THE ACUTE METABOLIC RESPONSES TO LIGHT WEARABLE RESISTANCE DURING SUBMAXIMAL RUNNING IN ENDURANCE TRAINED RUNNERS

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ABSTRACT

Understanding training methods to elicit the appropriate adaptation to the determinants of endurance performance is of interest to both athletes and coaches. The Exogen™ exoskeleton technology by Lila™ is a compressive garment designed to allow small weights (50-200grams) to be applied to all areas of the body for site-specific loading. The experimental studies in this thesis sort to describe how the relative loading of both the proximal (i.e. thigh) lower limb (PLL) and distal (i.e. calf) lower limb (DLL) impact the metabolic cost of submaximal running.

In study one, 20 (40.8 ± 8.2 years; 75.4 ± 9.2 kg) endurance trained runners (59.6 ± 7.9 $ml\cdot kg^{-1}\cdot min^{-1}$) completed six submaximal running trials with the PLL either un-loaded or loaded with 1, 2, 3, 4 and 5% of their own body weight. We found a 1.59% (±0.62%) increase in oxygen consumption for every 1%BM of addition load. Inferential based analysis identified that loading of at least 3%BM was needed to elicit any substantial responses, with a *likely moderate increase* (ES ± 90%CI: 0.24 ±0.07), while maximal loading (5%BM) elicit a *most likely very large increase* (0.43 ± 0.07). Using the heart rate (HR) data collected, a training load score (TLS) was extrapolated to help quantify the amount of internal stress each loaded trial would have over a 10-minute running period. For every 1%BM of additional load there is an extra 0.17(±0.06) estimated increase in training load. PLL loading of at least 3%BM was needed to elicit any substantial responses in lactate (La) production, with a *very likely large increase* (ES ± 90%CI: 0.41 ± 0.18). No loads reported substantial increases above 4mmol/L.

In study two, 15 (37.8 ± 6.4 years; 72.5 ± 9.8) endurance trained runners (58.9 ± 7.4 $ml\cdot kg^{-1}\cdot min^{-1}$) completed seven submaximal running trials with DLL either un-loaded or loaded with 0.5, 1, 1.5, 2, 2.5 and 3% of their own body weight. We found a 2.56% (±0.75) increase in oxygen consumption for every 1%BM of addition load. Inferential based analysis identified that loading of at least 1%BM was needed to elicit any substantial responses, with a *possible small increase* (ES ± 90%CI: 0.22 ± 0.12), while maximal loading (3%BM) produced a *most likely very large increase* (0.51 ± 0.09). As with Study 1, using the HR data collected, a TLS was extrapolated to help quantify the amount of internal stress each loaded trial would have over a 10-minute running period. For every 1%BM of additional load there is an extra 0.39(±0.06) increase in internal stress. DLL loading elicit substantial increases in La production from the lightest loading (0.5%BM), with a *likely moderate increase* (0.49 ± 0.28). No loads reported substantial increases in La production above 4mmol/L.

This thesis provides evidence on the sensitivity of loading the PLL and DLL between 0.5-5%BM on the metabolic cost of submaximal running. The metabolic data collected by both studies will help guide future studies investigating the impact of lower body limb loading both acutely and longitudinally.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

%BM	Percentage of body mass
%$\dot{V}O_2$max	Percent of maximum oxygen consumption
CC	Contractile component
DLL	Distal lower limb
ES	Explosive strength
FITT principle	Frequency, intensity, time, type
GXT	Graded exercise test
HR	Heart rate
La	Lactate
MS	Maximal strength
PEC	Parallel elastic component
PLL	Proximal lower limb
RE	Running economy
RER	Respiratory exchange ratio
RM	Repetition maximum
RPE	Rate of perceived exertion
RS	Reactive strength
RT	Resistance training
SEC	Series elastic component
TLS	Training load score
$\dot{V}O_2$max	Maximum oxygen consumption
$\dot{V}E$	Ventilation
$\dot{V}E/\dot{V}CO_2$	Ventilatory equivalent for carbon dioxide
$\dot{V}E/\dot{V}O_2$	Ventilatory equivalent for oxygen
vMART	Peak running velocity achieved in a maximal anaerobic running test
$\dot{V}T_1$	First ventilatory threshold
$\dot{V}T_2$	Second ventilatory threshold
v$\dot{V}T_2$	Running velocity capable at $\dot{V}T_2$
WRT	Wearable resistance technology

LIST OF FIGURES

LIST OF TABLES

DECLARATION

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning."

