et al.*, 2002); 16 - 500 Hz (Larsson *et al.*, 2003), 10 - 20 Hz to 400 - 500 Hz (Clancy *et al.*, 2002). Hof (1984) suggested a bandwidth of 100 - 300 Hz which might have suited their sEMG hardware configuration at the time of publication however the advancement of equipment to reduce noise and signal impedance since the mid-1980's might mean more of the true signal present in the spectrum can be analysed.

Signal rectification either removes negative values of the EMG (half-wave rectification) or converts all of the negative values in the signal into positive integers (full-wave rectification) (Burden, 2008). Full-wave rectification is preferred as there is no loss of the signal power (Basmajian and De Luca, 1985). Although the analysis of the rectified EMG signal is limited to visual inspection of amplitude and timing, its main purpose is to prepare the signal for further processing (Winter, 2005).

There appears to be some debate over the use of average rectified value (ARV) and root mean square (RMS) as the next step in the processing procedure. Both processes apply an averaging window of 'n' number of successive data points. The ARV is the calculation of the integral of the EMG signal over the averaging window whereas RMS is the square root of the average power of the raw EMG signal (Burden, 2008). Although both are used and recommended by SENIAM, RMS is preferred as it was described to have a greater physical meaning (EMG signal power) and yields a greater amplitude than ARV (area under the curve) (Burden, 2008). In addition, it is more sensitive to changes in EMG and less variable than ARV (Merletti and Torino, 1999). Obviously the duration of the RMS window will affect the signal significantly and

literature suggests that the window depends on the action being analysed. For slow or isometric contractions a larger RMS window of up to 1 s (Hof, 1984) or up to 2 s (Merletti and Torino, 1999) were regarded suitable since erroneous fluctuations in the signal will be attenuated. Faster more dynamic actions require smaller RMS windows so that the fluctuations in the EMG are not attenuated, hence RMS windows of 10 to 50 ms (Grimshaw *et al.*, 2007), 100 to 200 ms (Basmajian and De Luca, 1985) to 250 ms (Hof, 1984) have been recommended.

The linear envelope involves the application of a low-pass filter (preferably a zero-lag filter such as Butterworth fourth order) to a full-wave rectified signal thus smoothing the signal (Winter, 2005). The linear envelope is often implemented to aid the acquisition of area, slope, onset and shape characteristics of the muscle activity (Kamen and Gabriel, 2010). In addition, Inman *et al.*, (1952) stated that linear envelope followed the rise and falls of muscle tension. An appropriate cut-off frequency is crucial since a very low cut-off frequency will over attenuate the signal thus the onset and amplitude of the EMG could be misrepresented and a high frequency cut-off will contain much of the same erratic data. Winter (1990) suggested that a cut-off frequency of 10 Hz was appropriate for EMG data. Similarly, Shiavi *et al.*, (1998) reported a minimum cut-off frequency of approximately 9 Hz is necessary for EMG derived from 6 to 10 walking strides based on ensemble average rectified EMG and the associated measurement error. However, Winter and Yack (1987) used lower cut-off frequencies of 3 Hz since this was similar to the twitch response frequency and peak frequency reported by Milner-Brown *et al.*, (1973) and Olney and Winter (1985) respectively. Higher frequencies of 50 Hz have been

suggested (Kamen and Gabriel, 2010), however this was for computer-automated detection of EMG activity.

2.8.2.1.6. Normalising the EMG signal

To render EMG data as comparable, the EMG amplitude captured during a data collection trial can be normalised (%) relative to the peak EMG amplitude (100%) during an isometric maximum voluntary contraction (%MVC) (Burden, 2008). The normalisation of EMG relative to %MVC also allows comparisons of EMG across participants. Although %MVC normalisation of EMG signals is the most widely used reference point for EMG data, the signal has to be interpreted cautiously. Firstly, the %MVC method is dependent on the exertion of the participant being truly maximal. Allen *et al.*, (1995) reported that most individuals are able to produce MVC during isometric contraction, however the subjectivity of this approach might lead to a degree of error (Marras and Davis, 2001). Also, a true maximal exertion is unlikely to be observed in individuals who are untrained and therefore the %MVC is inappropriate for these individuals. Secondly, there is an assumption that the EMG-muscular force relationship is linear, an assumption that is highly debated. Inman *et al.*, (1952) reported that EMG-muscular force relationship was linear during isometric contractions and non-linear during isotonic contractions. Furthermore, Woods and Bigland-Ritchie (1983) investigated the EMG-muscular force relationship across a range of isometric forces. Linear relationships were found in the muscles with homogenous fibre composition, whereas muscles with a mixed fibre composition demonstrated non-linear relationship. During exercise or sport, many muscles undertake isotonic activity for movement. If indeed the EMG-muscular force relationship is non-linear as suggested by Inman *et al.* (1952), comparisons of submaximal EMG amplitudes relative to %MVC

would be questionable. Thirdly, supramaximal EMG signals have been observed in EMG studies using the %MVC method, especially in dynamic movements (Clarys, 2000). During the acceleration phase of an over arm baseball throw, peak EMG was 226% of the peak EMG achieved in the MVC (Jobe *et al.*, 1984), hence the %MVC method is subject to poor reliability (Clarys, 2000). Lastly, the time taken for individuals to become accustomed to exercise for inducing their true peak EMG and also perform MVC trials for each muscle before the data collection is a lengthy process.

Other normalisation techniques such as submaximal MVC (for example 50% of the average of 3 MVC), the peak EMG in the movement or the mean EMG during an ensemble of movements (numerous gait cycles) had been shown to be more reliable than %MVC method (Yang and Winter (1983); Kollmitzer *et al.*, (1999); Clarys (2000)). For example, Dankaerts *et al.*, (2004) reported excellent within-day reliability for MVC (resisted isometric sit-ups) and submaximal MVC (unresisted isometric leg raise) in healthy individuals and those with chronic lower back pain (Intra Class Correlation (ICC) mean 0.91; range 0.75 to 0.98; Standard Error Measurement (SEM%) mean 4%; range 1 to 12%). The submaximal MVC for both healthy and chronic lower back pain sufferers between-days (1 week) were more reliable when compared with between-days MVC measures (ICC mean 0.88; range 0.78 to 0.97; SEM% mean 7%; range 3 to 11% vs. ICC mean 0.70; range 0.19 to 0.99; SEM% mean 17%; range 4 to 36%, respectively). Consequently, Dankaerts *et al.*, (2004) advocate the use of submaximal MVC for between-days measures.

In this chapter, the methods that relate to the individual studies of this thesis are presented. This chapter includes detailed descriptions of: 1) the vertical treadmill modification, maintenance and habituation; 2) the pre-exercise procedures; 3) the statistical procedures used; 4) equipment used and its calibration for biomechanical procedures; 5) the reliability of biomechanical procedures; 6) the equipment used and its calibration for physiological procedures and 7) reliability of physiological procedures.

3.1.   Vertical treadmill modification and maintenance

The vertical treadmill (VertiRun, Sheffield, UK) required considerable modification and maintenance by the author to standardise the vertical treadmill before any research could be performed. General maintenance duties included cleaning each component, lubricating rotary components, adjusting the tension of the treadmill belt as the rotary components wore and repairing the back rest and seat after intense use.

3.1.1. Determination of the vertical treadmill speed

The vertical treadmill employs a non-motorised treadmill belt and therefore the treadmill belt speed is determined by participant. To gauge treadmill belt speed the circumference of treadmill belt was measured with an unbranded measuring tape. A magnet (Power Magnet, Sigma Sport, Neustadt, Germany) was adhered to the treadmill belt and a magnetic reed switch (Speed Sensor, Sigma Sport, Neustadt, Germany) was adhered to the frame of the vertical treadmill. A

15V charge from an unbranded transformer was emitted to the reed switch. As participants rotated the treadmill belt the reed switch was triggered by the magnet and the circuit was temporarily complete (pulse). The time between each pulse was detected by a PowerLab 8.0 M data acquisition system (ADInstruments, Germany) and the complimentary software (LabChart 5, ADInstruments, Germany) calculated and recorded the treadmill belt speed and distance. For the first study (Chapter 4), the treadmill belt circumference was inputted into a cycle computer and was used to display the treadmill belt speed. The cycle computer (Sigma Sport BC906, Sigma Sport, Neustadt, Germany) displayed the treadmill belt speed in 0.5 km·h^{-1} increments which was deemed not sensitive enough for the retest protocol of the reliability of the physiological measures study (see 3.10.2.2.2.). Participants viewed treadmill belt speed on a computer screen positioned at eye-level and displayed treadmill belt speed in 0.01 m increments.

3.1.2. Resistance cables

3.1.2.1. Determination and verification of the resistance

The resistance was determined by suspending a 10 N cradle from each resistance cable and the changes in displacement of the cradle were recorded as 10 N weights were added to the cradle (displacement : load relationship). The displacement of the cradle determined the force required to overcome the resistance of the bands (20 N) and draw the leg downwards to the lowest portion of the treadmill (<70 N). This was repeated on a daily basis during the testing periods to ensure the resistance was consistent (20 – 70 N). The rubber

bands were tautened to increase the resistance and slackened to decrease the resistance.

3.1.2.2.   Replacement of the resistance bands

When the bands could not match the original displacement : load relationship, the bands were replaced. The original resistance bands perished within 2 months due to exposure to sunlight, more specifically ultra violet light and were replaced. After unsuccessfully trialing metal springs, rubber bands used for powerlifting (41", '#3 small' Iron Woody Bands, Iron Woody Fitness, Montana) were selected which were resistant to ultra violet light, the mechanical stress (maximum stretch) was within the tolerances of the bands and the displacement : load relationship was matched to the original rubber bands.

3.1.3. Ankle attachment

The original resistance cable-ankle attachment used a leather over-shoe which cradled the hind foot and had a sports trainer sole adhered to the underside to grip the treadmill belt. The over-shoe attached to the resistance cable via a metal D-ring and carabiner (Figure 2 (A)).
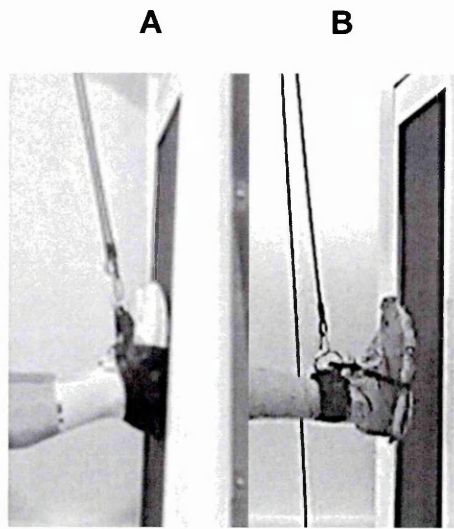
Figure 2. Original over-shoe design (A) and modified ankle cradle (B).

In pilot studies, the over-shoe did not grip the treadmill belt effectively and was replaced with a neoprene and VELCRO® ankle cuff with a metal D-ring (Figure 2 (B)). Bicycle toe-clip straps were looped through the metal D-ring of the ankle cuff and under the participant's foot between the forefoot and hind foot thus creating a foot cradle (Figure 2 (B)) where the participants' shoes could grip the vertical treadmill effectively and remove some of the shear stress off the Achilles tendon as the leg descended the treadmill belt. Participants plantarflexed maximally and the toe-clip was tightened as not to disrupt the motion of the ankle.

3.1.4. Fore and aft settings

The vertical treadmill was manufactured with fore and aft settings at 0.05 m intervals. The fore and aft setting positioned the user at distance whereby the knee was flexed by 20° when the foot was flat against the treadmill belt and vertically aligned with the hip. In pilot studies, the 20° knee angle could not be achieved by some participants with the original fore and aft settings and therefore the author drilled extra notches at 0.025 m intervals.

3.2. Vertical treadmill habituation

For all studies, participants were habituated to vertical treadmill in 2 induction sessions lasting approximately 30 minutes each on separate days. During each session, a range of self-selected speeds and postures (supine (0°), 40° and 70°) were sampled. It was the participants' preference to begin the habituation process in the 70° posture so that the foot placement on the treadmill could be viewed and evaluated before exercising at 40° and supine where the treadmill is not visible and proprioception is relied upon. Participants were allowed to view their performance throughout by means of the speedometer (Sigma BC906, Sigma Sport, Germany).

3.3. Pre-exercise procedures

3.3.1. Ethics

Ethics approval was sought and granted by the Faculty of Health and Wellbeing Ethics committee in accordance with the World Medical Association declaration of Helsinki (2008).

3.3.2. Informed consent

All participants in each study were given a participant information sheet (Appendix 2.1., 2.2., 2.3.) detailing the rationale of each study, their involvement in the study and that they could withdraw from the study at any point. Participants were given the opportunity to ask questions regarding the study by email, telephone and face-to-face prior to commencing the tests. Once

participants were content with their involvement in the study, institutional informed consent form was signed (Appendix 3).

3.3.3. Pre-exercise screening

All participants completed an institutional pre-exercise medical questionnaire to screen for previous and/or current medical conditions and musculoskeletal injuries (Appendix 4). Participants identified as having medical conditions and/or injuries that might predispose participants to harm during the studies or might contaminate the results of the studies did not proceed with test protocols.

3.4. Statistical procedures

This thesis has employed several statistical analyses to ascertain the reliability of measures, the strength of relationships between measures and sport performance and differences between postures and intensities during vertical treadmill exercise. Statistical analysis was performed using PASW statistics 17.0.2. (SPSS Inc., Chicago, IL., USA) and Microsoft Excel 2007 (Microsoft Corporation, Redmond, WA., USA). Justification for the statistical analyses performed in this thesis are given in Appendix 5.

3.4.1. Comparison of group means

3.4.1.1. t-test

The t-test examined the differences between two groups (Foster et $al.$, 2006). The data was 'scale' level data (interval or ratio data), normally distributed as indicated by Shapiro-Wilks test (>0.05), the sphericity of the data was confirmed

by Mauchley's test (>0.05) and the homogeneity of variance between data sets was assumed as indicated by a Levene's test (>0.05) (Field, 2005). The independent t-test was used when different participants were assigned to one of two conditions. A dependent t-test was used when participants were tested in both conditions (Field, 2005).

3.4.1.2. Analysis of variance

Analysis of Variance (ANOVA) examined the differences between the means of three or more groups and identified interactions between variables (De Sá Marques, 2007). The data was 'scale' level data (interval or ratio data), normally distributed as indicated by Shapiro-Wilks test (>0.05), the sphericity of the data was confirmed by Mauchley's test (>0.05) (Greenhouse-Geisser if sphericity was not assumed) and the homogeneity of variance between data sets was assumed as indicated by a Levene's test (>0.05) (Field, 2005). A within-subjects ANOVA test was used on data from the same participants under several conditions (repeated measures). A between-subjects ANOVA test was used on data from different participants assigned to one condition. A mixed design ANOVA test was used on data from a combination of within and between-subjects data (Field, 2005). If a difference is detected by ANOVA, Bonferroni post-hoc tests were employed in which multiple paired comparisons are made on all variables. When the assumptions of the ANOVA were not met the data was subject to Friedman test and post-hoc Wilcoxon signed ranks test.

3.4.1.3. Effect size

To determine whether a statistical significance demonstrates a sizable and therefore a meaningful effect, effect size calculations were performed. Effect size was calculated using Cohen's d:

$$d = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\dfrac{SD_1{}^2\, df_1 + SD_2{}^2 df_2}{df_1 + df_2}}}$$

Where '$\bar{x}_1$' is the mean of variable 1, '$\bar{x}_2$' is the mean of variable 2, 'SD$_1$' is the standard deviation of variable 1 and 'SD$_2$' is the standard deviation of variable 2 'df$_1$' is the degrees of freedom of variable 1 (n-1) and 'df$_2$' is the degrees of freedom of variable 2 (n-1).

Cohen (1988) constructed guidelines on what constitutes as a large (0.8), medium (0.5) and small effect (0.2). Effect size was used to assess the meaningfulness of statistical significances between variables (Bakeman, 2005).

3.4.2. Reliability

Reliability refers to the consistency or repeatability of measurements when an individual is retested at random (Bruton *et al.*, 2000). Lachin (2004) advocated the publication of reliability of measurements as to allow the authors to better describe and readers to better understand the sources of error in the results. Several methods were used to estimate the reliability of measurement techniques as there does not appear to be one single acceptable measure of reliability.

3.4.2.1. Coefficient of variation

The coefficient of variation (CV) was used to assess the degree of variation in the data set (Atkinson and Nevill, 1998). The CV is the ratio of the standard deviation to the mean was expressed as a percentage and was calculated as:

$$CV = \frac{SD}{\bar{x}} \; x \; 100$$

Where 'SD' is the standard deviation of the data set and '$\bar{x}$' is the mean of the data set.

3.4.2.2. Technical error measurement

Technical Error Measurement (TEM) was used as an index of accuracy and is representative of the quality of the measurement and control dimension (Perini et al., 2005 and Geeta et al., 2009). To express this error in the data absolutely, the following TEM equation was used:

$$TEM = \sqrt{\frac{\Sigma D^2}{2n}}$$

Where 'D' is the difference between the measures and 'n' is the number in the sample.

The TEM was expressed in relative terms as a percentage to enable comparisons across variables. The relative TEM is acquired by:

$$Relative \; TEM = \frac{TEM}{\text{Global mean}} x \; 100$$

Where 'Global mean' is the combined mean of measure 1 and measure 2.

3.4.2.3. Limits of agreement

The LOA indicates the range in which 95% of the differences lie within ± 1.96 standard deviations of the mean difference (Bland and Altman, 1986). The homogeneity of variance between data sets was assumed as indicated by a Levene's test (>0.05) (Field, 2005). If the variance was not homogenous then the data was log-transformed before the LOA was executed. The absolute LOA was calculated by:

$$\pm\, 95\%\, LOA = 1.96\; x\; SD_{diff}$$

Where 'SD$_{diff}$' is the standard deviation of the differences between measure 1 and measure 2.

The LOA was expressed relative to the combined mean of measure 1 and measure 2 as a percentage. The relative LOA was calculated by:

$$relative\; LOA = \frac{1.96\; x\; SD_{diff}}{Global\; mean}\; x100$$

Where 'SD$_{diff}$' is the standard deviation of the differences between measure 1 and measure 2, 'Global mean' is the combined mean of measure 1 and measure 2.

3.4.2.4. Intra-class correlation coefficient

Intra-class Correlation Coefficient (ICC) was used to quantify the reliability by means of a ratio of variances on a test-retest basis. The total sum of squares and between-subjects sum of squares derived from an ANOVA was inputted in to the equation by Bland and Altman (1995):

$$ICC = \frac{n\,SS_B{}^2 - SS_T}{(n-1)SS_T}$$

where 'n' is the number of trials per participant, 'SS_T' is the total sum of squares and 'SS_B' is the between-subjects sum of squares.

An ICC of 0 indicated no reliability and 1 indicated perfect reliability (Weir, 2005).

3.4.2.5.   Standard error of measurement

Standard Error of Measurement (SEM) was used as an absolute measure of reliability and indicated the precision of a score (Weir, 2005). SEM was calculated using the following equation:

$$SEM = SD\,\sqrt{(1 - ICC)}$$

Where 'SD' is the global standard deviation and ICC is the intra-class correlation coefficient.

The inclusion of the standard deviation was reported to 'cancel' out the between-subjects variability that is evident in the calculation of ICC (Bland and Altman, 1990).

3.4.2.6.   Confidence intervals

Confidence intervals (CI) were used to represent the lower and upper boundaries of which 95% (2 standard deviations) of the sample population was distributed around the mean. The calculation of the 95% lower and upper CI were calculated by the following equation by Weir, (2005):

$$95\% \ CI \ Lower = Test \ score - (1.96 \ x \ S \quad)$$

$$95\% \ CI \ Upper = Test \ score + (1.96 \ x \ SEM)$$

Where CI is confidence interval and SEM is the standard error of measurement.

3.5. Biomechanical Procedures

3.5.1. 3-D optical motion analysis

Six 'Eagle' passive cameras (Motion Analysis Corporation, CA USA) were positioned 180° around the vertical treadmill as demonstrated in Figure 3. Pilot data identified this as the best configuration in the limited space and a wall prevented the 360° positioning of the cameras and was limited to unilateral analysis. The sample frequency during kinematic data capture was 200 Hz.

3.5.1.1. 3-D optical motion analysis calibration

The 3-D optical motion analysis system and the complimentary 'Cortex' software (Motion Analysis Corporation, CA, USA) were calibrated dynamically using an 'L' frame and 'wand' calibration technique. The L-frame defined the global coordinate system and the 500 mm T-shaped wand was used for a dynamic calibration of the volume for 1 minute. The system was considered to be calibrated if the error residual of each camera was <1 mm.
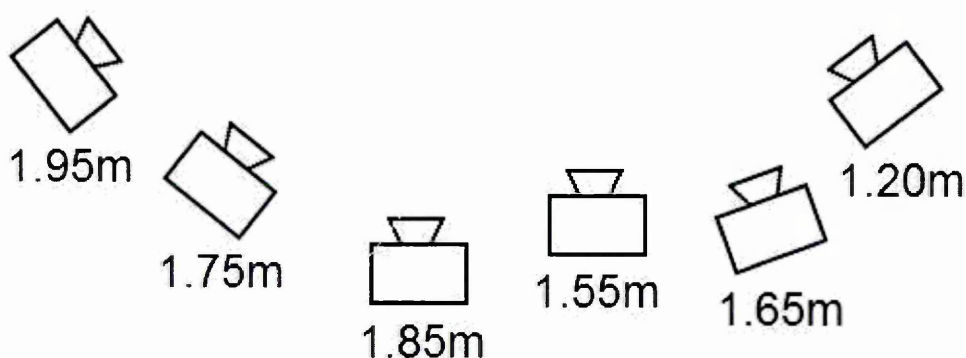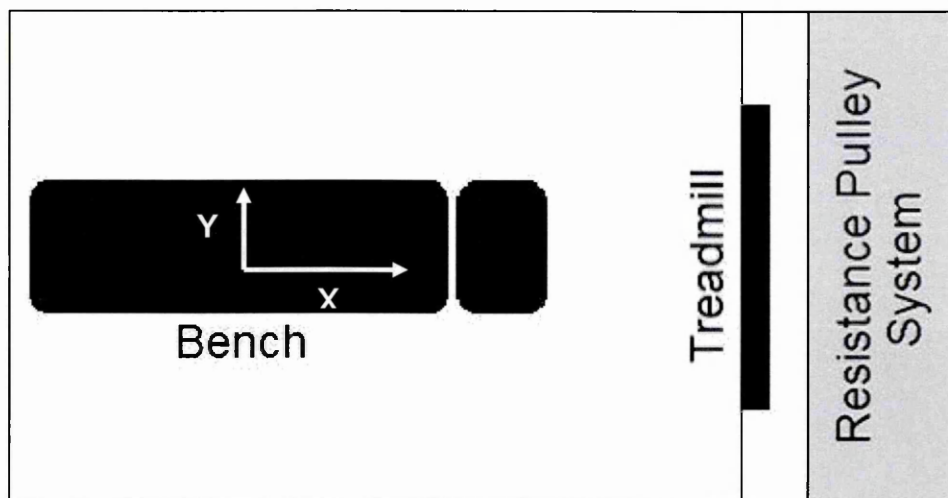
Figure 3. Position of the six motion analysis cameras around the vertical treadmill and the height of the cameras.

3.5.1.2. Marker Configuration

Participants wore their own tight-fitting shorts, T-shirt and trainers. Retroreflective markers were adhered to the skin and clothing of the participants' right leg overlying medial and lateral aspects of the metatarsals, malleolus, femoral epicondyle, greater trochanter, as well as the right and left anterior superior iliac spine, posterior superior iliac spine, iliac crests and the first and fifth metatarsals. Four-marker clusters were bound by 2" Fabrifoam SuperWrap ® (Applied Technology International Ltd., Pennsylvania, USA) to

the lateral aspect of the right shank and right thigh. The marker configuration is demonstrated in Figure 4.

Figure 4. Unilateral marker configuration for 3-D motion analysis.

3.5.1.3.   Determination of kinematic data

Raw coordinate data were imported into Visual 3D software (C-motion, Maryland USA) and filtered using a zero-lag fourth order low-pass Butterworth filter (8 Hz cut-off). The 2-D sagittal plane joint angles of the hip, knee and ankle were calculated relative to a static standing model. A 4-point angle (femoral epicondyle to lateral malleolus and calcaneus to fifth metatarsal) was used to calculate the ankle plantarflexion (-ve) and dorsiflexion (+ve) angles from the static standing model. Three-point angle were used to calculate the knee angle (greater trochanter to femoral epicondyle to lateral malleolus) and the hip (iliac crest to greater trochanter to femoral epicondyle). The knee flexion, and hip extension (-ve) and flexion (+ve) were calculated relative to that in the static standing model. For each participant, ten complete gait cycles were analysed.

Foot contact was established using a kinematic technique modified from Fellin *et al.*, (2010), which was deemed appropriate for vertical treadmill exercise. Foot strike was defined as the zero horizontal acceleration of the calcaneus or fifth metatarsal marker (whichever occurred first). This procedure allowed gait events to be determined in participants with different foot strike patterns. Toe-off was defined by the minimum horizontal velocity of the fifth metatarsal marker during the contact phase. Kinematic data were cropped and normalised to 100% of the gait cycle. All variables of interest were calculated for each of the ten cycles and averaged within participants and averaged across participants.

3.5.2. EMG system

Surface EMG data for selected muscles were collected using a Delsys Bagnoli 8-channel EMG system (Delsys Inc. MA, USA). The sampling frequency was 1000 Hz and the signal was amplified 20 times at the electrode and an overall differential amplified gain of 1000.

3.5.2.1.   EMG electrode configuration

The EMG surface electrodes (Delsys Inc. MA, USA) were active and therefore extensive site preparation was not required (De Luca and Knaflitz, 1992). The electrodes were adhered to the skin using 19 mm double sided tape (3M™, Minnesota, USA) overlying the vastus lateralis, vastus medialis, rectus femoris, biceps femoris, semitendinosus, tibialis anterior and medial gastrocnemius and lateral gastrocnemius in accordance with SENIAM guidelines on electrode preparation and positioning (Freriks *et al.*, 1999). Electrodes were bound to the leg with Coban™ self-adherent wrap (3M™, Minnesota, USA) to improve the

adherence of the electrodes to the skin and reduce movement artefact in the wires.

3.5.2.2.   Determination of EMG activity

Raw EMG data were subjected to both a 500 Hz low-pass and a 10 Hz high-pass filter, before being root-mean-squared (Hermens *et al.*, 2000) over an 11-frame moving window in Visual 3D software. The timing of muscle activation and periods of inactivity were of interest in this study. Muscle activation was established when the EMG signal rose 2 standard deviations above the mean resting signal and inactivity was established when the EMG signal fell below 2 standard deviations of the resting signal (Ives and Wigglesworth, 2003). EMG data were cropped and normalised to 100% of the gait cycle. All variables of interest were calculated for each of the ten gait cycles and averaged within participants and averaged across participants.

3.6. Reliability of kinematic data and neuromuscular recruitment

3.6.1. Introduction

Ferber *et al.*, (2002) suggested that for motion analysis data to be of value it firstly needs to be reliable. The reliability of motion analysis from previous research has ranged from moderate to high (ICC <0.98, <5°) (Ferber *et al.*, 2002; McGinley *et al.*, 2009 and Doma *et al.*, 2012), however, the reliability is specific to the authors' research facility and the methods of data collection. Similarly, the reliability of EMG data will be specific to the research facility and selected procedures, hence the reliability of both kinematic and EMG measures specifically for this thesis were warranted. The participants' posture can be manipulated on the vertical treadmill and this could alter the reliability of biomechanical measures as posture alters the relative position of body segments and compensatory movements were observed in other exercise modes (Massion, 1992 and Doma *et al.*, 2012). The exercise intensity can be altered by altering the treadmill speed and it was reported that during over ground running the reliability of lower limb kinematics varied with changes in velocity (Doma *et al.*, 2012), however, the effect of increments in vertical treadmill exercise speed on the reliability of biomechanical measures are unknown. In addition, the ability of the participants to reproduce movements and muscular recruitment patterns during a novel and unfamiliar exercise mode might predispose the data to poor reliability. Therefore the aim of this study was to determine the kinematics and neuromuscular recruitment patterns during vertical treadmill exercise in selected postures and intensities.

3.6.2. Methods

This study employed a test, re-test method to assess the reliability of the 3-D optical motion analysis and sEMG.

3.6.2.1.   Participants

After institutional ethics approval, 21 male participants (age 24.8 ± 7.1 years, stature 1.79 ± 0.07 m, body mass 77.7 ± 8.8 kg) were recruited for the study. All participants were healthy, physically active individuals, who were free from musculoskeletal disease or injury at the time of testing.

3.6.2.2.   Test protocol

Participants wore their own training shoes, tight fitting shorts and T-shirt to complete the protocol. Participants were prepared for kinematic and EMG data collection as described in 3.5.1.2. and 3.5.2.1. Participants stood on the base of the vertical treadmill facing the cameras with their feet shoulder width apart, standing up straight and with their arms crossed as not to obstruct markers on the pelvis. A static segment model of the participants was captured for 1 frame and to capture the posterior superior iliac spine markers, another static segment model was captured while facing the treadmill.

Participants were then positioned on the vertical treadmill and undertook a very light (RPE 9) warm up for 5 minutes and 5 minutes of dynamic stretching (hip flexion/extension leg swings, abduction/adduction leg swings, skips, high knees, heel flicks, step-overs, hurdle walks). Following the warm up participants exercised for 5 minutes at a speed that they perceived to replicate their over ground walking speed (described to participants as though going for a casual

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walk for 1 hour), jogging speed (described to participants as the pace when going for a casual jog for 1 hour) and running speed (described to participants as the pace when going for a training run for 1 hour) for 5 minutes each in the supine, 40° and 70° postures. These postures were selected as they were the extremes (supine and 70° posture) and the intermediate posture (40° posture) available on the vertical treadmill. Each bout of exercise was separated by 5 minutes of rest while the vertical treadmill was reconfigured. Simultaneous 3-D motion capture and EMG data were recorded during each condition (see 3.5.1. and 3.5.2.). The treadmill belt speed was logged continuously (PowerLab 8.0 M, ADInstruments, Germany) and participants were not permitted view to the speedometer. The participants were asked to rate their perceived exertion for each condition using Borg's RPE scale (Borg, 1998) (Appendix 6). The order of posture and the order of intensity in each posture were assigned randomly using the random function in Microsoft Excel 2007. The cadence exhibited in each condition was determined retrospectively from the cyclic motion of the fifth metatarsal. The speed and cadence exhibited in each condition were used as targets for the forthcoming retest protocol. Following a minimum of 24 hours but no longer than a week of rest, participants returned to complete the retest protocol.

3.6.2.3.   Retest Protocol

The retest protocol required participants to undertake the same retroreflective and sEMG electrode placement procedure and warm up as in the test protocol. In a random order, the participants exercised at the treadmill speed (± 0.5 km·h^{-1}) and cadence that they exhibited in the test protocol using a speedometer (Sigma BC906, Sigma Sport, Germany) and a metronome (Digital

Metronome DM-11, Seiko S-Yard Co. Ltd. Tokyo, Japan) while simultaneous 3-D motion capture and EMG data were recorded in each condition (see 3.5.1. and 3.5.2.).

3.6.2.4.   Data analysis

The raw coordinate data and EMG data were imported and analysed in Visual 3D software. The kinematic and EMG data were processed and the patterns were determined using the motion of the fifth metatarsal marker to determine initial contact and toe-off with the treadmill belt (modified from Fellin *et al.*, 2010) (see 3.5.1.3. and 3.5.2.2.). The kinematic and EMG data were cropped and normalised to 100% of the gait cycle. All variables of interest were calculated for each of the ten gait cycles and averaged within participants and averaged across participants. Temporal variables of interest were treadmill belt speed, cadence and stride length. Kinematic variables of interest were the range of motion of the hip, knee and ankle during the gait cycle. EMG variables of interest were the activation and deactivation of the rectus femoris, vastus lateralis, vastus medialis, biceps femoris, semitendinosus lateral gastrocnemius, medial gastrocnemius and tibialis anterior.

3.6.2.5.   Statistical Analysis

To satisfy the numerous aspects of reliability limits of agreement (first measure - second measure), intra-class correlation, standard error of measurement, technical error measurement and CV% were performed on the range of motion at each joint and the on and off timing (% gait cycle) of all muscles.

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3.7. Results

3.7.1. Vertical treadmill speed

Table 1. Mean (SD) and the reliability of the speed (m·s⁻¹) during vertical treadmill exercise that was perceived to replicate participants' over ground walking, jogging and running speed in the supine (0°) 40° and 70° posture. CV%= % coefficient of variation, TEM%= % technical error measurement, LOA= limits of agreement, ICC= intraclass correlation coefficient, SEM= standard error measurement, CI= confidence interval. (n=21).

Perceived speed	Posture (°)	Mean 1	(SD)	Mean 2	(SD)	CV%	TEM%	LOA -	LOA +	ICC	SEM	95% CI Lower	95% CI Upper
Walking	0	1.01	(0.26)	1.03	(0.26)	6.2	6.5	-0.7	0.6	0.965	0.2	3.3	4.0
	40	1.11	(0.24)	1.14	(0.25)	4.5	4.3	-0.5	0.3	0.984	0.1	3.8	4.3
	70	1.12	(0.28)	1.14	(0.30)	3.9	5.2	-0.7	0.5	0.982	0.1	3.8	4.3
Jogging	0	1.49	(0.29)	1.5	(0.31)	4.6	4.3	-0.7	0.6	0.974	0.2	5.1	5.7
	40	1.69	(0.28)	1.69	(0.33)	5.1	4.4	-0.8	0.7	0.970	0.2	5.7	6.5
	70	1.73	(0.32)	1.72	(0.33)	2.3	2.6	-0.5	0.5	0.990	0.1	6.0	6.5
Running	0	2.02	(0.39)	2.03	(0.38)	4.9	4.3	-0.9	0.9	0.972	0.2	6.8	7.7
	40	2.17	(0.28)	2.17	(0.31)	2.6	2.3	-0.5	0.5	0.986	0.1	7.6	8.0
	70	2.25	(0.45)	2.25	(0.42)	2.5	2.7	-0.6	0.6	0.989	0.2	7.8	8.4

The reliability of the vertical treadmill speed between the first and second measurements as measured by CV%, TEM%, LOA ranged from 2.3 – 6.2%, 2.3 – 6.5% and -0.9 – 0.9 respectively. The ICC and SEM ranged from 0.965 – 0.990 and 0.1 – 0.2 respectively. The 95% CI ranged from 3.3 – 4.3, 5.1 – 6.5 and 6.8 – 8.4 for perceived walking, jogging and running respectively.

3.7.2. Cadence

Table 2. Mean (SD) and the reliability of cadence (strides·min⁻¹) during vertical treadmill exercise that was perceived to replicate participants' over ground walking, jogging and running speed in the supine (0°) 40° and 70° posture. CV%= % coefficient of variation, TEM%= % technical error measurement, LOA= limits of agreement, ICC= intraclass correlation coefficient, SEM= standard error measurement, CI= confidence interval. (n=21).

Perceived speed	Posture (°)	Mean 1	(SD)	Mean 2	(SD)	CV%	TEM%	LOA -	LOA +	ICC	SEM	95% CI Lower	95% CI Upper
Walking	0	93	(20.2)	92	(20.3)	3.0	3.3	-6.9	9.6	0.989	2.1	88	96
	40	97	(18.1)	98	(18.6)	3.8	4.1	-12.1	10.3	0.975	2.9	92	103
	70	99	(16.8)	98	(18.8)	3.4	4.1	-10.3	12.5	0.973	2.9	93	104
Jogging	0	124	(15)	123	(16)	3.8	4.1	-13.2	15.3	0.939	3.7	117	131
	40	134	(20)	134	(19)	3.0	3.1	-12.3	10.9	0.976	3.0	128	140
	70	135	(15)	133	(15)	2.3	3.8	-11.3	16.1	0.941	3.6	127	141
Running	0	147	(18)	145	(18)	4.7	3.6	-11.9	16.4	0.958	3.6	139	153
	40	155	(19)	154	(18)	3.7	2.5	-9.4	11.3	0.979	2.6	149	159
	70	159	(16)	157	(14)	4.9	4.9	-20.6	23.5	0.840	6.0	146	170

The reliability of the cadence between the first and second measurements as measured by CV%, TEM%, LOA ranged from 2.3 – 4.9%,

2.5 – 4.9% and -13.2 – 23.5 respectively. The ICC and SEM ranged from 0.939 – 0.890 and 2.1 – 6.0 respectively. The 95% CI ranged

from 88 –104 strides·min⁻¹, 117 – 141 strides·min⁻¹ and 139 – 170 strides·min⁻¹ for perceived walking, jogging and running respectively.

3.7.3. Stride length

Table 3. Mean (*SD*) and the reliability of stride length (m) during vertical treadmill exercise that was perceived to replicate participants' over ground walking, jogging and running speed in the supine (0°) 40° and 70° posture. CV%= % coefficient of variation, TEM%= % technical error measurement, LOA= limits of agreement, ICC= intraclass correlation coefficient, SEM= standard error measurement, CI= confidence interval. (n=21).

Perceived speed	Posture (°)	Mean 1	(SD)	Mean 2	(SD)	CV%	TEM%	LOA -	LOA +	ICC	SEM	95% CI Lower	95% CI Upper
Walking	0	1.31	(0.18)	1.35	(0.18)	6.4	6.6	-0.3	0.2	0.869	0.1	1.20	1.46
	40	1.38	(0.21)	1.41	(0.20)	5.2	6.5	-0.3	0.2	0.893	0.1	1.29	1.50
	70	1.35	(0.21)	1.41	(0.23)	4.9	5.4	-0.2	0.1	0.954	0.1	1.27	1.48
Jogging	0	1.44	(0.23)	1.50	(0.19)	6.3	4.9	-0.2	0.2	0.936	0.2	1.04	1.85
	40	1.50	(0.24)	1.52	(0.23)	6.1	3.7	-0.2	0.3	0.922	0.1	1.38	1.68
	70	1.54	(0.28)	1.60	(0.24)	3.7	3.9	-0.2	0.2	0.965	0.1	1.45	1.66
Running	0	1.70	(0.25)	1.67	(0.21)	5.6	5.0	-0.2	0.2	0.935	0.1	1.55	1.77
	40	1.70	(0.19)	1.7	(0.18)	4.5	3.7	-0.2	0.2	0.941	0.1	1.59	1.80
	70	1.70	(0.29)	1.71	(0.28)	4.2	3.9	-0.2	0.2	0.967	0.1	1.60	1.81

The reliability of the stride length between the first and second measurements as measured by CV%, TEM%, LOA ranged from 3.7 –

6.4%, 3.7 – 6.6% and -0.3 – 0.3 respectively. The ICC and SEM ranged from 0.869 – 0.967 and 0.1 – 0.2 respectively. The 95% CI

ranged from 1.20 – 1.48 m, 1.04 – 1.68 m and 1.55 – 1.81 m for perceived walking, jogging and running respectively.

Table 4. Mean (*SD*) and the reliability of the range of motion (°) at the ankle during vertical treadmill exercise that was perceived to replicate participants' over ground walking, jogging and running speed in the supine (0°) 40° and 70° posture. CV%= % coefficient of variation, TEM%= % technical error measurement, LOA= limits of agreement, ICC= intraclass correlation coefficient, SEM= standard error measurement, CI= confidence interval. (n=21).

Perceived speed	Posture (°)	Mean 1	(SD)	Mean 2	(SD)	CV%	TEM%	LOA -	LOA +	ICC	SEM	95% CI Lower	95% CI Upper
Walking	0	27.1	(6.4)	27.2	(7.4)	16.9	15.4	-12.0	11.8	0.771	3.3	20.8	33.5
	40	31.8	(7.9)	31.3	(6.9)	10.0	10.5	-8.9	9.8	0.889	2.4	26.8	36.3
	70	32.4	(9)	31.8	(7.5)	9.2	9.2	-7.7	9.0	0.931	2.1	27.9	36.3
Jogging	0	29.9	(6.1)	28.9	(4.5)	9.3	9.5	-6.7	8.6	0.843	2.1	25.3	33.5
	40	34.5	(8.4)	32.4	(5.5)	12.8	13.2	-9.8	13.9	0.764	3.4	26.7	40.2
	70	33.7	(6.9)	33.4	(5.6)	8.4	7.8	-7.1	7.7	0.906	1.9	29.9	37.3
Running	0	30.8	(4.7)	30.6	(3.9)	10.0	9.5	-8.1	8.5	0.693	2.3	26.1	35.3
	40	34.6	(7.1)	33.9	(5.6)	10.3	10.5	-9.5	10.8	0.811	2.8	28.8	39.6
	70	33	(7.1)	33.6	(5.7)	12.8	11.1	-11.1	9.9	0.799	2.9	27.7	38.9

The reliability of the ankle range of motion between the first and second measurements as measured by CV%, TEM%, LOA ranged from 8.4 – 16.9%, 7.8 – 15.4% and -12.0 – 13.9 respectively. The ICC and SEM ranged from 0.693 – 0.931 and 1.9 – 3.4 respectively. The 95% CI ranged from 20.8 – 36.3°, 25.3 – 40.2° and 26.1 – 39.6° for perceived walking, jogging and running respectively.

Table 5. Mean (SD) and the reliability of the range of motion (°) at the knee during vertical treadmill exercise that was perceived to replicate participants' over ground walking, jogging and running speed in the supine (0°) 40° and 70° posture. CV%= % coefficient of variation, TEM%= % technical error measurement, LOA= limits of agreement, ICC= intraclass correlation coefficient, SEM= standard error measurement, CI= confidence interval. (n=21).

Perceived speed	Posture (°)	Mean 1	(SD)	Mean 2	(SD)	CV%	TEM%	LOA -	LOA +	ICC	SEM	95% CI Lower	95% CI Upper
Walking	0	35.5	(8.6)	35.5	(8.8)	13.2	13.0	-13.1	13.1	0.834	3.5	28.6	42.3
	40	32.6	(6.9)	33.2	(6.9)	13.0	12.1	-11.8	10.7	0.801	3.1	26.9	38.9
	70	32.5	(9)	32.8	(7.8)	16.6	14.3	-13.5	13.1	0.816	3.6	25.7	39.6
Jogging	0	35.6	(8.6)	35.4	(7.1)	14.3	13.7	-13.5	14.0	0.765	3.8	28.1	42.9
	40	31.7	(7.1)	32.1	(6.6)	12.3	12.2	-11.4	10.6	0.807	3.0	26.0	37.7
	70	33.8	(8.9)	33.6	(7.3)	12.0	9.6	-8.9	9.4	0.914	2.4	29.1	38.3
Running	0	37.1	(8.7)	38.6	(7.8)	16.7	16.4	-18.8	15.8	0.610	5.1	27.8	47.9
	40	32.9	(7.6)	32.6	(7.2)	17.9	17.8	-16.2	16.9	0.543	5.0	23.0	42.5
	70	36.9	(10.7)	35.2	(8.5)	16.0	14.5	-12.7	16.2	0.830	4.0	28.3	43.8

The reliability of the range of motion at the knee between the first and second measurements as measured by CV%, TEM%, LOA ranged from 12.0 – 17.9, 9.6 – 17.8% and -18.8 – 16.9 respectively. The ICC and SEM ranged from 0.543 – 0.914 and 2.4 – 5.1 respectively.