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CHAPTER ONE – INTRODUCTION

Rationale and Significance of Thesis

Endurance running attracts millions of participants both recreationally and competitively across the globe. Modifiable factors such as training play a vital role in enhancing the qualities that determine running performance. The physiological mechanisms that determine endurance running performance include the maximum volume of oxygen that can be ventilated, delivered and used by the body's cells at sea level ($\dot{V}O_2max$) (Noakes et al., 1990), the percentage of $\dot{V}O_2max$ that a runner can sustain before blood lactate accumulation exceeds clearance (%$\dot{V}O_2max$ at $\dot{V}T_2$) (Bassett & Howley, 2000; Nicholson & Sleivert, 2001; Tjelta & Shalfawi, 2016;) and the metabolic cost of running at a given velocity (RE) (Conley & Krahenbuhl, 1980; Noakes et al., 1990). Many runners also use resistance training (RT) to improve running performance be it by indirectly improving RE, muscular power capabilities or running performance (Alcaraz-Ibañez & Rodríguez-Pérez, 2018). It is therefore the objective of the athlete and coach to fully understand these determinants, to be able to effectively and efficiently programme training, ensuring optimal transfer to performance and minimise injury. At elite levels, the concepts of progressive overload and specificity become more important. Potential to elicit adaptations through more effective and efficient ways could potentially be the difference between first and second place.

Wearable resistance technology (WRT) is explained by an external load being attached to areas of the body allowing increased movement opportunities that are loaded, hands-free, with limited movement restriction (Macadam et al., 2017). Increasing exercise intensity using WRT has been investigated by Puthoff and colleagues (2006). The researchers wanted to investigate how incorporating a loaded vest (10, 15 and 20%BM) would increase the metabolic demands of walking. Each loading parameter over five different walking/running velocities was measured. The researchers found that using a weighted vest during treadmill walking could generate metabolic costs that were similar to walking at higher speeds un-loaded. Additionally, the ground reaction forces of weighted walking (20%BM) were similar to running. As such, WRT could be implemented in a running programme to generate the same metabolic stress in less duration, possibly producing greater ground reaction forces. This may suit runners who have restricted training time or wish to overload the musculotendinous unit and possibly improve RE (Berryman et al., 2010; Saunders, Telford, Pyne, & Peltola, 2006).

Comparatively, limb loading (0.3-8.5%BM) has shown a greater increase in metabolic demand to unloaded walking and running, indicated by increases in oxygen consumption ($\dot{V}O_2$), heart rate (HR), energy workload and energy cost. With metabolic demands being greater with lower body limb loading and demands increasing as comparable load is moved more distal (Claremont & Hall, 1988; Jones et al., 1984; Martin, 1985; Soule & Goldman, 1969). Walking for 20-minutes with hands weighted at 4 and 7kg at 5.6 km▪h^{-1} increased $\dot{V}O_2$ 1.9 times greater than un-loaded trials and as much as 6.3 times greater when feet were loaded with 6 kg under the same condition (Soule & Goldman, 1969). This suggests that the impact on metabolic cost of lower body limb loading during walking is greater compared to upper body limb loading with similar loads. However, is unclear as to how the addition of upper body limb loading impacts the metabolic demands on endurance runners. Jones and colleagues (1984) used running speeds of 8.7, 10.5 and 12.1 km▪h^{-1} and weighted shoes of 1.77 kg and found an increase in $\dot{V}O_2$ of up to 6.3% compared to running in normal athletic shoes (0.16 ± 0.13 kg). The same researchers also included walking speeds of 4.0, 5.6 and 7.3 km▪h^{-1} and discussed an average increase in oxygen consumption of 8% across all loads equating to a 0.7% increase per 100g (Jones et al., 1984). Martin (1985) found that adding 0.25 (0.69%BM) and 0.50 kg (1.39%BM) to each thigh at a running velocity of 12 km▪h^{-1} increased $\dot{V}O_2$ by 1.7 and 3.5% respectively, with responses almost doubling (3.3 and 7.5% respectively) when the same load was added to the ankles. The researchers noted that HR increases were consistent with increases in $\dot{V}O_2$ but also noted that HR was less sensitive to lower extremity loading (Martin, 1985).

The accelerated growth in technology and continued research into human performance constantly challenges current training methods to enhance performance. To enhance performance in endurance runners using WRT as a training tool is very much in its infancy. Little is understood about how this technology may be appropriately applied to training regimes. The Exogen™ exoskeleton technology by Lila™ is a compressive garment that is designed to allow small weights (50-200grams) to be applied to all areas of the body for site-specific loading. This opens up opportunities to implement various training and programming options.

Purpose Statement:

Therfore the purpose of this research was to investigate how utilising the Exogen^{TM} exoskeleton technology by Lila^{TM} to load the proximal (i.e thigh) lower limb (PLL) and distal (i.e. calf) lower limb (DLL) impacts the acute metabolic ($\dot{V}O_2$, HR and lactate) responses to submaximal running in endurance trained runners. It is hoped that such information will give practitioners and athletes information to help effectively integrate this technology into their training regimes.

Variable loads between 1-5%BM were used for PLL loading, while variable loads between 0.5-3%BM were used for DLL loading. Ventilatory measures were used to identify metabolic stress to determine relative running intensities from for each subject, through visual inspection of time graphed against $\dot{V}E/\dot{V}O_2$ (ratio of ventilation and oxygen consumption) and $\dot{V}E/\dot{V}CO_2$ (ratio of ventilation and carbon dioxide production). Submaximal running trials were set at a running velocity that corresponds to each participants $\dot{V}T1$ (point at which VE starts to increase at a faster rate than $\dot{V}O_2$) which ensures a submaximal intensity.

Study Aims:

The specific aims of this thesis were:

1. To review current literature concerning the determinants of endurance running performance, as well as to review the current literature on both acute and chronic impacts of wearing additional load during locomotion.

2. To determine the acute metabolic effects of variable PLL loading using WRT during submaximal running (Study 1).

3. To determine the acute metabolic effects of variable DLL loading using WRT during submaximal running (Study 2).

Thesis Outline and Structure

This thesis consists of five chapters which include the review of current literature and original research. References are included for the entirety of review and research at the end of the thesis. The overall structure of this thesis is shown detailed by a flowchart in Figure 1. The first chapter is an introduction to the thesis highlighting the purpose and aims of this research project. The second chapter gives an overview of existing literature and are separated into three parts; the first part details the determinants of endurance running performance; the second part focuses on the current training methods of endurance runners focusing on resistance training methods in detail and the final part reviews the current literature within the metabolic cost of loading on locomotion. The third chapter details the methods used in both studies included in this thesis. The fourth chapter shows the results found within the research. Finally, the fifth chapter discusses the findings of the thesis and highlights the limitations, practical applications and suggested areas for future research. Please note that some of the information provided in this thesis appears repetitive in parts, which is due to the chosen format of this thesis application. Nonetheless, this thesis fulfils the AUT Master of Health Science guidelines for thesis submission.