The 95% CI ranged from 25.7 – 42.3°, 26.0 – 42.9° and 23.0 – 47.9° for perceived walking, jogging and running respectively.

Table 6. Mean (SD) and the reliability of the range of motion (°) at the hip during vertical treadmill exercise that was perceived to replicate participants' over ground walking, jogging and running speed in the supine (0°) 40° and 70° posture. CV%= % coefficient of variation, TEM%= % technical error measurement, LOA= limits of agreement, ICC= intraclass correlation coefficient, SEM= standard error measurement, CI= confidence interval. (n=21).

Perceived speed	Posture (°)	Mean 1	(SD)	Mean 2	(SD)	CV%	TEM%	LOA -	LOA +	ICC	SEM	95% CI Lower	95% CI Upper
Walking	0	30.4	(5.8)	31	(3.6)	10.7	10.2	-9.4	8.2	0.734	2.5	25.8	35.5
	40	40.7	(7.6)	41.9	(7.4)	8.9	8.5	-10.9	8.5	0.875	2.6	36.2	46.5
	70	43.9	(12.6)	47.7	(11.1)	16.2	12.4	-18.0	10.5	0.875	4.2	37.6	54.0
Jogging	0	32.4	(7.7)	31.9	(5.9)	13.2	13.8	-12.1	13.0	0.737	3.5	25.3	39.0
	40	42.8	(10.3)	41.9	(7.0)	11.4	12.0	-13.5	15.2	0.801	3.9	34.7	50.0
	70	45.5	(10.7)	46.7	(10.1)	6.7	6.1	-8.9	6.4	0.962	2.0	42.2	50.0
Running	0	33.7	(7.4)	34.3	(7.3)	12.9	14.1	-14.1	12.9	0.730	3.8	26.6	41.4
	40	43.8	(11.3)	44.4	(9.4)	12.7	12.8	-16.5	15.4	0.828	4.3	35.7	52.4
	70	46.7	(12.4)	47.1	(11.2)	10.6	9.1	-12.6	11.9	0.929	3.1	40.8	53.0

The reliability of the range of motion at the hip between the first and second measurements as measured by CV%, TEM%, LOA ranged from 6.7 – 16.2%, 6.1 – 13.8% and –18.0 – 15.4 respectively. The ICC and SEM ranged from 0.730 – 0.962 and 2.0 – 4.3 respectively.

The 95% CI ranged from 25.8 – 54.0°, 25.3 – 50.0° and 26.6 – 53.0° for walking jogging and running respectively.

Table 7. Mean (SD) and the reliability of rectus femoris activation (% gait cycle) during vertical treadmill exercise at an intensity that was perceived to replicate participants' over ground walking, jogging and running speed in the supine (0°) 40° and 70° posture. CV%= % coefficient of variation, TEM%= % technical error measurement, LOA= limits of agreement, ICC= intraclass correlation coefficient, SEM= standard error measurement, CI= confidence interval. (n=21).

Perceived speed	ON/OFF (% Gait Cycle)	Posture (°)	Mean 1	(SD)	Mean 2	(SD)	CV%	TEM%	LOA -	LOA +	ICC	SEM	95% CI Lower	95% CI Upper
Walking	ON	0	36.1	(7.1)	36.8	(6.6)	4.2	8.5	-9.3	8.0	0.888	2.3	32.0	40.9
		40	35.5	(6.4)	35.0	(6.0)	4.1	7.9	-7.4	8.4	0.887	2.1	31.2	39.3
		70	34.3	(7.1)	35.9	(7.3)	5.7	13.1	-14.2	11.2	0.742	3.6	28.0	42.2
	OFF	0	81.6	(5.4)	81.4	(7.9)	4.2	3.9	-8.8	9.3	0.875	2.4	76.9	86.1
		40	79.8	(5.9)	81.6	(4.9)	4.1	4.1	-10.4	6.8	0.781	2.5	75.7	85.7
		70	82.7	(5.5)	84.0	(5.9)	5.7	5.7	-14.4	11.9	0.463	4.1	75.3	91.4
Jogging	ON	0	28.0	(5.8)	27.4	(5.4)	3.9	13.2	-9.7	10.9	0.731	2.9	22.0	33.4
		40	24.0	(6.9)	22.4	(5.9)	5.4	17.3	-9.3	12.5	0.759	3.1	17.1	29.3
		70	22.9	(6.3)	23.1	(6.6)	5.0	15.6	-10.4	9.9	0.818	2.7	17.7	28.3
	OFF	0	74.6	(6.7)	75.0	(6.2)	3.9	3.8	-8.4	7.6	0.892	2.1	70.7	78.9
		40	72.3	(4.7)	72.7	(6.4)	5.4	5.5	-11.6	10.8	0.666	3.2	66.2	78.8
		70	74.8	(5.3)	75.5	(4.4)	5.0	5.0	-11.2	9.9	0.571	3.1	69.0	81.3
Running	ON	0	19.2	(6.9)	19.7	(6.5)	6.1	15.8	-9.1	8.3	0.883	2.3	15.0	23.9
		40	18.0	(6.7)	16.5	(6.6)	4.7	21.3	-8.5	11.5	0.820	2.8	11.8	22.8
		70	13.5	(8.0)	15.7	(7.6)	6.0	38.6	-17.7	13.3	0.643	4.6	5.7	23.7
	OFF	0	68.1	(6.2)	69.3	(6.3)	6.1	5.9	-12.5	10.1	0.729	3.2	62.4	75.0
		40	68.8	(5.4)	67.5	(4.2)	4.7	4.7	-7.6	10.1	0.716	2.6	63.1	73.2
		70	70.4	(6.0)	67.7	(5.5)	6.0	6.1	-8.1	13.4	0.648	3.5	62.3	75.8

The reliability of the rectus femoris activation between the first and second measurements as measured by CV%, TEM%, LOA ranged from 3.9 – 6.1%, 3.8 – 38.6% and -17.7 – 13.4 respectively. The ICC and SEM ranged from 0.463 – 0.892 and 2.1 – 4.6 respectively.

The 95% CI for rectus femoris activation ranged from 28 – 42.2%, 17.1 – 33.4% and 17.1 – 33.4% gait cycle, and inactivity ranged from 75.3 – 91.4%, 66.2 – 81.3% and 62.3 – 75.8% during perceived walking, jogging and running respectively.

Table 8. Mean (*SD*) and the reliability of semitendinosus activation (% gait cycle) during vertical treadmill exercise at an intensity that was perceived to replicate participants' over ground walking, jogging and running speed in the supine (0°) 40° and 70° posture. CV%= % coefficient of variation, TEM%= % technical error measurement, LOA= limits of agreement, ICC= intraclass correlation coefficient, SEM= standard error measurement, CI= confidence interval. (n=21).

Perceived speed	ON/OFF (% Gait Cycle)	Posture (°)	Mean 1	(SD)	Mean 2	(SD)	CV%	TEM%	LOA -	LOA +	ICC	SEM	95% CI Lower	95% CI Upper
Walking	ON	0	76.1	(5.5)	76.9	(6.3)	3.4	3.4	-7.9	6.4	0.896	1.9	72.8	80.2
		40	75.3	(5.3)	76.1	(4.5)	4.0	4.0	-9.3	7.7	0.760	2.4	71.0	80.4
		70	76.6	(4.8)	79.3	(6.6)	5.2	5.3	-13.0	7.6	0.682	3.3	71.4	84.4
	OFF	0	42.2	(7.1)	40.5	(6.3)	7.9	7.8	-6.8	10.2	0.872	2.4	36.6	46.0
		40	36.1	(7.6)	38.2	(8.0)	11.6	12.8	-14.9	10.7	0.775	3.7	29.9	44.4
		70	38.3	(7.1)	39.2	(6.7)	13.0	12.2	-14.2	12.3	0.690	3.8	31.3	46.2
Jogging	ON	0	69.6	(4.7)	69.7	(5.6)	3.4	3.3	-6.7	6.4	0.889	1.7	66.3	73.0
		40	67.6	(4.5)	66.0	(4.5)	4.5	4.5	-6.3	9.4	0.731	2.4	62.2	71.4
		70	68.7	(6.2)	70.1	(4.9)	4.5	4.5	-9.9	7.0	0.812	2.4	64.7	74.1
	OFF	0	33.8	(5.4)	33.4	(5.3)	9.5	9.6	-8.7	9.5	0.777	2.5	28.7	38.5
		40	27.2	(5.6)	26.3	(6.4)	16.8	15.8	-11.0	12.8	0.667	3.4	20.1	33.5
		70	25.9	(6.8)	25.4	(6.2)	16.4	17.2	-12.1	13.0	0.693	3.6	18.7	32.6
Running	ON	0	63.2	(5.9)	63.2	(5.3)	6.1	5.9	-10.6	10.6	0.711	3.0	57.3	69.0
		40	62.8	(5.1)	61.1	(5.8)	7.4	6.9	-10.0	13.4	0.558	3.6	54.8	69.1
		70	63.9	(6.8)	65.0	(5.9)	6.3	6.4	-12.6	10.4	0.736	3.3	58.1	70.8
	OFF	0	25.7	(7.9)	27.1	(7.0)	20.2	18.5	-15.0	12.1	0.782	3.5	19.6	33.2
		40	22.9	(5.8)	19.9	(4.8)	20.3	20.6	-8.1	14.0	0.530	3.8	14.0	28.8
		70	20.5	(7.9)	18.7	(6.9)	23.7	24.7	-11.4	15.0	0.734	3.8	12.1	27.1

The reliability of the semitendinosus activation between the first and second measurements as measured by CV%, TEM%, LOA ranged from 3.4 – 23.7%, 3.4 – 4.7% and -15.0 – 15.0 respectively. The ICC and SEM ranged from 0.530 – 0.896 and 1.9 – 3.8 respectively.

The 95% CI for semitendinosus activation ranged from 71.0 – 84.4%, 62.2 – 74.1% and 54.8 – 70.8% gait cycle, and inactivity ranged from 29.9 – 46.2%, 18.7 – 38.5% and 12.1 – 33.2% gait cycle during perceived walking, jogging and running respectively.

Table 9. Mean (SD) and the reliability of biceps femoris activation (% gait cycle) during vertical treadmill exercise at an intensity that was perceived to replicate participants' over ground walking, jogging and running speed in the supine (0°) 40° and 70° posture. CV%= % coefficient of variation, TEM%= % technical error measurement, LOA= limits of agreement, ICC= intraclass correlation coefficient, SEM= standard error measurement, CI= confidence interval. (n=21).

Perceived speed	ON/OFF (% Gait Cycle)	Posture (°)	Mean 1	(SD)	Mean 2	(SD)	CV%	TEM%	LOA -	LOA +	ICC	SEM	95% CI Lower	95% CI Upper
Walking	ON	0	77.7	(4.8)	77.3	(6.0)	3.6	3.5	-7.4	8.1	0.850	2.1	73.5	81.5
		40	77.0	(5.6)	76.8	(5.1)	4.0	4.1	-8.8	9.0	0.788	2.4	72.1	81.6
		70	77.9	(5.8)	80.0	(5.5)	5.6	5.6	-13.9	9.6	0.573	3.7	71.7	86.2
	OFF	0	41.5	(7.1)	40.8	(6.9)	7.8	7.5	-8.0	9.4	0.891	2.3	36.7	45.6
		40	37.4	(7.0)	38.2	(6.3)	9.4	9.0	-10.3	8.8	0.849	2.6	32.8	42.8
		70	38.0	(6.8)	40.0	(7.1)	12.7	12.5	-15.3	11.3	0.679	3.9	31.3	46.7
Jogging	ON	0	71.1	(4.8)	69.9	(4.7)	4.4	4.3	-7.1	9.6	0.743	2.4	65.8	75.2
		40	68.3	(9.8)	65.9	(8.9)	5.6	6.0	-7.9	12.7	0.902	2.9	61.4	72.8
		70	70.5	(5.3)	70.4	(4.5)	4.9	4.9	-9.7	9.9	0.668	2.8	65.0	75.9
	OFF	0	33.9	(5.6)	33.5	(6.4)	9.3	9.3	-8.5	9.3	0.841	2.4	29.0	38.3
		40	27.8	(8.0)	26.7	(6.9)	14.9	13.7	-9.3	11.4	0.857	2.8	21.8	32.7
		70	26.0	(6.7)	25.6	(7.4)	18.5	17.8	-12.6	13.5	0.727	3.6	18.6	32.9
Running	ON	0	63.6	(5.0)	63.8	(5.4)	5.7	5.4	-10.0	9.6	0.711	2.8	58.3	69.1
		40	63.5	(4.7)	62.8	(4.0)	4.7	4.7	-7.6	9.1	0.690	2.4	58.5	67.9
		70	65.0	(5.7)	64.9	(5.7)	5.4	5.5	-10.0	10.1	0.758	2.8	59.5	70.3
	OFF	0	27.0	(6.2)	26.7	(5.1)	13.3	12.8	-9.4	10.0	0.776	2.7	21.6	32.0
		40	23.8	(6.7)	22.5	(6.6)	15.9	15.3	-8.4	11.0	0.837	2.7	17.9	28.4
		70	21.6	(6.8)	19.0	(6.4)	21.3	21.9	-8.9	14.1	0.714	3.5	13.4	27.3

The reliability of the biceps femoris activation between the first and second measurements as measured by CV%, TEM%, LOA ranged from 3.6 – 21.3%, 3.5 – 21.9% and -15.3 – 13.5 respectively. The ICC and SEM ranged from 0.573 – 0.902 and 2.1 – 3.9 respectively.

The 95% CI for biceps femoris activation ranged from 71.7 – 86.2%, 61.4 – 75.9% and 58.3 – 70.3% gait cycle, and inactivity ranged from 31.3 – 46.7%, 18.6 – 38.3% and 13.4 – 32.0% gait cycle during perceived walking, jogging and running respectively.

Table 10. Mean (*SD*) and the reliability of lateral gastrocnemius activation (% gait cycle) during vertical treadmill exercise at an intensity that was perceived to replicate participants' over ground walking, jogging and running speed in the supine (0°) 40° and 70° posture. CV%= % coefficient of variation, TEM%= % technical error measurement, LOA= limits of agreement, ICC= intraclass correlation coefficient, SEM= standard error measurement, CI= confidence interval. (n=21).

Perceived speed	ON/OFF (% Gait Cycle)	Posture (°)	Mean 1	(SD)	Mean 2	(SD)	CV%	TEM%	LOA -	LOA +	ICC	SEM	95% CI Lower	95% CI Upper
Walking	ON	0	1.6	(17.2)	1.0	(16.2)	12.6	12.6	-35.5	36.8	0.581	10.7	80.4	122.2
		40	12.5	(15.6)	6.2	(15.9)	13.6	13.4	-33.3	45.9	0.269	13.6	82.7	136.0
		70	6.7	(16.3)	2.3	(16.5)	8.2	8.6	-19.6	28.4	0.825	6.8	91.1	117.9
	OFF	0	49.6	(6.5)	49.2	(9.0)	14.8	16.2	-22.4	23.1	0.800	3.5	42.6	56.2
		40	50.2	(11.0)	48.1	(5.2)	13.7	17.1	-21.4	25.6	0.082	8.2	33.0	65.2
		70	45.7	(7.3)	48.6	(6.2)	12.1	11.1	-16.6	10.7	0.594	4.4	38.6	55.7
Jogging	ON	0	90.1	(21.9)	93.2	(18.8)	19.6	19.6	-53.9	48.9	0.364	16.2	60.6	124.3
		40	88.5	(22.5)	96.8	(13.2)	28.4	20.7	-60.2	43.7	0.800	8.4	76.3	109.0
		70	96.3	(13.4)	96.9	(13.1)	7.1	7.4	-20.8	19.7	0.830	5.4	86.0	107.2
	OFF	0	42.6	(15.1)	42.1	(6.5)	22.3	22.3	-26.2	27.5	0.532	8.1	26.5	58.1
		40	39.4	(6.7)	38.8	(7.2)	9.3	9.2	-9.5	10.7	0.846	2.7	33.8	44.4
		70	38.7	(5.9)	39.3	(6.4)	8.5	8.1	-9.4	8.3	0.850	2.4	34.4	43.6
Running	ON	0	86.3	(15.4)	83.7	(16.5)	18.8	18.2	-41.0	46.1	0.089	15.1	55.4	114.6
		40	89.7	(13.4)	87.4	(14.4)	14.9	13.9	-32.5	37.0	0.331	11.3	66.5	110.6
		70	84.8	(14.4)	89.8	(13.2)	14.1	13.0	-35.5	25.5	0.507	9.7	68.2	106.3
	OFF	0	35.4	(8.3)	33.9	(7.6)	20.7	19.3	-17.2	20.2	0.450	5.8	23.2	46.1
		40	35.0	(6.8)	34.4	(6.8)	8.1	8.9	-8.1	9.3	0.884	2.3	30.3	39.2
		70	33.1	(7.2)	35.5	(11.0)	21.5	21.0	-22.2	17.5	0.571	6.1	22.4	46.2

The reliability of the lateral gastrocnemius activation between the first and second measurements as measured by CV%, TEM%, LOA ranged from 7.1 – 28.4%, 7.4 – 22.3% and -60.2 – 48.9 respectively. The ICC and SEM ranged from 0.082 – 0.884 and 2.3 – 16.2 respectively. The 95% CI for the activation ranged from 80.4 – 136.0%, 60.6 – 124.3% and 55.4 – 114.6% gait cycle, and inactivity ranged from 33.0 – 65.2%, 26.5 – 58.1% and 22.4 – 46.2% gait cycle during perceived walking, jogging and running respectively.

Table 11. Mean (SD) and the reliability of medial gastrocnemius activation (% gait cycle) during vertical treadmill exercise at an intensity that was perceived to replicate participants' over ground walking, jogging and running speed in the supine (0°) 40° and 70° posture. CV%= % coefficient of variation, TEM%= % technical error measurement, LOA= limits of agreement, ICC= intraclass correlation coefficient, SEM= standard error measurement, CI= confidence interval. (n=21).

Perceived speed	ON/OFF (% Gait Cycle)	Posture (°)	Mean 1	(SD)	Mean 2	(SD)	CV%	TEM%	LOA -	LOA +	ICC	SEM	95% CI Lower	95% CI Upper
Walking	ON	0	80.5	(8.1)	82.1	(8.3)	11.0	11.5	-27.9	24.8	0.700	4.5	72.5	90.1
		40	79.7	(11.7)	79.8	(9.1)	10.4	9.0	-19.6	21.3	0.393	6.9	66.6	93.8
		70	85.0	(9.4)	85.0	(5.4)	7.0	7.5	-18.1	18.2	0.461	5.6	74.1	95.9
	OFF	0	47.0	(45.5)	45.5	(6.1)	9.5	9.1	-10.1	13.1	0.700	3.4	39.6	52.9
		40	43.0	(10.3)	46.9	(6.1)	21.3	16.6	-23.6	15.8	0.400	6.6	31.9	58.0
		70	45.9	(6.2)	49.6	(9.7)	13.4	14.8	-22.4	15.0	0.415	6.3	35.4	60.1
Jogging	ON	0	73.9	(8.1)	73.2	(5.7)	6.6	7.1	-14.1	15.5	0.604	4.4	65.0	82.1
		40	76.6	(10.3)	73.4	(6.2)	7.5	8.4	-13.5	19.9	0.631	5.2	64.8	85.1
		70	77.1	(7.9)	75.5	(5.7)	4.7	5.1	-9.0	12.1	0.813	3.0	70.5	82.1
	OFF	0	39.4	(6.1)	40.4	(6.1)	6.9	6.4	-8.0	6.1	0.902	1.9	36.2	43.6
		40	38.4	(6.9)	38.3	(7.1)	7.3	7.6	-8.1	8.4	0.905	2.1	34.2	42.5
		70	39.3	(7.3)	39.3	(5.2)	10.1	10.5	-11.8	11.8	0.725	3.3	32.9	45.8
Running	ON	0	67.4	(8.2)	68.7	(6.7)	7.4	6.7	-13.9	11.3	0.777	3.5	61.1	74.9
		40	69.3	(7.3)	67.3	(5.9)	6.3	6.8	-10.6	14.6	0.684	3.7	61.0	75.6
		70	70.8	(7.7)	70.5	(7.2)	4.7	4.7	-9.1	9.7	0.889	2.4	65.9	75.5
	OFF	0	33.9	(6.6)	34.6	(7.0)	11.7	11.1	-11.5	9.9	0.814	2.9	28.5	39.9
		40	34.3	(6.2)	33.7	(5.6)	11.6	12.2	-11.2	12.3	0.669	3.4	27.4	40.6
		70	32.8	(6.6)	33.0	(8.7)	12.6	12.5	-11.9	11.3	0.836	3.1	26.8	39.0

The reliability of the medial gastrocnemius activation between the first and second measurements as measured by CV%, TEM%, LOA ranged from 4.7 – 21.3%, 4.7 – 16.6% and -27.9 – 24.8 respectively. The ICC and SEM ranged from 0..393 – 0.905 and 1.9 – 6.9 respectively. The 95% CI for the activation ranged from 66.6 – 95.9%, 64.8 – 85.1% and 61.0 – 75.6% gait cycle during perceived walking, jogging and running respectively. The 95% CI for the activation ranged from 66.6 – 95.9%, 64.8 – 85.1% and 61.0 – 75.6% gait cycle, and inactivity ranged from 31.9 – 60.1%, 32.9 – 45.8% and 26.8 – 40.6% gait cycle during perceived walking, jogging and running respectively.

3.8. Discussion

The primary aim of this study was to assess the reliability of the unilateral sagittal plane kinematic data (temporal-spatial parameters, lower-limb joint range of motion) and the neuromuscular activity during vertical treadmill exercise at different intensities and postures.

Low CV%, TEM% and SEM, coupled with high ICC and narrow LOA and 95% CI in the temporal-spatial parameters (speed, cadence and stride length) indicated that the measures to get participants to replicate their first trial were successful (metronome and speedometer). In addition, it showed that the calculation of stride length was consistent.

There appeared to be intermittent reliability issues in the variables without any discernible pattern. Generally, the reliability measures of the ROM at the hip, knee and ankle joint demonstrated satisfactory to moderate reliability across intensities and postures. The reliability was poor compared to the moderate to high reliability for lower limb sagittal plane kinematics reported in the literature. Doma et al., (2012) reported a CV% ranging from 2.0 – 6.0% during incremental treadmill running (70, 90 and 110% of second ventilatory threshold). The variation in the data set in this study was larger in this study (CV% 6.9 – 7.9%). A greater range of ICC measures was also evident in this study (0.543 – 0.962) compared with the ICC range 0.76 – 0.97 reported by Doma et al., (2012). It is important to note that the vast majority (24/27) of the ICC values in this study were >0.7 and was similar to that of Doma et al., (2012). McGinley et al., (2009) reported that many kinematic studies exhibited sagittal plane ICC of >0.8 and higher, however it is not clear whether

this referred to peak and minimum angles, ROM or an amalgamation of the two. The poorest reliability tended to be at the knee joint. For example, in accordance with Vincent (2012) (ICC 0.7-0.8 indicated 'questionable' reliability, 0.8-0.89 indicated moderate reliability and >0.9 indicated high reliability), the ICC of the knee ROM in Table 2 deemed the reliability as questionable. A potential reason could be the obstruction of the ASIS by the thigh as the hip flexed during the upward phase of the exercise. In the absence of the hip segment the thigh could not be constructed in Visual 3D, resulting in the loss of the knee angle and the hip at potentially critical times (peak flexion and extension), thus affecting the ROM measures. The ability of the investigator to accurately locate and adhere markers to anatomical landmarks on both occasions might also be another source of error. Ferber *et al.*, (2002) reported good between-day reliability (ICC 0.85-0.93) however the investigators were highly experienced.

The reliability of the neuromuscular recruitment patterns tended to be greater than the joint ROM data however there were some exceptions. The TEM% frequently indicated a questionable reliability, thus raising concerns over the quality of measurement (Geeta *et al.*, 2009). In contrast, a tendency for low CV% suggested a small variation within the data set and moderate ICC with low SEM suggest a good level of consistency and precision between the measures. Like this study, the reported reliability of EMG differs. For example Hof (1984) suggested that EMG reliability was poor due to the erratic nature of the signal. Conversely, the identification of muscle activation using the method described by Ives and Wigglesworth, (2003) (when signal rose 2 standard deviations above resting value) was shown to have high inter-rater correlation (0.98) and a high between-day intra-rater (ICC 0.99). Generally, the timing of EMG in this

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study was not as reliable as amplitudes and frequency analysis that was previously reported. The most unreliable measures tended to be around the timing of hamstring deactivation as indicated questionable reliability. Possible reasons for the poorer reliability in the hamstring deactivation especially could be due to variance in the contact distance. The longer the leg is drawn down the treadmill the longer the hamstring activity is required, or it could be noise in the signal as a result of movement artefact masking the true time of deactivation. It could be argued that the unreliable measures were brought about by the participants being unaccustomed to vertical treadmill exercise, therefore they demonstrated an irregular kinematics and neuromuscular pattern. This could have been compounded by the very measures designed to ensure they exercised at the same speed and cadence between trials to aid the reliability of the study. Instead, exercising to a prescribed speed and cadence via a speedometer and metronome could have altered the kinematics and neuromuscular recruitment and impacted on reliability.

In conclusion, the reliability of temporal-spatial parameters was very good; however, the kinematic reliability could only be described as satisfactory since the measures varied greatly. The neuromuscular recruitment was more reliable than kinematic measures and could be considered as demonstrating good reliability. For the purpose of identifying the muscles recruited and the fundamental movement patterns during vertical treadmill, the reliability of kinematic and EMG data is sufficient, however, caution should be exercised when comparing the kinematic differences between postures and speeds.

3.9. Physiological Procedures

3.9.1. Conventional motorised treadmills

A conventional motorised treadmill (Saturn, HP Cosmos, Nussdorf-Traunstein, Germany) was used to assess the $\dot{V}O_{2max.}$ and maximal anaerobic running power of the participants. The maximum speed of the treadmill was 40 $km \cdot h^{-1}$ and could be incremented by 0.01 $km \cdot h^{-1}$. The inclination of the treadmill could be adjusted from 0% to 25% (0 to 14°) in 0.1% increments.

3.9.2. Stadiometry

Stature was measured using an unbranded wall mounted stadiometer. Participants wore their socks to protect their feet and stood against the stadiometer backboard and the head in the Frankfort plane. Participants inhaled and stature was measured.

3.9.3. Body mass

Body mass was measured using a balance beam scales (Weylux, England). Participants wore socks, shorts and a T-shirt and stood still on the platform while the scales were adjusted.

3.9.4. Rate of perceived exertion

A psychophysical assessment of exercise bouts were achieved using the rate of perceived exertion 6-20 scale (RPE) (Borg, 1998). The participants were read the instructions from the creator of the RPE scale (Borg, 1998) prior to any

exercise session and testing protocol in which the RPE was recorded. The 6-20 RPE scale and instructions can be found in Appendix 6.

3.9.5. Heart rate

During exercise tests on the vertical treadmill, electrocardiograms (ECG) were recorded continuously using the 3-lead ECG bio-amp input on the PowerLab 8.0 M. The silver chloride ECG electrodes used were pre-gelled and self-adhesive (Comepa Solutions, Bagnolet, France). The positive and negative electrodes were positioned either side of the Sternum, at the level of the heart. The earth electrode was positioned on the Acroniom. Lab Chart 5 software recorded the raw ECG signal and HR was determined using the default 'Human ECG' detection algorithm with a minimum detection setting of 1 standard deviation.

Test protocols whereby the vertical treadmill was not the mode of exercise, HR was monitored by a telemetric Polar T31 coded chest strap (Polar Electro Oy, Kempele, Finland) and the complimentary Polar heart rate watch (Polar FS2C, Kempele, Finland).

3.9.6. Blood lactate analysis

Blood lactate samples were taken by finger prick method. The researcher wore non-latex gloves during blood lactate sampling. The participants' fingertips were cleaned using an alcohol swab (Alcotip Swabs (70% isopropyl), Uhs, Enfield, England). Once dry, the fingertips were pricked using a single use lancet (Safe-T-Pro, ACCU-CHEK, Roche Diagnostics Limited, West Sussex, UK). The initial drop of blood was wiped away with an absorbent tissue. The researcher applied

light pressure around the puncture and drew 25 µl of blood into a capillary tube. The lactate concentration in the blood samples were analysed immediately using YSI 1500 Sport Lactate Analysers (YSI Inc., Yellow Springs, Ohio, USA).

3.9.6.1.   Blood lactate analyser calibration

The calibration procedure entailed priming the analyser with a buffer solution (YSI 2387 buffer concentrate dissolved in 475 ml ± 25 ml of laboratory quality, deionised water) to remove any contaminates from the membranes and enzyme electrodes. The lactate analyser was calibrated by decanting 5 mmol·L^{-1} lactate standard into a 25 µl capillary tube and using the capillary injector to inject the sample into the mixing chamber of the lactate analyser. Another 25 µl of the lactate standard calibration was injected into the lactate analyser to confirm the calibration. Calibration was assumed if the returned value was between 4.95 and 5.05 mmol·L^{-1} (± 2% of the 5 mmol·L^{-1} standard). Approximately every month the lactate analyser was checked for linearity measurement errors by injecting a 15 mmol.L^{-1} standard. If the lactate analyser returned a value of outside of 14.9-15.1 mmol·L^{-1}, linearity was not assumed and the lactate analyser membranes were repaired or the whole unit replaced.

3.9.7. Pulmonary gaseous exchange analysis

Breath-by-breath analysis of the pulmonary gaseous exchange was performed using zirconian O_2 and infra-red CO_2 analyser (CPX Ultima, MedGraphics Corporation, St. Paul, Minnesota, USA) and the complimentary 'BreezeSuite 3' software (MedGraphics Corporation, St. Paul, Minnesota, USA). During gas analysis, participants wore a nose clip and breathed through a rubber mouthpiece into a bi-directional differential pressure PreVent™ pneumotach

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(39 ml dead space) (MedGraphics Corporation, St. Paul, Minnesota, USA). Prior to each gas analysis the CPX underwent volume calibration followed by simultaneous gas and lag-time calibration.

3.9.7.1. Volume calibration

Firstly, the capillary tubes of the sampling cord were inserted directly into the pneumatach. The gas analyser sampled a state of 'zero flow' during which all fans and air conditioning units were turned off. The flow of 3 L of air through the pneumotach was sampled using a syringe (3 L Calibration Syringe, MedGraphics Corporation, St. Paul, Minnesota, USA) to inject and withdraw the air at a rate of 0.5 to 6.0 $L \cdot s^{-1}$. Volume calibration was assumed if the flow rate was within 1% of the 3 L. To account for the environmental effects on airflow and gaseous exchange, the room temperature, humidity (Oregon Scientific Model No.: ETHG 912, Portland, USA) and barometric pressure (Darton Mercury Barometer, London, UK) were inputted to the BreezeSuite software.

3.9.7.2. Gas sensor calibration

The capillary tubes of the CPX sampling cord were inserted into the CPX Ultima unit. A calibration gas (12% O_2, 5% CO_2 and Bal N_2) was passed through the CPX sampling cord followed by a reference gas (21% O_2, 0% CO_2 and Bal N_2), both at a pressure of 15 PSI. Gas sensor calibration was assumed when the reference gas measured within 0.03% of the stated gas concentrations.

3.9.7.3.   Lag-time verification

During the gas sensor calibration, the time taken for the CPX, in conjunction with the BreezeSuite software, to detect the near square-wave alterations in the O_2 and CO_2 concentrations (lag-time) between the calibration and reference gases was measured. The lag-time was verified if the changes in the O_2 and CO_2 gas concentrations were within 0.1 to 0.6 s.

3.9.8. Measurement of $\dot{V}O_{2max.}$

The measurement of $\dot{V}O_{2max.}$ was achieved using an incremental test on a conventional motorised treadmill (see 3.9.1.). The treadmill remained inclined by 1° throughout the session.

The stature and mass of the participants was measured (see 3.9.2. and 3.9.3.), they were affixed a HR monitor (see 3.9.5.), gas analyser mouthpiece, nose clip and a harness fixed to the cut-off switch on the treadmill before resting in a standing position for 5 minutes. Resting pulmonary gas exchange was measured between minutes 4 and 5. At 5 minutes of rest, HR was recorded and was followed by a fingertip blood sample for lactate analysis. Participants undertook a light warm-up (RPE 9) on the treadmill (see 3.9.1.) at self-selected speed for 5 minutes and 5 minutes off the treadmill for self-selected preparation for the $\dot{V}O_{2max.}$ test protocol. After warming up participants were re-harnessed and began the test protocol. Treadmill speed began at 9 $km \cdot h^{-1}$ and increased by 1 $km \cdot h^{-1}$ every minute until volitional fatigue. HR and RPE were recorded in the last 15 s of every minute and at volitional fatigue. Immediately after volitional fatigue, a fingertip blood lactate sample was taken. Participants undertook a self-selected cool down.

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3.9.8.1. Determination of $\dot{V}O_{2max}$.

Determination of an individual's $\dot{V}O_{2max}$. ($ml \cdot kg^{-1} \cdot min^{-1}$) was performed post-$\dot{V}O_{2max}$. test using the gas analysis data obtained during the $\dot{V}O_{2max}$. test. The $\dot{V}O_2$ data was exported from BreezeSuite software and was averaged over 30 sand was plotted against exercise intensity in Microsoft Excel 2007. If a plateau of the $\dot{V}O_2$-intensity relationship was observed, HR was within 10 bpm of the age-predicted HR_{max}. (220-age), a respiratory exchange ratio of 1.15 and volitional fatigue was achieved as indicated by an RPE of 19-20 (British Association of Sport Exercise Sciences (BASES), 1997), the highest interval indicated $\dot{V}O_{2max}$.. If a plateau or the other criteria were not observed then $\dot{V}O_{2peak}$ was determined.

3.9.8.2. Determination of ventilatory threshold

The researcher/author and two experienced researchers who were blinded to the participant details determined TVent independently. Initially, the V-slope method was used to identify TVent. The TVent from the V-slope method was confirmed or adjusted by examining the ventilatory equivalents ($\dot{V}E / \dot{V}CO_2$ and $\dot{V}E / \dot{V}O_2$), excessive $\dot{V}CO_2$ and $\dot{V}E$ methods.

3.9.8.3. Determination of respiratory compensation point

The author and two experienced researchers who were blinded to the participant details determined the RCP independently. The second inflection point in $\dot{V}E / \dot{V}O_2$ in the relationship was firstly identified. The RCP was confirmed or adjusted on examining the end tidal PCO_2 for decrease after a phase of plateauing and an increase in $\dot{V}E / \dot{V}O_2$ relationship.

3.9.9. Measurement of maximal anaerobic running power (MART)

Participants undertook a light warm up (RPE 9) for 5 minutes on the treadmill with 1% gradient (see 3.9.1.). The MART involved several 20 s bouts of running on a treadmill with a gradient of 10.5% with 100 s recovery between each run until exhaustion. The first 20 s run was performed at 14.3 $km \cdot h^{-1}$ and increased every stage by 1.2 $km \cdot h^{-1}$ until volitional fatigue (Maxwell and Nimmo, 1996). The [BLa] is an index of anaerobic capacity and was taken within 1 minute of exhaustion. Anaerobic running power was expressed as O_2 equivalents by the ACSM (2000) formula for treadmill running (Figure 5):

$$\dot{V}O_2 = 3.5 + 12v + 54gv \text{ (ACSM, 2000)}$$

Figure 5. $\dot{V}O_2$ equivalents for running. Where 'v' was the peak treadmill speed ($m \cdot s^{-1}$) and 'g' was the treadmill gradient expressed as a fraction.

Maximal anaerobic power is calculated from the treadmill speed of the last completed 20 s bout and the time to exhaustion in the subsequent bout, if there was one. An incomplete bout will incur an additional 1 $ml \cdot kg^{-1} \cdot min^{-1}$ to the anaerobic power score if at least 10 s was completed and another 1 $ml \cdot kg^{-1} \cdot min^{-1}$ for every 2s after (Rusko *et al.*, 1993).

3.10. Reliability of physiological measures

3.10.1. Introduction

This thesis intends to use several physiological measures including HR, gas analysis ($\dot{V}O_2$ and $\dot{V}O_{2max.}$), [BLa] and the MART as a performance measure. The reliability or knowledge of the degree of reliability of these measures is important if the data is to form the basis of a conclusion or future research.

As a performance measure, the $\dot{V}O_{2peak}$ achieved in the MART was reported to be reliable (r=0.92) (Nummela *et al.*, 1996). Nummela *et al.*, (1996) used a protocol with a lower inclination (8%) and faster initial running speed (14.6 km·h^{-1}) when compared with the MART protocol devised by Maxwell and Nimmo, (1996) and selected for this thesis (10.5% and 14.3 km·h^{-1}). The reliability of this protocol was unknown, thus the specific reliability of all of these measures is required.

The reliability of gas analysis machines was suggested to be dependent on physiologic (e.g. exercise mode and intensity) and instrument factors (e.g. brand of unit, configuration of the unit and software, unit calibration) (Cooper *et al.*, 2009) and therefore the reliability of measures is specific to each research facility. Therefore the unacceptable reliability (10.9% CV) of the CPX Ultima gas analyser (MedGraphics Corporation, St. Paul, Minnesota, USA) reported by Cooper *et al.*, (2009) might be improved to acceptable standards (< 3% CV as suggested by Cooper *et al.*, 2009) in our laboratory and experimental setup. Likewise, the purported good reliability of HR (coefficient correlation 0.97 – 0.99) (Laukkanen and Virtenan, 1998) and [BLa] measures (r=0.99) (White *et al.*, 2009) might not be the case in our research laboratory. In addition, the

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reliability of such measures on the vertical treadmill exercise has not been investigated previously. Therefore, the aim of this study was to determine the reliability of the MART score as well as HR, $\dot{V}O_2$ and [BLa] during the $\dot{V}O_{2max.}$ test and during incremental vertical treadmill exercise.

3.10.2.   Methods

This study employed a test, re-test method to assess the reliability of the MART score as well as HR, $\dot{V}O_2$ and [BLa] during the $\dot{V}O_{2max.}$ test and during incremental vertical treadmill exercise.

3.10.2.1.   Participants

After institutional ethics approval, 8 male participants (age 25 ± 3 years, stature 1.80 ± 0.04 m, body mass 77.5 ± 7.32 kg) volunteered for this study. All participants were healthy, physically active individuals, who were free from illness, musculoskeletal disease or injury at the time of testing. Four participants were experienced vertical treadmill exercisers and 4 underwent the habituation protocol described previously (see 3.2.).

3.10.2.2.   Test protocols

Participants wore their own trainers and shorts and T-shirt to complete all the testing protocols. The selected testing protocols aimed to characterise the participants in terms of their maximum aerobic and anaerobic running power. The $\dot{V}O_{2max.}$ of the participants was determined using an incremental test on a conventional treadmill (see 3.9.8.). The $HR_{max.}$ exhibited during the $\dot{V}O_{2max.}$ test and the [BLa] immediately after volitional fatigue were recorded. The MART was

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performed as a measure of anaerobic running power (see 3.9.9.). The MART score (peak $\dot{V}O_2$ equivalents) and the [BLa] immediately after volitional fatigue were recorded.

3.10.2.2.1. Incremental vertical treadmill exercise

The stature and mass of the participants was measured (see 3.9.2. and 3.9.3.), they were affixed ECG HR electrodes (see 3.9.5.) and gas analysis mouth piece with nose clip (see 3.9.7.), before being positioned on the vertical treadmill in the 40° posture and resting for 10 minutes. Only the 40° posture was sampled because the participants perceived the supine posture to be difficult for relative novices and the difficulty of remaining in the seat during exercise in the 70° posture (Discussed later in the thesis). Gas analysis, HR, cadence and treadmill speed were recorded throughout the protocol. Participants were asked to exercise at an RPE of 9 (very light exercise), RPE of 12 (fairly light to somewhat hard exercise), RPE of 15 (hard exercise) for 3 minutes each followed by an all-out sprint for 1 minute. Between each of the 3 minute stages and immediately after the 1 minute sprint, participants rested for 1 minute while a blood lactate sample was taken. The treadmill belt speed was logged continuously (PowerLab 8.0 M, ADInstruments, Germany) and cadence was determined with a metronome.

3.10.2.2.2. Retest protocol

The retest protocol required participants to repeat the $\dot{V}O_{2max}$ and MART testing protocol within a week. The participants also repeated the incremental vertical treadmill protocol, however, the participants exercised at the treadmill speed and cadence that they exhibited in previous incremental vertical treadmill exercise protocol. Participants viewed treadmill belt speed on a computer

screen (Toshiba Satellite 15.5", Toshiba, Japan) positioned at eye-level and displayed treadmill belt speed in 0.01 m increments (Lab Chart 5 software and PowerLab 8.0 M, ADInstruments, Germany) and exercised in time with a metronome (Digital Metronome DM-11, Seiko S-Yard Co. Ltd. Tokyo, Japan).

3.10.3. Data analysis

The highest $\dot{V}O_2$ 30 s interval during conventional treadmill test was taken as the participants' $\dot{V}O_{2max.}$ (see 3.9.8.1.). The MART score was calculated using the ACSM (2000) $\dot{V}O_2$ equivalents for running power (see 3.9.9., Figure 5). The cadence and treadmill speed were sampled every 60 s during each stage of incremental vertical treadmill exercise protocol to detect any changes over the 3 minute period. The mean $\dot{V}O_2$ exhibited in the final 30 s of each stage and HR in the final 15 s of the incremental vertical treadmill exercise was established for each participant in preparation for statistical analysis.

3.10.4. Statistical analysis

To satisfy the numerous aspects of reliability CV%, limits of agreement (first measure - second measure), technical error measurement, ICC and 95% confidence intervals were performed on key variables ($\dot{V}O_2$, HR and [BLa]) during incremental vertical treadmill exercise, $\dot{V}O_{2max.}$ test and MART.

3.10.5. Results

Table 12. Mean (SD) and the reliability of physiological measures during $\dot{V}O_{2max.}$ test and Maximum Anaerobic Running Test (MART). CV%= % coefficient of variation, TEM%= % technical error measurement, LOA= limits of agreement, ICC= intraclass correlation coefficient, SEM= standard error measurement, CI= confidence interval. (n=13).

Variable	Mean 1 (SD)	Mean 2 (SD)	CV%	TEM%	LOA -	LOA +	ICC	SEM	95% CI Lower	95% CI Upper
$\dot{V}O_{2max.}$ test $VO_{2max.}$ (ml·kg⁻¹·min⁻¹)	49.47 (4.55)	48.43 (3.59)	2.1	2.2	-1.3	3.4	0.966	0.7	46.19	51.71
$HR_{max.}$ (bpm)	187 (9)	186 (11)	1.5	1.5	-6.4	9.6	0.959	1.9	179	194
$[BLa]_{max.}$ (mmol·L⁻¹)	7.99 (1.14)	7.75 (0.97)	8.6	8.6	-1.8	2.3	0.730	0.5	5.86	9.88
MART Peak O_2 equiv. (ml·kg⁻¹·min⁻¹)	107.6 (5.5)	105 (4.5)	10.9	10.9	-3.6	3.7	0.843	2.0	98.8	113.8
$[BLa]_{max.}$ (mmol·L⁻¹)	10.83 (1.45)	10.77 (2.64)	2.5	2.5	-3.4	8.6	0.812	0.9	7.5	14.1

The variation in the $\dot{V}O_{2max.}$ between the first and second measures was low which is reflected in CV% of 2.1%, LOA of -1.3 – 3.4 and 95% CI ranging from 46.19 – 51.71 ml·kg·min⁻¹ and exhibited the highest reliability (ICC of 0.966). The $HR_{max.}$ during the $\dot{V}O_{2max.}$ test was the least variable measure in terms of CV% (1.5%) and the 95% CI for $HR_{max.}$ during the $\dot{V}O_{2max.}$ test ranged from 179 – 194 bpm. The [BLa] measure immediately following the $\dot{V}O_{2max.}$ test was more variable (CV% of 8.6%) than [BLa] measures taken after the MART and the least reliable (ICC= 0.730) measure during maximal exercise. The MART score ($\dot{V}O_{2peak}$ equivalents) was the most variable measure as indicated by a CV% of 10.9% and a 95% CI of 98.8 – 113.8 ml·kg·min⁻¹, however it was not the least reliable as indicated by an ICC of 0.843.

Table 13. Mean (*SD*) and the reliability of physiological measures during incremental vertical treadmill exercise (n=8). CV%= % coefficient of variation, TEM%= % technical error measurement, LOA= limits of agreement, ICC= intraclass correlation coefficient, SEM= standard error measurement, CI= confidence interval. (n=13).

	Variable	Mean 1 (*SD*)	Mean 2 (*SD*)	CV%	TEM%	LOA -	LOA +	ICC	SEM	95% CI Lower	95% CI Upper
RPE 9	VO_2 (ml·kg^{-1}·min^{-1})	14.31 (1.87)	15.23 (2.22)	5.4	5.7	-20.3	15.8	0.912	0.6	12.50	17.04
	HR (bpm)	96 (14)	99 (17)	5.8	6.2	-1.1	0.4	0.917	4.2	81	114
	[Bla] (mmol·L^{-1})	1.33 (0.32)	1.66 (0.21)	23.3	22.3	-2.6	0.8	0.520	0.2	0.68	2.31
RPE 12	VO_2 (ml·kg^{-1}·min^{-1})	19.59 (2.11)	21.41 (2.32)	10.1	10.4	-23.2	11.1	0.282	2.0	13.01	27.99
	HR (bpm)	113 (18.59)	119 (19)	6.2	6.0	-1.0	0.9	0.927	4.9	98	135
	[Bla] (mmol·L^{-1})	2.13 (0.64)	2.12 (0.52)	14.9	14.2	-7.1	3.4	0.829	0.2	1.30	3.04
RPE 15	VO_2 (ml·kg^{-1}·min^{-1})	29.32 (2.08)	28.92 (2.64)	9.9	9.7	-23.6	29.0	0.700	1.2	24.39	33.85
	HR (bpm)	145 (16)	142 (20)	6.2	6.1	-0.9	1.5	0.867	6.3	120	168
	[Bla] (mmol·L^{-1})	4.79 (1.74)	4.51 (1.22)	9.4	9.5	-8.3	9.1	0.955	0.3	3.49	5.81
All-out	VO_2 (ml·kg^{-1}·min^{-1})	35.88 (4.08)	37.71 (3.18)	7.2	6.9	-27.2	26.8	0.690	2.0	29.14	44.46
	HR (bpm)	159 (15)	159 (25)	6.0	5.5	-2.0	1.4	0.898	6.2	135	182
	[Bla] (mmol·L^{-1})	6.73 (1.17)	7.03 (1.78)	8.3	8.7	-8.6	4.9	0.913	0.4	5.26	8.50

The reliability of the $\dot{V}O_2$ between the first and second measurements as measured by CV%, TEM%, LOA ranged from 5.4 – 10.1%,

5.7 – 10.4% and -27.2 – 29.0 respectively. The ICC and SEM ranged from 0.282 – 0.912 and 0.6 – 2.0 respectively. The 95% CI ranged

from 12.50 – 17.04 ml·kg·min^{-1}, 13.01 – 27.99 ml·kg·min^{-1}, 24.39 – 33.85 ml·kg·min^{-1}, 29.14 – 44.46 ml·kg·min^{-1} for RPE 9, 12, 15 and

all-out effort respectively. The reliability of heart rate as measured by CV%, TEM%, LOA, ICC and SEM ranged from 5.8 – 6.2%, 5.5 –

6.2%, -2.0 – 1.5, 0.867 – 0.927, 4.2 – 6.3 respectively. The 95% CI ranged from 81 – 114 bpm, 98 – 135 bpm, 120 – 168 bpm and 135 – 182 bpm for RPE 9, 12, 15 and all-out effort respectively. The reliability of [BLa] as measured by CV%, TEM%, LOA, ICC and SEM ranged from 8.3 – 23.3%, 8.7 – 22.3%, -8.6 – 9.8, 0.520 – 0.955 and 0.2 – 0.3 respectively. The 95% CI ranged from 0.68 – 2.31 mmol·L^{-1}, 1.03 – 3.04 mmol·L^{-1}, 3.49 – 5.81 mmol·L^{-1} and 5.26 – 8.50 mmol·L^{-1} for RPE 9, 12, 15 and all-out effort respectively.

3.10.6.   Discussion

The primary aim of this study was to assess the reliability of MART scores as well as HR, $\dot{V}O_2$ and [BLa] measures during the $\dot{V}O_{2max}$ test and during incremental vertical treadmill exercise. During the $\dot{V}O_{2max}$ test, the $\dot{V}O_{2max}$ demonstrated excellent reliability in terms of low CV%, narrow LOA and 95% CI, and high ICC values. The $\dot{V}O_{2max}$ was more reliable in this study than previously reported in the literature. For example, the CV% of $\dot{V}O_{2max}$ measures in this study (2.1%) was lower than that found by Granja Filho et al., (2005) of 5.5% and also met the criteria for acceptable reliability of <3% suggested by Cooper et al., (2009). The ICC for the $\dot{V}O_{2max}$ (0.966) was similar to that of Deakin et al., (2011) and the Granja Filho et al., (2005) (0.97). Lastly, the relative TEM indicated greater reliability in this study (2.2%) than that of Deakin et al., (2011) (4.35%), therefore the $\dot{V}O_{2max}$ protocol used in this study produced highly reliable results.

The $\dot{V}O_2$ observed during the incremental vertical treadmill might be considered as satisfactory generally (CV% 5.4 – 10.1, ICC 0.690 – 0.912), however unacceptable reliability was evident in terms of the ICC (0.282) of

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vertical treadmill exercise at RPE 12. This could be a result of the intensity of submaximal exercise being more open to subjective interpretation, therefore the between-subjects variation could be greater thus influencing the resultant ICC.

The $HR_{max.}$ during the $\dot{V}O_{2max.}$ test demonstrated excellent reliability (ICC 0.959) and the lowest variation in the data set (CV% 1.5%) and small LOA and 95% CI. The HR exhibited during each stage of the incremental vertical treadmill exercise were also very reliable, with ICC ranging from 0.867 – 0.927 and a satisfactory variation in the data as measured by CV% which was very similar between stages and ranged from 5.8 – 6.2%. The LOA for HR in each stage were small and demonstrated good agreement between the two measures. The 95% CI indicated that 95% of the HR sample lay within approximately 20-25 bpm of the mean which could be considered as a large range around the mean. This could be explained by the differences in the interpretation of the intensity of exercise and increments in RPE.

The MART score (Peak $\dot{V}O_2$ equivalent) presents an unclear reliability. Nummela *et al.*, (1996) reported a favourable CV% of 2.7%, however in this study a CV% of 10.9% was found suggesting that there was a large variation in the data set that could jeopardise the reliability of the study. Despite a large CV%, an ICC of 0.843 and narrow LOA and 95% CI suggests the MART in this study actually exhibited good reliability.

The [BLa] measures varied in terms of reliability. The post-MART [BLa] exhibited a small variation (CV% = 2.5) and TEM (2.5%) and good reliability (ICC = 0.812). The [BLa] following the all-out effort on the vertical treadmill also produced favourable ICC value (0.913) and reasonable variation within the data set of 8.3% (CV%). During submaximal vertical treadmill exercise, the [BLa]

reliability was good across most increments in RPE in terms of ICC (0.829 – 0.955). An anomaly was evident in the reliability of [BLa] during vertical treadmill exercise at an RPE 9, where ICC dropped to an unacceptable level of 0.520. The same model of [BLa] analyser (YSI 1500 Sport Lactate Analysers, YSI Inc., Yellow Springs, Ohio, USA) as used in this study was previously reported have excellent instrument reliability in terms of pearson's 'r' correlation coefficient (r = 0.99) and intra-investigator reliability (r = 0.99) (White *et al.*, 2009). Therefore the poor reliability of [BLa] measures during vertical treadmill exercise could be due to differences in the interpretation of intensity and associated changes in physiology for each increment in RPE. Another possibility was that during lower intensity exercise the leg was exposed to the resistive forces of the overhanging resistance cables. It could be postulated that weaker participants will meet the demand mainly through anaerobic energy systems thus producing lactic acid. Stronger participants might meet the demand through a higher aerobic contribution, thus influencing the between-subjects variation and subsequently the ICC could be lowered. In addition, the novelty of the vertical treadmill and the inexperience of the participants could result in inconsistent responses from energy systems despite attempts at habituating participants to vertical treadmill exercise. Potentially, a longer period of habituation to vertical treadmill exercise could remedy the large variation.

In conclusion, the physiological measures taken in the current research facility are reliable when maximal exercise was employed ($\dot{V}O_{2max.}$, $HR_{max.}$ during the $\dot{V}O_{2max.}$ test, MART score and $[BLa]_{max.}$ during the MART, and $[BLa]_{max.}$ and $HR_{max.}$ during all-out effort vertical treadmill exercise). This, coupled with low TEM% suggests that the instruments ([BLa] analysers and

CPX Ultima) and methods ($\dot{V}O_{2max.}$ and MART) used in this study were reliable. During submaximal vertical treadmill exercise the reliability of measures tended to be lower than during maximal exercise. The intensity of submaximal exercise was susceptible to interpretation when compared with maximal exercise, thus variability and between-subjects variation is increased and a likely culprit for the reduced reliability. Therefore, it was important that habituation to vertical treadmill exercise was sufficient and should be greater than that used in this study of 2 x 30 minutes. Also, the current fitness of the participants to meet the demands of the exercise was an important factor in the observed physiological responses and will require consideration in future research.

4.1. Introduction

The novelty of the vertical treadmill means that currently there is not a body of knowledge regarding the fundamentals of vertical treadmill exercise regarding the muscles used and the associated movement patterns. Knowledge of such fundamental principles might identify populations or training programmes for which vertical treadmill exercise might be most suitable. A key characteristic of the vertical treadmill is the ability to adjust the posture of the user while remaining recumbent. The back rest is adjustable and ranges from supine (0°) to 70° in 10° increments. The adjustment of the seat angle (0° to 30° in 10° increments) allows the body weight of the user to be supported as the back rest angle changes. It was purported that small changes in posture, even when remaining recumbent, will influence the performance of the neuromuscular and musculoskeletal systems, thus the kinematic profile of an exercise mode could be altered (Egana *et al.*, (2010) and Jones *et al.*, (2004)). Egana *et al.*, (2010) also reported posture-related deviations in muscle recruitment were only evident during high intensity cycling rather than low intensity cycling (20 vs. 80% peak power output). Therefore differences in posture and the intensity of the exercise might target different musculature and different range of motion. Whether there are demonstrable differences in the neuromuscular recruitment and subsequent kinematic profiles during vertical treadmill exercise in different postures is not known, nor is it known whether differences might exist between intensities of exercise. Therefore, the aim of this study was to determine the neuromuscular recruitment and kinematic profile of vertical treadmill exercise in selected postures and intensities of exercise.

4.2. Methods

4.2.1. Participants

After institutional ethics approval, 21 male participants (age 24.8 ± 7.1 years, stature 1.79 ± 0.07 m, body mass 77.7 ± 8.8 kg) were recruited for the study. All participants were healthy, physically active individuals, who were free from musculoskeletal disease or injury at the time of testing.

4.2.2. 3-D optical motion analysis and EMG system

Six 'Eagle' passive cameras (Motion Analysis Corporation, CA USA) were used to track retroreflective markers at 200 Hz that were adhered to anatomical landmarks, cluster markers and joints centres of the right leg (see 3.5.1. to 3.5.1.2.). A 'Delsys Bagnoli' 8-channel EMG system (Delsys Inc. MA, USA (1000 Hz) was used to capture the neuromuscular recruitment patterns of the rectus femoris, vastus medialis, vastus lateralis, semitendinosus, biceps femoris, lateral gastrocnemius, medial gastrocnemius and tibialis anterior (see 3.5.2. and 3.5.2.1.).

4.2.2.1.   Test protocol

The test protocols used to measure the kinematics and neuromuscular recruitment of vertical treadmill exercise in the various postures and intensities has been described previously (see 3.6.2.2.). In brief, participants were prepared for lower limb kinematics and EMG data collection (see 3.5.1.2. and 3.5.2.1.). Participants undertook a warm up at a very light rate of perceived exertion (RPE 9) for 5 minutes with dynamic stretches. Participants exercised

for 5 minutes at a speed that they perceived to replicate their over ground walking velocity (described to participants as though going for a casual walk for 1 hour), jogging velocity (described to participants as the pace when going for a casual jog for 1 hour) and running velocity (described to participants as the pace when going for a training run for 1 hour) for 5 minutes in the selected postures of the supine, 40° and 70° postures. These postures were selected as they were the extremes (supine and 70° posture) and the intermediate posture (40° posture) available on the vertical treadmill. The order of postures and speeds was randomised using the 'random' function in Microsoft Excel 2007. Simultaneous 3-D motion (200 Hz) and EMG data (1000 Hz) were recorded during each condition. The treadmill belt speed was logged continuously (PowerLab 8.0 M, ADInstruments, Germany) and participants were not permitted view to the speedometer.

4.2.3. Data analysis

Raw kinematic and EMG data were processed as described in 3.5.1.3. and 3.5.2.2.. Foot strike and toe-off were identified for ten gait cycles (see 3.5.1.3.). Kinematic variables of interest were the range of motion, peak flexion and peak extension of the hip, knee and ankle during the contact phase and swing phases of the gait cycle. The temporal variables of interest were treadmill belt speed, cadence, stride time, stride length, percentage of the gait cycle in contact and swing phases, and contact distance (vertical displacement of the foot during the contact phase). EMG variables of interest were the timing of muscle activation and deactivation. Muscle activation was established when the EMG signal rose 2 standard deviations above the mean resting signal and inactivity was established when the EMG signal fell below 2 standard deviations

of the resting signal. All data were cropped and normalised to 100% of the gait cycle. All variables of interest were calculated for each of the ten gait cycles and averaged within participants and averaged across participants.

4.2.4. Statistical analysis

Parametric variables of interest were subject to a two-way repeated measures ANOVA with pairwise comparisons (Bonferroni) and Cohen's 'd' effect sizes (ES). Non-parametric variables of interest (RPE) were subject to Friedman test and post-hoc Wilcoxon signed ranks test.

4.3. Results

4.3.1. Temporal-spatial parameters

The mean and standard deviation of the temporal-spatial parameters are presented in Appendix 7.1. Significance values, p values of main effects and pairwise comparisons and ES are also presented.
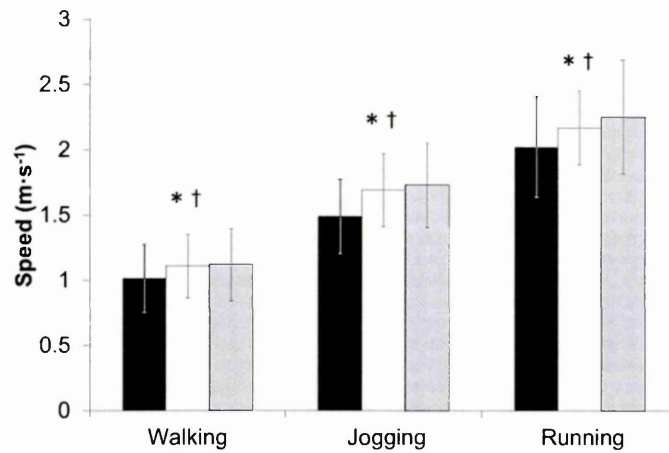
Figure 6. Mean (*SD*) speed during incremental vertical treadmill exercise in the supine ■, 40° ☐ and 70° ▨ postures. * indicates main effect for posture. † indicates main effect for speed (*p*<0.05). (n= 21).

Figure 6 shows that the vertical treadmill speed differed between postures ($F_{(2,40)}$=10.338, *p*<0.001). Bonferroni pairwise comparisons suggested that the 40° and 70° posture were similar (*p*=1.000, small ES), however, both postures exhibited greater speeds than the supine posture (*p*=0.007, medium ES and *p*=0.001, medium ES respectively). A posture x speed interaction ($F_{(4,80)}$=2.690, *p*=0.037) indicated that increments in vertical treadmill speed were greater in the 40° and 70° postures than supine. Differences were also observed between perceived speeds (perceived walking, jogging and running) ($F_{(1.4,28.5)}$=25.219, *p*=<0.001). As the perceived speed increased, vertical treadmill speed also increased (*p*<0.001, large ES for all speed comparisons).

4.3.1.2. Cadence
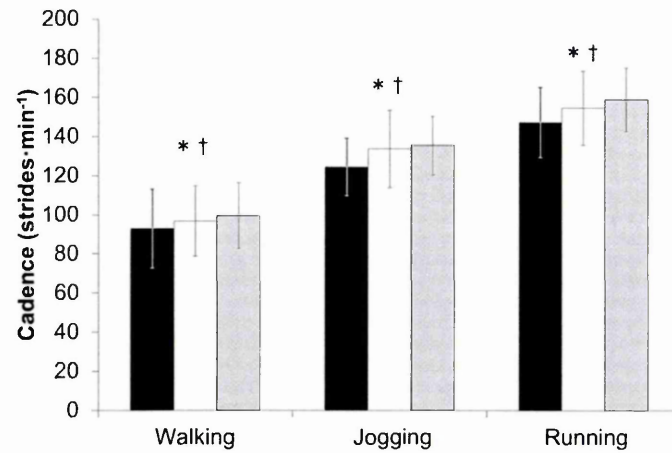
Figure 7. Mean (*SD*) cadence during incremental vertical treadmill exercise in the supine ■, 40° ☐ and 70° ▨ postures. * indicates main effect for posture. † indicates main effect for speed (*p*<0.05). (n= 21).

With regards to posture, the cadence also differed between postures ($F_{(2,40)}$=11.748, *p*<0.001) as shown in Figure 7. The 40° and 70° postures were similar (*p*=0.614, small ES), however, both postures exhibited higher cadences than the supine posture (*p*=0.003, medium ES and *p*=0.001, medium ES respectively). As the perceived speed increased, the cadence also increased ($F_{(1.3,27.5)}$=195.472, *p*<0.001). Differences in cadence were also observed between perceived speeds ($F_{(1.4,27.7)}$=25.219, *p*=<0.001). As the perceived speed increased, cadence also increased (*p*<0.001, large ES for all speed comparisons).

4.3.1.3. Stride length
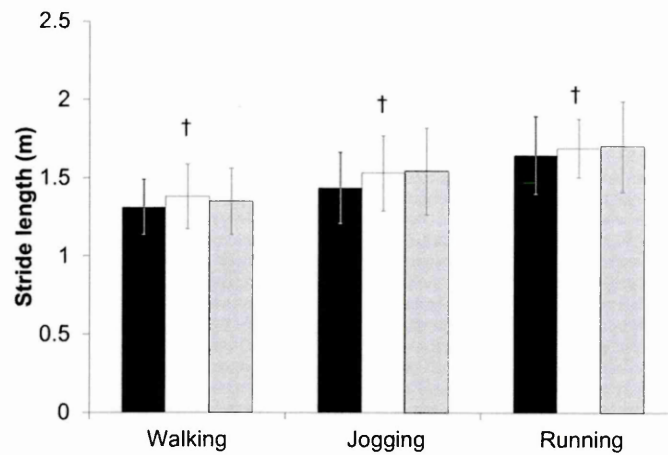
Figure 8. Mean (*SD*) stride length during incremental vertical treadmill exercise in the supine ■, 40° □ and 70° ▨ postures. † indicates main effect for speed (*p*<0.05). (n= 21).

As demonstrated in Figure 8, there were no differences between posture in stride length ($F_{(2,40)}$=2.801, *p*<0.073), however differences in stride length were also observed between perceived speeds ($F_{(2,40)}$=111.623, *p*<0.001). As the perceived speed increased, stride length increased (*p*<0.001, large ES for all speed comparisons).

4.3.1.4.　　Gait cycle time
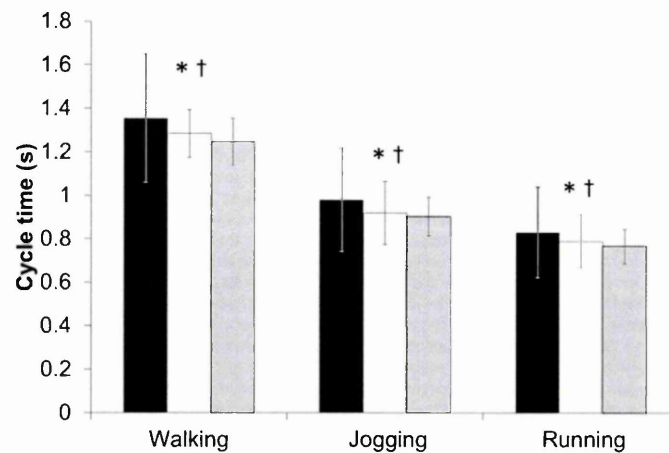
Figure 9. Mean (*SD*) vertical treadmill speed during incremental vertical treadmill exercise in the supine ■, 40° ☐ and 70° ▨ postures. * indicates main effect for posture. † indicates main effect for speed (*p*<0.05). (n= 21).

In Figure 9, the gait cycle time differed between postures ($F_{(2,40)}$=8.703, *p*=0.001) and there was no difference indicated between the 40° and 70° postures (*p*=0.438, small ES), but both were faster than in the supine posture (p=0.035 and p=0.004 respectively). Differences in gait cycle time were also observed between perceived speeds ($F_{(2,40)}$=116.508, *p*<0.001). As the perceived speed increased, gait cycle time decreased (*p*<0.001, large ES for all speed comparisons).

4.3.1.5.   Contact distance
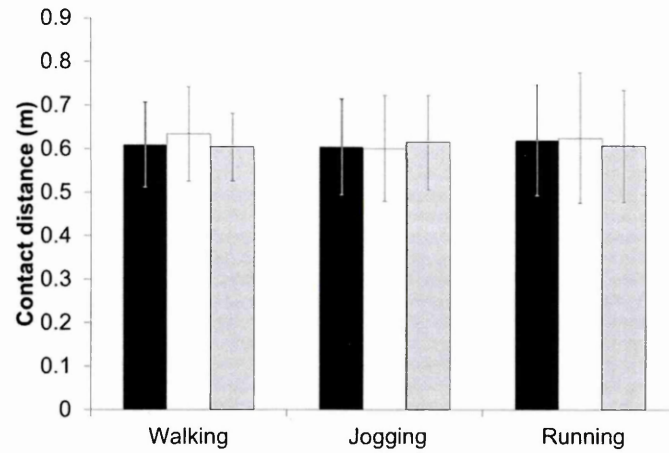
Figure 10. Mean (*SD*) contact distance during incremental vertical treadmill exercise in the supine ■, 40° ☐ and 70° ▨ postures. (n= 21).

As demonstrated in Figure 10, there were no differences in the contact distance between the postures ($F_{(2,40)}$=0.259, p=0.773) nor were there differences between perceived speeds ($F_{(1.5,28.8)}$=0.416, p=0.608).

4.3.1.6.   Percentage of the gait cycle in contact phase
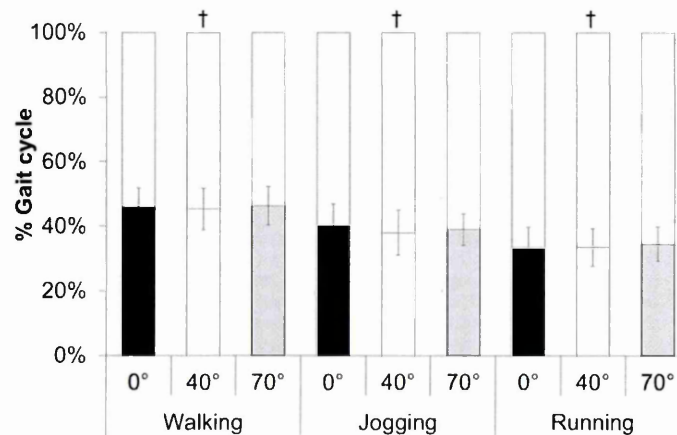
Figure 11. Mean (*SD*) percentage of gait cycle in contact phase during incremental vertical treadmill exercise in the supine ■, 40° ☐ and 70° ▨ postures. † indicates main effect for speed (p<0.05). (n= 21).

Figure 11 demonstrates that the percentage of the gait cycle spent in contact with the treadmill did not differ between postures ($F_{(2,40)}$=0.963, p=0.390), however differences were observed between perceived speeds ($F_{(1.5,29.7)}$=70.331, $p<0.001$). As the perceived speed increased, percentage of the gait cycle in contact phase decreased ($p<0.001$, large ES for all speed comparisons).

4.3.1.7. Rate of perceived exertion

The RPE differed between postures ($\chi^2_{(2,21)}$=11.606, p=0.003, $\chi^2_{(2,21)}$=11.534, p=0.003 and $\chi^2_{(2,21)}$=17.072, $p<0.001$ for walking, jogging and running respectively). Wilcoxon tests indicated a higher RPE in the supine posture when compared with the 40° (Z=2.480, p=0.013, Z=2.170, p=0.030 and Z=3.351, p=0.001 for walking, jogging and running speed respectively) and 70° postures (Z=3.173, p=0.002, Z=2.801, p=0.005 and Z=3.113, p=0.002 for walking, jogging and running speed respectively). As the perceived speed increased the RPE also increased ($\chi^2_{(2,21)}$=37.075, $p<0.003$, $\chi^2_{(2,21)}$=37.544, $p<0.001$ and $\chi^2_{(2,21)}$=39.098, $p<0.001$ for perceived walking, jogging and running).

4.3.2. Kinematics

The mean and standard deviation of the ankle, knee and hip joint angles are presented in Appendix 7.2. Significance values, p values of main effects and pairwise comparisons and ES are also presented.

4.3.2.1. Ankle

Figure 12. Mean ankle angle during incremental vertical treadmill exercise (perceived walking (A), jogging (B) and running (C)) in the supine (——), 40° (----) and 70° (······) postures.* indicates main effect for posture ($p<0.05$), † indicates main effect for speed ($p<0.05$). (n= 21).

As demonstrated in Figure 12, the initial contact the ankle angle differed between postures ($F_{(2,40)}=18.561$, $p<0.001$). In the 40° and 70° posture the ankle angle was similar ($p=1.000$, small ES) and both were more dorsiflexed than in the supine posture ($p<0.001$, large ES). Peak dorsiflexion in the contact phase differed between postures ($F_{(2,40)}=13.563$, $p<0.001$) and perceived speeds ($F_{(1.6,31.3)}=5.180$, $p=0.017$), and a posture x speed interaction was observed ($F_{(4,80)}=3.538$, $p=0.010$). In the 40° and 70° postures, the ankle was similarly dorsiflexed ($p=0.629$, small ES), however, both postures exhibited

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greater peak dorsiflexion than the supine posture (p=0.035, and p=0.004 respectively, medium-large ES). Perceived running speed tended to exhibit less dorsiflexion than perceived walking speed. Peak plantarflexion differed between speeds ($F_{(1.5,29.5)}$=16.076, p<0.001). During walking pace, the ankle was less plantarflexed than in jogging (p=0.002, small-medium ES) and running (p=0.001, medium-large ES). The range of motion differed between postures ($F_{(2,40)}$=12.494, p<0.001) and speeds ($F_{(1.5,29.4)}$=6.984, p=0.007). The range of motion was similar between 40° and 70° postures (p=1.000, small ES) and both were greater than supine (p<0.001, medium ES and p=0.004 respectively). The range of motion was similar between jogging and running (p=1.000, no ES), and both were greater than walking (p=0.022, small ES and p=0.037, small-medium ES respectively).

4.3.2.2.   Knee

Figure 13. Mean knee angle during incremental vertical treadmill exercise (perceived walking (A), jogging (B) and running (C)) in the supine (——), 40° (----) and 70° (······) postures.* indicates main effect for posture ($p<0.05$), † indicates main effect for speed ($p<0.05$). (n= 21).

Figure 13 shows that at initial contact, knee flexion differed between postures ($F_{(2,40)}=14.207$, $p<0.001$) and speeds ($F_{(2,40)}=28.923$, $p<0.001$). The 40° and 70° were similar ($p=0.702$, small ES) and was more flexed than the supine posture ($p<0.001$ and $p=0.002$ respectively, large ES). Initial contact knee angle was similar in the jogging and running speeds ($p=0.101$, small ES) and was more flexed than the walking speed ($p<0.001$, medium-large ES). In swing phase, peak knee flexion was observed and differed between postures ($F_{(2,40)}=5.718$, $p=0.007$) and speeds ($F_{(2,40)}=55.849$, $p<0.001$). Peak knee flexion was greater in the 40° posture than 70° posture ($p<0.001$, small-medium ES) and as the speed increased the knee flexion increased ($p<0.001$, small-medium ES for all speed comparisons). Peak knee extension in the swing phase differed between postures ($F_{(2,40)}=22.952$, $p<0.001$) and speeds ($F_{(2,40)}=19.265$, $p<0.001$). In the supine posture, knee extension was less than the 40° ($p<0.001$, large ES) and 70° postures ($p<0.001$, large ES). As speed increased, the knee extension

reduced ($p<0.001$, small-large ES for all speed comparisons). The range of motion at the knee was similar between postures ($F_{(2,40)}=3.107$, $p=0.056$) and speeds ($F_{(2,40)}=2.896$, $p<0.067$).

4.3.2.3.   Hip

Figure 14. Mean hip angle during incremental vertical treadmill exercise (perceived walking (A), jogging (B) and running (C)) in the supine (——), 40° (----) and 70° (······) postures. * indicates main effect for posture ($p<0.05$), † indicates main effect for speed ($p<0.05$). (n= 21).

As demonstrated in Figure 14, at initial contact the hip flexion differed between all postures ($F_{(2,34)}=334.738$, $p<0.001$) with the greatest flexion exhibited in the 70° posture followed by 40° and then supine ($p<0.001$, large ES for all posture comparisons). The minimum hip flexion differed between all postures ($F_{(2,38)}=177.041$, $p<0.001$) with the least hip flexion exhibited in the supine posture, followed by 40° and 70° posture ($p<0.001$, large ES for all posture comparisons). Peak hip flexion in swing differed between postures ($F_{(2,38)}=396.046$, $p<0.001$) and speed ($F_{(2,38)}=40.989$, $p<0.001$). Peak hip flexion in swing was greatest in the 70° followed by the 40° and the supine ($p<0.001$, large ES for all posture comparisons). As speed increased the peak hip flexion

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in late swing increased ($p<0.001$, small effect). The range of motion at the hip differed between postures ($F_{(1.5, 28.6)}=33.165$, $p<0.001$) with greater range of motion observed in the 40° ($p<0.001$, large ES) and 70° ($p<0.001$, large ES) when compared with supine.

4.3.3. Neuromuscular recruitment

The mean and standard deviation of the muscle activity are presented in Appendix 7.3. Significance values, p values of main effects and pairwise comparisons and ES are also presented.

4.3.3.1. Rectus femoris

Figure 15. Mean rectus femoris activity during incremental vertical treadmill exercise (perceived walking (A), jogging (B) and running (C)) in the supine (——), 40° (----) and 70° (·····) postures. * indicates main effect for posture ($p<0.05$), † indicates main effect for speed ($p<0.05$). (n= 21).
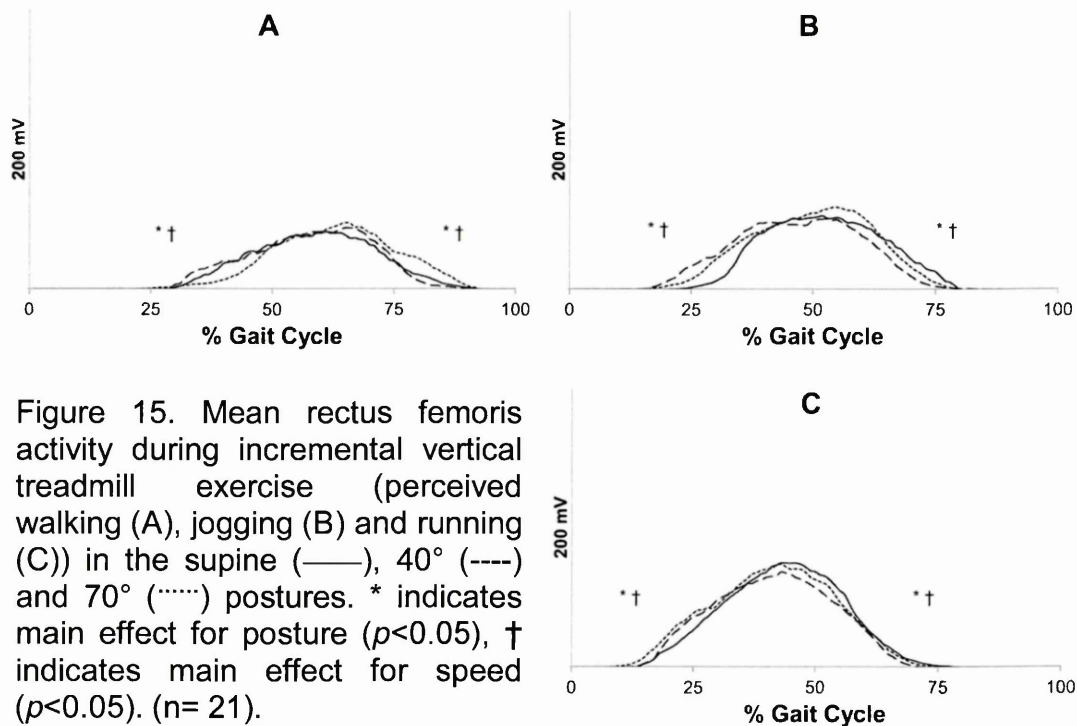
In general, the rectus femoris was active in the late contact phase to approximately mid-swing. The activity (on) and inactivity (off) differed between postures ($F_{(2,40)}=11.110$, $p<0.001$ and $F_{(2,40)}=4.063$, $p=0.025$ respectively) and speeds ($F_{(1.3,25)}=33.165$, $p<0.001$ and $F_{(1.4,28.4)}=58.500$, $p<0.001$ respectively). In the 40° and 70° posture the rectus femoris activation was similar (p=0.052, medium ES), however, they were both active earlier in the gait cycle when compared with the supine ($p<0.001$, small ES). The rectus femoris was active earlier in the gait cycle as speed increased ($p<0.001$, large ES for all speed

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comparisons) and ceased activity earlier in the gait cycle as speed increased ($p<0.001$, large ES for all speed comparisons).

4.3.3.2. Vastii

The mean vastus lateralis and vastus medialis did not show any discernible pattern during vertical treadmill exercise and therefore were not active during vertical treadmill exercise.

4.3.3.3. Semitendinosus

Figure 16. Mean semitendinosus activity during incremental vertical treadmill exercise (perceived walking (A), jogging (B) and running (C)) in the supine (——), 40° (----) and 70° (······) postures.* indicates main effect for posture ($p<0.05$), † indicates main effect for speed ($p<0.05$). (n= 21).
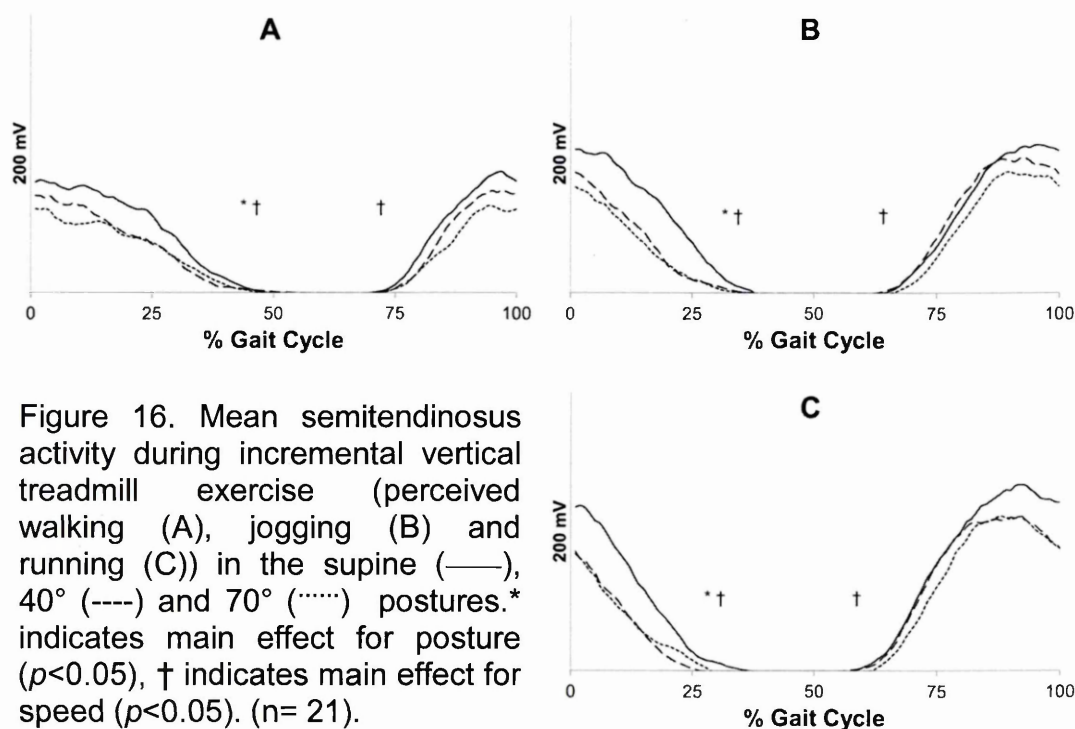
Figure 16 indicates that the semitendinosus was active from the late swing phase and ceased in late contact phase. The semitendinosus activation differed with respect to speed ($F_{(1.6,73.1)}=73.068$, $p<0.001$ respectively) and was active earlier in the gait cycle as the speed increased ($p<0.001$, large ES for all speed comparisons). The cessation of semitendinosus activity differed between postures ($F_{(2,40)}=22.133$, $p<0.001$ respectively) and speed ($F_{(1.5,30.7)}=89.896$,

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$p<0.001$ respectively). In the supine posture, semitendinosus activity ceased later in the gait cycle than the 40° and 70° postures ($p<0.001$, medium-large ES) and ceased earlier as speed increased ($p<0.001$, large ES for all speed comparisons).

4.3.3.4. Biceps femoris

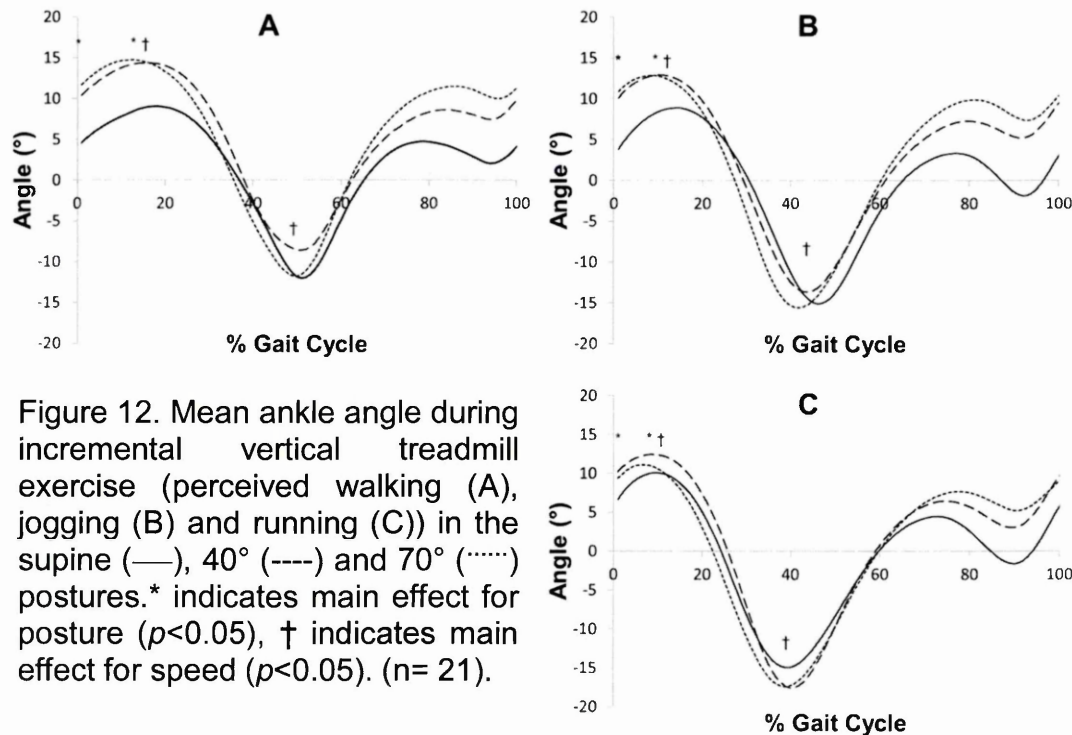Figure 17. Mean biceps femoris activity during incremental vertical treadmill exercise (perceived walking (A), jogging (B) and running (C)) in the supine (———), 40° (----) and 70° (······) postures.* indicates main effect for posture ($p<0.05$), † indicates main effect for speed ($p<0.05$). (n= 21).
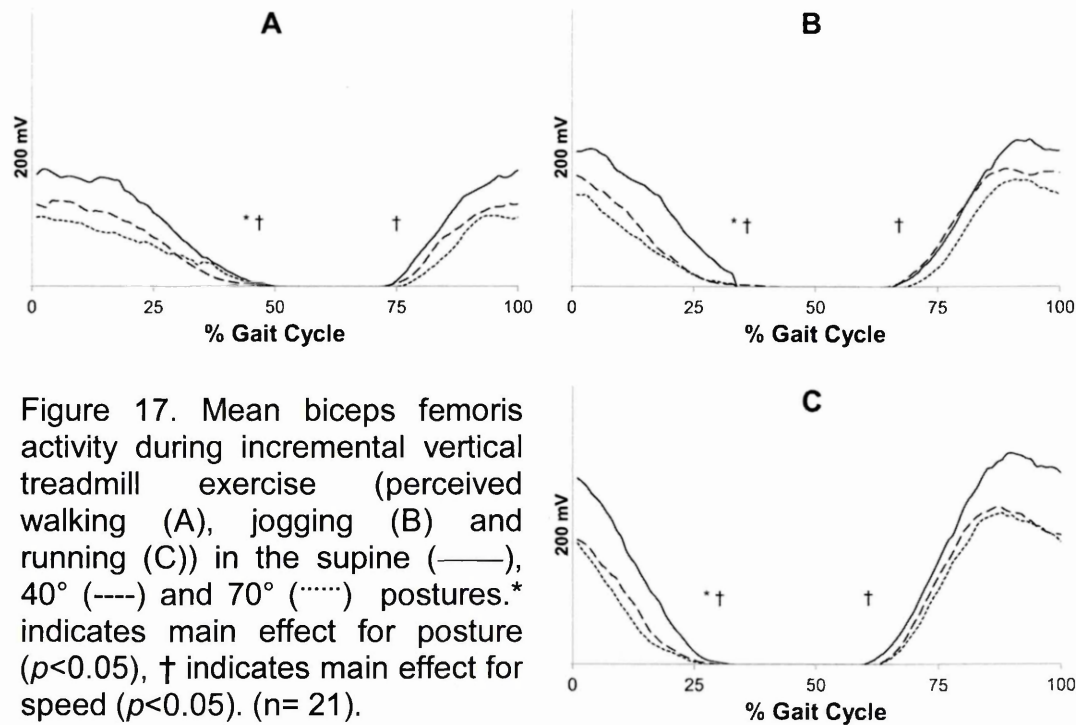
Figure 17 demonstrates that the biceps femoris were active from the late swing phase and ceased in late contact phase. The biceps femoris activation differed with respect to speed ($F_{(2,40)}=66.775$, $p<0.001$) and was active earlier in the gait cycle as the speed increased ($p<0.001$, large ES for all speed comparisons). The cessation of biceps femoris activity differed between postures ($F_{(2,40)}=32.956$, $p<0.001$) and speed ($F_{(1.4,27.4)}=85.966$, $p<0.001$). In the supine posture the biceps femoris activity ceased later in the gait cycle than the 40° and 70° postures ($p<0.001$, medium-large ES) and ceased earlier as speed increased ($p<0.001$, large ES for all speed comparisons).

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4.3.3.5.   Lateral gastrocnemius

Figure 18. Mean lateral gastrocnemius activity during incremental vertical treadmill exercise (perceived walking (A), jogging (B) and running (C)) in the supine (—), 40° (----) and 70° (······) postures.* indicates main effect for posture ($p<0.05$), † indicates main effect for speed ($p<0.05$). (n= 21).
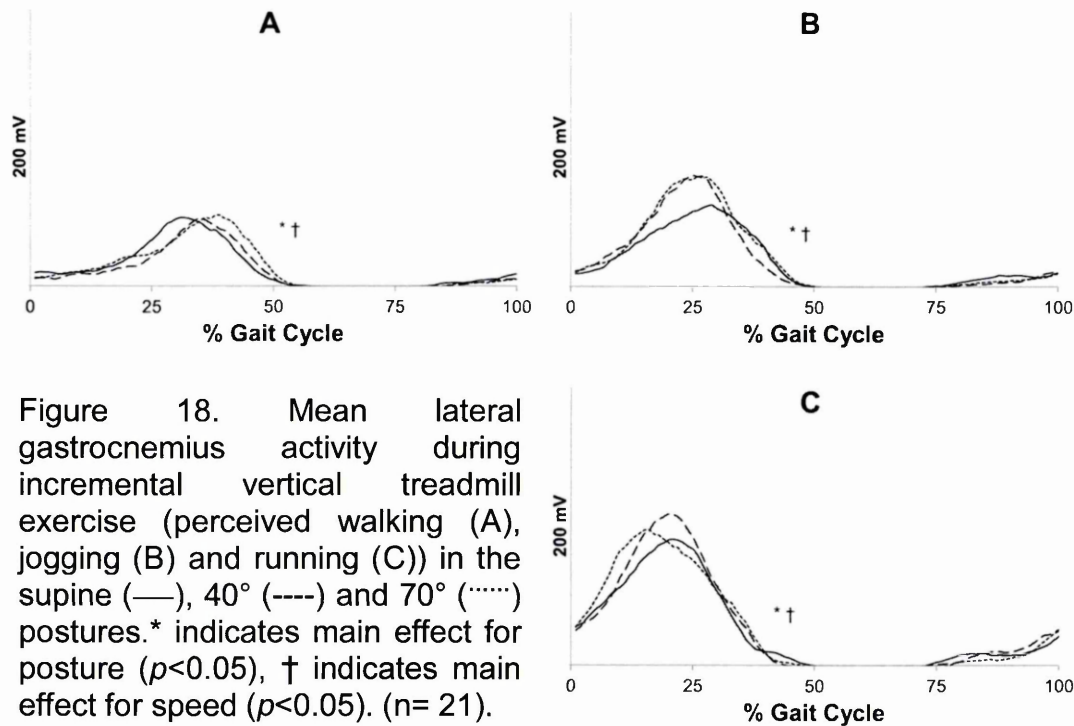
As demonstrated in Figure 18, the lateral gastrocnemius was active between the late swing phase and late contact phase. The activation of the lateral gastrocnemius differed with respect to speed ($F_{(2,40)}$=29.711, $p<0.001$) and occurred earlier in the gait cycle as speed increased ($p<0.001$, large ES for all speed comparisons). The cessation of gastrocnemius muscles differed with speed ($F_{(2,40)}$=50.338, $p<0.001$ and $F_{(2,38)}$=40.687, $p<0.001$ respectively) and ceased earlier as the speed increased ($p<0.001$, small-large ES for all speed comparisons). A posture-related difference was found in the cessation of lateral gastrocnemius activity ($F_{(2,38)}$=3.660, $p=0.035$) which indicated a later cessation of activity in the 70° posture compared with the supine posture ($p<0.001$, small-medium ES).

4.3.3.6.   Medial gastrocnemius

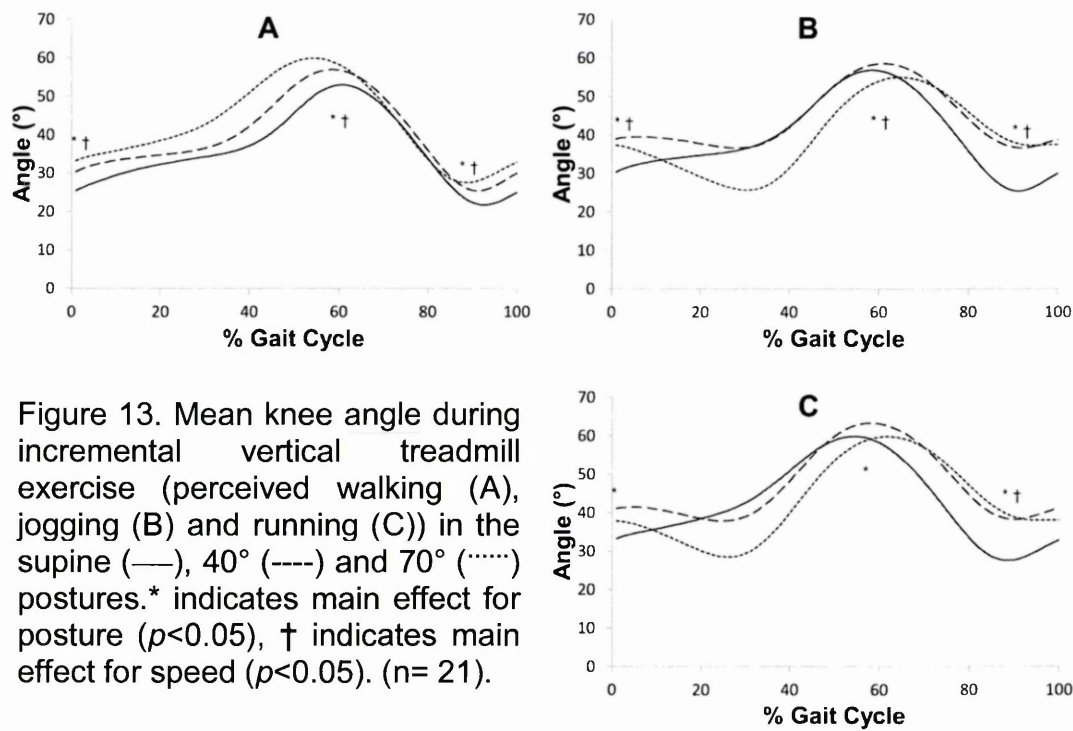Figure 19. Mean medial gastrocnemius activity during incremental vertical treadmill exercise (perceived walking (A), jogging (B) and running (C)) in the supine (——), 40° (----) and 70° (······) postures. * indicates main effect for posture ($p<0.05$), † indicates main effect for speed ($p<0.05$). (n= 21).
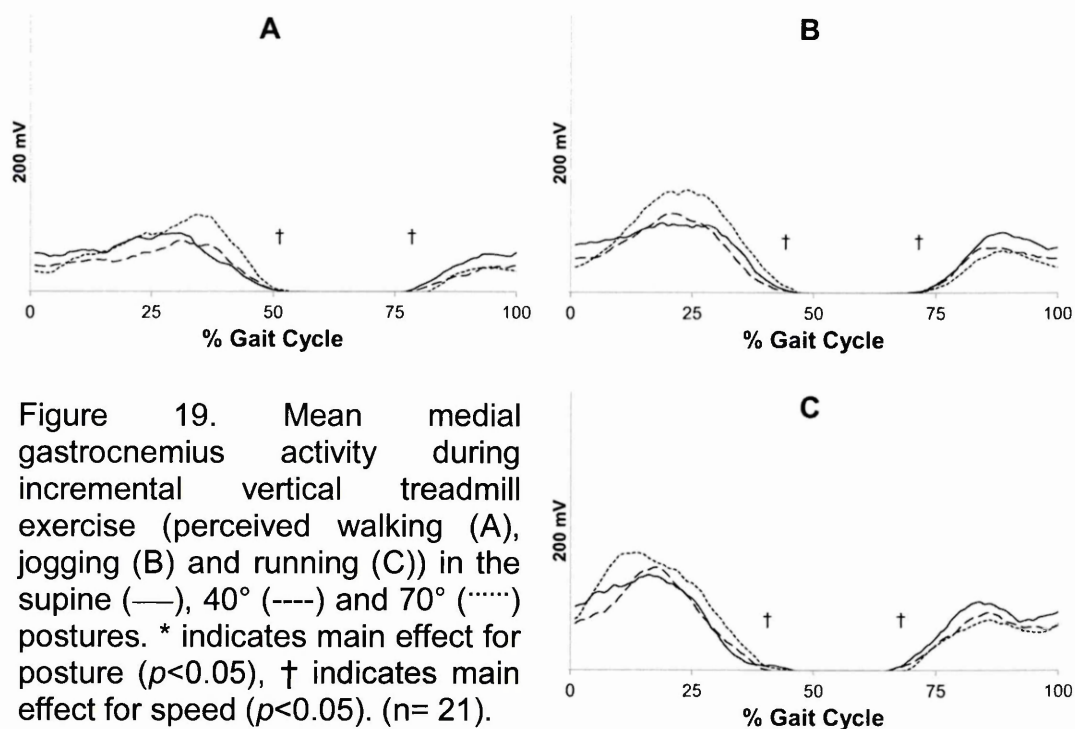
Figure 19 shows that the medial gastrocnemius was active between the late swing phase and late contact phase. The activation of the medial gastrocnemius differed with respect to speed ($F_{(2,40)}=39.721$, $p<0.001$) and occurred earlier in the gait cycle as speed increased ($p<0.001$, large ES for all speed comparisons). The cessation of medial gastrocnemius differed with speed ($F_{(2,40)}=50.338$, $p<0.001$) and ceased earlier as the speed increased ($p<0.001$, small-large ES for speed comparisons).

4.3.4. Tibialis anterior

A

B

C

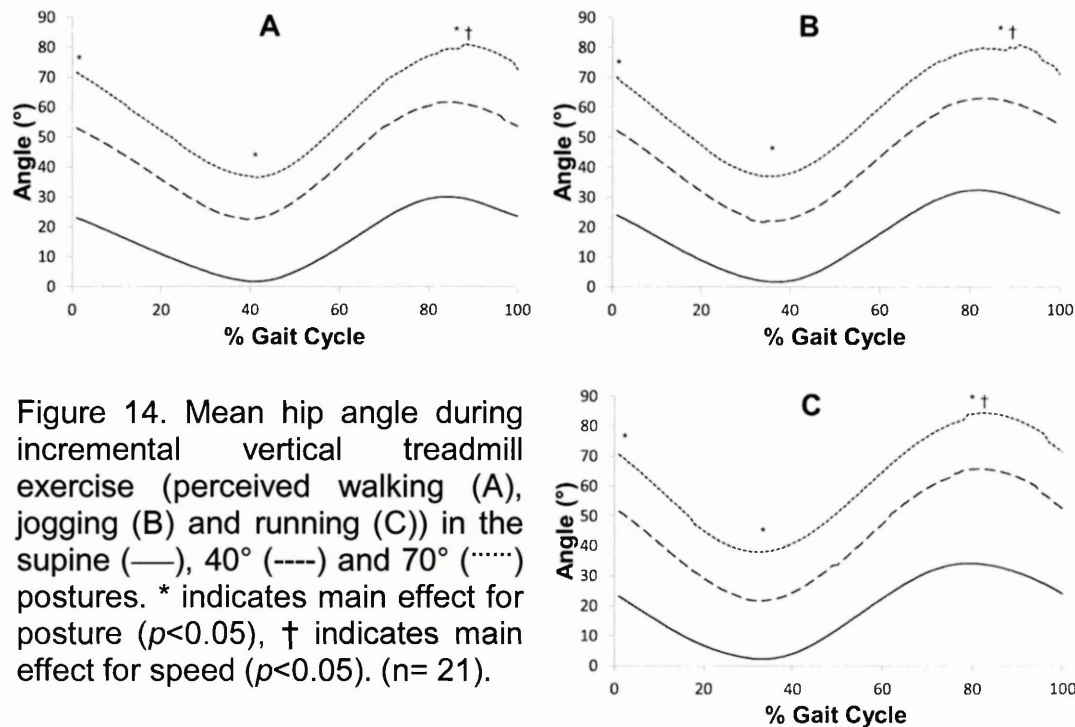Figure 20. Mean tibialis anterior activity during incremental vertical treadmill exercise (perceived walking (A), jogging (B) and running (C)) in the supine (——), 40° (----) and 70° (······) postures. (n= 21).
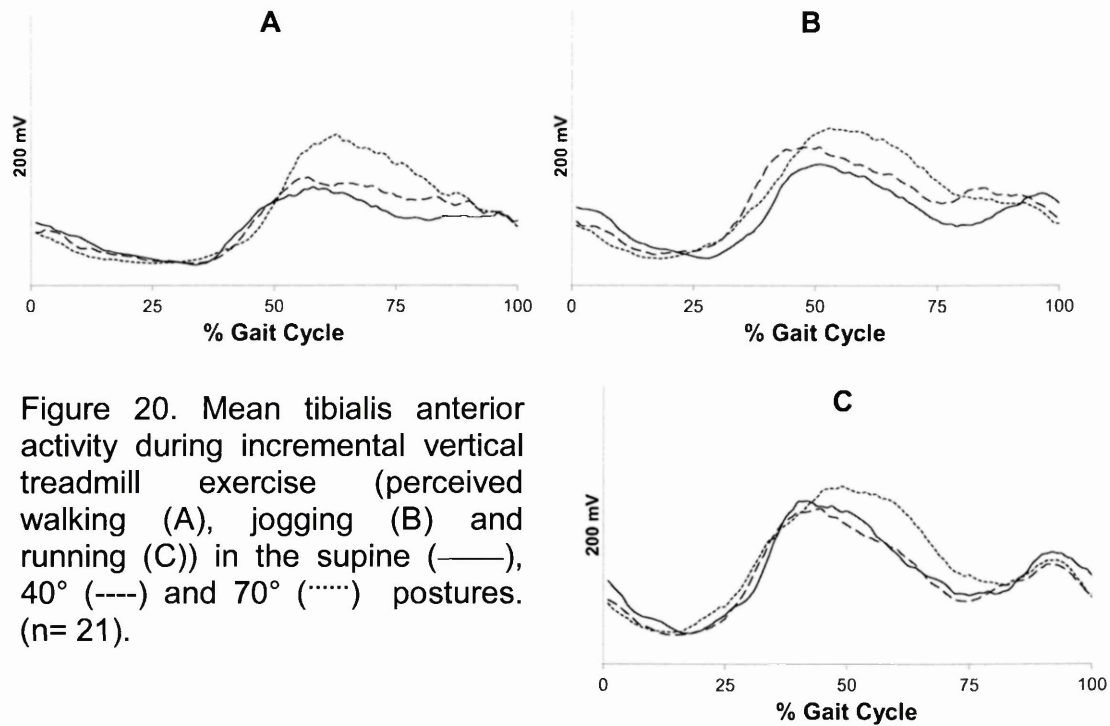
As demonstrated in Figure 20, the tibialis anterior did not demonstrate any discernible period of inactivity during the gait cycle and was constantly active, however, the magnitude of activity appeared to be greater in the swing phase.

4.4. Discussion

The aim of this study was to identify the kinematics and neuromuscular recruitment during vertical treadmill exercise in different postures and speeds. The key findings of this study were that the posterior leg muscles were active to draw the leg down the treadmill belt in opposition to the resistance cables. During the swing phase, the rectus femoris was responsible for drawing the leg upwards against gravity. Generally, the kinematic and neuromuscular recruitment patterns were similar in the 40° and 70° postures with many comparisons exhibiting small ES. These inclined postures differed from the supine posture in many aspects and differences were supported with larger ES.

The vertical treadmill speed increased as the perceived speed increased. In terms of posture, the vertical treadmill speed exhibited in the 40° and 70° postures were similar and both faster than supine. Running speed is the product of cadence and stride length (Mann and Hagy, 1980). Both stride length and cadence increased with respect to the perceived speed, however, no difference in stride length was found across postures, thus cadence was the major contributing factor to increasing speed between postures. The increases in cadence were reflected in a reduced gait cycle time as posture and speeds increased. The contact distance did not differ between conditions, however, a reduction in the proportion of the gait cycle spent in contact with the treadmill suggested that during the higher perceived speeds the same contact distance was covered in less time, potentially accelerating the treadmill belt further per step.

At initial contact, the ankle angle was seen to vary between postures and speeds. In the supine the ankle was less dorsiflexed than 40° and 70° posture, however, a large standard deviation (6.2 – 8.3°) suggested that a range of different strike patterns were used during vertical treadmill exercise. In all conditions, the participants demonstrated dorsiflexion of the ankle during the early contact phase. A rear-foot contact was improbable because, in horizontal ambulation, rear-foot contact is followed by plantarflexion into 'flat foot' phase of ambulation (Novacheck, 1998) which was not observed during vertical treadmill exercise. Instead, a forefoot or mid-foot contact was made with the treadmill belt and visual inspection of the exercise action supported this finding. A similar strategy was reported during horizontal running whereby a forefoot contact is made and dorsiflexion in the early contact was attributed to the absorption of body weight (Novacheck, 1998). At initial foot contact, a co-contraction of the tibialis anterior and gastrocnemius muscles occurred, this was possibly a strategy employed to stabilise the ankle joint at initial contact in a similar way to horizontal running (Mann and Hagy, 1980). In the mid-late contact phase of vertical treadmill exercise, the gastrocnemius muscles plantarflexed the foot to maintain foot contact with the treadmill belt and the tibialis anterior activity was increasing to control the plantarflexion. This is consistent with horizontal running where tibialis anterior activity eccentrically controls the plantarflexion of the foot brought about by gastrocnemius activity (Mann and Hagy, 1980).

In all conditions, the knee was flexed at initial foot contact, more so as posture and speed increased. As the leg descended the treadmill belt in the early contact phase, the knee gradually flexed in the supine posture whereas a brief period of reduced flexion during jogging and running in the 40° and 70° postures. The hamstrings were active in the contact phase to maintain stability

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of the knee joint whilst opposing the resistance cables. Subjective analysis of the hamstrings activity suggested that the hamstring activity was greater in the supine posture than the 40° and 70° postures. The primary function of the hamstrings is to flex the knee, therefore, the greater activation in the supine posture could have been responsible for the gradual flexion or the higher neuromuscular recruitment could have compensated for mechanical inefficiency around the hip joint since the hamstrings span both the knee and the hip joint.

The general motion of the hip was similar between conditions, only the degree of hip angle differed. Large differences and large ES were to be expected since the hip angle was measured as the relative angle between the thigh and pelvis. As the posture increased, the position of the pelvis was tilted toward the thigh in the inclined positions when compared with the supine, thus the hip angle was reduced throughout the gait cycle. In all conditions the hip flexion reduced throughout contact to draw the leg down the treadmill belt face. The reduction in hip flexion was, in part, due to the hamstrings as they extend the hip as well as flex the knee. The gluteals might have contributed to extend the hip during late contact phase, as has been shown in horizontal running (Mann and Hagy, 1980, and Luttgens and Hamilton, 1997). The gluteals were not measured in this study because of movement artefact during vertical treadmill exercise exacerbated by the body weight of the participants pressed on the EMG cables thus increasing the noise to the signal. The minimum hip flexion occurred just before toe-off in all conditions and the supine posture was closest to achieving hip extension ($0.3 \pm 6.8°$, $0.7 \pm 8.3°$ and $1.4 \pm 7.7°$ for perceived walking, jogging and running pace). Hip extension is a major contributor to over ground running speed (Novacheck, 1998), however, it was limited by a few factors. The rectus femoris was active in the latter stages of the

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contact phase to control or limit the extension of the hip for the transition into the swing phase as observed during over ground running (Novacheck, 1998). In the 40° and 70° posture the hip extension might have been limited by the geometry of the seat and back rest, where hip extension would require the participant to lift the pelvis out of the seat. A large standard deviation in the minimum hip flexion in all conditions suggested that many participants achieved hip extension. Therefore, the achievement of hip extension might be dependent on an individual's current hip extensor strength especially in the supine posture. In addition to muscular strength, hip extension might be facilitated by stretch-shortening cycle in the posterior hip musculature in the inclined postures. Gregor *et al.*, (2002) examined the kinetic differences between upright and recumbent cycling and reported that in the recumbent posture the hip was in a more flexed position thus the hamstrings and gluteals at the posterior of the leg were stretched around the hip joint. It was hypothesised that the stretch-shortening cycle might be employed in the recumbent posture thus facilitating the hip extension during vertical treadmill exercise in the inclined postures. When the hip is in a more extended position as observed in the supine posture the contribution of the stretch-shortening of hip musculature is reduced and the dependency on muscular force is increased. This was supported by Perell *et al.*, (2002) who examined the kinetics of upright and recumbent cycling in healthy controls and diabetics. In the healthy individuals the hip extensor moment was found to be greater in the recumbent postures. If this were extrapolated it could inferred that a greater hip extensor moment would be required in the supine posture when compared with the 40° and 70°. This posture-related mechanical inefficiency might be attributed to the slower speeds, greater neuromuscular recruitment and subsequent higher RPE that

was exhibited in the supine posture. This highlights the vertical treadmill as a potential conditioning tool for the hip extensors, which have been implemented in the improvement of sprint performance (Askling *et al.,* 2003), with the potential to overload the hip musculature by reducing the posture from inclined postures toward the supine.

In early swing phase, peak plantarflexion was observed in all conditions and increased with posture and speed. This could be a result of an increased momentum of the foot from a speedier downward motion of the leg which was mediated by eccentric activity of the tibialis anterior. In all conditions, the ankle was dorsiflexed in the mid-swing phase by the increasing activity of tibialis anterior. The rectus femoris activity peaked in early swing phase to flex the hip and draw the leg upwards. Hip flexion advances the thigh upward and the lower leg lags behind, resulting in passive knee flexion. In horizontal running these actions of hip and knee flexion with dorsiflexion were associated with ensuring foot clearance (Novacheck, 1998) and appear to have also been employed during vertical treadmill exercise.

In late swing the hip flexion peaked as the rectus femoris activity reduced and the momentum transferred to the lower leg resulted in a passive knee extension. Passive knee extension was observed since the knee extensors, the vastii muscles, were not active during the vertical treadmill exercise and the resistance cables facilitate the extension. The onset of hamstrings activity at this time suggested that the hamstrings controlled the rapid knee extension as observed in over ground running (Mann and Hagy, 1980). The decrease in hip flexion was due to an increasing hamstring activity (and probably the gluteals) was indicative of the transition from upward motion of the leg to the downward

motion of the leg just before initial contact. The ankle angle in the latter stages of the swing phase undertook a brief reduction in dorsiflexion, achieving plantarflexion in the perceived jogging and running speed in the supine posture and this coincided with the onset of gastrocnemius activity. The reason for this is unclear. Potentially, it could have been an attempt to 'feel' for the treadmill belt, especially in the supine posture where the position of the foot in relation to the treadmill belt was not visible. As the leg descended towards the treadmill belt, the foot began to dorsiflex under tibialis anterior activity in preparation for the initial contact. The co-contraction of the gastrocnemius and tibialis anterior acted to stabilise the ankle joint in preparation for initial contact.

Large kinematic variability was evident in all conditions and could be attributed to questionable reliability which, in turn, could be attributed to unfamiliarity with the exercise mode and inter-individual differences in participant anthropometrics. The resistance of the exercise increased from 20 N at the uptake of tension up to 70 N as the leg descended the treadmill. Therefore, the range of motion exhibited by the participant will determine the resistance experienced and will have differing effects on the observed kinematic and neuromuscular recruitment patterns between strides and/or participants. This coupled with an unfamiliar exercise mode might account for the large kinematic variability during vertical treadmill exercise. There were many differences in the timing of neuromuscular recruitment, especially across speeds. Differences in the timing of the neuromuscular recruitment could be attributed to the normalisation of the EMG signal to 100% of the gait cycle. In the walking speeds the contact phase accounted for 45 – 46% of the gait cycle whereas running speed accounted for 33 – 35% of the gait cycle. Therefore muscle activity associated with the contact phase (hamstrings and

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gastrocnemius) is prolonged and muscular activity of the swing phase (rectus femoris) is delayed. Therefore the neuromuscular recruitment patterns were similar between conditions, however, a time-shift was evident and differed in response to the proportion of gait spent in contact.

With regards to the perceived exertion in each condition, the supine posture was considered the most demanding of the postures as evidenced by the higher RPE scores across intensities and a medium ES. Anecdotally, participants reported that the supine posture incurred a greater postural demand. Perceived postural demand might be reflective of compensatory muscle recruitment to provide a more rigid body from which the posterior chain of the appending lower limbs can work from to overcome the resistance of the overhanging cables. In the 70° posture, participants reported a difficulty in remaining in the seat. As hip flexion reduced in the downward portion of the gait cycle the descending thigh tended to lift the participant out of the seat. Such difficulties were not made regarding the 40° posture. Therefore future models of the VertiRun might look at addressing this issue if indeed exercising at 70° posture provides any additional benefit than the 40° posture. The results of this study suggest that the differences between the 40° and 70° posture were minimal and therefore the value of 70° posture is questionable. For future research, the 40° posture was preferred given the demanding nature of the supine posture which might be too much for relative novices without the postural strength to sustain exercise and the difficulty of remaining in the seat during exercise in the 70° posture.

In conclusion, the vertical treadmill exercise recruited many of the major muscle groups and sizeable ranges of motion were demonstrated at each lower

limb joint. A secondary finding was some similarities characteristics of exercise modes (running and cycling) were demonstrated in vertical treadmill exercise. Although many differences were exhibited between postures and speeds, principally, the hamstrings and gastrocnemius as the leg is drawn downwards against the resistance cables, the rectus femoris and tibialis anterior were predominantly active in the swing phase as the leg is drawn upwards assisted by the supporting cables and against gravity. The vastii were not recruited which might need to be addressed if the vertical treadmill is to offer full lower limb conditioning. The vertical treadmill primarily targets some of the muscles of the posterior chain (hamstrings and gastrocnemius). Exercise programmes that condition the posterior muscles have been shown to improve horizontal running performance and prevent injuries (Askling *et al.*, 2003). Therefore, early indications are that the vertical treadmill exercise might be used to supplement physical conditioning for sports or activities involving horizontal ambulation. Further research should focus on whether vertical treadmill exercise can elicit appropriate acute physiological responses and training adaptations.

5.1. Introduction

Exercise was reported to disrupt the homeostasis brought about by muscle activity which alters the function and the physiologic responses of body systems (Winter and Fowler, 2009). The physiological responses to exercise can be used to monitor the fitness of an individual and used to inform the prescription of exercise programmes (ACSM, 2000). The most common method of monitoring or assessing physiological responses to exercise is HR (Karvonen and Vuorimaa, 1988, and Laukkanen and Virtanen, 1998). The HR is an indicator of the cardiovascular stress brought about by metabolic changes during exercise and is highly correlated with exercise intensity (Karvonen and Vuorimaa, 1988). HR is also reflective of the aerobic activity as evidenced by a strong correlation between HR and $\dot{V}O_2$ (Hale, 2008).

An indication of the anaerobic metabolism at a given exercise intensity can be achieved by measuring lactate from anaerobic glycolysis in the muscle (Goodwin *et al.*, 2007). Lactate measurement has been used to monitor and assess exercise performance (Gollnick *et al.*, 1986 and Pyne *et al.*, 2000). The profiling of [BLa] through incremental test can be used to identify OBLA measures which have strong correlations with athletic performance (Pyne *et al.*, 2000).

During exercise, metabolic changes in the active muscles are also reflected in the changes in ventilatory parameters (Gaskill *et al.*, 2001). Therefore, the analysis of pulmonary gases has been used extensively to determine multiple physiological responses to exercise. The $\dot{V}O_2$ is indicative of

the aerobic metabolism at a given exercise intensity where as TVent and RCP can identify the responses of the anaerobic system and has been shown to be a good predictor anaerobic threshold (Davis *et al.*, 1983). The determination of respiratory exchange ratio ($\dot{V}CO_2 / \dot{V}O_2$) can also be established which is indicative of the substrate utilisation in response to exercise. Davis *et al.*, (1983) reported that the ventilatory responses were valid for steady-state exercise due to disturbance in homeostasis and ventilation at the onset of exercise or in the initial stages after an increase in exercise intensity.

To the author's knowledge, the physiological responses of these parameters to vertical treadmill exercise are unknown. Physiological responses to other exercise modes have indicated that the intensity of exercise and current fitness might affect the physiological responses. For example, Morgan *et al.*, (1995) assessed $\dot{V}O_2$ during submaximal and maximal ($\dot{V}O_{2max}$) running in trained and untrained runners. Submaximal $\dot{V}O_2$ and HR were lower in the trained than untrained, however, during maximal running a greater $\dot{V}O_{2max}$ was observed in the trained runners than untrained individuals. Therefore, the participant fitness could influence the observed physiological responses in submaximal and maximal exercise and so participant fitness should be defined and related to the physiological responses.

The previous study (Chapter 4) identified the 40° posture as the preferable posture for tests because the postural demand in the supine posture would suit more experienced vertical treadmill exercisers with the postural strength to sustain exercise and the difficulty of remaining in the seat during exercise in the 70° posture. Wasserman *et al.*, (1987) reported that incremental exercise, at equal intervals from light to maximum exercise, can profile the

changes in physiology. Therefore, the aim of this study was to determine the physiological responses to incremental vertical treadmill exercise in the 40° posture.

5.2. Methods

5.2.1. Participants

After institutional ethics approval, 13 male participants (age 24 ± 3 years, stature 1.83 ± 0.06 m, body mass 77.0 ± 7.9 kg) volunteered for this study. All participants were healthy, physically active individuals, who were free from illness, musculoskeletal disease or injury at the time of testing. Seven participants were experienced vertical treadmill exercisers and 6 underwent the habituation protocol described previously (see 3.2.).

5.2.2. Test protocols

The aerobic power of the participants was measured by an incremental $\dot{V}O_{2max}$ test (see 3.9.8.) on a conventional treadmill (3.9.1.). A minimum of 48 hours later, the anaerobic power of the participants was measured by a MART (see 3.9.9.) followed by 48 hours of rest. The protocol for determining the acute physiological responses to incremental vertical treadmill exercise was reported previously (see 3.10.2.2.1). In brief, participants rested for 15 minutes on the vertical treadmill undertook vertical treadmill exercise for 3 minutes at an RPE 9, 12 and 15 and 1 minute of all-out effort. These RPE were based on the RPE reported in Chapter 4 for perceived walking, jogging and running (RPE 9, 12 and 14 respectively), but were adjusted to ensure equal increments in perceived exertion. The speed, cadence, HR (see 3.9.5.), [BLa] (see 3.9.6.) and

$\dot{V}O_2$ (see 3.9.7.), were recorded a rest and during exercise at each RPE (see 3.10.2.2.1). An additional supramaximal verification bout in accordance with Scharhag-Rosenberger *et al.*, (2011) was performed. The verification bout required participants to rest for 10 minutes after the all-out effort and then exercised on the vertical treadmill at 110% of the mean speed exhibited in the all-out effort (target speed) while HR and $\dot{V}O_2$ were recorded. The verification bout ended when the speed dropped below the target speed for 5 s and a [BLa] was taken within a minute of the test termination.

5.2.3. Data analysis

Data analysis was the same as that described previously (see 3.10.3.). The $\dot{V}O_2$ data was averaged over 30 s intervals. The highest $\dot{V}O_2$ 30 s interval during conventional treadmill test was taken as the participants' $\dot{V}O_{2max.}$ (3.9.8.1.) and the TVent and RCP were determined for each participant (see 3.9.8.2. and 3.9.8.3.). The MART score was calculated using the ACSM (2000) $\dot{V}O_2$ equivalents for running power (3.9.9., Figure 5). The cadence and treadmill speed were recorded every 60 s during each stage of incremental vertical treadmill exercise protocol to detect any changes in effort over the 3 minute period. The mean $\dot{V}O_2$ exhibited in the final 30 s and HR in the final 15 s of rest and at each RPE during the incremental vertical treadmill exercise was established for each participant in preparation for statistical analysis. Lactate-E software (Newell *et al.*, 2007) was used to determine the RPE at which 2 and 4 mmol·L^{-1} OBLA occurred during incremental vertical treadmill exercise.

5.2.4. Statistical analysis

Parametric variables of interest were subject to one-way repeated measures ANOVA with pairwise comparisons (Bonferroni) and Cohen's 'd' effect size (ES). Non-parametric variables of interest were subject to Friedman test and post hoc Wilcoxon signed ranks test.

5.3. Results

5.3.1. Participant characteristics

The aerobic running power of the participants, as measured by $\dot{V}O_{2max.}$ was 49.4 (4.4) ml·kg^{-1}·min^{-1}. The TVent and RCP was identified at 29.3 (4.0) ml·kg-^{1}·min^{-1} (59% $\dot{V}O_{2max.}$) and 40.8 (4.0) ml·kg^{-1}·min^{-1} (83% $\dot{V}O_{2max.}$) respectively. The HR$_{max.}$ during the $\dot{V}O_{2max.}$ test was 184 (10) bpm and this was 12 bpm lower than the age-predicted HR$_{max.}$ (196 bpm). The RER at $\dot{V}O_{2max.}$ (RER$_{max.}$) was 1.24 (0.08).

The anaerobic running power of the participants, as measured by MART in $\dot{V}O_2$ equivalents was 106.7 (5) ml·kg^{-1}·min^{-1}, which was 215% of the $\dot{V}O_{2max.}$. The [BLa] within 1 minute after the MART was 10.21 (1.69) mmol·L^{-1}.

5.3.2. Incremental vertical treadmill exercise

The responses to incremental vertical treadmill exercise are presented in Table 8. Participants maintained a constant speed and cadence throughout the 3 minutes at each RPE ($F_{(1.2,14.2)}$=3.609, p=0.073 and $F_{(2,24)}$=2.930, p=0.073). As the RPE increased, the mean treadmill speed increased ($F_{(2,24)}$=146.668, p< 0.001) 29% from RPE 9-12 (p< 0.001, ES=1.97), 23% from RPE 12-15

(p< 0.001, ES=1.59) and 32% from the mean speed during RPE 15-all-out effort ($t_{(12)}$=-9.710, p<0.001, ES=2.39). There was no difference between the target speed and the verification speed ($t_{(12)}$=1.581, p=0.140). The mean cadence also increased ($F_{(1.4,16.6)}$=115.742, p<0.001) from RPE 9-12 (p<0.001, ES=1.15) and from RPE 12-15 (p<0.001, ES=1.03).

HR increased as exercise intensity increased ($F_{(2.6, 30.6)}$=207.296, p<0.001) by 54% from resting-RPE 9 (p<0.001, ES=3.21), 18% from RPE 9-12 (p<0.001, ES=1.18), 18% from RPE 12-15 (p<0.001, ES=1.41) and 10% from RPE 15-all-out (p=0.020, ES=0.90).

The $\dot{V}O_2$ increased as exercise intensity increased ($F_{(2.4, 29.2)}$= 238.404, p<0.001) by 223% from rest-RPE 9 (p<0.001, ES=5.88), 31% from RPE 9-12 (p<0.001, ES=1.74), 31% from RPE 12-15 (p<0.001, ES=2.11) and 21% from RPE 15-all-out effort (p=0.002, ES=1.47).

The [BLa] increased as exercise intensity increased ($F_{(2.7, 31.9)}$=109.622, p<0.001) by 81% from rest-RPE 9 (p=0.042, ES=1.43), non-significant 7% increase from RPE 9-12 (p=0.051, ES=0.76), 7% from RPE 12-15 (p<0.001, ES=1.61) and 21% from RPE 15-all-out effort (p<0.001, ES=1.25). The 2 and 4 mmol·L^{-1} OBLA occurred at RPE 9 (1.1) and RPE 15 (1.2) respectively during incremental vertical treadmill exercise.

RER tended to increase as RPE increased ($F_{(2.4, 29.2)}$=238.404, p<0.001), but only increased significantly above rest and peaked at RPE 15 (p=0.041, ES=1.12). RER was similar between RPE 15 and all-out and reduced in the verification back to resting RER (p<1.000, ES=0.63).

Table 14. Mean *(SD)* speed, cadence, HR, $\dot{V}O_2$, respiratory exchange ratio (RER) and blood lactate concentration [BLa] during incremental vertical treadmill exercise. * indicates significant difference ($p<0.05$) from preceding RPE bout and † indicates significant difference from resting ($p<0.05$). (n=13).

Variable	Rest	RPE 9	RPE 12	RPE 15	All-Out	Verification
Speed $(m \cdot s^{-1})$		0.95 *(0.18)*	1.34* *(0.22)*	1.74* *(0.27)*	2.56* *(0.41)*	2.78 *(0.45)*
Cadence $(strides \cdot min^{-1})$		80.2 *(18.2)*	102.5* *(20.3)*	121.8* *(17.1)*		
HR (bpm)	67 *(7)*	103* *(18)*	122* *(16)*	144* *(14)*	158* *(17)*	158 *(18)*
$\dot{V}O_2$ $(ml \cdot kg^{-1} \cdot min^{-1})$	5.67 *(1.11)*	18.37* *(3.19)*	24.06* *(3.35)*	31.63* *(3.8)*	38.37* *(5.23)*	37.76 *(6.01)*
RER	1.01 *(0.1)*	1.04 *(0.25)*	1.11 *(0.25)*	1.19† *(0.25)*	1.19* *(0.21)*	1.07 *(0.19)*
[BLa] $(mmol \cdot L^{-1})$	1.12 *(0.25)*	2.09* *(0.67)*	2.69* *(0.87)*	4.62* *(1.46)*	6.66* *(1.78)*	7.67 *(1.44)*

5.4. Discussion

The primary aim of this study was to determine the acute physiological responses of vertical treadmill exercise. The key findings were that as the exercise intensity increased, large increases in both aerobic and anaerobic physiological markers were evident. The physiological responses (HR, $\dot{V}O_2$, RER and [BLa]) in all-out effort were verified, thus peak values that were specific to vertical treadmill exercise were demonstrated.

The mean aerobic power of the participants in this study, as measured by $\dot{V}O_{2max.}$, were classified by Lawler *et al.*, (1988) as 'untrained' individuals ($33 - 49$ $ml \cdot kg^{-1} \cdot min^{-1}$), compared with 'endurance trained' athletes ($56 - 75$ $ml \cdot kg^{-1} \cdot min^{-1}$). Normative data to classify MART scores is non-existent, possibly due to a relatively small quantity of research regarding the MART being available. Nummela *et al.*, (1996) reported that participants, not too dissimilar to the participants in this study (physical education students, age 24 ± 3 years, stature 1.80 ± 0.05 m and mass 71.2 ± 5.8 kg), demonstrated MART scores of 119.5 (8.0) $ml \cdot kg^{-1} \cdot min^{-1}$ which was 12% higher than in this study. These results are not strictly comparable since the treadmill gradient was 0.5° greater than the

gradient used in this study. Nummela *et al.*, (1996) reported that the MART scores increased with the gradient of the treadmill, hence a difference was to be expected. Maxwell and Nimmo (1996) studied a similar cohort (male students with variety of sporting backgrounds) at the same gradient and speeds used in this study (10.5%, 14.3 $km \cdot h^{-1}$ increasing by 1.2 $km \cdot h^{-1}$ per bout) and reported a lower mean MART score of 112.2 (5.2) $ml \cdot kg^{-1} \cdot min^{-1}$ than Nummela *et al.*, (1996). Maxwell and Nimmo (1996) MART scores were 5% higher than the MART score exhibited in this study, indicating a less anaerobically fit population in this study than reported previously.

5.4.1. The HR response to incremental vertical treadmill exercise

The HR increased as RPE increased and peaked during all-out exercise at 158 bpm. The $HR_{max.}$ during the all-out effort did not differ from the $HR_{max.}$ exhibited in the verification bout, suggesting that 158 bpm was the $HR_{max.}$ specific to vertical treadmill exercise. The vertical treadmill $HR_{max.}$ (158 bpm) was 81% of the age-predicted $HR_{max.}$ (196 ± 3 bpm), and when compared with the $HR_{max.}$ achieved during the treadmill running $\dot{V}O_{2max.}$ test, the vertical treadmill HR_{max} was 16% lower.

The vertical treadmill $HR_{max.}$ was lower than the $HR_{max.}$ achieved during other forms of recumbent exercise. Billinger *et al.*, (2008a) reported $HR_{max.}$ of 181 (3) bpm during maximal exercise on a recumbent stepper (adapted incremental $\dot{V}O_{2max.}$ test) which was 15% higher than the vertical treadmill $HR_{max.}$. Possible reasons for the lower $HR_{max.}$ during maximal vertical treadmill exercise that running and recumbent stepping is the reported increased venous return on resuming a recumbent posture, more so in a supine posture due to

lower gravitational pull drawing the blood to the lower extremities and a relatively more uniform hydrostatic pressure (Coonan *et al.,* 1983). In response to increased venous return the stroke volume increases in accordance with the Frank-Starling law, therefore the cardiac output required for the exercise intensity can be achieved by a lower HR (Poliner *et al.,* 1980). In both vertical treadmill and recumbent stepper exercise the users were in a recumbent posture, however the degree of recumbency appeared to differ. Recumbent stepper adopted a more upright angle of the back rest was evident in the recumbent stepper when compared to the 40° posture used in this study. Therefore, one might expect the venous return to be greater in the 40° posture on the vertical treadmill configuration and HR to be lowered further under the Frank-staling law (Poliner *et al.,* 1980).

Another reason for lower HR could be due to differences in the mass of musculature being utilised in the exercises. The previous study identified that large muscle groups, the vastii muscles, were not active during vertical treadmill, hence the demand for oxygenated blood might have been reduced when compared with over ground ambulation and recumbent stepping. In over ground ambulation, the vastii undertake eccentric activity during early contact phase to absorb impact forces and also extend the knee joint in the latter stages of the contact phase to propel the limb into the swing phase. The nature of recumbent stepping probably required extension of the knee (Billinger *et al.*, 2008 a and b) which probably required vastii muscle activity. The recumbent stepper also utilises the arms as well as the legs thus the mass of muscle being used and associated increase in the demand for oxygenated blood could be greater than in vertical treadmill exercise, hence differences in $HR_{max.}$ were observed. It could be proposed that the major muscle group used in vertical

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treadmill exercise: the hamstrings were not conditioned for such activity and thus could opt for higher anaerobic ATP resynthesising energy systems (PCr and anaerobic glycolysis) rather than aerobic metabolism, hence the demand on the heart to deliver oxygen-rich blood to the working muscles would be reduced.

5.4.2. The $\dot{V}O_2$ response to incremental vertical treadmill exercise

The $\dot{V}O_2$ increased as the intensity increased and peaked during all-out effort at 38.37 (5.23) ml·kg^{-1}·min^{-1}. Although this $\dot{V}O_2$ was similar to that achieved in the verification it might not be appropriate to state that the vertical treadmill exercise $\dot{V}O_{2max.}$ was achieved. The determination of $\dot{V}O_{2max.}$ as defined by BASES, (1997) required a plateau in the $\dot{V}O_2$-intensity relationship to be established. Plateaus in $\dot{V}O_2$ were normally achieved after 3-4 minutes as the aerobic metabolism attempts to match the demands of the exercise (possibly sooner depending on fitness of the participants) (Hargreaves, 2000). The all-out effort in this study lasted for 1 minute therefore it was unlikely that a steady-state was achieved and visual inspection of the $\dot{V}O_2$ in the all-out effort confirmed this in all cases. Thus, a criterion for the determination of $\dot{V}O_{2max.}$ by BASES (1997) was violated and so in this study $\dot{V}O_{2peak}$ was achieved in all-out effort.

When compared with the $\dot{V}O_{2max.}$ achieved during the conventional treadmill running test, the vertical treadmill $\dot{V}O_{2peak}$ was 22% lower. Similarly, Billinger et al., (2008a) reported a 15% lower $\dot{V}O_{2max.}$ during recumbent stepping when compared with treadmill running $\dot{V}O_{2max.}$. Billinger et al., (2008a) only reported absolute $\dot{V}O_{2max.}$ data (3.13 L·min^{-1}). A greater absolute $\dot{V}O_{2peak.}$ of

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3.8 L·min^{-1} was exhibited during vertical treadmill exercise than recumbent stepping. A greater $\dot{V}O_{2peak.}$ suggested a greater metabolic demand so one would expect HR to be greater than recumbent stepping. This was not the case, thus lending support to the Frank-starling mechanism being responsible for lower HR during vertical treadmill exercise rather than a reduced metabolic demand of a smaller muscle mass as previously hypothesised. The comparison of absolute $\dot{V}O_{2max.}$ data should be made cautiously for a few reasons. The study of Billinger *et al.,* (2008a) differed from this study in the gender of the cohort (mixed gender) and did not provide sufficient detail on the participant characteristics (unknown mass and stature). The cohort was partly female which typically demonstrated 15-30% lower $\dot{V}O_{2max.}$ than males (Sharp *et al.,* 2002) so the mean absolute $\dot{V}O_{2max.}$ could have been lowered by their inclusion, thus rendering this comparison as flawed and therefore should be interpreted cautiously.

The lower $\dot{V}O_{2peak}$ of vertical treadmill exercise compared with treadmill running $\dot{V}O_{2max.}$ could be due to differences in muscular recruitment. Again the lack of vastii activity during vertical treadmill exercise was a prime example of reduced muscle activity and thus the reduced demand for oxygen when compared with treadmill running. In addition, it is possible that anaerobic energy systems were favoured over aerobic energy production due to a relatively smaller muscle mass undertaking a high physical and metabolic demand, thus oxygen demand and $\dot{V}O_{2peak}$ during vertical treadmill exercise was lower than treadmill running.

5.4.3. The RER response to incremental vertical treadmill exercise

During very low intensity vertical treadmill exercise the RER did not increase significantly above resting RER which coincidentally was high at 1.01 (0.10) $mmol \cdot L^{-1}$ compared to the previously reported resting mean RER of between 0.72 – 0.93 (Goedecke *et al.*, 2000). At rest the suggested RER indicated a mix of fat and carbohydrate utilisation whereas an RER of 1 was indicative of 100% carbohydrate utilisation. A large standard deviation (± 0.10) indicated that some participants were utilising a mixed substrate composition and agrees with previous research suggesting large inter-individual variability (Goedecke *et al.*, 2000). A high RER at rest could be due to many factors including muscle glycogen content, exercise volume, proportion of type I fibres and dietary intake of fat and carbohydrate (Goedecke *et al.*, 2000). At the onset of 'very light' exercise (RPE 9) on the vertical treadmill, the RER did not rise significantly above resting but was still >1. The perceived vertical treadmill exercise intensity increased significantly from RPE 12 to all-out, the RER also increased. The further increases in RER (>1) could be the result of an increased $\dot{V}CO_2$ purported to originate from lactic acid (H^+) buffering system, thus anaerobic glycolysis was evident at low intensity exercise and its contribution increased as exercise intensity increased. The peak RER during the all-out effort was verified despite a 0.12 lower RER in the verification bout. Statistical insignificance was probably caused by large inter-individual variability as shown by a large standard deviation (0.19), which could be explained by some of the aforementioned reasons by Goedecke *et al.*, (2000) for RER variability at rest. At an intensity set at 110% of their mean speed during the all-out effort one would expect a high anaerobic largely supplied by anaerobic glycolysis given the mean duration of the verification bout being beyond the

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time frame for PCr system alone and too intense for aerobic energy system to supply. The availability of glycogen and the rate of glycogenolysis could have been affected by the exercise volume and intensity of the exercise performed during the incremental exercise and the individual ability to recover during the 10 minute rest period immediately preceding the verification bout. Inter-individual differences in the proportion of type I fibres, their utilisation during the incremental exercise bout and their ability to recover from preceding exercise could be another factor affecting RER in the verification bout.

5.4.4. The [BLa] response to incremental vertical treadmill exercise

The [BLa] increased with every increment in exercise intensity up to all-out effort indicating an increased contribution from anaerobic energy systems. Using the 2 mmol·L^{-1} OBLA as a measure of lactate threshold (Aunola and Rusko, 1984) the results showed that lactate threshold occurred during vertical treadmill exercise at RPE 9 (1) suggesting an anaerobic contribution to the energy demand even during very light exercise. MLSS as measured by OBLA of 4 mmol·L^{-1} occurred during hard exercise (RPE 15 ± 1) on the vertical treadmill. Similarly, Okuno *et al.*, (2011) reported that MLSS occurred at an RPE of 15.7 (1.8) during treadmill running. Therefore, 'hard' vertical treadmill exercise (RPE 15) required a high anaerobic contribution and the MLSS was similar to that reported during conventional treadmill running.

Although a high anaerobic contribution was evident during vertical treadmill exercise, the participants were capable of tolerating greater [BLa] as indicated by the higher [BLa] achieved during the MART. The [BLa] was 35% lower in the vertical treadmill all-out effort than the MART. This could be

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accounted for by a lower muscle mass being used during vertical treadmill exercise (inactive vastii). The lower muscle mass reduces the capacity for the production of lactic acid when compared with treadmill running where additional muscle mass (vastii) would produce lactic acid, thus increasing the [BLa]. Another reason could be postural effects on blood flow. For example, it was reported that the elimination of lactate via oxidation is, in part, dependent on the redistribution of lactate via the blood to highly oxidative tissues such as muscles, heart and liver (Gladden, 2004 and Wasserman et $al.$, 1986). It could be postulated that the more uniform hydrostatic pressure and tendency to flow toward the centre of the body while in the recumbent posture when compared with the erect posture (Coonan, 1983) might be advantageous since oxidisers of lactate: the liver and heart are located there. In addition, the CO_2 produced by the buffering of H^+ can be expelled by the lungs. However, this was an unlikely mechanism for the lower [BLa] during all-out vertical treadmill exercise because the circulatory dynamics and kinetics of ventilation differed even between recumbent postures. Circulatory dynamics, kinetics of ventilation and $\dot{V}O_2$ kinetics were slower during supine cycle ergometry than upright cycling ergometry (Convertino, 1984; Hughson et $al.$, 1991 and Leyk et $al.$, 1994) and were proposed to be due to an impaired muscle pump action and perfusion at the muscle (Leyk et $al.$, 1994). When comparing the recumbent posture with the erect posture, a greater muscle pump action, ventilatory and perfusion muscle rates were reported in erect exercise (Coonan et $al.$, 1983). Therefore the reduced muscle mass utilisation was a more probable cause for the lower [BLa] during all-out effort on the vertical treadmill than exhibited in the MART.

The [BLa] following the all-out effort on the vertical treadmill was lower than the verification bout, but this difference was not significant and

consequently the post-all-out [BLa] was verified. A large standard deviation was most likely responsible for the lack of significant difference. The large standard deviation could be a result of differences in the fitness between participants. Weltman *et al.*, (2008) reported that in previously untrained women exercising above the lactate threshold increased lactate threshold and running speed at the fixed [BLa] of 2, 2.5, 4 $mmol \cdot L^{-1}$ and peak [BLa] when compared with control group exercising at lactate threshold ($p < 0.05$). Therefore differences in trained status influenced the production and tolerance of maximum [BLa]. Thomas *et al.*, (2004) reported that the maximal oxidative capacity was related to the removal of lactate following a 1-minute all-out effort and also delayed fatigue in subsequent continuous and intermittent supramaximal exercise. Therefore those who are aerobically fit could have buffered or oxidised more lactate in the 10 minute rest period between all-out effort and verification bout than those less aerobically fit. The immediate sampling of blood after exercise bout meant that whether a true peak [BLa] was measured was questionable since peak [BLa] was reported to occur between 3-8 minutes after an exercise bout (Goodwin *et al.*, 2007). The [BLa] measures in this study were taken within 1 minute of exercise bouts and therefore [BLa] profiles are only indicative of the anaerobic demand. The consistent sampling (within 1 minute) meant that the comparisons between increments of RPE were valid.

In conclusion, in individuals considered as untrained in terms of aerobic and anaerobic fitness, the vertical treadmill placed less of a demand on the cardiovascular system as indicated by lower $HR_{max.}$ and $\dot{V}O_{2peak}$ than in the treadmill running $\dot{V}O_{2max}$. test. It is suggested that the dependency on the smaller muscle mass and no vastii activity in vertical treadmill exercise limited the oxygen consumption, hence $\dot{V}O_{2peak}$ and $HR_{max.}$ were lower than in

conventional treadmill running $\dot{V}O_{2max.}$ where a greater muscle mass utilisation contributed to the higher $\dot{V}O_{2max.}$. The vertical treadmill required an anaerobic energy contribution even during low intensity exercise (RPE 9) as indicated by the RER (>1), [BLa] and 2 mmol·L^{-1} OBLA, which increased as with intensity. The anaerobic contribution, the [BLa] of vertical treadmill was also limited by the relatively small muscle mass undertaking anaerobic metabolism and producing lactic acid when compared to treadmill sprinting in the MART where greater muscle mass was recruited (inclusion of vastii). Therefore, the vertical treadmill could be described as a predominantly anaerobic exercise mode.

6.1. Introduction

The preceding chapters (Chapters 4 and 5) indicated that vertical treadmill exercise principally targeted the muscles of the posterior chain and the demand on a relatively small muscle mass demanded a high contribution from anaerobic energy systems as indicated by [BLa] and high RER even at exercise perceived as low intensity. Therefore, the development of a training programme on the vertical treadmill should utilise predominantly anaerobic exercise. High intensity intermittent training programmes (HIIT) require high levels of anaerobic contribution (Buchheit and Laursen, 2013). HIIT consists of durations of high intensity exercise work with rest periods. As with any other training programme the adaptations depend on the nature of training and the subsequent stimulus thus the intensity, frequency, duration and recovery have to be considered. The intensity of HIIT ranges in the literature from 90-95% $HR_{max.}$ for several minutes by Helgerud *et al.*, (2007) and Bravo *et al.*, (2008) to maximal or all-out efforts over short specified distances (30-80m by Dawson *et al.*, 1998 and Bravo *et al.*, 2008) or time such as a few seconds up to 30 s (Ørtenblad *et al.*, 2000; Burgomaster *et al.*, 2005, 2008; Bravo *et al.*, 2008 and Gibala *et al.*, 2006), with the latter being referred to as sprint interval training (SIT). The gauging of intensity has proven difficult on the vertical treadmill because of the postural effects on HR, an inability to regulate the physiological responses at a set cadence and treadmill speed and obtain a measure of power (Watts). Without such information, sprint interval training might be more appropriate given that the intensity could be standardised as 'all-out' effort and therefore comparable with other exercise modes. In addition, SIT has been used by practitioners on

the vertical treadmill and anecdotal evidence suggests it has been successful in improving sport performance in a variety of athletes such as footballers, boxers and triathletes (from personal contact with VertiRun) where aerobic and anaerobic performance are crucial to performance (Bangsbo *et al.*, 2006; Smith, 2006 and Bernard *et al.*, 2009).

There are numerous SIT in the literature with differing work : rest ratios. Laursen and Jenkins (2002) reported that the optimal recovery duration was unknown and probably dependent on the intended outcomes of the training. One could argue that athletes would configure a programme to demonstrate some specificity to their sport for example a team sport would be short duration and short recovery periods (Coutts *et al.*, 2003 and Bangsbo *et al.*, 2006) as was demonstrated in the study by Bravo *et al.*, (2008) (40 m sprints with 20 s rest vs. 4 minutes at 90-95% $HR_{max.}$ with 4 minutes of rest). A common SIT protocol consists of several 30 s all-out efforts were completed separated by 4 – 4.5 minutes of passive or low intensity exercise recovery repeated 3 times per week for 2-7 weeks (Burgomaster *et al.*, 2005; 2006; 2007; 2008; Gibala *et al.*, 2006; Babraj *et al.*, 2009, Whyte *et al.*, 2010 and Bayati *et al.*, 2011). It has been described as a time-efficient training programme for health improvements in sedentary and obese individuals as well as inducing metabolic and morphological adaptations to improve aerobic power and capacity and anaerobic power in the physically active and trained individuals (Creer *et al.*, 2004; Burgomaster *et al.*, 2005; 2006; 2007; 2008; Gibala *et al.*, 2006; Whyte *et al.*, 2010 and Bayati *et al.*, 2011). It is important to note that aerobic and anaerobic adaptations were also shown in other work : rest ratios proposed by McDougall *et al.*, (1998) (30 s : 4 – 2.5 minutes rest) and Ørtenblad *et al.*, (2000) (10 s : 50 s rest), however, the popularity and

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improvements in condition of participants with differing sports or physical activity levels make the 30 s : 4 – 4.5 minutes rest an attractive protocol for the first SIT intervention on the vertical treadmill.

The vertical treadmill was designed to provide an alternative low-impact exercise mode for conditioning and rehabilitation for over ground ambulation and running performance, however, no training studies utilising the vertical treadmill have been carried out. Therefore, the aim of this study was to determine the effect of a 6-week of SIT programme performed on the vertical treadmill compared with over ground sprinting on aerobic and anaerobic running power.

6.2.   Methods

6.2.1. Participants

After institutional ethics approval, 30 male participants (age 22 ± 4 years, stature 1.79 ± 0.08 m, body mass 78.5 ± 12.6 kg) volunteered for this study. All participants were healthy, physically active individuals, who were free from illness, musculoskeletal disease or injury at the time of testing.

6.2.2. Test protocols

The test protocols were performed pre and post-intervention on 2 days separated by 48 hours of rest. On the first testing day, the stature and mass of the participants was measured (see 3.9.2. and 3.9.3.). This was followed by a MART from which anaerobic power and [BLa] were established (see 3.9.9.).

A minimum of 48 hours later, but no later than a week, a conventional treadmill running [BLa] profile was performed. The stature and mass of the participants was measured (see 3.9.2. and 3.9.3.) and rested for 10 minutes, after which a [BLa] sample was taken for analysis (see 3.9.6.). The treadmill (see 3.9.1.) was inclined by 1% throughout the test. Participants ran for 3 minutes at an RPE of 9, 12, 15 and 18. The speed at each RPE was recorded every minute for the purpose of replication in the post-intervention tests. Each 3 minute bout was separated by 1 minute of rest while a [BLa] sample was taken. A final [BLa] sample was taken in the minute immediately after the last bout (RPE 18). Participants rested for 15 minutes before undertaking an incremental running $\dot{V}O_{2max.}$ test on the treadmill to assess the aerobic power of the participants and a [BLa] measure was taken within a minute of volitional fatigue (see 3.9.6.).

6.2.3. Training group assignment

Participants were matched based upon their anaerobic power (MART score) and assigned to a vertical treadmill group, sprint group or control group. The control group were instructed to maintain their normal activities and dietary habits.

6.2.4. SIT programme

Participants in the vertical treadmill and sprint groups undertook the same SIT programme, only the exercise mode differed. Participants performed the SIT programme in accordance with the study of Burgomaster *et al.*, (2008) and Whyte *et al.*, (2010) which consisted of 4-6, 30 s all-out efforts separated by 4.5 minutes of low intensity active recovery (RPE 9), 3 times per week (Monday,

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Wednesday and Friday) for 6 weeks. Access to a large enough indoor area or track for the 30 s sprints meant that the sprint group had to perform 20 m sprint shuttles in a sports hall. The increments in the number of 30 s all-out repetitions are detailed in Table 9.

Table 15. SIT increments in 30 s all-out repetitions.

Week	Repetitions
0	Pre-tests
1-2	4
3-4	5
5-6	6
7	Post-tests

6.2.5. SIT session protocol

Each SIT session began with a very light 10 minute warm-up. The initial 5 minutes consisted of low intensity (RPE 9) vertical treadmill exercise or jogging for the sprint group. The last 5 minutes was reserved for dynamic stretches (hip flexion/extension leg swings, abduction/adduction leg swings, skips, high knees, heel flicks, step-overs, hurdle walks). Participants then engaged in the assigned SIT. Between sprints, the participants undertook very light (RPE 9) exercise in the respective exercise modes to prevent blood pooling and nausea (Burgomaster *et al.*, 2008). After each SIT session, the participants undertook a light cool down (RPE 9) on the vertical treadmill exercise or jogging for 5 minutes followed by 5 minutes of static stretching (quadriceps, hamstrings and gastrocnemius and groins) with each stretch being held for 30 s. Participants were supervised for 20-30 minutes after the cool down before leaving the laboratory or sports hall.

6.2.6. Data analysis

The $\dot{V}O_2$ data in the $\dot{V}O_{2max.}$ test was averaged over 30 s intervals. The highest $\dot{V}O_2$ 30 s interval during conventional treadmill test was taken as the participants' $\dot{V}O_{2max.}$ (see 3.9.8.1.) and the TVent and RCP were determined from the $\dot{V}O_{2max.}$ data (see 3.9.8.2. and 3.9.8.3.). The MART score was calculated using the ACSM (2000) $\dot{V}O_2$ equivalents for running power (see 3.9.9., Figure 5). In the conventional treadmill [BLa] profile, the HR exhibited 15 s before the end of the 3 minute bouts at each intensity (RPE 9, 12, 15 and all-out) was recorded for analysis. The [BLa] exhibited in each RPE was inputted to the Lactate-E software (Newell *et al.*, 2007) to determine the RPE at which 2 and 4 $mmol \cdot L^{-1}$ OBLA occurred during incremental vertical treadmill exercise.

6.2.7. Statistical analysis

The $\dot{V}O_{2max.}$ and MART score of the vertical treadmill group, sprint group and control group were assessed for differences by a one-way ANOVA with Bonferroni pairwise comparisons prior to the intervention. The pre and post-intervention parametric variables of interest ($\dot{V}O_{2max.}$, MART score, [BLa] following the MART and $\dot{V}O_{2max.}$ test, and HR and [BLa] responses to submaximal conventional treadmill running) were subject to a mixed repeated measures ANOVA with Bonferroni pairwise comparisons and Cohen's 'd' effect sizes (ES). Non-parametric variables of interest were subject to Friedman test and post hoc Wilcoxon signed ranks test. In addition, an independent t-test was used to assess compliancy rates of the SIT groups to the programme.

6.3. Results

6.3.1. Pre-intervention group characteristics

Table 16. Mean (*SD*) pre-intervention group characterisitics (n=30).

Group	Age (years)	Stature (m)	Mass (kg)	MART (ml·kg^{-1}·min^{-1})	$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})
Vertical treadmill (n=10)	22 *(4)*	1.82 *(0.07)*	82.1 *(5.2)*	105.2 *(8.6)*	46.8 *(5.4)*
Sprint (n=10)	22 *(3)*	1.79 *(0.07)*	73.2 *(16.3)*	104.8 *(9.3)*	47.1 *(4.5)*
Control (n=10)	21 *(4)*	1.80 *(0.1)*	80.2 *(13.1)*	104.9 *(7.14)*	46.9 *(4.9)*

Table 10 indicates no differences between groups with respect to their MART score ($F_{(2,27)}$=0.005, p=0.995) or their $\dot{V}O_{2max}$ as measured by $\dot{V}O_{2max}$ ($F_{(2,27)}$=0.009, p=0.991). Therefore the vertical treadmill, sprint and control groups were considered homogenous in terms of aerobic and anaerobic power prior to beginning the intervention.

6.3.2. SIT compliancy

The compliancy rate was similar between SIT groups (p=0.918). The vertical treadmill group completed 92.7 (7.2)% and the sprint group completed 92.4 (9.7)% of the whole programme.

6.3.3. Aerobic and anaerobic running power
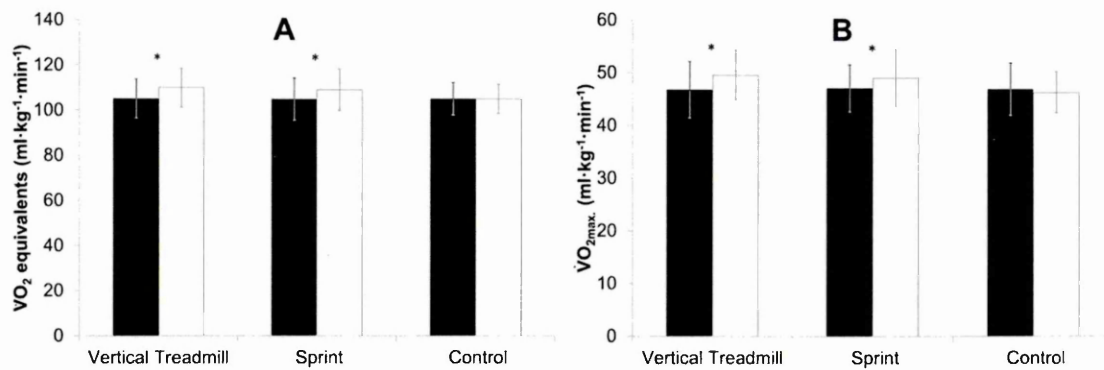
Figure 21. Mean (*SD)* MART score (A) and $\dot{V}O_{2max.}$ (B) pre-SIT ■ and post-SIT □ * indicates difference between pre-SIT and post-SIT ($p<0.05$).

Figure 21 (A) demonstrates a main effect for anaerobic running power (MART) pre and post-intervention ($F_{(1,27)}=16.233$, $p<0.001$) and a time x group interaction ($F_{(2,27)}=4.891$, $p=0.015$). Bonferroni pairwise comparisons were unable to find any differences between the groups over time. Paired t-tests of pre and post-intervention were performed with Bonferroni adjustment indicated that the vertical treadmill and sprint group both increased MART score by 4% following SIT ($t_{(9)}=-4.256$, $p=0.006$, ES=0.55 and $t_{(9)}=-6.092$, $p<0.001$, ES=0.45 respectively), whereas the control group was unchanged ($t_{(9)}=1.984$, $p=0.910$, ES=0.00). The increases in MART scores were similar between over ground and vertical treadmill group ($t_{(18)}=-0.466$, p=0.647).

A main effect ($F_{(1,27)}=16.233$, $p<0.001$) and time x group interaction ($F_{(1,27)}=4.891$, $p=0.015$) was observed between pre and post-intervention $\dot{V}O_{2max.}$ scores (Figure 21 (B)). Bonferroni pairwise comparison was unable to demonstrate differences between the groups over time. Paired t-tests of pre and post-intervention were performed with Bonferroni adjustment and indicated that the vertical treadmill and sprint group both increased $\dot{V}O_{2max.}$ by 4 and 6%

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respectively following SIT ($t_{(9)}$=-4.118, p=0.009, ES=0.56 and $t_{(9)}$=-3.257, p=0.020, ES=0.40 respectively), whereas the control group were unchanged ($t_{(9)}$=0.110, p=0.915, ES=0.14). The increases in $\dot{V}O_{2max.}$ were similar between over ground and vertical treadmill group ($t_{(18)}$=-0.943, p=0.358).

There were no differences in the [BLa] exhibited after the MART or $\dot{V}O_{2max.}$ test between pre and post-intervention ($F_{(1,27)}$=0.094, p=0.761, ES=0.08 and $F_{(1,27)}$=0.769, p=0.391, ES=0.07 respectively). The TVent and RCP could not be consistently identified using the V-slope method or by examining ventilatory equivalents. In some cases it was unclear whether inflections in the $\dot{V}O_2$-intensity relationships were indicative of TVent or RCP. In some cases the inflections were subtle and consequently not detected. Therefore, TVent and RCP could not be analysed.

6.3.4. Response to submaximal exercise

6.3.4.1. Conventional treadmill speed
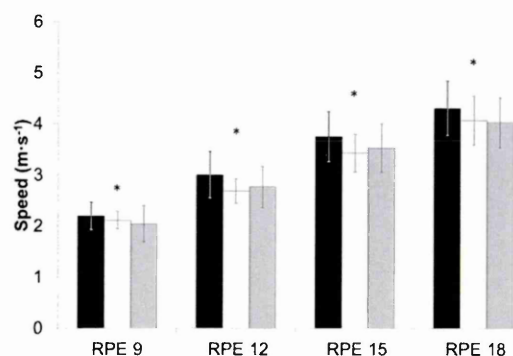
Figure 22. Mean (*SD*) running speed of the vertical treadmill group ■ (n=10), sprint group ☐ (n=10) and control group ▨ (n=10) during incremental conventional treadmill running. * indicates main effect for intensity (RPE).

Figure 22 demonstrates an increased running speed on the conventional treadmill as RPE increased from RPE 9, 12, 15 to 18 ($F_{(1.8,49.5)}=550.125$, $p<0.001$). There was no RPE x group interaction ($F_{(3.7,49.9)}=0.881$, $p=0.476$) indicating no difference in the running speeds between groups at each RPE.

6.3.4.2.   HR response
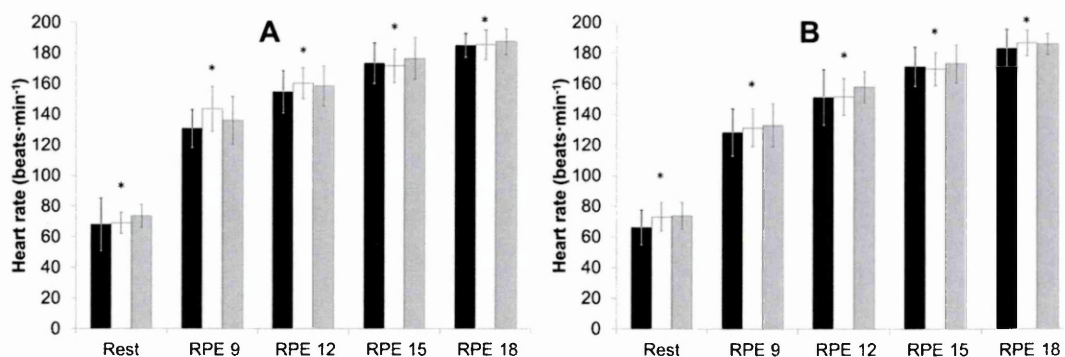
Figure 23. Mean (*SD*) pre-SIT heart rate (A) and post-SIT heart rate (B) of the vertical treadmill group ■ (n=10), sprint group □ (n=10) and control group ▨ (n=10) at rest and during incremental conventional treadmill running (RPE 9, 12, 15 and 18). * indicates main effect for intensity (RPE).

Irrespective of group (vertical treadmill, sprint and control) or time (pre or post-SIT), the HR increased as RPE increased during submaximal treadmill running ($F_{(1.7,42.7)}=330.865$, $p<0.001$) and there was no RPE x group interaction ($F_{(3.4,42.7)}=0.905$, $p=0.457$). The HR response did not demonstrate any differences between pre and post-SIT ($F_{(1,25)}=0.849$, $p=0.336$, ES=0.14-0.31) or time x group interaction ($F_{(2,25)}=0.987$, $p=0.387$). At the fixed [BLa] of 2 mmol·L^{-1} and 4 mmol·L^{-1}, the corresponding HR did not differ between pre and post-SIT. ($F_{(1,23)}=0.768$, $p=0.390$, ES=0.16-0.89).

6.3.4.3. [BLa] response
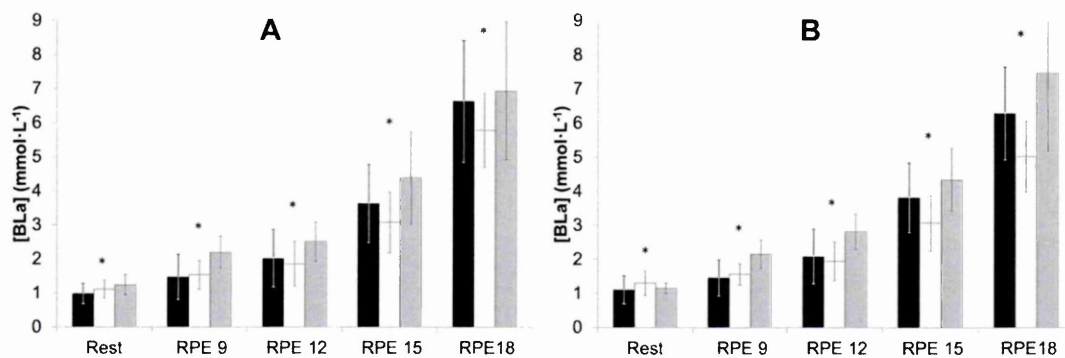
Figure 24. Mean (*SD*) pre-SIT [BLa] (A) and post-SIT [BLa] (B) of the vertical treadmill group ■ (n=10), sprint group ☐ (n=10) and control group ▨ (n=10) at rest and during incremental conventional treadmill running (RPE 9, 12, 15 and 18). * indicates main effect for intensity (RPE).

Irrespective of group or time (pre or post-SIT), the [BLa] increased as RPE increased in response to submaximal treadmill running ($F_{(1.3,34.8)}$=279.899, p<0.001) and there was no RPE x group interaction ($F_{(2.6,34.8)}$=1.871, p=0.160). The [BLa] response did not demonstrate any differences between pre and post-SIT ($F_{(1,27)}$=0.084, p=0.774, ES=0.0-0.32) or time x group interaction ($F_{(1,25)}$=0.618, p=0.547). The RPE at which the fixed [BLa] of 2 mmol·L^{-1} and 4 mmol·L^{-1} occurred did not differ between pre and post-SIT ($\chi^2_{(1,30)}$=1.143, p=0.285, ES=0.01-0.11 and $\chi^2_{(1,30)}$=0.143, p=0.705, ES=0.00-0.17 respectively).

6.4. Discussion

The aim of this study was to identify the effects of a 6-week SIT programme performed on the vertical treadmill on aerobic and anaerobic running power. These results were contextualised by comparison with over ground sprint training and a control group. The key findings of this study were that over ground and vertical treadmill SIT increased the MART score by 4% and

increased $\dot{V}O_{2max.}$, by 4% and 6%, respectively. There were no differences in the increases in $\dot{V}O_{2max.}$, and MART score between SIT groups and the control group was unchanged.

The transference of the training effect from recumbent exercise modes to running performance has been reported previously (Loy et al., 1994), however not using a SIT protocol on the vertical treadmill. Hass et al., (2001) found that a 12-week endurance training programme on a recumbent stepper increased conventional treadmill running $\dot{V}O_{2max.}$ by 11%. A similar improvement was exhibited following the same endurance programme on a conventional treadmill suggesting transference of the training effect from recumbent exercise training without detriment to running performance (Hass et al., 2001). After 9-weeks of work-matched high-intensity cycle ergometry with treadmill running training both groups exhibited improvements in the cycle ergometer $\dot{V}O_{2max.}$, treadmill $\dot{V}O_{2max.}$ and 1-mile run time suggesting a degree of transference of the training effect. The treadmill $\dot{V}O_{2max.}$ and 1-mile run time were greater in the running group, therefore improvements can be observed from cross training but specificity of training elicited greater adaptations. Similarly, cross training on the vertical treadmill elicited similar improvements in running performance when compared with over ground sprint group, thus highlighting the potential for the vertical treadmill to be used as a conditioning tool.

Similar improvements in anaerobic performance parameters in response to various SIT have been reported previously. A 3.6% increase in mean power during a 30 s Wingate Anaerobic Test was reported after SIT (MacDougall et al., 1998) as was a decrease in over ground 40 m sprint time (Dawson et al., 1998) and improved repeated sprint ability (Dawson et al., 1998; 12%

Ørtenblad *et al.*, 2000 and Bravo *et al.*, 2008;). A few studies employing the same 30 s SIT protocol used in this study reported anaerobic performance improvements on cycle ergometers. Peak power during a 30 s Wingate anaerobic cycle test increased by 5.4% (Burgomaster *et al.*, 2006) and by 8% (Whyte *et al.*, 2010). The peak power, mean power and total work performed in 4 x 30 s Wingate anaerobic cycle tests were reported to increase by 6% in all variables following 30 s SIT (Creer *et al.*, 2004). Under the specificity principle, improvements in anaerobic performance parameters might be expected given the high intensity exercise and very high/exhaustive demand on the anaerobic system.

There have been several metabolic and morphological adaptations reported to be responsible for the anaerobic performance improvements. These include a higher H^+ buffering capacity (Gibala *et al.*, (2006), increased glycolytic enzyme activity (MacDougall *et al.*, 1998) such as an increased concentration of phosphorylase (Dawson *et al.*, 1998), increased proportion of and cross-sectional area of type II muscle fibres (~10%) (Dawson *et al.*, 1998). Neurological adaptations to SIT included an increased sarcoplasmic reticulum volume and Ca^{2+} released during neuromuscular stimulation (Ørtenblad *et al.*, 2000), potentially leading to greater motor unit activation as reported by Creer *et al.*, (2004) and delaying of neurological fatigue during high intensity exercise (Ørtenblad *et al.*, 2000). Whether any of these adaptations were responsible for the anaerobic improvements observed following vertical treadmill SIT requires further research. The literature concerning the 30 s : 4.5 minutes SIT protocol used in this study has been reported to elicit aerobic adaptations with little mention of anaerobic adaptations. This study confirms, firstly, that a 6-week SIT utilising 30 s : 4.5 minutes SIT protocol elicits

anaerobic running power improvements and secondly, vertical treadmill can be used as a form cross training for improving anaerobic running power since improvements were similar to over ground SIT.

An increase in aerobic running power was observed in the vertical treadmill group and over ground running group following SIT. Previous research reported improvements in $\dot{V}O_{2max.}$ following the 30 s SIT protocol used in this study but these were performed on cycle ergometers (Burgomaster et al., 2005; 2006; 2007; 2008; Gibala et al., 2006; Babraj et al., 2009; Whyte et al., 2010 and Bayati et al., 2011). Bayati et al., (2011) observed an increase in $\dot{V}O_{2max.}$ of 9.6% after 4 weeks of 30 s SIT. Similar to this study, Burgomaster et al., (2008) reported a 6.8% increase in $\dot{V}O_{2max.}$ after 6 weeks of 30 s SIT.

Many metabolic and morphological adaptations have been attributed to the improvement of $\dot{V}O_{2max.}$ and aerobic performance. Firstly muscle glycogen stores were reported to increase by 26%-50% (Gibala et al., 2006 and Burgomaster et al., 2006) after just 2 weeks of SIT, thus the substrate availability for metabolism is increased. An improved enzymatic activity associated with increased muscle oxidative capacity and substrate use have been reported (Burgomaster et al., 2005; 2006). Citrate synthase activity increased by 38% in 2 weeks (Burgomaster et al., 2005), pyruvate dehydrogenase concentration increased (Burgomaster et al., 2006), thus enhancing the capacity for aerobic metabolism. The higher oxidative potential reduced the lactate response to submaximal exercise (Burgomaster et al., 2006) indicating reduced anaerobic metabolism during submaximal exercise following SIT. If coupled with an increased 3-hydroxyacyl-Coenzyme A dehydrogenase increases, lipid oxidation during exercise was reported to

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increase (Burgomaster *et al.*, 2008) thus reserving glycogen and PCr (Burgomaster *et al.*, (2008) for a prolongation of higher intensity exercise.

In this study, the increased anaerobic and aerobic running power following SIT was observed in both SIT groups without changes in the [BLa] in submaximal and maximal exercise. The [BLa] following the MART did not change, suggesting that the contribution of anaerobic glycolysis in the MART was unchanged following SIT. The increase in anaerobic performance without an increase in [BLa] was indicative of an inhibition of anaerobic glycolysis by metabolic acidosis (Gaitanos *et al.*, 1993). The H^+ buffering systems are responsible for the reducing the H^+ and consequently metabolic acidosis (Gaitanos *et al.*, 1993). Therefore, it appears that the H^+ buffering systems did not improve in this study. In contrast, Gibala *et al.*, (2006) reported an increased H^+ buffering capacity as evidenced by reduced blood pH following 6 weeks of 30 s SIT. The increased H^+ buffering capacity reduces metabolic acidosis and could therefore, be responsible for an increased capacity for anaerobic metabolism as evidenced by a 15.5% increase in the peak [BLa] during a Wingate anaerobic test following 4 weeks of SIT (Bayati *et al.*, 2011). In submaximal exercise, Burgomaster *et al.*, (2006) reported a 13% reduction in [BLa] (10 minutes at ~60 and ~90% $\dot{V}O_2$ peak) which was indicative of an increased aerobic metabolism, reduced anaerobic metabolism in lower intensity exercise and a SIT-induced increase in H^+ buffering capacity. In this study, however, the submaximal [BLa] response was unchanged following SIT, which suggests that there were no changes in anaerobic metabolism or buffering capacity during submaximal exercise.

The aerobic adaptations to 30 s SIT were reported to be comparable with or greater than continuous traditional endurance training on cycle ergometers (Burgomaster *et al.*, 2008; Gibala *et al.*, 2006). Therefore aerobic improvements can be achieved through SIT without engaging in prolonged exercise, however, whether these improvements from SIT were transferable into over ground running performance was not determined in previous research. This study found that vertical treadmill can also improve over ground aerobic running power despite differences in the exercise mode and that the improvements were comparable to those achieved from over ground SIT. When coupled with the improvements in the anaerobic running power, the vertical treadmill could be considered a cross training tool for both aerobic and anaerobic running power.

The HR responses to submaximal exercise could not offer any reason for the change in maximal performance since no differences were found. In contrast, Lesmes *et al.*, (1978) reported a 6% reduction in submaximal HR and an unchanged $\dot{V}O_2$ after 8 weeks of SIT (varying sprint lengths, work : rest of 1 : 2-3). Lesmes *et al.*, (1978) suggested that training-induced bradycardia at the same absolute intensity indicated a decreased sympathetic drive. The training stimulus from SIT is has been shown to demonstrate peripheral adaptations in the muscle (for example citrate synthase, pyruvate dehydrogenase, % fibre composition), rather than central adaptations of the cardiovascular system (Bugomaster *et al.*, 2005; 2006). There is however, a high aerobic contribution to repeated sprint exercise (Bogdanis *et al.*, 1996) so one might expect the high aerobic demand to induce central adaptations to improve the O_2 delivery. Potentially, the central cardiovascular adaptations might be secondary to peripheral adaptations to improve the O_2 utilisation at the muscle to resynthesise ATP and PCr for the subsequent sprint. An

improvement in O_2 utilisation at the muscle might still result in a lower HR as the requirement for nutrient and O_2 rich blood flow would be reduced therefore the cardiovascular stress would be less at the same submaximal exercise intensity. Furthermore, the increases oxidative capacity would be expected to increase the anaerobic threshold and therefore the [BLa] was expected to be reduced during the submaximal exercise at the same submaximal intensity. Therefore the reasons for no differences in submaximal HR and [BLa] are unclear and might require further research. The lack of significant differences in the responses to submaximal exercise (HR and [BLa]) are partially supported by small effect sizes in the overwhelming majority of cases suggesting that SIT has not had an effect on these variables. However, these could be attributed to a large variability and a small sample size for the number of comparisons being made, thus reducing the effect size and increasing the potential for type II error. Therefore further research is required with larger sample sizes.

In conclusion, 6 weeks of SIT on the vertical treadmill increased the aerobic and anaerobic running power. The improvement in aerobic running power and anaerobic running power was similar to that observed in the over ground SIT group despite being different exercise modes. Therefore, the vertical treadmill could be used as a low-impact conditioning tool and is an appropriate substitute for exercise programmes involving prolonged over ground running. There have been many SIT-related metabolic and morphological adaptations reported in the literature that might be responsible for the performance enhancements, however, these were from cycling or running SIT literature. The variables measured in this study (HR and [BLa] responses to submaximal exercise and aerobic and anaerobic maximum tests) could not offer an explanation for the improvements observed in the SIT groups.

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This chapter provides an overall discussion and summary of the thesis. Firstly, the aim of the thesis is re-stated. Secondly, a brief summary of each experimental study (Chapter 4, 5 and 6) is presented. Thirdly, the implications of the findings of this thesis are discussed in relation to the potential use of the vertical treadmill for conditioning and the limitations of the study are given. Lastly, the conclusion to the thesis is presented.

7.1. Overall aim

To the author's knowledge, there is no empirical research to substantiate the anecdotal evidence of the vertical treadmill as a physical conditioning tool. Therefore the overall aim of this thesis was to establish whether the vertical treadmill could be used as a conditioning tool for the physical conditioning of physically active males.

7.2. Summary of findings

7.2.1. Kinematics and neuromuscular recruitment during vertical treadmill exercise

To fully understand the role of the vertical treadmill in a training programme the first study (Chapter 4) sought to determine the kinematics and neuromuscular recruitment patterns during vertical treadmill exercise in the supine, 40° and 70° postures at speeds that were perceived to replicate their over ground walking, jogging and running speed. The results indicated that irrespective of posture

and intensity of vertical treadmill exercise the hamstrings and gastrocnemius muscles were active to draw the leg downwards against the treadmill belt and resistance cables. The rectus femoris and tibialis anterior were active in the upward phase. The vastii muscles were not active during vertical treadmill exercise. The 40° and 70° postures demonstrated similar kinematic and neuromuscular profiles when compared with supine posture. The rate of perceived exertion was greater in the supine posture in all speeds when compared with the 40° and 70°. The key findings were that the vertical treadmill primarily targets some of the muscles of the posterior chain (hamstrings and gastrocnemius) and hip flexors which are essential components for over ground running performance (Askling *et al.*, 2003, Novacheck, 1998 and Deane *et al.*, 2005).

7.2.2. Acute physiological responses to vertical treadmill exercise

Given the importance of the acute physiological responses to chronic adaptations to a training programme, the second study (Chapter 5) sought to determine the physiological responses to submaximal and maximal intensity vertical treadmill exercise to support the identification of an appropriate training programme. The physiological responses to submaximal and maximal vertical treadmill exercise (RPE 9, 12, 15 and all-out effort) in the 40° posture revealed a high contribution of anaerobic metabolism as evidenced by OBLA 2 mmol$\cdot$L^{-1} occurring during exercise perceived as very light (RPE 9). The $\dot{V}O_{2peak}$ and $HR_{max.}$ achieved during vertical treadmill exercise were 22% and 16% lower than the $\dot{V}O_{2max.}$ and $HR_{max.}$ on the conventional treadmill. The high anaerobic contribution during low intensity exercise and lower $\dot{V}O_2$ and cardiovascular

response identified the vertical treadmill exercise as a predominantly anaerobic exercise mode.

7.2.3. Sprint interval training on the vertical treadmill

The third study (Chapter 6) sought to determine the effects of 6 weeks of SIT (4-6, 30 s sprints with 4.5 minutes of recovery performed on the vertical treadmill on conventional treadmill $\dot{V}O2_{max.}$ and anaerobic running power (MART) and HR and [BLa] responses to submaximal conventional treadmill running. Comparisons were made with an over ground SIT group (4-6, 30 s of 20 m shuttle sprints with 4.5 minutes recovery) and a control group. The key findings of this study were that over ground and vertical treadmill SIT increased the MART score by 4% each, and that $\dot{V}O_{2max.,}$ increased by 4% and 6%, respectively. There were no differences between pre and post-intervention in the control group. The HR and [BLa] response to submaximal conventional treadmill running were unchanged in all the groups and therefore other physiological adaptations responsible for the improvement in aerobic and anaerobic performance require further research. In conclusion, the vertical treadmill can be used for the physical conditioning of athletes and can yield similar performance benefits as over ground sprint training.

7.3. Vertical treadmill as a conditioning tool

The vertical treadmill improved maximum aerobic and anaerobic running power to similar proportions as over ground running SIT despite being vastly different exercise modes. In terms of the vertical treadmill exercise, Chapter 4 showed that the vertical treadmill recruited the rectus femoris, hamstrings,

gastrocnemius and tibialis anterior. Metabolic and morphological adaptations might be more pronounced in the hamstrings since they were found to be the major contributor to vertical treadmill exercise, however, the rectus femoris was also active. The specific conditioning of the rectus femoris and hamstrings has been shown to improve running performance (Deane et al., 2005). The rectus femoris flexes the hip and hip flexor strength was described as integral in sprint and sports performance (Deane et al., 2005). During the acceleration phase of a sprint (<20 m), a pronounced forward body lean is evident (Delecluse, 1997). The main contributors to forward propulsion are the quadriceps to extend the knee and gluteals to extend the hip, however, hip flexor strength is required draw the leg forwards in a quick but controlled manner in preparation for the next foot contact (Novacheck, 1998 and Deane et al., 2005). Hip flexor strength also increases the stride length in the acceleration phase and maximum velocity phase of sprints (>20 m) (Novacheck, 1998 and Deane et al., 2005), hence, following specific hip flexor training, 40-yard sprint and repeated shuttle sprint times decreased by 3.8% and 9% respectively (Deane et al., 2005). Therefore a potential conditioning of the rectus femoris from vertical treadmill exercise could contribute to running performance.

The hamstrings are also major contributors to over ground running performance (Mann and Hagy, 1980; Wiemann and Tidow, 1995 and Delecluse, 1997). During maximum velocity sprinting (>20 m) an upright running posture is assumed (Delecluse, 1997). Running velocity in the upright posture is directly related to the posterior motion of the leg which begins at the high point of knee lift down to foot contact and into the contact phase (Wiemann and Tidow, 1995 and Delecluse, 1997). Due to the upright posture, the main contributors to forward propulsion change from the quadriceps and gluteals to

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the hamstrings and gluteals (Wiemann and Tidow, 1995 and Delecluse, 1997). The hamstrings are active in the first 80% of the contact phase to draw the leg backwards thus increasing running velocity (Mann and Hagy, 1980), hence, peak running velocity increased and 30 m sprint time reduced by 2.4% following hamstring-specific conditioning (Askling *et al.*, 2003). In addition, Pinniger *et al.*, (2000) reported that in a hamstring specific fatiguing protocol followed by 3 x 40 m sprints, the joint motions were restricted in the latter sprint (decreased hip flexion, decreased knee extension in late swing phase and decreased angular velocity of the leg before ground contact). This restriction of joint motion in the latter sprints was deemed a protective mechanism for the hamstrings and was at detriment to sprint velocity (Pinniger *et al.*, 2000). Therefore if the hamstrings were specifically conditioned by vertical treadmill SIT, the detrimental protective mechanism might be delayed thus enhancing running performance as observed in Chapter 6.

In Chapter 5 demonstrated that the anaerobic systems were under considerable stress as indicated by the onset of [BLa] during vertical treadmill exercise that was perceived to be very light (OBLA 2 mmol·L^{-1} at RPE 9, OBLA 4 mmol·L^{-1} at RPE 15) up to maximum intensity. A considerable aerobic contribution (vertical treadmill $\dot{V}O_{2peak}$ was 78% of conventional treadmill $\dot{V}O_{2max}$.) was also evident during vertical treadmill exercise. Therefore the metabolic stresses in SIT likely provided a stimulus for metabolic adaptations to improve aerobic and anaerobic running performance as observed in other SIT programmes using cycle ergometers and over ground sprinting (MacDougall *et al.*, 1998; Burgomaster *et al.*, 2005; 2006; 2007; 2008 and Bravo *et al.*, 2008).

SIT on the vertical treadmill improved maximum aerobic and anaerobic running power and despite different exercise modes the improvements were comparable to those achieved in over ground running. Therefore, vertical treadmill SIT can be considered a cross training tool where athletes obtain performance gains in one exercise mode by training in other exercise modes (Foster *et al.*, 1995). Therefore, the vertical treadmill could have many potential applications for a wide range of situations and populations. For athletic populations, the enhancement of $\dot{V}O_{2max.}$ and anaerobic performance on the vertical treadmill could be beneficial for many sports. Anaerobic power and $\dot{V}O_{2max.}$ have been shown to correlate positively with endurance performance and repeated sprint-type team sports performance such as soccer (Tanaka *et al.*, 1986 and Helgerud *et al.*, 2001). Therefore, the vertical treadmill SIT could be used to supplement training programmes of both team sport and endurance athletes. Furthermore, SIT type activity is usually performed by team sports athletes in the pre-competition phase once athletes have acquired a strong aerobic fitness in the pre-season (Bompa and Claro, 2008). The pre-season training is characterised by a high training volume and relatively low intensity whereas pre-competition is characterised by a decrease in training volume and high intensity work (Fry *et al.*, 1992 and Bompa and Carrera, 2005) Therefore, the vertical treadmill SIT could be used specifically in the pre-competition phase of a training programme to enhance the performance of athletes prior to the competitive season. Whether prolonged, lower intensity vertical treadmill exercise could be used in the pre-season requires further research. This is especially poignant given the high incidence of overuse injuries in the pre-season (28%; Engström *et al.*, 1991).

Prolonged over ground running predisposes the lower extremities to overuse injuries (Hreljac, 2004). Hreljac, (2004) reported that impact causes micro-trauma of body tissues and without sufficient recovery between exercise sessions, overuse injuries might occur. Overuse injuries have been observed in both team sports and endurance athletes and were reported to be higher in the preseason due to the high volume of training involving running (Nielsen and Yde, (1989); Engström *et al.*, 1991; Söderman *et al.*, 2001 and Hreljac, 2004). The low-impact nature of vertical treadmill exercise means that, potentially, athletes could exercise without the impact loading, micro-trauma and consequently reduce the likelihood of overuse injuries associated with running. With a reduced likelihood of overuse injury, the athlete could train more often for longer thus encouraging greater physiological adaptations to improve performance. Furthermore, in team sports characterised by many repeated sprints, hamstring injuries are prevalent (Orchard *et al.*, 1998 and Croisier *et al.*, 2008). In Australian football the injury prevalence (percentage of players missing through injury) at any given time is 15-18%, of which 13% are due to hamstring injuries (Orchard *et al.*, 1997) and this equated to 86.4 hamstring injuries per 10,000 player hours and 30.2 hours of training missed per 1000 hours of exercise (Orchard *et al.*, 1998). In soccer players, Croisier *et al.*, (2008) reported that 35 of 462 (7.5%) experienced a hamstring injury in one season. Hamstring injuries are detrimental to an athlete's development since time off training is required and this is compounded by nearly a third of hamstring injuries recurring within a year (Heiderscheit *et al.*, 2010). A mechanism for the injury is the imbalance between the quadriceps and hamstrings strength (Croisier *et al.*, 2008). Hamstring injuries often occur during rapid extension of the knee by the quadriceps which is controlled eccentrically

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by the hamstrings. In weaker hamstrings the athlete surpasses the mechanical limits of the hamstring muscle during high intensity running, thus resulting in injury (Croisier *et al.*, 2008). Therefore, hamstring strength training is recommended for injury prevention as well as running performance (Askling *et al.*, 2003 and Croisier *et al.*, 2008). The vertical treadmill primarily targets the hamstrings and therefore might condition the hamstrings to improve the performance and prevent injury, thus supporting the use of the vertical treadmill for team sports athletes.

7.4.   Limitations

7.4.1. Technical limitations

The standardisation of the vertical treadmill for monitoring the intensity of exercise was difficult for several reasons. The material properties of the rubber bands that are anchored to the base of the treadmill and were responsible for the resistance experienced by the user were prone to changes with temperature. In warmer environments, rubber is more compliant and therefore less resistive to movement. The room temperature ranged from ~15-20° could and therefore the resistance experienced would change between vertical treadmill exercise sessions. In addition to ambient temperature, the mechanical stretching of rubber also creates heat and so as vertical treadmill exercise continues, the less resistance is offered. Differences in the resistance to the vertical treadmill action might incur different physiological responses. A more compliant and therefore less resistive system would require less hamstring activity to draw the leg downward and more rectus femoris activity to draw the leg upwards. Therefore the intensity of exercise at a given treadmill speed or

cadence might vary over the duration of an exercise sessions and between days. Consequently, treadmill speed might not be an appropriate method of monitoring intensity. RPE however is an indicator of exercise intensity that is independent of the resistance and the exercise mode, thus supporting the use of RPE for monitoring intensity during vertical treadmill exercise.

The freedom of the lower limb to perform variable ranges of motion presents another problem for the standardisation of the exercise intensity. As mentioned previously, the resistance increased as the leg descended. Therefore the range of motion that a user employs will affect the resistance experienced and consequently the exercise intensity. The range of motion employed could be attributed to participant anthropometrics as those with longer lower limbs might descend the leg further thus the inter-individual exercise intensity might vary considerably. Therefore another limitation of the vertical treadmill is that the resistance cannot be measured or set to a specific resistance.

7.4.2. Methodological limitations

In Chapter 4, the kinematic and neuromuscular recruitment was limited to unilateral analysis and a full lower limb analysis was not possible. Bilateral analysis is favourable because perturbations of the contralateral limb can be compensated by the ipsilateral limb thus altering the kinematics displayed. The activation and contribution of the gluteals in the extension of the hip during vertical treadmill exercise in relation to the posture could also be investigated. This would require a modification of the seat to allow the surface EMG electrodes to be unhindered. The relatively poor reliability of the kinematic data

could have been attributed to the marker reapplication between days and the relative unfamiliarity of the participant to the vertical treadmill exercise. The ability of the participants to accurately reproduce the movements they exhibited previously is essential to the reliability of the study. To remedy these limitations, the position of the vertical treadmill should be considered to allow 360° camera placement for 3-D motion analysis. Participants should engage in a longer habituation process than the 2×30 minutes before analysis or engaging in vertical treadmill training.

In Chapter 5 the responses to incremental vertical treadmill were determined. During the all-out effort, $\dot{V}O_{2peak}$ was achieved and verified by a supramaximal effort to exhaustion. In light of this comparisons were made between the vertical treadmill peak $\dot{V}O_{2peak}$ and $\dot{V}O_{2max.}$ of conventional treadmill exercise. The comparison was made tentatively because they are not strictly comparable. Potentially, a $\dot{V}O_{2max.}$ test where a plateau in the $\dot{V}O_2$-intensity curve might be possible on the vertical treadmill by intensity increased by one interval on the RPE 6-20 scale every minute until volitional fatigue, thus determining vertical treadmill-specific $\dot{V}O_{2max.}$.

In both Chapter 5 and 6, the MART was used to assess the anaerobic performance of the participants. The MART was described as an assessment of anaerobic power since a high dependency on the anaerobic system was evident during the 20 s sprints ($73.5 \pm 1.0\%$, Zagatto et al., 2011) and high correlation with anaerobic performance measures (Rusko et al., 1993). During the 140 s rest periods in the MART, a high degree of aerobic metabolism occurs as evidenced by a high aerobic contribution when the rest periods were included ($65.4 \pm 1.1\%$, Zagatto et al., 2011). Therefore, the aerobic fitness of

the participant might influence the performance in the MART. In terms of the findings of Chapter 6, it is unclear whether the improvement in the anaerobic power was solely due to adaptations in the anaerobic energy systems and muscle morphology or an increase in the resynthesis of ATP and PCr between sprints, brought about by an increased aerobic power.

In chapter 6, the identification of TVent and RCP could have provided a useful insight to changes in the aerobic and anaerobic activity of the body pre and post-SIT. The TVent and RCP of some of the participants could not be determined pre or post-SIT. This could be attributed to the range varying fitness of the participants. Less fit participants might have exercising above Tvent in the initial stage of the $\dot{V}O_{2max}$. test, therefore a fitter and more homogenous participant group was required to accurately determine TVent and RCP.

7.4.3. Future directions

The findings of this thesis have provided a basis for future research on vertical treadmill exercise, influenced the design of subsequent models of the vertical treadmill and could be used to identify potential uses of the vertical treadmill for various populations which will require further research.

In terms of future research in physical conditioning, the vertical treadmill was identified as a predominantly anaerobic exercise mode, however, this finding was specific to the population in the study which were described as untrained athletes. In addition, the adaptations observed were specific to this population and their current trained status. Fitter participants or elite athletes might be able to meet the demands of the exercise with aerobic metabolism, thus the vertical treadmill could offer an aerobic-based exercise. Whether

performance improvements observed in this thesis would be evident in elite athletes that are highly trained should be investigated. In addition, the effect of an aerobic-based training programme could also be performed to fully understand the nature and vertical treadmill exercise and its possible uses. Further research might also focus on the effects of vertical treadmill exercise on cycling performance. The results of such a study could have implications on the use of the vertical treadmill for runners and cyclists, and even larger implications for triathletes as they could use the vertical treadmill as a cross-trainer to improve both cycling and running performance in the triathlon competition.

The metabolic adaptations and muscle morphology to the vertical treadmill SIT requires further investigation. These should include the examination of metabolic markers such as citrate synthase, pyruvate dehydrogenase, 3-hydroxylacyl-Coenzyme A as examined in previous SIT research (Burgomaster *et al.*, 2005 and 2006). Muscle biopsies of the major muscles of the lower limbs could be used to determine the muscle morphology (changes in the proportion of muscle fibre types) of major muscle groups, especially the hamstrings in response to SIT on the vertical treadmill. Other performance measures could be used to determine whether the vertical treadmill offers any additional training effect that other exercise modes do not provide. For example, isokinetic dynamometer strength tests on the major muscles of the lower limbs could be performed. Young *et al.*, (2001) reported that linear sprint training has limited transference to performances involving fast changes of direction as observed in team sports (Coutts *et al.*, 2003 and Bangsbo *et al.*, 2006). The limited transference was purported to result from different muscle recruitment and movement patterns during changing direction

when compared with linear running (Young *et al.*, 2001). Therefore, the effect of vertical treadmill training on sport-specific performance tests such as the YoYo intermittent recovery test for soccer players could be investigated to determine the effects on sports performance rather than linear running in laboratory tests as performed in this thesis. Determining the precise physiological adaptations will differentiate vertical treadmill adaptations from other exercise modes and therefore identify where vertical treadmill exercise might be most appropriate within an athlete's training programme.

In Chapter 4 it was demonstrated that the vertical treadmill did not recruit the vastii muscles and there were some concerns over the use of rubber bands for the resistance as previously reported. This led to the re-design of the vertical treadmill and a new model with resistance straps positioned below and above the supporting bench (Figure 25). The resistance has been changed to metal springs that offer a more consistent resistance as the leg descends the treadmill. These resistance straps can be attached below or above the knee to alter the recruitment patterns. For vastii recruitment, the straps below the bench can be attached to the posterior of ankle to resist the extension of the knee as the leg ascends the treadmill belt. Further research is required to confirm the activation of vastii with this configuration and the effect of the new configurations on muscle recruitment and physical conditioning.
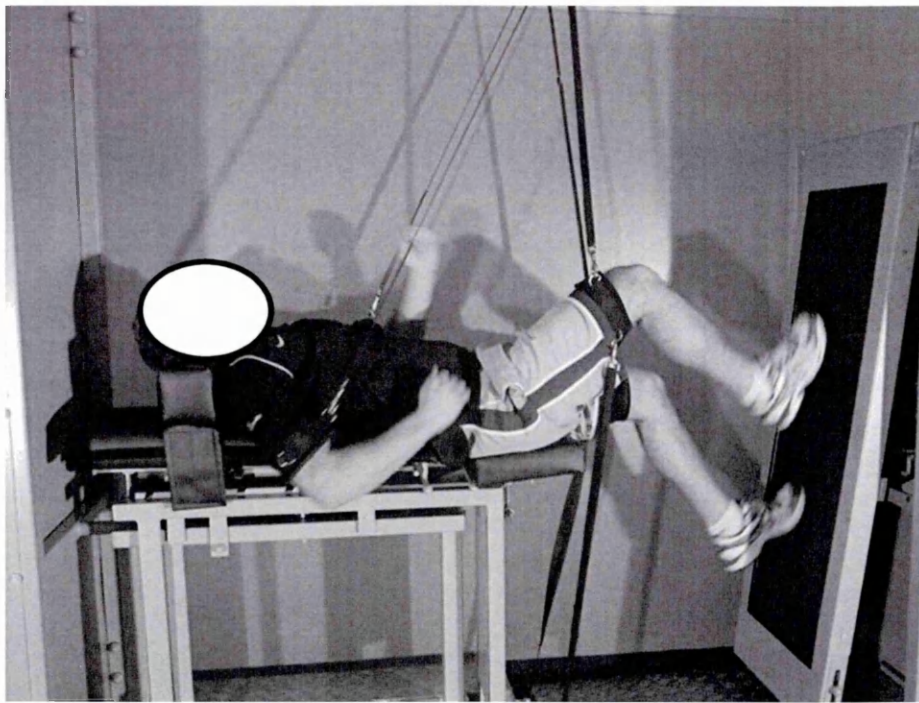
Figure 25. Re-designed vertical treadmill (VertiRun) used in the supine posture with resistance straps positioned below and above the knee that are attached above the knee and to the arms.

If an athlete has sustained an injury, whether it is overuse or trauma, the vertical treadmill might be useful. The non-weight bearing nature of vertical treadmill exercise might reduce the loading of injured tissues and allow exercise to continue throughout the rehabilitation process thus maintaining the aerobic and anaerobic fitness of the athlete. Obese or pathological populations might also benefit from the safety of the supported body weight in a recumbent posture as observed in recumbent steppers (Billinger *et al.*, 2008b). An advantage of the vertical treadmill over other forms of recumbent exercise is that the lower limbs are free to perform the motions that the injury or pathology will allow therefore the vertical treadmill has many applications for various athletes and potential applications for rehabilitation. For example, those with lower limb injuries might be able to use the vertical treadmill and maintain their fitness without exacerbating the injury.

The vertical treadmill could also be used to train unilaterally. The ability to work the limbs unilaterally and in a recumbent posture could provide an exercise mode for lower limb amputees to increase or maintain fitness and potentially strengthen the musculature of the intact hip without the risk of falling and further injury. The hip strength was reported to be an important aspect of stability, progression and transference of weight on to the prosthetic limb during over ground ambulation (Vanicek *et al.*, 2009). The re-designed vertical treadmill could also be used to improve the strength of the hip musculature in the transtibial amputated leg if the attachment was above the knee. The hip muscular strength of the amputated leg is also an important aspect of gait retraining to advance the leg in the swing phase and stabilise the leg during the transference of weight in the contact phase (Vanicek *et al.*, 2009).

7.5.   Conclusion

The vertical treadmill primarily targets the hamstrings, demonstrates a sizeable range of motion and places a high metabolic demand on users. The vertical treadmill and over ground SIT both increased aerobic and anaerobic running power to a similar extent despite differences in the exercise modes. The precise reasons for the improvements following vertical treadmill SIT require further research, but it is likely that the vertical treadmill is predominantly a hamstring conditioning tool and this conditioning enabled an improved running performance. Therefore vertical treadmill could be used to supplement training programmes for any athletes that require both aerobic and anaerobic running power.

References

American College of Sports Medicine. (2000). ACSM's guidelines for exercise testing and prescription. *Philadelphia, Lea and Febiger,* .

ALBERTON, CL., *et al.* (2011). Correlation between rating of perceived exertion and physiological variables during the execution of stationary running in water at different cadences. *The journal of strength & conditioning research,* **25** (1), 155-162.

ALLEN, GM. GANDEVIA, SC. and MCKENZIE, DK. (1995). Reliability of measurements of muscle strength and voluntary activation using twitch interpolation. *Muscle & nerve,* **18** (6), 593-600.

ARMOUR, W., *et al.* (1998). Effects of exercise position on the ventilatory responses to exercise in chronic heart failure. *International journal of cardiology,* **66** (1), 59-63.

ASKLING, C. KARLSSON, J. and THORSTENSSON, A. (2005). Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. *Scandinavian journal of medicine & science in sports,* **15** (1), 65-65.

ASTORINO, TA., *et al.* (2004). Reinvestigation of optimal duration of VO_{2max} testing. *Journal of exercise physiology,* **7** (6), 1-8.

ASTRAND, PO. (2003). *Textbook of work physiology-4th: Physiological bases of exercise.* Human Kinetics.

ATKINSON, G and NEVILL, AM. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports medicine,* **26** (4), 217-238.

AUNOLA, S. and RUSKO, H. (1984). Reproducibility of aerobic and anaerobic thresholds in 20–50 year old men. *European journal of applied physiology and occupational physiology,* **53** (3), 260-266.

BABAULT, N., *et al.* (2003). Effect of quadriceps femoris muscle length on neural activation during isometric and concentric contractions. *Journal of applied physiology,* **94** (3), 983-990.

BABRAJ, JA., *et al.* (2009). Extremely short duration high intensity interval training substantially improves insulin action in young healthy males. *BMC endocrine disorders,* **9** (1), 3.

BADRUDDIN, SM., *et al.* (1999). Supine bicycle versus post–treadmill exercise echocardiography in the detection of myocardial ischemia: A randomized single-blind crossover trial. *Journal of the american college of cardiology,* **33** (6), 1485-1490.

BAKEMAN, R. (2005). Recommended effect size statistics for repeated measures designs. *Behavior research methods,* **37** (3), 379-384.

BANGSBO, J. *et al.*, (1996). Effect of muscle acidity on muscle metabolism and fatigue during intense exercise in man. *The journal of physiology,* **495** (Pt 2), 587-596.

BANGSBO, J, MOHR, M. and KRUSTRUP, P. (2006). Physical and metabolic demands of training and match-play in the elite football player. *Journal of sports sciences,* **24** (07), 665-674.

BARTLETT, R. BUSSEY, M. and FLYGER, N. (2006). Movement variability cannot be determined reliably from no-marker conditions. *Journal of biomechanics,* **39** (16), 3076-3079.

BASMAJIAN, JV. and DE LUCA, CJ. (1985). *Muscles alive: Their functions revealed by electromyography.* Williams and Wilkins.

BASSETT, DR. and HOWLEY, ET. (2000). Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Medicine and science in sports and exercise,* **32** (1), 70-84.

BAYATI, M., *et al.* (2011). A practical model of low-volume high-intensity interval training induces performance and metabolic adaptations that resemble 'all-out' sprint interval training. *Journal of sports science and medicine,* **10**, 571-576.

BEAVER, WL. WASSERMAN, K. and WHIPP, BJ. (1986). A new method for detecting anaerobic threshold by gas exchange. *Journal of applied physiology,* **60** (6), 2020-2027.

BECK, T., *et al.* (2005). The effects of interelectrode distance on electromyographic amplitude and mean power frequency during isokinetic and isometric muscle actions of the biceps brachii. *Journal of electromyography and kinesiology: Official journal of the international society of electrophysiological kinesiology,* **15** (5), 482-495.

BENEKE, R. and VON DUVILLARD, SP. (1996). Determination of maximal lactate steady state response in selected sports events. *Medicine and science in sports and exercise,* **28** (2), 241.

BERGMAN, BC. and BROOKS, GA. (1999). Respiratory gas-exchange ratios during graded exercise in fed and fasted trained and untrained men. *Journal of applied physiology,* **86** (2), 479-487.

BERNARD, T., *et al.* (2009). Distribution of power output during the cycling stage of a triathlon world cup. *Medicine science in sports exercise,* **41** (6), 1296.

BEVEGÅRD, BS. HOLMGREN, A. and JONSSON, B. (1963). Circulatory studies in well trained athletes at rest and during heavy exercise, with special reference to stroke volume and the influence of body position. *Acta physiologica scandinavica,* **57** (1-2), 26-50.

BILLINGER, SA. LOUDON, JK. and GAJEWSKI, BJ. (2008a). Validity of a total body recumbent stepper exercise test to assess cardiorespiratory fitness. *The journal of strength & conditioning research,* **22** (5), 1556.

BILLINGER, SA., TSENG, BY. and KLUDING, PM. (2008b). Modified total-body recumbent stepper exercise test for assessing peak oxygen consumption in people with chronic stroke. *Physical therapy,* **88** (10), 1188.

BLACKBURN, H., *et al.* (1960). The electrocardiogram in population studies: A classification system. *Circulation,* **21** (6), 1160-1175.

BLAND, MJ. and ALTMAN, DG. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *The lancet,* **327** (8476), 307-310.

BLAND, MJ. and ALTMAN, DG. (1990). A note on the use of the intraclass correlation coefficient in the evaluation of agreement between two methods of measurement. *Computers in biology and medicine, 20* (5), 337-340.

BLAND, MJ. and ALTMAN, DG. (1995). Comparing methods of measurement: Why plotting difference against standard method is misleading. *The lancet, 346* (8982), 1085-1087.

BLOMQVIST, CG. and SALTIN, B. (1983). Cardiovascular adaptations to physical training. *Annual review of physiology, 45* (1), 169-189.

BOGDANIS, GC., *et al.* (1995). Recovery of power output and muscle metabolites following 30 s of maximal sprint cycling in man. *The journal of physiology, 482* (Pt 2), 467-480.

BOGDANIS, GC., *et al.* (1996). Contribution of phosphocreatine and aerobic metabolism to energy supply during repeated sprint exercise. *Journal of applied physiology, 80* (3), 876-884.

BOOBIS, LH. (1987). Metabolic aspects of fatigue during sprinting. *Exercise: Benefits, limits and adaptations,* 116-140.

BOMPA, TO. and CARRERA, MC. (2005). *Periodization training for sports.* Human Kinetics.

BOMPA, TO. and CLARO, F. (2008). *Periodization in rugby.* Meyer & Meyer Verlag.

BORG, G. (1998). *Borg's perceived exertion and pain scales.* Human kinetics.

BOSQUET, L., *et al.* (2008). A comparison of methods to determine maximal accumulated oxygen deficit in running. *Journal of sports sciences, 26* (6), 663-670.

BRAVO, FD., *et al.* (2008). Sprint vs. interval training in football. *International journal of sports medicine, 29* (8), 668-674.

British Association of Sport and Exercise Sciences, BIRD, SR. and DAVISON, R. (1997). *Guidelines for the physiological testing of atheletes.* British Association of Sport and Exercise Sciences.

BRUTON, A. CONWAY, JH. and HOLGATE, ST. (2000). Reliability: What is it, and how is it measured? *Physiotherapy,* **86** (2), 94-99.

BUCHHEIT, M., *et al.* (2009). Effect of body posture on postexercise parasympathetic reactivation in men. *Experimental physiology,* **94** (7), 795-804.

BUCHHEIT, M. and LAURSEN, PB. (2013). High-intensity interval training, solutions to the programming puzzle: Part I: cardiopulmonary emphasis. *Sports medicine,* **43** (5):313-38.

BURDEN, A. (2008). Surface electromyography. In Payton, CJ. and Bartlett, RM. Biomechanical evaluation of movement in sport and exercise. London: Routledge, 2008, pp. 77-102.

BURGOMASTER, KA., *et al.* (2005). Six sessions of sprint interval training increases muscle oxidative potential and cycle endurance capacity in humans. *Journal of applied physiology,* **98** (6), 1985-1990.

BURGOMASTER, KA., HEIGENHAUSER, GJF. and GIBALA, MJ. (2006). Effect of short-term sprint interval training on human skeletal muscle carbohydrate metabolism during exercise and time-trial performance. *Journal of applied physiology,* **100** (6), 2041-2047.

BURGOMASTER, KA., *et al.* (2007). Divergent response of metabolite transport proteins in human skeletal muscle after sprint interval training and detraining. *American journal of physiology-regulatory, integrative and comparative physiology,* **292** (5), R1970-R1976.

BURGOMASTER, KA., *et al.* (2008). Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. *The journal of physiology,* **586** (1), 151-160.

CAREY, D., *et al.* (2005). The respiratory rate as a marker for the ventilatory threshold: Comparison to other ventilatory parameters. *Journal of exercise physiology,* **8** (2), 30-38.

CHICHARRO, JL., *et al.* (1999). Physiological parameters determined at OBLA vs. a fixed heart rate of 175 beats·min^{-1} in an incremental test performed by amateur and professional cyclists. *The japanese journal of physiology,* **49** (1), 63-69.

CHEN, Y., *et al.* (2013). Comparative analysis of physical static and dynamic exercises using Borg's RPE 6-20 scale In: *Proceedings of the International Conference of Engineers and Computer Scientists* 13-15 March. Vol. 2.

CHRISTENSEN, E. HEDMAN, R. and SALTIN, B. (1960). Intermittent and continuous running. *Acta physiologica scandinavica,* **50** , 269-286.

CLANCY, EA. MORIN, EL. and MERLETTI, R. (2002). Sampling, noise-reduction and amplitude estimation issues in surface electromyography. *Journal of electromyography and kinesiology: Official journal of the international society of electrophysiological kinesiology,* **12** (1), 1.

CLARYS, JP. (2000). Electromyography in sports and occupational settings: An update of its limits and possibilities. *Ergonomics,* **43** (10), 1750-1762.

COHEN, J. (1988). *Statistical power analysis for the behavioral sciences.* Routledge Academic.

COMETTI, G., *et al.* (2001). Isokinetic strength and anaerobic power of elite, subelite and amateur french soccer players. *International journal of sports medicine,* **22** (1), 45-51.

CONVERTINO, VA. GOLDWATER, DJ. and SANDLER, H. (1984). Oxygen uptake kinetics of constant-load work: Upright vs. supine exercise. *Aviation, space, and environmental medicine,* **55** (6), 501-506.

COONAN, TJ. and HOPE, CE. (1983). Cardio-respiratory effects of change of body position. *Canadian anaesthetists' society journal,* **30** (4), 424-437.

COOPER, JA., *et al.* (2009). Assessing validity and reliability of resting metabolic rate in six gas analysis systems. *Journal of the american dietetic association,* **109** (1), 128-132.

COUTTS, A. REABURN, P. and ABT, G. (2003). Hearth rate, blood lactate concetration and estimated energy expediture in a semi-profesional rugby league team during a match: Case study. *Journal of sports sciences,* **21** (2), 97-103.

CREER, AR., *et al.* (2004). Neural, metabolic, and performance adaptations to four weeks of high intensity sprint-interval training in trained cyclists. *International journal of sports medicine,* **25** (2), 92-98.

CUNNINGHAM, DA. MCCRIMMON, D. and VLACH, LF. (1979). Cardiovascular response to interval and continuous training in women. *European journal of applied physiology and occupational physiology,* **41** (3), 187-197.

DANKAERTS, W., *et al.* (2004). Reliability of EMG measurements for trunk muscles during maximal and submaximal voluntary isometric contractions in healthy controls and CLBP patients. *Journal of electromyography and kinesiology: Official journal of the international society of electrophysiological kinesiology,* **14** (3), 333.

DAUSSIN, FN., *et al.* (2008). Effect of interval versus continuous training on cardiorespiratory and mitochondrial functions: Relationship to aerobic performance improvements in sedentary subjects. *American journal of physiology-regulatory, integrative and comparative physiology,* **295** (1), R264-R272.

DAVIS, HA., *et al.* (1983). Anaerobic threshold and lactate turnpoint. *European journal of applied physiology and occupational physiology,* **50** (3), 383-392.

DAVIS, RB., *et al.* (1991). A gait analysis data collection and reduction technique. *Human movement science,* **10** (5), 575-587.

DAWSON, B., *et al.* (1998). Changes in performance, muscle metabolites, enzymes and fibre types after short sprint training. *European journal of applied physiology and occupational physiology,* **78** (2), 163-169.

DE LUCA, CJ. and KNAFLITZ, M. (1992). *Surface electromyography: What's new?* CLUT Publishers.

DEKERLE, J., *et al.* (2003). Maximal lactate steady state, respiratory compensation threshold and critical power. *European journal of applied physiology,* **89** (3-4), 281-288.

DEAKIN, GB. DAVIE, AJ. and ZHOU, Shi. (2011). Reliability and validity of an incremental cadence cycle VO_{2max} testing protocol for trained cyclists. *Journal of exercise science & fitness,* **9** (1), 31-39.

DERRICK, TR. (2004). The effects of knee contact angle on impact forces and accelerations. *Medicine and science in sports and exercise,* **36** (5), 832-837.

DOHERTY, M. SMITH, PM. and SCHRODER, K. (2000). Reproducibility of the maximum accumulated oxygen deficit and run time to exhaustion during short-distance running. *Journal of sports sciences,* **18** (5), 331-338.

DOMA, K., DEAKIN, GB. and SEALEY, RM. (2012). The reliability of lower extremity and thoracic kinematics at various running speeds. *International journal of sports medicine,* **33** (05), 364-369.

EGAÑA, M., *et al.* (2010). Effect of body tilt angle on fatigue and EMG activities in lower limbs during cycling. *European journal of applied physiology,* **108** (4), 649-656.

ELSTAD, M., *et al.* (2009). Stroke volume decreases during mild dynamic and static exercise in supine humans. *Acta physiologica,* **195** (2), 289-300.

ESTON, RG. and CONNOLLY, D. (1996). The use of ratings of perceived exertion for exercise prescription in patients receiving β-blocker therapy. *Sports medicine,* **21** (3), 176-190.

ESTON, RG. and THOMPSON, M. (1997). Use of ratings of perceived exertion for predicting maximal work rate and prescribing exercise intensity in patients taking atenolol. *British journal of sports medicine,* **31** (2), 114-119.

ESTON, RG. and WILLIAMS, JG. (1988). Reliability of ratings of perceived effort regulation of exercise intensity. *British journal of sports medicine,* **22** (4), 153-155.

FARINA, D., *et al.* (2002). Standardising surface electromyogram recordings for assessment of activity and fatigue in the human upper trapezius muscle. *European journal of applied physiology,* **86** (6), 469-478.

FELLIN, RE., *et al.* (2010). Comparison of methods for kinematic identification of footstrike and toe-off during overground and treadmill running. *Journal of science and medicine in sport / sports medicine australia,* **13** (6), 646-650.

FERBER, R., *et al.* (2002). A comparison of within-and between-day reliability of discrete 3D lower extremity variables in runners. *Journal of orthopaedic research,* **20** (6), 1139-1145.

FERBER, R. MCCLAY DAVIS, I. and WILLIAMS, DS. (2003). Gender differences in lower extremity mechanics during running. *Clinical biomechanics,* **18** (4), 350-357.

FERBER, R., *et al.* (2010). Competitive female runners with a history of iliotibial band syndrome demonstrate atypical hip and knee kinematics. *Journal of orthopaedic & sports physical therapy,* **40** (2), 52-58.

FERRONE, C. RIEBE, D. and MANFREDI, T. (2001). A comarison of the physiological and perceptual responses to upright and recumbent cycling. *Medicine & science in sports & exercise,* **33** (5), S107.

FIELD, A. (2005). Discovering statistics using SPSS. SAGE Publications Ltd.

FOSTER, JJ., BARKUS, E. and YAVORSKY, C. (2006). *Understanding and using advanced statistics: A practical guide for students.* SAGE Publications Limited.

FOX, JE. MEREDITH, D. and HALESTRAP, AP. (2000). Characterisation of human monocarboxylate transporter 4 substantiates its role in lactic acid efflux from skeletal muscle. *The journal of physiology,* **529** (2), 285-293.

FRERIKS, B., *et al.* (1999). The recommendations for sensors and sensor placement procedures for surface electromyography. *SENIAM,* **8**, 13-54.

FRY, RW. MORTON, AR. and KEAST, D. (1992). Periodisation of training stress--a review. *Canadian journal of sport sciences= journal canadien des sciences du sport,* **17** (3), 234.

FRYER, MW. *et al.* (1995). Effects of creatine phosphate and P (i) on Ca2 movements and tension development in rat skinned skeletal muscle fibres. *The journal of physiology,* **482** (Pt 1), 123-140.

GAESSER, GA. and BROOKS, GA. (1984). Metabolic bases of excess post-exercise oxygen consumption: A review. *Medicine and science in sports and exercise,* **16** (1), 29-43.

GAESSER, GA. and RICH, RG. (1984). Effects of high-and low-intensity exercise training on aerobic capacity and blood lipids. *Medicine and science in sports and exercise,* **16** (3), 269.

GAITANOS, GC., *et al.* (1993). Human muscle metabolism during intermittent maximal exercise. *Journal of applied physiology,* **75** (2), 712-719.

GASKILL, SE., *et al.* (2001). Validity and reliability of combining three methods to determine ventilatory threshold. *Medicine and science in sports and exercise,* **33** (11), 1841-1848.

GASTIN, PB. (2001). Energy system interaction and relative contribution during maximal exercise. *Sports medicine,* **31** (10), 725-741.

GEETA, A., *et al.* (2009). Reliability, technical error of measurements and validity of instruments for nutritional status assessment of adults in Malaysia. *Singapore medical journal,* **50** (10), 1013.

GIBALA, MJ., *et al.* (2006). Short-term sprint interval versus traditional endurance training: Similar initial adaptations in human skeletal muscle and exercise performance. *The journal of physiology,* **575** (3), 901-911.

GIBALA, MJ. (2009). Molecular responses to high-intensity interval exercise this paper is one of a selection of papers published in this special issue, entitled 14th international biochemistry of exercise conference-muscles as molecular and metabolic machines, and has undergone the journal's usual peer review process. *Applied physiology, nutrition, and metabolism,* **34** (3), 428-432.

GLADDEN, LB. (2004). Lactate metabolism: A new paradigm for the third millennium. *The journal of physiology,* **558** (1), 5-30.

GLAISTER, M. (2005). Multiple sprint work. *Sports medicine,* **35** (9), 757-777.

GLEESON, N. (2008). Assessment of neuromuscular performance using electromyography. *Kinanthropometry and exercise physiology laboratory manual: Tests, procedures and data: Volume two: Physiology,* **2** , 41.

GOEDECKE, JH., *et al.* (2000). Determinants of the variability in respiratory exchange ratio at rest and during exercise in trained athletes. *American journal of physiology-endocrinology and metabolism,* **279** (6), E1325-E1334.

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GOLLNICK, PD. and KING, DW. (1969). Energy release in the muscle cell. *Medicine & science in sports & exercise*, 1 (1), 23-31.

GOLLNICK, PD. BAYLY, WM. and HODGSON, DR. (1986). Exercise intensity, training, diet, and lactate concentration in muscle and blood. *Medicine and science in sports and exercise,* **18** (3), 334-340.

GONZALEZ, CR. and CARRASCO, SS. (1989). Direct and indirect maximum oxygen consumption in sedentary subjects living at a moderate altitude. *Archivos del instituto de cardiologia de mexico,* **59** (3), 273-278.

GOODWIN, ML., *et al.* (2007). Blood lactate measurements and analysis during exercise: A guide for clinicians. *Journal of diabetes science and technology (online),* **1** (4), 558.

GOROSTIAGA, EM., *et al.* (1991). Uniqueness of interval and continuous training at the same maintained exercise intensity. *European journal of applied physiology and occupational physiology,* **63** (2), 101-107.

GRANIER, P., *et al.* (1995). Aerobic and anaerobic contribution to wingate test performance in sprint and middle-distance runners. *European journal of applied physiology and occupational physiology,* **70** (1), 58-65.

GRANJA FILHO, PCN. POMPEU, FAMS. and Silva, APRS. (2005). Accuracy of VO_{2max}. and anaerobic threshold determination. *Revista brasileira de medicina do esporte,* **11** (3), 167-171.

GREGOR, SM., *et al.* (2002). Lower extremity general muscle moment patterns in healthy individuals during recumbent cycling. *Clinical biomechanics,* **17** (2), 123-129.

GRIMSHAW, P. (2007). *Sport & exercise biomechanics.* Taylor & Francis.

GRÖNKVIST, M. BERGSTEN, E. and GUSTAFSSON, PM. (2002). Effects of body posture and tidal volume on inter-and intraregional ventilation distribution in healthy men. *Journal of applied physiology,* **92** (2), 634-642.

GUIJT, AM. SLUITER, JK. and FRINGS-DRESEN, MHW. (2007). Test-retest reliability of heart rate variability and respiration rate at rest and during light

physical activity in normal subjects. *Archives of medical research,* **38** (1), 113-120.

HALE, T. (2008). History of developments in sport and exercise physiology: AV hill, maximal oxygen uptake, and oxygen debt. *Journal of sports sciences,* **26** (4), 365-400.

HAMILL, J. and SELBIE, WS. (2004). Three-dimensional kinetics. *Research methods in biomechanics,* 145-160.

HARGREAVES, M. (2000). Skeletal muscle metabolism during exercise in humans. *Clinical and experimental pharmacology and physiology,* **27** (3), 225-228.

HASS, C., *et al.* (2001). Concurrent improvements in cardiorespiratory and muscle fitness in response to total body recumbent stepping in humans. *European journal of applied physiology,* **85** (1-2), 157-163.

HAWLEY, JA. (2002). Adaptations of skeletal muscle to prolonged, intense endurance training. *Clinical and experimental pharmacology and physiology,* **29** (3), 218-222.

HECK, H., *et al.* (1985). Justification of the 4-mmol/L lactate threshold. *International journal of sports medicine,* **6** (3), 117-130.

HELGERUD, J., *et al.* (2001). Aerobic endurance training improves soccer performance. *Medicine and science in sports and exercise,* **33** (11), 1925-1931.

HELGERUD, J., *et al.* (2007). Aerobic high-intensity intervals improve VO_{2max}. more than moderate training. *Medicine and science in sports and exercise,* **39** (4), 665.

HERMENS, HJ. and FRERIKS, B. (1997). The state of the art on sensors and sensor placement procedures for surface electromyography: A proposal for sensor placement procedures. *Deliverable of the SENIAM project,* .

HERMENS, HJ., *et al.* (1999). *European recommendations for surface electromyography: Results of the SENIAM project.* Roessingh Research and Development The Netherlands.

HERMENS, HJ., *et al.* (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of electromyography and kinesiology,* **10** (5), 361.

HILL, DW. (1999). Energy system contributions in middle-distance running events. *Journal of sports sciences,* **17** (6), 477-483.

HILL, DW. and VINGREN, JL. (2011). Maximal accumulated oxygen deficit in running and cycling. *Applied physiology, nutrition, and metabolism,* **36** (6), 831-838.

HIRVONEN, J., *et al.* (1992). Fatigue and changes of ATP, creatine phosphate, and lactate during the 400-m sprint. *Canadian journal of sport sciences = journal canadien des sciences du sport,* **17** (2), 141-144.

HOF, AL. (1984). EMG and muscle force: An introduction. *Human movement science,* **3** (1), 119-153.

HOPKINS, WG. (2000). Measures of reliability in sports medicine and science. *Sports medicine,* **30** (1), 1-15.

HRELJAC, A. (2004). Impact and overuse injuries in runners. *Medicine and science in sports and exercise,* **36** (5), 845-849.

HUGHSON, RL. WEISIGER, KH. and SWANSON, GD. (1987). Blood lactate concentration increases as a continuous function in progressive exercise. *Journal of applied physiology,* **62** (5), 1975-1981.

HUGHSON, RL., *et al.* (1991). Kinetics of ventilation and gas exchange during supine and upright cycle exercise. *European journal of applied physiology and occupational physiology,* **63** (3-4), 300-307.

HULTMAN, E. BERGSTRÖM, J. and ANDERSON, NM. (1967). Breakdown and resynthesis of phosphorylcreatine and adenosine triphosphate in connection with muscular work in man. *Scandinavian journal of clinical & laboratory investigation,* **19** (1), 56-66.

INMAN, VT., *et al.* (1952). Relation of human electromyogram to muscular tension. *Electroencephalography and clinical neurophysiology,* **4** (2), 187-194.

IVES, JC. and WIGGLESWORTH, JK. (2003). Sampling rate effects on surface EMG timing and amplitude measures. *Clinical biomechanics,* **18** (6), 543-552.

JOBE, FW., *et al.* (1984). An EMG analysis of the shoulder in pitching: A second report. *The american journal of sports medicine,* **12** (3), 218-220.

JONES, AYM. and DEAN, E. (2004). Body position change and its effect on hemodynamic and metabolic status. *Heart & lung: The journal of acute and critical care,* **33** (5), 281-290.

JONES, AM. and CARTER, H. (2000). The effect of endurance training on parameters of aerobic fitness. *Sports medicine,* **29** (6), 373-386.

JONES, AM. and DOUST, JH. (1996). A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. *Journal of sports sciences,* **14** (4), 321-327.

KABBARA, AA. and ALLEN, DG. (2001). The use of the indicator fluo-5N to measure sarcoplasmic reticulum calcium in single muscle fibres of the cane toad. *The journal of physiology,* **534** (1), 87-97.

KADABA, MP., *et al.* (2005). Repeatability of kinematic, kinetic, and electromyographic data in normal adult gait. *Journal of orthopaedic research,* **7** (6), 849-860.

KADABA, MP. RAMAKRISHNAN, HK. and WOOTTEN, ME. (1990). Measurement of lower extremity kinematics during level walking. *Journal of orthopaedic research,* **8** (3), 383-392.

KAISER, JF. and REED, WA. (1977). Data smoothing using low-pass digital filters. *Review of scientific instruments,* **48** (11), 1447-1457.

KAMEN, G. (2004). Electromyographic kinesiology. *Research methods in biomechanics.* Human Kinetics.

KAMEN, G. and GABRIEL, DA. (2010). *Essentials of electromyography.* Human Kinetics.

KARVONEN, J. and VUORIMAA, T. (1988). Heart rate and exercise intensity during sports activities. *Sports medicine,* **5** (5), 303-311.

KAVANAGH, MF. and JACOBS, I. (1988). Breath-by-breath oxygen consumption during performance of the wingate test. *Canadian journal of sport sciences= journal canadien des sciences du sport,* **13** (1), 91.

KERTIS, JD., *et al.* (2010). Static and dynamic calibration of an eight-camera optical system for human motion analysis. *Critical reviews in physical and rehabilitation medicine,* **22** (1), 49.

KINFU, H., *et al.* (2011). Correlation of heart rate and anthropometric parameters with performance scores obtained from IAAF tables in elite ethiopian middle distance runners. *Open sports medicine journal,* **5** , 12-18.

KOLLMITZER, J. EBENBICHLER, GR. and KOPF, A. (1999). Reliability of surface electromyographic measurements. *Clinical neurophysiology,* **110** (4), 725-734.

KOMI, PV. and BUSKIRK, ER. (1970). Reproducibility of electromyographic measurements with inserted wire electrodes and surface electrodes. *Electromyography,* **10** (4), 357-367.

KRUSTRUP, P., *et al.* (2003). The yo-yo intermittent recovery test: Physiological response, reliability, and validity. *Medicine and science in sports and exercise,* **35** (4), 697-705.

KUMAGAI, S., *et al.* (1982). Relationships of the anaerobic threshold with the 5 km, 10 km, and 10 mile races. *European journal of applied physiology and occupational physiology,* **49** (1), 13-23.

LACHIN, JM. (2004). The role of measurement reliability in clinical trials. *Clinical trials,* **1** (6), 553-566.

LANDRY, F. BOUCHARD, C. and DUMESNIL, J. (1985). Cardiac dimension changes with endurance training. *JAMA: The journal of the american medical association,* **254** (1), 77-80.

LARIVIERE, C., *et al.* (2002). Evaluation of measurement strategies to increase the reliability of EMG indices to assess back muscle fatigue and recovery. *Journal of electromyography and kinesiology,* **12** (2), 91-102.

LARSSON, B., *et al.* (2003). Test-retest reliability of EMG and peak torque during repetitive maximum concentric knee extensions. *Journal of electromyography and kinesiology: Official journal of the international society of electrophysiological kinesiology,* **13** (3), 281.

LAUKKANEN, RMT. and VIRTANEN, PK. (1998). Heart rate monitors: State of the art. *Journal of sports sciences,* **16** (sup1), 3-7.

LAURSEN, PB. and JENKINS, DG. (2002). The scientific basis for high-intensity interval training. *Sports medicine,* **32** (1), 53-73.

LAWLER, J. POWERS, SK. and THOMPSON, D. (1988). Linear relationship between VO_{2max} and VO_{2max} decrement during exposure to acute hypoxia. *Journal of applied physiology,* **64** (4), 1486-1492.

LESMES, GR., *et al.* (1978). Metabolic responses of females to high intensity interval training of different frequencies. *Med sci sport exerc,* **10** , 229-232.

LEVITZKY, MG. (2007). *Pulmonary physiology.* McGraw-Hill Medical New York.

LEYK, D., *et al.* (1994). Postural effect on cardiac output, oxygen uptake and lactate during cycle exercise of varying intensity. *European journal of applied physiology and occupational physiology,* **68** (1), 30-35.

LI, Y., *et al.* (2006). Cytochrome c oxidase subunit IV is essential for assembly and respiratory function of the enzyme complex. *Journal of bioenergetics and biomembranes,* **38** (5-6), 283-291.

LOY, SF., *et al.* (1994). Effect of running versus cycle training on cycle ergometer, treadmill, and running performance. *Research in sports medicine: An international journal,* **5** (1), 7-15.

LUTTGENS, K. and HAMILTON, N. (1996). *Kinesiology: Scientific basis of human motion.* Brown & Benchmark.

MACDOUGALL, DJ., *et al.* (1998). Muscle performance and enzymatic adaptations to sprint interval training. *Journal of applied physiology,* **84** (6), 2138-2142.

MAFFIULETTI, NA. and LEPERS, R. (2003). Quadriceps femoris torque and EMG activity in seated versus supine position. *Medicine and science in sports and exercise,* **35** (9), 1511-1516.

MANN, RA. and HAGY, J. (1980). Biomechanics of walking, running, and sprinting. *The american journal of sports medicine,* **8** (5), 345-350.

MARRAS, WS. and DAVIS, KG. (2001). A non-MVC EMG normalization technique for the trunk musculature: Part 1. method development. *Journal of electromyography and kinesiology,* **11** (1), 1-9.

MARSHALL, RN., Elliott, BC. (1992). *Biomechanical analysis in science and medicine in sport.* Oxford, Blackwell Scientific Publications.

MATHUR, S. ENG, JJ. and MACINTYRE, DL. (2005). Reliability of surface EMG during sustained contractions of the quadriceps. *Journal of electromyography and kinesiology,* **15** (1), 102-110.

MAUGHAN, RJ. and GLEESON, M. (2004). *The biochemical basis of sports performance.* Oxford University Press Oxford.

MAXWELL, NS. and NIMMO, MA. (1996). Anaerobic capacity: A maximal anaerobic running test versus the maximal accumulated oxygen deficit. *Canadian journal of applied physiology,* **21** (1), 35-47.

MCGINLEY, JL., *et al.* (2009). The reliability of three-dimensional kinematic gait measurements: A systematic review. *Gait & posture,* **29** (3), 360-369.

MCGREGOR, M. ADAM, W. and SEKELJ, P. (1961). Influence of posture on cardiac output and minute ventilation during exercise. *Circulation research,* **9** (5), 1089-1092.

MCLAUGHLIN, JE., *et al.* (2001). Validation of the COSMED K4 b2 portable metabolic system. *International journal of sports medicine,* **22** (04), 280-284.

MEDBO, JI. and TABATA, I. (1989). Relative importance of aerobic and anaerobic energy release during short-lasting exhausting bicycle exercise. *Journal of applied physiology,* **67** (5), 1881-1886.

MERLETTI, R. and DI TORINO, P. (1999). Standards for reporting EMG data. *Journal of electromyography and kinesiology, 9* (1), 3-4.

MEYER, T., *et al.* (2004). Is lactic acidosis a cause of exercise induced hyperventilation at the respiratory compensation point? *British journal of sports medicine, 38* (5), 622-625.

MIDGLEY, AW., *et al.*, (2007). Criteria for determination of maximal oxygen uptake. *Sports medicine, 37* (12), 1019-1028.

MILLET, GP. VLECK, VE. and BENTLEY, DJ. (2009). Physiological differences between cycling and running. *Sports medicine, 39* (3), 179-206.

MILNER, CE. (2008). Motion analysis using on-line systems. *Biomechanical evaluation of movement in sport and exercise,* 33. Routledge. New York, US.

MILNER-BROWN, HS. STEIN, RB. and YEMM, R. (1973). The contractile properties of human motor units during voluntary isometric contractions. *The journal of physiology, 228* (2), 285-306.

MOHRMAN, DE. and HELLER, LJ. (1997). Homeostasis and cardiovascular transport. *Cardiovascular physiology, 4th editon. McGraw-hill co., New York.*

MORGAN, DW., *et al.* (1995). Variation in the aerobic demand of running among trained and untrained subjects. *Medicine and science in sports and exercise, 27* (3), 404-409.

MORGAN, WP. (1973). Psychological factors influencing perceived exertion. *Med sci sports, 5* (2), 97-103.

MUELLER, WH. and MARTORELL, R. (1988). Reliability and accuracy of measurement. *Anthropometric standardization reference manual,* 83-86.

NEWELL, J., *et al.* (2007). Software for calculating blood lactate endurance markers. *Journal of sports sciences, 25* (12), 1403-1409.

NIELSEN, AB. and YDE, J. (1989). Epidemiology and traumatology of injuries in soccer. *The american journal of sports medicine, 17* (6), 803-807.

NOORDHOF, DA., DE KONING, JJ. and FOSTER, C. (2010). The maximal accumulated oxygen deficit method: A valid and reliable measure of anaerobic capacity? *Sports medicine,* **40** (4), 285.

NOVACHECK, TF. (1998). The biomechanics of running. *Gait & posture,* **7** (1), 77-95.

NUMMELA, A., *et al.* (1996). Reliability and validity of the maximal anaerobic running test. *International journal of sports medicine,* **17** (S 2), S97-S102.

NUMMELA, A., *et al.* (2007). Effect of inclination on the results of the maximal anaerobic running test. *International journal of sports medicine,* **17** (S 2), S103-S108.

NUMMELA, A., HÄMÄLÄINEN, I. and RUSKO, H. (2007). Comparison of maximal anaerobic running tests on a treadmill and track. *Journal of sports sciences,* **25** (1), 87-96.

OKUNO, NM., *et al.* (2011). Physiological and perceived exertion responses at intermittent critical power and intermittent maximal lactate steady state. *The journal of strength & conditioning research,* **25** (7), 2053-2058.

OLNEY, SJ. and WINTER, DA. (1985). Predictions of knee and ankle moments of force in walking from EMG and kinematic data. *Journal of biomechanics,* **18** (1), 9-20.

ØRTENBLAD, N., *et al.* (2000). Enhanced sarcoplasmic reticulum Ca2 release following intermittent sprint training. *American journal of physiology-regulatory, integrative and comparative physiology,* **279** (1), R152-R160.

PARRA, J., *et al.* (2000). The distribution of rest periods affects performance and adaptations of energy metabolism induced by high-intensity training in human muscle. *Acta physiologica scandinavica,* **169** (2), 157-166.

PATE, E. *et al.,* (1995). Reduced effect of pH on skinned rabbit psoas muscle mechanics at high temperatures: Implications for fatigue. *The journal of physiology,* **486** (Pt 3), 689-694.

PERELL, KL., *et al.* (2002). Comparison of cycling kinetics during recumbent bicycling in subjects with and without diabetes. *Journal of rehabilitation research and development,* **39** (1), 13-20.

PERINI, TA., *et al.* (2005). Technical error of measurement in anthropometry. *Revista brasileira de medicina do esporte,* **11** (1), 81-85.

POLINER, LR., *et al.* (1980). Left ventricular performance in normal subjects: A comparison of the responses to exercise in the upright and supine positions. *Circulation,* **62** (3), 528-534.

POOLE, DC. WILKERSON, DP. and JONES, AM. (2008). Validity of criteria for establishing maximal O2 uptake during ramp exercise tests. *European journal of applied physiology,* **102** (4), 403-410.

POWERS, SK., *et al.* (1983). Ventilatory threshold, running economy and distance running performance of trained athletes. Research quarterly for exercise and sport, **54** (2), 179-182.

PRISK, GK., *et al.* (2007). Pulmonary perfusion in the prone and supine postures in the normal human lung. *Journal of applied physiology,* **103** (3), 883-894.

PYNE, DB., *et al.* (2000). Evaluation of the lactate pro blood lactate analyser. *European journal of applied physiology,* **82** (1-2), 112-116.

RAINOLDI, A., *et al.* (2000). Geometrical factors in surface EMG of the vastus medialis and lateralis muscles. *Journal of electromyography and kinesiology,* **10** (5), 327-336.

RAINOLDI, A. MELCHIORRI, G. and CARUSO, I. (2004). A method for positioning electrodes during surface EMG recordings in lower limb muscles. *Journal of neuroscience methods,* **134** (1), 37.

RAMOS-JIMÉNEZ, A., *et al.* (2008). The respiratory exchange ratio is associated with fitness indicators both in trained and untrained men: A possible application for people with reduced exercise tolerance. *Clinical medicine.circulatory, respiratory and pulmonary medicine,* **2**, (1).

REAZ, M. HUSSAIN, MS. and MOHD-YASIN, F. (2006). Techniques of EMG signal analysis: Detection, processing, classification and applications. *Biological procedures online,* **8** (1), 11-35.

ROBERGS, RA. and LANDWEHR, R. (2002). The surprising history of the "$HR_{max.}= 220$-age" equation. *Journal exercise physiology,* **5** (2), 1-10.

RUSKO, H. and NUMMELA, A. (1996). Measurement and submaximal anaerobic performance capacity: Concluding chapter. *International journal of sports medicine,* **17** (S), 125-129.

RUSKO, H. NUMMELA, A. and MERO, A. (1993). A new method for the evaluation of anaerobic running power in athletes. *European journal of applied physiology and occupational physiology,* **66** (2), 97-101.

SACCO, I., *et al.* (2009). A method for better positioning bipolar electrodes for lower limb EMG recordings during dynamic contractions. *Journal of neuroscience methods,* **180** (1), 133-137.

SADY, SP., *et al.* (1988). Prediction of VO_{2max} during cycle exercise in pregnant women. *Journal of applied physiology,* **65** (2), 657-661.

SAFRIT, MJ. and WOOD, TM. (1986). *Introduction to measurement in physical education and exercise science.* Times Mirror/Mosby St-Louis, MO.

SAHLIN, K., *et al.* (1976). Lactate content and pH in muscle samples obtained after dynamic exercise. *Pflügers archive,* **367** (2), 143-149.

SAHLIN, K. (1992). Metabolic factors in fatigue. *Sports medicine,* **13** (2), 99-107.

SAHLIN, K. TONKONOGI, M. and SÖDERLUND, K. (1998). Energy supply and muscle fatigue in humans." *Acta Physiologica Scandinavica.* **162** (3), 261-266.

SAITOH, M., *et al.* (2005). Comparison of cardiovascular responses between upright and recumbent cycle ergometers in healthy young volunteers performing low-intensity exercise: Assessment of reliability of the oxygen uptake calculated by using the ACSM metabolic equation. *Archives of physical medicine and rehabilitation,* **86** (5), 1024-1029.

SALTIN, B., *et al.* (1976). The nature of the training response; peripheral and central adaptations to one-legged exercise. *Acta physiologica scandinavica,* **96** (3), 289-305.

SALTIN, B., et al. (1998). Skeletal muscle blood flow in humans and its regulation during exercise. *Acta physiologica scandinavica,* **162** (3), 421-436.

SCHARHAG-ROSENBERGER, F., *et al.* (2011). How to test maximal oxygen uptake: A study on timing and testing procedure of a supramaximal verification test. *Applied physiology, nutrition, and metabolism,* **36** (1), 153-160.

SHARP, RL., *et al.* (1986). Effects of eight weeks of bicycle ergometer sprint training on human muscle buffer capacity. *International journal of sports medicine,* **7** (01), 13-17.

SHARP, MA., *et al.* (2002). Comparison of the physical fitness of men and women entering the US army. *Med sci sport exerc,* **3** , 56-363.

SHIAVI, R. FRIGO, C. and PEDOTTI, A. (1998). Electromyographic signals during gait: Criteria for envelope filtering and number of strides. *Medical and biological engineering and computing,* **36** (2), 171-178.

SHIMIZU, M. *et al.* (1991). The ventilatory threshold: Method, protocol, and evaluator agreement. *American heart journal,* **122** (2), 509-516.

SMITH, GDP. and MATHIAS, CJ. (1995). Postural hypotension enhanced by exercise in patients with chronic autonomic failure. *Qjm,* **88** (4), 251-256.

SMITH, JC. and HILL, DW. (1991). Contribution of energy systems during a wingate power test. *British journal of sports medicine,* **25** (4), 196-199.

SMITH, MS. (2006). Physiological profile of senior and junior england international amateur boxers. *Journal of sports science and medicine,* **5** , 74-89.

SÖDERMAN, K., *et al.* (2001). Risk factors for leg injuries in female soccer players: A prospective investigation during one out-door season. *Knee surgery, sports traumatology, arthroscopy,* **9** (5), 313-321.

SPECTOR, B. (1979). Surface electromyography as a model for the development of standardized procedures and reliability testing. *Journal of manipulative and physiological therapeutics,* **2** (4), 214.

SPENCER, MR. and GASTIN, PB. (2001). Energy system contribution during 200-to 1500-m running in highly trained athletes. *Medicine and science in sports and exercise,* **33** (1), 157-162.

ST CLAIR GIBSON, A., *et al.* (1999). Measurement of maximal oxygen uptake from two different laboratory protocols in runners and squash players. *Medicine and science in sports and exercise,* **31** (8), 1226.

STEGEMAN, D. and HERMENS, H. (2007). Standards for surface electromyography: The european project surface EMG for non-invasive assessment of muscles (SENIAM). *Línea).disponible en: [consultado en agosto de 2008],* .

STOLOFF, RH. ZEHR, EP. and FERRIS, DP. (2007). Recumbent stepping has similar but simpler neural control compared to walking. *Experimental brain research,* **178** (4), 427-438.

TABATA, I., *et al.* (1996). Effects of moderate-intensity endurance and high-intensity intermittent training on anaerobic capacity and VO_{2max}. *Medicine and science in sports and exercise,* **28** (10), 1327-1330.

TAKAHASHI, T., *et al.* (2000). Difference in human cardiovascular response between upright and supine recovery from upright cycle exercise. *European journal of applied physiology,* **81** (3), 233-239.

TAKANO, N. (2000). Respiratory compensation point during incremental exercise as related to hypoxic ventilatory chemosensitivity and lactate increase in man. *The japanese journal of physiology,* **50** (4), 449-455.

TANAKA, H. MONAHAN, KD. and SEALS, DR. (2001). Age-predicted maximal heart rate revisited. *Journal of the American college of cardiology,* **37** (1), 153-156.

TANAKA, K., *et al.* (1986). Longitudinal associations between anaerobic threshold and distance running performance. *European journal of applied physiology and occupational physiology,* **55** (3), 248-252.

THARP, GD., *et al.* (1985). Comparison of sprint and run times with performance on the wingate anaerobic test. *Research quarterly for exercise and sport,* **56** (1), 73-76.

THOMAS, C., *et al.* (2004). Relationships between maximal muscle oxidative capacity and blood lactate removal after supramaximal exercise and fatigue indexes in humans. *Journal of applied physiology,* **97** (6), 2132-2138.

TOKMAKIDIS, SP. LÉGER, LA. and PILIANIDIS, TC. (1998). Failure to obtain a unique threshold on the blood lactate concentration curve during exercise. *European journal of applied physiology and occupational physiology,* **77** (4), 333-342.

TOMLIN, DL. and WENGER, HA. (2001). The relationship between aerobic fitness and recovery from high intensity intermittent exercise. *Sports medicine,* **31** (1), 1-11.

VANICEK, N., *et al.* (2009). Gait patterns in transtibial amputee fallers vs. non-fallers: Biomechanical differences during level walking. *Gait & posture,* **29** (3), 415-420.

VINCENT, WJ. and WEIR, JP. (2012). *Statistics in kinesiology, 4E.* Human Kinetics.

WANK, V. FRICK, U. and SCHMIDTBLEICHER, D. (1998). Kinematics and electromyography of lower limb muscles in overground and treadmill running. *International journal of sports medicine,* **19** , 455-461.

WASSERMAN, K. (1987). Determinants and detection of anaerobic threshold and consequences of exercise above it. *Circulation,* **76** (6 Pt 2), VI29-39.

WASSERMAN, K., *et al.* (1973). Anaerobic threshold and respiratory gas exchange during exercise. *Journal of applied physiology,* **35** (2), 236.

WASSERMAN, K. BEAVER, WL. and WHIPP, BJ. (1986). Mechanisms and patterns of blood lactate increase during exercise in man. *Medicine and science in sports and exercise,* **18** (3), 344-352.

WATENPAUGH, DE., et al. (2000). Supine lower body negative pressure exercise during bed rest maintains upright exercise capacity. *Journal of applied physiology,* **89** (1), 218-227.

WELTMAN, A., et al. (2008). Exercise training at and above the lactate threshold in previously untrained women. *International journal of sports medicine,* **13** (03), 257-263.

WENGER, HA. and MACNAB, RB. (1975). Endurance training: The effects of intensity, total work, duration and initial fitness. *The journal of sports medicine and physical fitness,* **15** (3), 199-211.

WESTERBLAD, H. ALLEN, DG. and LÄNNERGREN, J. (2002). Muscle fatigue: Lactic acid or inorganic phosphate the major cause? *Physiology,* **17** (1), 17-21.

WESTERBLAD, H. BRUTON, JD. and LÄNNERGREN, J. (1997). The effect of intracellular pH on contractile function of intact, single fibres of mouse muscle declines with increasing temperature. *The journal of physiology,* **500** (Pt 1), 193-204.

WHITE, R. YAEGER, D. and STAVRIANEAS, S. (2009). Determination of blood lactate concentration: Reliability and validity of a lactate oxidase-based method. *International Journal of exercise science,* **2** , 83-93.

WEIR, JP. (2005). Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *The journal of strength & conditioning research,* **19** (1), 231-240.

WHELAN, RF and YOUNG, I. (1953). The effect of adrenaline and noradrenaline infusions on respiration in man. *British journal of pharmacology and chemotherapy,* **8** (1), 98-102.

WHYTE, G. (2006). *The physiology of training.* Churchill Livingstone. UK.

WHYTE, LJ. GILL, JMR. and CATHCART, AJ. (2010). Effect of 2 weeks of sprint interval training on health-related outcomes in sedentary overweight/obese men. *Metabolism,* **59** (10), 1421-1428.

WIEGAND, G. and REMINGTON, SJ. (1986). Citrate synthase: Structure, control, and mechanism. *Annual review of biophysics and biophysical chemistry,* **15** (1), 97-117.

WILMORE, JH. and COSTILL, DL. (1999). *Physiology of sport and exercise.* Human Kinetics.

WILSON, DJ., *et al.* (1999). Accuracy of digitization using automated and manual methods. *Physical therapy,* **79** (6), 558-566.

WINTER, DA. (2005). *Biomechanics and motor control of human movement.* 3rd Edition ed., New Jersey, USA, John Wiley & Sons.

WINTER, DA. and YACK, HJ (1987). EMG profiles during normal human walking: Stride-to-stride and inter-subject variability. *Electroencephalography and clinical neurophysiology,* **67** (5), 402-411.

WINTER, EM. and FOWLER, N. (2009). Exercise defined and quantified according to the systeme international d'unites. *Journal of sports sciences,* **27** (5), 447-460.

WINTER, EM. and MACLAREN, DP. (2008). Assessment of maximal-intensity exercise. *Kinanthropometry and exercise physiology laboratory manual: Tests, procedures and data: Volume two: Physiology,* **2** , 307.

WOODS, JJ. and BIGLAND-RITCHIE, B. (1983). Linear and non-linear surface EMG/force relationships in human muscles. an anatomical/functional argument for the existence of both. *American journal of physical medicine,* **62** (6), 287.

World Medical Association. (2008). *World medical association declaration of helsinki: Ethical principles for medical research involving human subjects.* World Medical Association.

WREN, T., *et al.* (2008). Use of a patella marker to improve tracking of dynamic hip rotation range of motion. *Gait & posture,* **27** (3), 530-534.

YANG, JF. and WINTER, DA. (1983). Electromyography reliability in maximal and submaximal isometric contractions. *Archives of physical medicine and rehabilitation,* **64** (9), 417-420.

YOON, B. KRAVITZ, L. and ROBERGS, R. (2007). VO_{2max}, protocol duration, and the VO2 plateau. *Med sci sports exerc,* **39** (7), 1186-1192.

YOUNG, WB. MCDOWELL, MH. and SCARLETT, BJ. (2001). Specificity of sprint and agility training methods. *The journal of strength & conditioning research,* **15** (3), 315-319.

YU, C., *et al.* (2006). A method for automatic identification of reliable heart rates calculated from ECG and PPG waveforms. *Journal of the american medical informatics association,* **13** (3), 309-320.

ZAGATTO, A., *et al.* (2011). Anaerobic contribution during maximal anaerobic running test: Correlation with maximal accumulated oxygen deficit. *Scandinavian journal of medicine & science in sports,* **21** (6), e222-e230.

APPENDIX 1.1.

KINEMATICS AND NEUROMUSCULAR RECRUITMENT OF VERTICAL TREADMILL RUNNING

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Introduction
A vertical treadmill (VT) is being developed for the physical conditioning or rehabilitation of athletes. It requires a running action in a recumbent or supine position on a vertically hung, non-motorised treadmill whilst the limbs are supported with overhanging resistance cables. The aim of this study was to describe the kinematics and neuromuscular recruitment pattern of VT running.

Methods
Thirteen active males aged 24.8 (7.1) years, height 1.8 (0.1) m, body mass 77.7 (8.8) kg undertook two familiarisation sessions to determine self-selected (SS) running speed. On a third visit, at the SS running speed, sagittal plane kinematics of the ankle, knee and hip were collected using a motion capture system (200Hz). Activation of major leg muscles was determined by synchronised electromyography.

Results
Participants adopted a SS running speed of 2.12 (0.38) m/s and a cadence of 150 (20) steps/min. with a stance phase of 32.9 (6.6)% of the gait cycle. Ranges of motion at the ankle, knee and hip were 29.8 (3.6), 38.9 (8.7) and 34.8 (6.6)° respectively. The hamstrings were active between 0-30% of gait cycle and again at 57-100%. Gastrocnemius (GA) were both active 0-49% and 68-100%. Tibialis Anterior was active 0-8% and 15-100%. Rectus Femoris (RF) was active between 10-83% of gait cycle.

Discussion
VT running elicits similar SS speed (2.25m/s, Koga *et al.* 2009) and stance phase (31.1%, Mann *et al.*, 1980) to horizontal treadmill running. During VT running, the hamstrings pull the leg against the treadmill and resistance cables. RF initiates in stance to flex the hip and to control hamstring activity which ceases in late stance, thus hip hyperextension does not occur (peak extension 0.3 (5.7)°) as observed in horizontal running (Mann *et al.*, 1980). GA activity and peak plantarflexion (20.4 (4.9)°) after toe off indicate a propulsion phase seen in horizontal running (Mann *et al.*, 1980). However, the muscular force is likely not as high due the absence of body mass loading. In swing, peak knee flexion (64.4 (8.1)°) was driven by the RF flexing the hip, not by hamstring activity. In late swing the RF extended the knee alone since the Vasti muscles were inactive. The results indicate that VT running targets some of the muscles associated with the posterior chain that are essential for running performance and injury prevention (Askling *et al.*, 2003). In conclusion, the VT shares many similarities with horizontal running without impact loading thus it might be appropriate for injury rehabilitation and physical conditioning for overground running.

References

Askling C, Karlsson J, Thorstensson A. (2003). Scand J Med and Sci In Sport 13(4):244
Koga P, Candelaria N, Tomaka J. (2009). Sports Biom, 8(1):52
Mann, R. Hagy, J. (1980). Am J Sports Med, 8:345

APPENDIX 1.2.

CHARACTERISING THE PHYSIOLOGICAL RESPONSES TO VERTICAL TREADMILL EXERCISE

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Introduction

A vertical treadmill (VerT) is being developed for the physical conditioning or rehabilitation of athletes. It requires a running action in a recumbent position on a vertically hung, non-motorised treadmill whilst the limbs are supported with overhanging resistance cables. To compare VerT exercise with horizontal treadmill running, a Rate of Perceived Exertion (RPE) of 15 was chosen as it approximates Maximum Lactate Steady-State (MLSS) which is the highest steady-state intensity without a continual blood lactate accumulation (Dekerle *et al.*, 2003). The aim of this study was to determine the acute physiological responses to VT exercise at an RPE of 15.

Methods

With institutional ethics approval, five males aged 26 (2) years, height 1.81 (0.6) m, body mass 76.3 (6.8) kg were recruited. The participants' maximum oxygen consumption (51.7 (2.7) mL/kg/min) and Respiratory Compensation Point (RCP) were determined on a horizontal treadmill. MLSS was predicted from RCP minus 10% when expressed as percentage of maximum oxygen uptake (Dekerle *et al.*, 2003). VertT exercise was performed for three minutes at an RPE of 15 during which treadmill belt speed and pulmonary gas exchange were continuously measured. Blood lactate was measured at rest and immediately after VerT exercise.

Results

Predicted MLSS during horizontal treadmill running elicited an oxygen uptake equivalent to 73.9 (2.9)% of the maximum oxygen uptake and a corresponding heart rate of 93.3 (8.4)% of the maximum. At an RPE of 15 on the VerT (equivalent to MLSS intensity), oxygen uptake was 58.7 (8.6)% of the horizontal maximum oxygen uptake, heart rate was 74.5 (5.7)% of the maximum, blood lactate rose from 1.41 (0.41) mmol/L rested to 3.67 (1.6) mmol/L and VerT belt speed was 1.60 (0.25) m/s.

Discussion

VerT exercise elicits lower cardiovascular stress (HR and oxygen uptake) than horizontal running at the same perceived intensity. This might be explained by the participants in the current study being accustomed to, but not conditioned for VerT exercise as well as the effects of load bearing. During VerT exercise muscular force is required to draw the leg downwards against the resistance cables which adds to the postural effort. This might result in a contribution of type II fibres during VerT as evidenced by the 2.6 fold increase in blood lactate. Further research should make direct comparisons with RPE-matched horizontal running as a framework for characterising VerT.

References

Dekerle J, Baron B, Dupont L Vanvelcenaher J, Pelayo P. (2003). Maximal lactate steady state, respiratory compensation threshold and critical power. Eur J Appl Physiol. 89, 281-288.

APPENDIX 1.3.

SPRINT INTERVAL TRAINING ON THE VERTICAL TREADMILL

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Introduction
Over a third of injuries throughout the soccer season are related to repetitive impacts on joints during running (1). Recumbent exercise modes have been employed to reduce impact on joints during training (2). A vertical treadmill (VerT), which requires a running action in a recumbent posture on a vertically hung, non-motorised treadmill whilst the limbs are supported with overhanging resistance cables, was designed for the physical conditioning of athletes. It has not yet been established if there are physiological adaptations or performance benefits of training using a VerT. The aim of this study was to determine the effects of sprint interval training (SIT) on the VerT compared with over ground sprint training on aerobic and anaerobic power.

Methods
With institutional ethics approval, twenty active males aged 23 (3) years, stature 1.79 (7.35) m, body mass 77.6 (12.6) kg volunteered for this study. Participants' aerobic and anaerobic running power were determined by incremental $\dot{V}O_{2max}$ treadmill test and a maximum anaerobic running test (MART) respectively. Participants were pair matched, based upon their aerobic and anaerobic power, and assigned to VerT or 20 m shuttle sprint group (SG). SIT consisted of 4-6, 30 s all-out efforts with 4 minutes recovery between bouts, 3 days a week for 6 weeks.

Results
SIT increased $\dot{V}O_{2max}$ from 46.8 (5.4) to 49.9 (4.9) ml/kg/min in the VerT (p= 0.00) and from 46.1 (4.4) to 49.1 (5.2) ml/kg/min in the SG (p= 0.00). MART score (O_2 equivalents) also increased from 105.2 (8.6) to 109.7 (8.7) ml/kg/min in the VerT (p= 0.00) and from 104.8 (9.3) to 108.9 (9.2) ml/kg/min in the SG (p=0.00). There were no group x time interactions.

Discussion
The improvement in aerobic and anaerobic power for SG was similar to that reported previously (3). The findings of this study suggest that SIT on the VerT results in similar improvements in aerobic and anaerobic running power to those from over ground sprint training. Therefore, the VerT could be used as a low-impact conditioning tool and might be a substitute for exercise involving prolonged over ground running.

References
1. Engström, B. Forssblad, M. Johansson, C. Törnkvist, H. (1990). Does a major knee injury definitely sideline an elite soccer player? Am. J. Sports Med. 18(1):101-5.
2. Billinger, S. Loudon, J. Gajewski, B. (2008). Validity of a Total Body Recumbent Stepper Exercise Test to Assess Cardiorespiratory Fitness. J. Strength and Cond. Res. 22(5):1556-1562.
3. Hazell, T. Macpherson, R. Gravelle, B. Lemon, P. (2010). 10 or 30-s sprint interval training bouts enhance both aerobic and anaerobic performance. Eur. J. Appl. Physiol. 110(1):153-60.

Sheffield Hallam University

Faculty of Health and Wellbeing Research Ethics Committee

Sport and Exercise Research Ethics Review Group

Participant Information Sheet

Project Title	The biomechanical and physiological profile of vertical treadmill exercise
Supervisor/Director of Studies	Mary Fysh
Principal Investigator	Alastair Jordan
Principal Investigator telephone/mobile number	Tel: 0114 255 5368 Mobile: 07931 633 677

Purpose of Study and Brief Description of Procedures

(Not a legal explanation but a simple statement)

Exercising in a recumbent position has been reported to reduce the gravitational gradient acting on the cardiovascular and respiratory systems thus altering their function and the capacity to exercise. A vertical treadmill has been developed to encompass reported benefits of recumbent exercise whilst employing a running action. It consists of a non-motorised treadmill that is suspended vertically from a steel frame, a horizontal bench and seat that can be used to manipulate the position of the user (more or less recumbent) and resistance is offered from overhanging cables attached to the legs and arms. To date there has not been any research regarding the use and feasibility of the vertical treadmill as a training or rehabilitation aid; hence you could be part of pioneering research.

As a voluntary participant in this study you will be asked to attend the Centre for Sport and Exercise Science (CSES) at Collegiate Crescent Campus, Sheffield on four days separated by at least 24hr recovery, but no longer than one week between visits. On your first day, you will be asked to fill out a pre-screening questionnaire to ensure it is safe for you to proceed with exercise on the vertical treadmill and an informed consent form. You will be given a demonstration of the vertical treadmill by the researcher; you will then have the chance to familiarise yourself with the vertical treadmill in different body positions. Once familiarised with the vertical treadmill action you will try exercising at set speeds whilst keeping in time with a

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metronome. The intensity during familiarisation process will be light and the session will take approximately 30 minutes. Participants are asked to wear normal sports kit for the first visit and preferably tight fitting clothing for subsequent visits. You will of course have the opportunity to ask questions throughout the familiarisation session. Following the familiarisation session you will be asked to return to CSES laboratories 24 hours-7days for testing.

When you return to CSES your height and mass will be measured. You will then lye on a plinth where reflective balls will be adhered to joints on the right side of the body and some electrodes to detect electrical activity of muscles of the right leg. This process will involve marking the skin with dots using non-toxic ink. We will position you on the treadmill and give you time for a brief warm up. Following your warm up, we will ask you to walk, jog and run for approximately a minute each or until you reach a constant speed and step rate in 3 different postures (seated upright, reclined and lying down). There will be brief periods of recovery between each posture change and cool down after all postures have been completed. Whilst you are on the vertical treadmill we will record movement of reflective balls and data regarding activity of your muscles as well as speed and step rate which you will try to replicate in subsequent visits. The session should take approximately 1.5 hours in total. You will then repeat the testing protocol on your third and fourth visit with at least 24hr between each visit but no longer than one week. You have the right to withdraw from the study at any time.

It has been made clear to me that, should I feel that these Regulations are being infringed or that my interests are otherwise being ignored, neglected or denied, I should inform Professor Edward Winter, Chair of the Faculty of Health and Wellbeing Research Ethics Committee (Tel: 0114 225 4333) who will undertake to investigate my complaint.

Sheffield Hallam University

Faculty of Health and Wellbeing Research Ethics Committee

Sport and Exercise Research Ethics Review Group

Participant Information Sheet

Project Title	The acute physiological responses to vertical treadmill exercise
Supervisor/Director of Studies	Mary Fysh
Principal Investigator	Alastair Jordan
Principal Investigator telephone/mobile number	Tel: 0114 255 5368 Mobile: 07931 633 677

Purpose of Study and Brief Description of Procedures

(Not a legal explanation but a simple statement)

Exercising in a recumbent position has been reported to reduce the gravitational gradient acting on the cardiovascular and respiratory systems thus altering their function and the capacity to exercise. A vertical treadmill has been developed to encompass reported benefits of recumbent exercise whilst employing a running-like action. It consists of a non-motorised treadmill that is suspended vertically from a steel frame, a horizontal bench and seat that can be used to manipulate the position of the user and resistance is offered from overhanging cables attached to the legs. To date there has not been any research regarding the use and feasibility of the vertical treadmill as a training or rehabilitation aid.

As a voluntary participant in this study you will be asked to attend the Centre for Sport and Exercise Science at Collegiate Crescent Campus, Sheffield on 3 separate days (additional familiarisation session for new vertical treadmill users). Participants are asked to wear normal sports kit for all visits. Please refrain from strenuous exercise 24 hours before testing.

Familiarisation session (for new exercisers)

If you have not used a vertical treadmill before you will asked to attend familiarisation session. You will be given a demonstration of the vertical treadmill by the researcher and you will then have the chance to familiarise yourself with the vertical treadmill in different body positions. You will of course have the opportunity to ask questions throughout the familiarisation session. The intensity during familiarisation process will be light and will take approximately 30 minutes.

1. Aerobic Fitness Test

After familiarisation session you will be given 24 hours to recover before you

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undertake a test of your aerobic fitness ($\dot{V}O_{2\,max.}$ test). On arrival you will also be asked to fill out a pre-screening questionnaire to ensure it is safe for you to proceed and an informed consent form. Your height and mass will be measured and you will rest supine for 15 minutes. After resting for 15 minutes a finger tip blood sample will be taken for blood lactate analysis followed by a blood pressure measurement. Then you will be fitted with a heart rate belt, gas analysis face mask that measures the gases you breathe in and out and then harnessed to the treadmill frame. The $\dot{V}O_{2\,max.}$ test involves running on a conventional treadmill starting off slow with a low inclination of the treadmill. The speed and inclination of the treadmill will be increased by 1km/h every minute until you can no longer maintain the speed. The test will last 9-12 minutes.

2. Anaerobic Fitness Test

After a minimum of 48 hours you will return to the laboratories to undertake an anaerobic fitness test. You will be weighed, height measured, fitted with a heart rate belt and will be rested in a supine posture for 15 minutes. After resting a finger tip blood sample will be taken for blood lactate analysis followed by a blood pressure measurement. You will then be harnessed on to a conventional treadmill and fitted with gas analysis face mask. The protocol consists of 20 s runs (with an additional 3 s acceleration phase) with a 100 s recovery between runs on the inclined treadmill (10.5%). The first 20 s run will be at 14.3 km/h and will increase every stage by 1.2 km/h until you can't do any more.

3. Steady-state and sprint exercise on vertical treadmill with verification sprint

After 48 hours of rest you will return to determine the physiological demands of low, moderate, high intensity exercise on the vertical treadmill. You will have a blood pressure reading and then fitted with a HR monitor and gas analysis mouthpiece with nose clip. You will then rest on the vertical treadmill for 15 minutes and then have a fingertip blood sample taken, followed by a blood pressure measurement. You will then be asked to undertake self-selected 'walking' on the vertical treadmill for 3 minutes, followed immediately by a 3 minute stage of jogging, run for a further 3 minutes followed by an all-out sprint for 1 minute. At the end of each stage, a fingertip blood sample will be taken. Participants will then rest for 15 minutes before undertaking the verification sprint. You will then exercise at 110% of the speed achieved in the all-out sprint until you fatigue and can no longer maintain the required speed. After you fatigue and cease exercising you will have a fingertip blood sample taken, gas analysis and nose clip removed and then encouraged to cool down.

Reliability study: To assess the reliability of the measures taken during horizontal and vertical treadmill exercise you might be asked to repeat the 3 testing protocols a week later. Once again this is not obligatory.

You have the right to withdraw from the study at any time.

Sheffield Hallam University

Faculty of Health and Wellbeing Research Ethics Committee

Sport and Exercise Research Ethics Review Group

Participant Information Sheet

Project Title	The effects of vertical treadmill high intensity interval training
Supervisor/Director of Studies	Mary Fysh
Principal Investigator	Alastair Jordan
Principal Investigator telephone/mobile number	Tel: 0114 255 5368 Mobile: 07931 633 677

Purpose of Study and Brief Description of Procedures

(Not a legal explanation but a simple statement)

A vertical treadmill has been developed for rehabilitation and strength and conditioning. It consists of a non-motorised treadmill that is suspended vertically from a steel frame, a horizontal bench and seat that can be used to manipulate the position of the user and resistance is offered from overhanging cables attached to the legs. To date there has been little research regarding the use and feasibility of the vertical treadmill as a training or rehabilitation aid.

As a voluntary participant in this study you will be assigned to either a "normal training" group or a "vertical treadmill" training group or a "control group".

If you are assigned to the normal training group, you will be asked to continue with your usual training regime supplemented with high intensity intermittent training (HIIT) on a treadmill. If you are assigned to vertical treadmill training group you will supplement your normal training with HIIT performed on the vertical treadmill. Both HIIT protocols have the same sets and reps, just the exercise mode is different (running or vertical treadmill). The protocol involves 6 weeks of HIIT with one week pre- and post-fitness testing. The HIIT sessions require participants to perform 4-6 all-out efforts for 30 s separated by 4.5 minutes recovery between sets, three times a week.

If you are in the vertical treadmill group and unaccustomed to vertical treadmill exercise you will be asked to undertake 2 additional visits for habituation prior to engaging in the testing and exercise programmes. You will be given a demonstration of the equipment and then have a go at a variety of exercise intensities. You will of course have the opportunity to ask questions throughout the familiarisation session.

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Familiarisation sessions will take approximately 30 minutes each.

To assess the effectiveness of the six week training programmes you will be required to undertake fitness tests prior to and after the completion of the training programme. In these weeks of fitness tests you will be asked to assess your current level of physical activity via a short questionnaire.

Pre- and post-HIIT testing

On your first visit (height and body composition measurement) you will be asked to fill out a pre-screening questionnaire to ensure it is safe for you to proceed, an informed consent form and a physical activity questionnaire before undertaking the tests.

1. Height and Body Composition

In bare feet, your height will be measured and you will be asked to stand on a machine which will determine your body mass and composition (fat, muscle, water etc.). You can then undertake one of the following tests in the same day.

2. Lactate threshold and aerobic fitness test

You should be rested for a minimum of 24 hours before attending the laboratory and you are asked not to eat in the preceding 3 hours. You will be weighed, height measured and rested for a few minutes, after which a fingertip blood sample (one drop) will be taken for analysis. The conventional treadmill will remain inclined by 1% throughout the test to mimic the demands of running over ground. You will undertake very light, somewhat hard and hard exercise for 3 minutes each. Each 3 minute bout will be separated by 1 minute of rest while a drop of blood is taken from the fingertip for blood lactate analysis. After 15 minutes of rest you will be asked to undertake a $\dot{V}O_{2\,max.}$ test.

After resting for 15 minutes you will be fitted with a heart rate belt, gas analysis face mask that measures the gases you breathe in and out and then harnessed to the treadmill frame. The test involves running on a conventional treadmill starting off slow (9 km/h) with a 1% gradient. The speed of the treadmill will be increased by 1km/h every minute until you can no longer maintain the speed. The test will last 9-12 minutes.

3. Anaerobic Fitness Test

After a minimum of 48 hours rest you will be weighed, height measured, fitted with a heart rate belt and a finger tip blood sample will be taken for blood lactate analysis. You will then be harnessed on to a conventional treadmill to warm up for 4 minutes on the inclined treadmill (10.5%) at a speed of 8 km/h interspersed with 2 x 20 s at 14.3 km/h. You will then undertake 10 minutes of dynamic stretching away from the treadmill. The test protocol consists of 20 s runs (with an additional 3 s acceleration phase) with a 100 s recovery between runs. The first 20 s run will be at 14.3 km/h and will increase every stage by 1.2 km/h until you can't do any more. A blood lactate sample will be taken immediately after the test.

Participants are asked to wear normal sports kit for all visits and please refrain from

strenuous exercise 24 hours before each testing session.

Once the exercise programme and the testing have been completed you can perform the HIIT protocol on the other exercise mode should you wish to do so with the full support of the researcher.

You have the right to withdraw from the study at any time.

It has been made clear to me that, should I feel that these Regulations are being infringed or that my interests are otherwise being ignored, neglected or denied, I should inform Professor Edward Winter, Chair of the Faculty of Health and Wellbeing Research Ethics Committee (Tel: 0114 225 4333) who will undertake to investigate my complaint.

APPENDIX 3.

Sheffield Hallam University

Faculty of Health and Wellbeing Research Ethics Committee

Sport and Exercise Research Ethics Review Group

INFORMED CONSENT FORM	
TITLE OF PROJECT:	
The participant should complete the whole of this sheet himself/herself	
Have you read the Participant Information Sheet?	YES/NO
Have you had an opportunity to ask questions and discuss this study?	YES/NO
Have you received satisfactory answers to all of your questions?	YES/NO
Have you received enough information about the study?	YES/NO
To whom have you spoken?... Do you understand that you are free to withdraw from the study: • at any time • without having to give a reason for withdrawing • and without affecting your future medical care	YES/NO
Have you had sufficient time to consider the nature of this project?	YES/NO
Do you agree to take part in this study?	YES/NO
Signed .... Date .... (NAME IN BLOCK LETTERS)..	
Signature of Parent / Guardian in the case of a minor	

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Consent to scientific illustration

I hereby confirm that I give consent for photographic and/or videotape and sound recordings (the 'material') to be made of me. I confirm that the purpose for which the material would be used has been explained to me in terms which I have understood and I agree to the use of the material in such circumstances. I understand that if the material is required for use in any other way than that explained to me then my consent to this will be specifically sought.

1. I understand that the material will form part of my confidential records and has value in scientific assessment and I agree to this use of the material.

Signed... Date...

Signature of Parent / Guardian in the case of a minor

....

2. I understand the material has value in teaching and I consent to the material being shown to appropriate professional staff for the purpose of education, staff training and professional development.

Signed... Date...

Signature of Parent / Guardian in the case of a minor

....

I hereby give consent for the photographic recording made of me on.......................... to be published in an appropriate journal or textbook. It is understood that I have the right to withdraw consent at any time prior to publication but that once the images are in the public domain there may be no opportunity for the effective withdrawal of consent.

Signed .... Date ....

Signature of Parent / Guardian in the case of a minor

....

Sheffield Hallam University

Faculty of Health and Wellbeing Research Ethics Committee
Sport and Exercise Research Ethics Review Group

Pre-Test Medical Questionnaire

Name:

_____

Date of Birth: _____ Age: _____ Sex: _____

Please answer the following questions by putting a circle round the appropriate response or filling in the blank.

1. How would you describe your present level of activity?
   Sedentary / Moderately active / Active / Highly active

2. How would you describe you present level of fitness?
   Unfit / Moderately fit / Trained / Highly trained

3. How would you consider your present body weight?
   Underweight / Ideal / Slightly over / Very overweight

4. Smoking Habits Are you currently a smoker?   Yes / No
   How many do you smoke   ......per day
   Are you a previous smoker?   Yes / No
   How long is it since you stopped?   ....years
   Were you an occasional smoker?   Yes / No
   ....per day
   Were you a regular smoker?   Yes / No
   ....per day

5. Do you drink alcohol?   Yes / No
   If you answered **Yes**, do you usually have?
   An occasional drink / a drink every day / more than one drink a day?

6. Have you had to consult your doctor within the last six months?Yes / No
   If you answered **Yes**, please give details.......................................
   ....
   ....

7. Are you presently taking any form of medication?   Yes / No
   If you answered **Yes**, please give details.......................................
   ....
   ....

8. As far as you are aware, do you suffer or have you ever suffered from:

a Diabetes?	Yes / No	**b** Asthma?	Yes / No
c Epilepsy?	Yes / No	**d** Bronchitis?	Yes / No
e *Any heart complaint?	Yes / No	**f** Raynaud's Disease	Yes / No
g *Marfan's Syndrome?	Yes / No	**h** *Aneurysm/embolism?	Yes/No
I Anaemia	Yes / No		

9. *Is there a history of heart disease in your family?   Yes/No

10. *Do you currently have any form of muscle or joint injury?   Yes/No
If you answered **Yes**, please give details…………………………………
………………………………………………………………………………
………………………………………………………………… …..

11. Have you had to suspend your normal training in the last two weeks?
Yes /No
    If   the   answer   is   **Yes**   please   give   details
………………………………………………………………………………
………………………………………………………………………………

If blood is not being taken from you please disregard Section 12. below.

12. * Please read the following questions:
    a)   Are you suffering from any known serious infection?   Yes/No
    b)   Have you had jaundice within the previous year?   Yes/No
    c)   Have you ever had any form of hepatitis?   Yes/No
    d)   Are you HIV antibody positive   Yes/No
    e)   Have you had unprotected sexual intercourse with any
          person from an HIV high-risk population?   Yes/No
    f)   Have you ever been involved in intravenous drug use?   Yes/No
    g)   Are you hemophiliac?   Yes/No

13. As far as you are aware, is there anything that might prevent you from
    successfully completing the tests that have been outlined to you?
    Yes/No

IF THE ANSWER TO ANY OF THE ABOVE IS YES: Discuss the nature of

the problem with the Principal Investigator. Questions indicated by (*)

Allow your Doctor to fill out the 'Doctors Consent Form provided.

As far as I am aware the information I have given is accurate.

Signature: ………………………………………………………………..

Signature of Parent or Guardian if the subject is under 18:

…………………………………………………………Date: ……/……/………

APPENDIX 5. Justification of statistical analyses.

Comparison of group means

t-test

The t-test is a simple analysis that examines the differences between 2 groups (Foster *et al.*, 2006). There are 2 types of t-test available, independent and dependent t-test, the selection of which depends on the experimental design. In an independent t-test, there are 2 conditions and different participants were assigned to either condition. A dependent t-test involves 2 conditions in which participants were tested in both conditions (Field, 2005).

Analysis of variance

Analysis of Variance (ANOVA) examines the differences between the means of three or more groups and tests a global null (De Sá Marques, 2007). A benefit of the ANOVA tests rather than performing multiple t-tests is the identification of interactions that exist between the variables. That is, whether the effect of one variable influences another (Foster *et al.*, 2006). Also performing multiple t-tests between variables does not consider all information and has a greater chance of incurring a 'type I' error whereby the null hypothesis is rejected when it is in fact true (Field, 2005). There are several types of ANOVA test available (with-in, between and mixed ANOVA), the selection of which is dependent on the experimental design. If a difference is detected by ANOVA, post-hoc tests such as Tukey's, Bonferroni or Sidak could be employed in which multiple paired comparisons are made on all variables. The post-hoc tests have correction factors to reduce the potential of acquiring a type I error and are therefore more favourable to performing multiple t-tests (Foster *et al.*, 2006).

Effect size

To determine whether a statistical significance demonstrates a sizable and therefore a meaningful effect, effect size calculations must be performed. Effect size is a standardised method of measuring the magnitude of an effect, whether it is the strength of a relationship between variables or differences between observed variables (Field, 2005). A common measure of effect size is cohen's d. Cohen's d. Cohen (1988) constructed guidelines on what constitutes as a large (0.8), medium (0.5) and small effect (0.2). Effect sizes should accompany reports of statistical significance to assess the meaningfulness of the differences between variables (Bakeman, 2005).

Reliability

Reliable measurement techniques are desirable as it implies a greater precision of single measures and superior tracking of changes in measures over an intervention (Hopkins, 2000). An observed measurement consists of the true measure and some degree of systematic and/or random error. The reliability can be quantified as the ratio between total variance (true measure + error) and the true data.

$$Reliability = \frac{true\ measure}{true\ measure + error}$$

Minimising the error in the data is key to improving reliability, however, some degree of error will always be present. Therefore, Lachin (2004) advocated the publication of reliability of measurements as to allow the authors to better describe and readers to better understand the sources of error in the results. There are several methods available to estimate the reliability of measurement

techniques, each with pros and cons. There does not appear to be one single acceptable measure of reliability and so several measures are often presented.

Coefficient of variation

The coefficient of variance (CV) indicates the degree of variation in the data set and is commonly used in the assessment of reliability. Lachin, (2004) stated that CV is not strictly speaking a measure of reliability since it does not measure the consistency between repeated measures, rather the variation in data sets. The CV is the ratio of the standard deviation to the mean and is often expressed as a percentage, thus making it unit independent. Therefore comparisons can be made between variables with different units. Bland and Altman (1986) expressed concerns with expressing the error as a percentage because the percentage of the smaller measures will differ from that of larger measures.

Technical error measurement

Perini *et al.*, (2005) and Geeta *et al.*, (2009) described the Technical Error Measurement (TEM) as an index of accuracy and is representative of the quality of the measurement and control dimension. In simpler terms, when measures of a variable are taken from the same individual on separate occasions, differences often exist that are due to the measurement technique and often stem from inaccuracies in the intra- and inter- examiner measurement technique (Perini *et al.*, 2005). Mueller and Marterell (1988) highlighted one potential disadvantage of the TEM by suggesting that the TEM requires a minimum of 50 samples if it is to be used as a measure of reliability, however reliability studies have reported TEM with lower samples sizes (Deakin *et al.*, 2011).

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The limits of agreement (LOA) technique has been used extensively since its development by Bland and Altman (1986) to assess the amount by which an independent variable varies from a dependent variable which is seen as the 'predictor' or 'gold standard' measure. The LOA indicates the range in which 95% of the differences lie within ± 1.96 standard deviations of the mean difference (Bland and Altman, 1986). If the variance from the regression line differs then the data requires a logarithm before the LOA can be executed. Although the LOA has been extensively used to indicate the reliability of measurement techniques, its use is heavily debated. The LOA provides a range for the data rather than a definitive figure of reliability and so its interpretation is subjective. Also, the LOA assumes one of the two measures is a gold standard and as such is free from error. This is seldom the case. Reliability in sport science often involves data, neither of which is the gold standard, especially in test retest situations and it is accepted that both measures contains an amount of error (Hopkins, 2000). A benefit of the LOA is that the LOA range produced is in the same units and therefore is easily understood in the context of the variable being measured. It is for these reasons that the LOA analysis was performed and the results collaborated with other reliability test results to collectively determine the reliability of the studies in this thesis.

Intra-class correlation coefficient

Intra-class Correlation Coefficient (ICC) has been implemented in the analysis of the agreement or consistency between two measurements (Bland and Altman, 1990). ICC quantifies the reliability by means of a ratio of variances derived from ANOVA. There are several forms of ICC, however Weir (2005)

suggests that in the sports science context where reliability is often measured on a test-retest basis requires a simple ICC measure defined by Bland and Altman (1995). A benefit of the ICC method is that it is unaffected by the order of the data unlike some other measures of reliability (LOA), because it represents the average correlation across all orderings of pairs (Bland and Altman, 1990).

Some authors have expressed concerns over the use of ICC. Firstly, attempts to clarify what constitutes a good or poor ICC are sparse. Vincent (2012) attempted to categorise ICC scores and suggested that an ICC of 0.7-0.8 indicated 'questionable' reliability, 0.8-0.89 indicated moderate reliability and >0.9 indicated high reliability. However, Atkinson and Nevill (1998) reported that there was no general consensus regarding what constitutes a good or poor ICC and this could be a result of the numerous versions of ICC that are available. Secondly, ICC was reported to be influenced by the between-subjects variability thus the heterogeneity of the participant groups influences the resultant ICC and so requires consideration (Atkinson and Nevill, 1998 and Weir, 2005). The result of this relationship with between subjects variance is that when measurement error is small, a poor ICC could still be demonstrated when the between-subjects variability is low. Similarly, when measurement error is a high, a high ICC could be demonstrated due to high between-subjects variability.

Although the between-subjects and ICC relationship is seen as disadvantageous, Weir (2005) states that ICC effectively normalises the measurement error to the heterogeneity of the group and provides an appropriate relative measure of reliability rather than an absolute measurement

error. If ICC is intended to be used as an absolute measure of reliability it is recommended that standard error of measurement (SEM) accompanies ICC reports.

Standard error of measurement

Standard Error of Measurement (SEM) was reported to be an absolute measure of reliability and provides an indication of the precision of a score (Weir, 2005). The inclusion of the standard deviation was reported to 'cancel' out the intra-individual variability that is evident in the calculation of ICC (Bland and Altman, 1990). It is however affected by the sample heterogeneity and the resultant SEM is also dependent on the correct type of ICC being selected. Despite these concerns the calculation of SEM is useful as it enables the calculation of confidence intervals.

Confidence intervals

Confidence intervals represent the lower and upper boundaries of which a specified percentage of the sample population are distributed around the mean. The most commonly presented is the 95% CI which is 2 standard deviations around the mean, with the less frequently used 68% CI (1 standard deviation) (Field, 2005).

Instructions to the Borg-RPE-Scale[®]

During the work we want you to rate your perception of exertion, i.e. how heavy and strenuous the exercise feels to you and how tired you are. The perception of exertion is mainly felt as strain and fatigue in your muscles and as breathlessness or aches in the chest.

Use this scale from 6 to 20, where 6 means "No exertion at all" and 20 means "Maximal exertion."

9   Very light. As for a healthy person taking a short walk at his or her own pace.

13   Somewhat hard. It still feels OK to continue.

15   It is hard and tiring, but continuing is not terribly difficult.

17   Very hard. It is very strenuous. You can still go on, but you really have to push yourself and you are very tired.

19   An extremely strenuous level. For most people this is the most strenuous exercise they have ever experienced.

Try to appraise your feeling of exertion and fatigue as spontaneously and as honestly as possible, without thinking about what the actual physical load is. Try not to underestimate, nor to overestimate. It is your own feeling of effort and exertion that is important, not how it compares to other people's. Look at the scale and the expressions and then give a number. You can equally well use even as odd numbers.

Any questions?

BORG

6	No exertion at all
7	
	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

APPENDIX 7.1.

Mean (SD), main effect, pairwise comparisons and effect size of temporal-spatial parameters during incremental (perceived walking, jogging and running) vertical treadmill exercise in the supine (0°), 40° and 70° postures. * indicates main effect for posture ($p<0.05$), † indicates main effect for speed ($p<0.05$).

		Walking		Jogging		Running			Posture		Effect size				Speed		Effect size		
Variable	Posture (°)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Main effect p	Posture (°)	Pairwise p	Walk	Jog	Run	Main effect p	Speeds	Pairwise p	0°	40°	70°
Speed (m·s⁻¹) * †	0	1.01	(0.26)	1.49	(0.29)	2.02	(0.39)	0.000	0-40	0.007	-0.37	-0.71	-0.44	0.000	W-J	0.000	-1.74	-2.22	-2.03
	40	1.11	(0.24)	1.69	(0.28)	2.17	(0.28)		40-70	1.000	-0.04	-0.13	-0.22		J-R	0.000	-1.57	-1.71	-1.36
	70	1.12	(0.28)	1.73	(0.32)	2.25	(0.45)		0-70	0.001	-0.38	-0.79	-0.56		W-R	0.000	-3.06	-4.03	-3.10
Cadence (steps·min⁻¹) * †	0	93.0	(20.2)	124.4	(14.7)	147.2	(17.8)	0.000	0-40	0.003	-0.20	-0.53	-0.40	0.000	W-J	0.000	-1.78	-1.94	-2.26
	40	96.7	(18.1)	133.6	(19.9)	154.5	(18.9)		40-70	0.614	-0.15	-0.09	-0.25		J-R	0.000	-1.39	-1.08	-1.52
	70	99.3	(16.8)	135.2	(14.9)	158.9	(16.2)		0-70	0.001	-0.34	-0.73	-0.68		W-R	0.000	-2.85	-3.12	-3.61
Stride length (m) †	0	1.31	(0.18)	1.43	(0.23)	1.65	(0.25)	0.073	0-40	0.166	-0.35	-0.40	-0.21	0.000	W-J	0.000	-0.61	-0.68	-0.79
	40	1.38	(0.21)	1.53	(0.24)	1.69	(0.19)		40-70	1.000	0.14	-0.05	-0.04		J-R	0.000	-0.89	-0.75	-0.56
	70	1.35	(0.21)	1.54	(0.28)	1.70	(0.29)		0-70	0.142	-0.19	-0.43	-0.20		W-R	0.000	-1.55	-1.59	-1.40
Gait cycle time (s) * †	0	1.35	(0.30)	0.98	(0.11)	0.83	(0.11)	0.001	0-40	0.035	0.26	0.46	0.42	0.000	W-J	0.000	1.69	1.86	2.02
	40	1.28	(0.24)	0.92	(0.15)	0.79	(0.09)		40-70	0.483	0.17	0.12	0.28		J-R	0.000	1.36	1.08	1.35
	70	1.25	(0.21)	0.90	(0.12)	0.76	(0.08)		0-70	0.004	0.42	0.66	0.69		W-R	0.000	2.36	2.77	3.05
Contact Distance (m)	0	0.61	(0.10)	0.60	(0.11)	0.62	(0.13)	0.773	0-40	1.000	-0.23	0.03	-0.04	0.608	W-J	1.000	0.05	0.29	-0.11
	40	0.63	(0.11)	0.60	(0.12)	0.62	(0.15)		40-70	1.000	0.31	-0.12	0.13		J-R	0.909	-0.13	-0.17	0.07
	70	0.60	(0.08)	0.61	(0.11)	0.61	(0.13)		0-70	1.000	0.06	-0.10	0.10		W-R	1.000	-0.09	0.07	-0.02
% Gait cycle in contact †	0	54.1	(5.9)	59.9	(6.4)	66.7	(6.0)	0.390	0-40	1.000	-0.09	-0.30	0.03	0.000	W-J	0.000	-0.94	-1.05	-1.18
	40	54.7	(6.8)	61.9	(6.9)	66.5	(4.8)		40-70	0.604	0.14	0.15	0.21		J-R	0.000	-1.09	-0.77	-0.81
	70	53.7	(6.4)	60.9	(5.8)	65.4	(5.3)		0-70	1.000	0.06	-0.17	0.22		W-R	0.000	-2.11	-2.01	-1.99
RPE * †	0	10.9	(2.0)	13.0	(2.2)	15.1	(1.8)	0.000	0-40	0.001	0.69	0.48	0.69	0.000	W-J	0.000	-0.97	-1.39	-1.04
	40	9.5	(2.1)	12.0	(1.5)	13.9	(1.9)		40-70	0.122	0.05	0.40	0.05		J-R	0.000	-1.11	-1.04	-1.24
	70	9.4	(2.0)	11.4	(1.8)	13.8	(2.0)		0-70	0.000	0.75	0.79	0.73		W-R	0.000	-2.22	-2.17	-2.19

APPENDIX 7.2.

Mean (SD), main effect, pairwise comparisons and effect size of joint kinematics during incremental (perceived walking, jogging and running) vertical treadmill exercise in the supine (0°), 40° and 70° postures. * indicates main effect for posture (p<0.05), † indicates main effect for speed (p<0.05).

Joint	Variable	Posture (°)	Walking Mean	(SD)	Jogging Mean	(SD)	Running Mean	(SD)	Main effect p	Posture (°)	Posture Pairwise p	ES Walk	ES Jog	ES Run	Main effect p	Speeds	Speed Pairwise p	ES 0°	ES 40°	ES 70°
Ankle	Initial contact (°) *	0	4.6	(7.2)	3.8	(7.5)	6.7	(8.3)	0.000	0-40	0.000	-0.86	-0.84	-0.46	0.709	W-J	1.000	0.10	0.03	0.11
		40	10.4	(6.2)	10.1	(7.6)	10.2	(6.9)		40-70	1.000	-0.21	-0.11	0.11		J-R	1.000	-0.36	-0.01	0.22
		70	11.7	(6.4)	10.9	(6.8)	9.4	(7.4)		0-70	0.000	-1.04	-1.00	-0.35		W-R	1.000	-0.27	0.03	0.33
	Peak dorsiflexion *† in contact (°)	0	10.5	(8.0)	10.1	(7.3)	11.2	(7.2)	0.000	0-40	0.000	-0.81	-0.61	-0.35	0.017	W-J	0.151	0.04	0.19	0.30
		40	16.2	(5.8)	14.9	(8.1)	13.7	(7.3)		40-70	0.629	0.09	0.16	0.24		J-R	0.552	-0.14	0.14	0.23
		70	15.6	(6.3)	13.6	(6.9)	12.0	(6.9)		0-70	0.006	-0.71	-0.49	-0.12		W-R	0.046	-0.09	0.37	0.54
	Peak plantarflexion (°) †	0	-16.2	(8.8)	-19.5	(6.9)	-19.5	(7.0)	0.847	0-40	1.000	-0.07	0.00	0.19	0.000	W-J	0.002	0.22	0.57	0.44
		40	-15.6	(6.3)	-19.5	(7.2)	-20.8	(6.1)		40-70	1.000	0.13	0.02	-0.02		J-R	0.412	0.01	0.20	0.16
		70	-16.5	(7.3)	-19.6	(6.8)	-20.7	(7.0)		0-70	1.000	0.04	0.02	0.17		W-R	0.001	0.42	0.84	0.59
	Peak dorsiflexion *† in swing (°)	0	6.3	(5.0)	5.2	(5.9)	5.8	(6.3)	0.000	0-40	0.002	-0.65	-0.53	-0.32	0.003	W-J	0.085	0.21	0.20	0.28
		40	9.3	(4.3)	8.3	(5.6)	7.7	(5.5)		40-70	0.005	-0.61	-0.44	-0.22		J-R	0.168	-0.09	0.10	0.34
		70	11.8	(4.0)	10.5	(4.8)	8.8	(5.2)		0-70	0.000	-1.22	-0.99	-0.53		W-R	0.009	0.08	0.32	0.63
	Range of motion (°) *†	0	27.1	(6.4)	29.9	(6.1)	30.8	(4.7)	0.000	0-40	0.000	-0.13	-0.33	-0.16	0.003	W-J	0.022	-0.65	-0.62	-0.63
		40	31.8	(7.9)	34.5	(8.4)	34.6	(7.1)		40-70	1.000	-0.17	-0.02	0.10		J-R	1.000	-0.08	0.09	0.22
		70	32.4	(9.0)	33.7	(6.9)	33.0	(7.1)		0-70	0.004	-0.67	-0.37	-0.07		W-R	0.037	-0.69	-0.59	-0.37
Knee	Initial contact (°) *†	0	-25.4	(9.2)	-30.4	(8.4)	-33.3	(8.7)	0.000	0-40	0.000	0.77	0.88	0.74	0.000	W-J	0.000	0.57	0.57	0.61
		40	-33.0	(10.3)	-39.1	(11.1)	-41.1	(12.1)		40-70	0.702	-0.04	-0.17	-0.30		J-R	0.101	0.33	0.18	0.06
		70	-32.6	(7.7)	-37.4	(8.1)	-37.9	(9.6)		0-70	0.002	0.85	0.84	0.50		W-R	0.000	0.87	0.72	0.61
	Peak knee flexion *† in swing (°)	0	-55.1	(10.3)	-58.7	(10.5)	-62.0	(10.3)	0.007	0-40	0.315	0.26	0.23	0.21	0.000	W-J	0.000	0.34	0.34	0.47
		40	-57.7	(9.5)	-61.2	(10.9)	-64.4	(11.9)		40-70	0.000	-0.60	-0.45	-0.25		J-R	0.000	0.32	0.28	0.45
		70	-52.1	(9.2)	-56.5	(9.8)	-61.4	(11.7)		0-70	0.594	-0.31	-0.21	-0.06		W-R	0.000	0.67	0.62	0.89
	Peak knee extension *† in swing (°)	0	-20.8	(8.5)	-24.5	(9.2)	-26.0	(9.6)	0.000	0-40	0.000	0.81	1.03	0.99	0.000	W-J	0.000	0.42	0.63	0.64
		40	-28.3	(10.0)	-34.9	(10.1)	-36.9	(12.1)		40-70	1.000	0.29	0.10	-0.06		J-R	0.415	0.16	0.17	0.04
		70	-30.8	(7.6)	-35.8	(8.3)	-36.2	(9.2)		0-70	0.000	1.25	1.30	1.08		W-R	0.000	0.58	0.77	0.63
	Range of motion (°)	0	35.5	(8.6)	35.6	(8.6)	37.1	(8.7)	0.056	0-40	0.048	0.37	0.50	0.50	0.094	W-J	1.000	-0.02	0.14	-0.14
		40	32.6	(6.9)	31.7	(7.1)	32.9	(7.6)		40-70	0.576	0.02	-0.25	-0.42		J-R	0.176	-0.17	-0.18	-0.32
		70	32.5	(9.0)	33.8	(8.9)	36.9	(10.7)		0-70	0.849	0.35	0.23	0.03		W-R	0.337	-0.18	-0.05	-0.45
Hip	Initial contact (°) *	0	23.0	(7.8)	24.0	(6.3)	23.2	(8.2)	0.000	0-40	0.000	-3.30	-2.75	-2.63	0.387	W-J	0.451	-0.14	0.06	0.11
		40	53.0	(10.2)	52.3	(13.1)	51.7	(12.9)		40-70	0.000	-1.49	-1.37	-1.42		J-R	1.000	0.11	0.05	-0.03
		70	71.6	(14.4)	70.2	(12.8)	70.6	(13.7)		0-70	0.000	-4.18	-4.57	-4.19		W-R	0.927	-0.02	0.11	0.07
	Minimum flexion * in swing (°)	0	0.3	(6.8)	0.7	(8.3)	1.4	(7.7)	0.000	0-40	0.000	-2.46	-1.96	-1.80	0.587	W-J	1.000	-0.04	0.12	-0.10
		40	21.2	(9.9)	20.0	(11.2)	20.5	(12.8)		40-70	0.000	-1.27	-1.34	-1.24		J-R	1.000	-0.09	-0.04	-0.07
		70	34.6	(11.2)	35.8	(12.4)	36.6	(13.2)		0-70	0.000	-3.69	-3.33	-3.27		W-R	1.000	-0.14	0.06	-0.17
	Peak flexion *† in swing (°)	0	30.7	(7.1)	33.0	(7.0)	35.1	(7.5)	0.000	0-40	0.000	-3.33	-3.01	-3.05	0.000	W-J	0.009	-0.33	-0.09	-0.03
		40	61.9	(11.2)	62.9	(12.2)	64.9	(11.6)		40-70	0.000	-1.48	-1.43	-1.52		J-R	0.000	-0.28	-0.16	-0.20
		70	80.6	(13.9)	81.0	(13.1)	83.7	(13.2)		0-70	0.000	-4.51	-4.57	-4.52		W-R	0.000	-0.60	-0.26	-0.23
	Range of motion (°) *	0	30.4	(5.8)	32.4	(7.7)	33.7	(7.4)	0.000	0-40	0.000	-1.49	-1.19	-1.08	0.056	W-J	0.165	-0.29	-0.25	-0.03
		40	40.7	(7.6)	42.8	(10.3)	43.8	(11.3)		40-70	0.115	-0.40	-0.21	-0.27		J-R	0.725	-0.18	-0.09	-0.18
		70	43.9	(12.6)	45.5	(10.7)	46.7	(12.4)		0-70	0.000	-1.53	-1.44	-1.36		W-R	0.148	-0.51	-0.33	-0.19

APPENDIX 7.3.

Mean (SD), main effect, pairwise comparisons and effect size of neuromuscular activation during incremental (perceived walking, jogging and running) vertical treadmill exercise in the supine (0°), 40° and 70° postures. * indicates main effect for posture (p<0.05), † indicates main effect for speed (p<0.05).

Variable	Activation	Posture (°)	Walking Mean	(SD)	Jogging Mean	(SD)	Running Mean	(SD)	Main effect p	Posture (°)	Posture Pairwise p	Effect size Walk	Effect size Jog	Effect size Run	Main effect p	Speeds	Speed Pairwise p	Effect size 0°	Effect size 40°	Effect size 70°
Rectus Femoris	ON (%GC) *†	0	36.1	(7.1)	28.0	(5.8)	19.2	(6.9)	0.000	0-40	0.148	0.32	0.40	-0.11	0.000	W-J	0.000	1.15	1.41	1.47
		40	35.5	(6.4)	24.0	(6.9)	18.0	(6.7)		40-70	0.053	-0.51	-0.50	-0.28		J-R	0.000	1.01	0.69	0.78
		70	34.3	(7.1)	22.9	(6.3)	13.5	(8.0)		0-70	0.000	-0.20	-0.37	-0.37		W-R	0.000	2.33	1.95	2.15
	OFF (%GC) *†	0	81.6	(5.4)	74.6	(6.7)	68.1	(6.2)	0.025	0-40	0.588	0.10	0.63	0.17	0.000	W-J	0.000	1.25	1.72	1.72
		40	79.8	(5.9)	72.3	(4.7)	68.8	(5.4)		40-70	0.007	0.17	0.17	0.62		J-R	0.000	1.37	0.88	1.30
		70	82.7	(5.5)	74.8	(5.3)	70.4	(6.0)		0-70	0.627	0.26	0.77	0.77		W-R	0.000	2.40	2.65	2.76
Semitendinosus	ON (%GC) †	0	76.1	(5.5)	69.6	(4.7)	63.2	(5.9)	0.308	0-40	0.502	0.15	0.43	0.07	0.000	W-J	0.000	1.28	1.56	1.42
		40	75.3	(5.3)	67.6	(4.5)	62.8	(5.1)		40-70	0.490	-0.25	-0.20	-0.18		J-R	0.000	-1.20	-0.98	-0.73
		70	76.6	(4.8)	68.7	(6.2)	63.9	(6.8)		0-70	1.000	-0.09	0.16	-0.11		W-R	0.000	2.27	2.39	2.14
	OFF (%GC) *†	0	42.2	(7.1)	33.8	(5.4)	25.7	(7.9)	0.000	0-40	0.000	0.83	1.19	0.41	0.000	W-J	0.000	1.34	1.33	1.80
		40	36.1	(7.6)	27.2	(5.6)	22.9	(5.8)		40-70	1.000	-0.30	0.22	0.34		J-R	0.000	-1.20	-0.77	-0.73
		70	38.3	(7.1)	25.9	(6.8)	20.5	(7.9)		0-70	0.000	0.55	1.29	0.66		W-R	0.000	2.21	1.96	2.38
Biceps Femoris	ON (%GC) †	0	77.7	(4.8)	71.1	(4.8)	63.6	(5.0)	0.204	0-40	0.550	0.14	0.36	0.01	0.000	W-J	0.000	1.37	1.09	1.33
		40	77.0	(5.6)	68.3	(9.8)	63.5	(4.7)		40-70	0.465	0.16	0.28	0.27		J-R	0.000	1.54	0.62	1.01
		70	77.9	(5.8)	70.5	(5.3)	65.0	(5.7)		0-70	1.000	-0.04	0.12	-0.26		W-R	0.000	2.90	2.62	2.24
	OFF (%GC) *†	0	41.5	(7.1)	33.9	(5.6)	27.0	(6.2)	0.000	0-40	0.000	0.58	0.89	0.50	0.000	W-J	0.000	1.20	1.28	1.77
		40	37.4	(7.0)	27.8	(8.0)	23.8	(6.7)		40-70	0.494	0.08	-0.24	-0.32		J-R	0.000	1.17	0.54	0.65
		70	38.0	(6.8)	26.0	(6.7)	21.6	(6.8)		0-70	0.000	0.51	1.28	0.83		W-R	0.000	2.19	1.99	2.41
Lateral Gastrocnemius	ON (%GC) †	0	1.6	(17.2)	90.1	(21.9)	86.3	(15.4)	0.415	0-40	0.720	-0.07	0.27	0.04	0.000	W-J	0.000	0.58	1.18	1.05
		40	12.5	(15.6)	88.5	(22.5)	89.7	(13.4)		40-70	1.000	0.49	0.11	0.28		J-R	0.194	-0.58	-0.64	-0.85
		70	6.7	(16.3)	96.3	(13.4)	84.8	(14.4)		0-70	1.000	0.57	0.34	0.29		W-R	0.000	1.90	1.65	1.73
	OFF (%GC) *†	0	49.6	(6.5)	42.6	(15.1)	35.4	(8.3)	0.035	0-40	0.995	-0.66	0.12	-0.23	0.000	W-J	0.000	0.53	1.24	0.70
		40	50.2	(11.0)	39.4	(6.7)	35.0	(6.8)		40-70	0.315	0.36	-0.42	0.35		J-R	0.005	-0.26	0.06	-0.83
		70	45.7	(7.3)	38.7	(5.9)	33.1	(7.2)		0-70	0.044	-0.30	-0.28	0.10		W-R	0.000	0.94	1.57	1.42
Medial Gastrocnemius	ON (%GC) †	0	80.5	(8.1)	73.9	(8.1)	67.4	(8.2)	0.800	0-40	0.584	-0.07	0.27	0.04	0.000	W-J	0.000	0.82	0.27	0.92
		40	79.7	(11.7)	76.6	(10.3)	69.3	(7.3)		40-70	0.798	0.49	0.11	0.28		J-R	0.000	-0.79	-0.71	-0.81
		70	85.0	(9.4)	77.1	(7.9)	70.8	(7.7)		0-70	0.125	0.57	0.34	0.29		W-R	0.000	1.60	0.93	1.66
	OFF (%GC) †	0	47.0	(45.5)	39.4	(6.1)	33.9	(6.6)	0.173	0-40	0.217	-0.66	0.12	-0.23	0.000	W-J	0.000	1.23	0.58	0.97
		40	43.0	(10.3)	38.4	(6.9)	34.3	(6.2)		40-70	0.997	0.36	-0.42	0.35		J-R	0.000	-0.88	-0.55	-0.95
		70	45.9	(6.2)	39.3	(7.3)	32.8	(6.6)		0-70	1.000	-0.30	-0.28	0.10		W-R	0.000	2.04	1.04	2.06