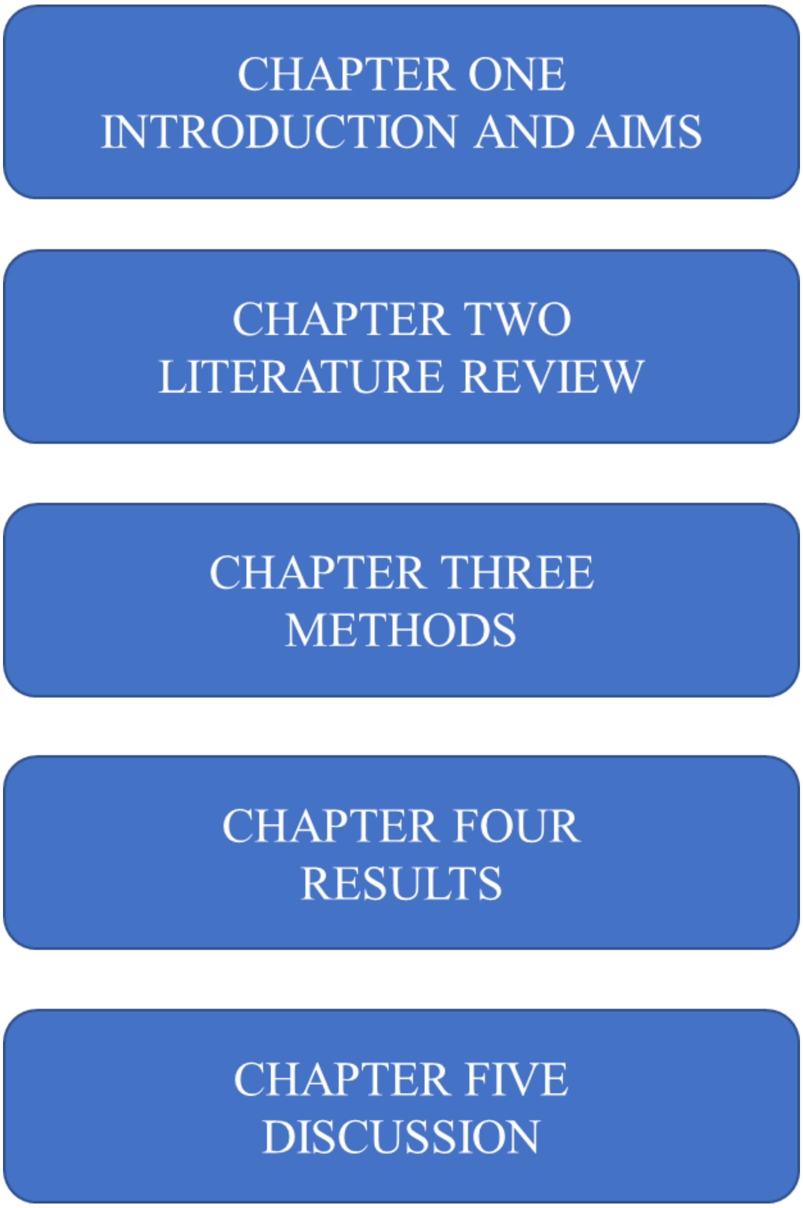

Figure 1: Thesis outline and structure

CHAPTER TWO - THE VIABILITY OF LIGHT WEARABLE RESISTANCE AS A TRAINING METHOD FOR IMPROVING ENDURANCE RUNNING PERFORMANCE, A REVIEW OF THE LITERATURE

Introduction

Understanding how the different components of fitness are best trained to elicit the adaptations required to enhance the qualities that determine running performance is essential to ensure efficient use of training time and minimise injury risk. Traditionally the literature has identified three pivotal components for predicting successful endurance running performance (McLaughlin, Howley, Bassett, Thompson, & Fitzhugh, 2010). These are having a high $\dot{V}O_2max$ (Noakes, Myburgh, & Schall, 1990), %$\dot{V}O_2max$ at $\dot{V}T_2$ (Bassett & Howley, 2000; Nicholson & Sleivert, 2001; Tjelta & Shalfawi, 2016) and RE (Conley & Krahenbuhl, 1980; Noakes et al., 1990). More recently, it has also been suggested that the ability for the neuromuscular system to drive force production substantially contributes to the performance of endurance trained runners (Alcaraz-Ibañez & Rodríguez-Pérez, 2017; Nummela et al., 2006; Paavolainen, Häkkinen, Hämäläinen, Nummela, & Rusko, 1999). This has been mostly measured in laboratory environments, expressed as either the peak running velocity achieved in a graded maximal aerobic test (v$\dot{V}O_2max$) (Peserico, Zagatto, & Machado, 2014) or the peak running velocity achieved in a maximal anaerobic running test (vMART) (Nummela et al., 2006). In terms of endurance running performance, an athlete must train in a fashion that develops these vital components. Understanding the appropriate training methods to elicit adaptation to each component, will help tailor effective periodised training programs to address individual weaknesses over a variety of event distances. The purpose of this literature review is to first discuss the determinants of endurance running performance in detail; and second, briefly discuss the current training methods that must be considered to improve endurance running performance. It is hoped that this will ultimately help identify a relatively unexplored area of WRT and how it's usage may provide an advantageous training stimulus for endurance runners.

Determinants of Endurance Running Performance

The interaction between the components that determine optimal endurance running performance are intricate and individual across both athlete and running distance. These have been best described by mechanical work performed and the metabolic cost associated with that work (Norman, 2014). Three major players appear to best predict endurance running performance and can account for > 70% of the between-subject variance (Di Prampero, Atchou, Brückner, & Moia, 1986). These determinants are; $\dot{V}O_2max$ (determines the upper limit for aerobic metabolism), %$\dot{V}O_2max$ at $\dot{V}T_2$, and RE (Joyner, 1991). McLaughlin and colleagues (2010) set out to compare a model (see Figure 2) for predicting endurance performance with assessments of force production capabilities (v$\dot{V}O_2max$). They concluded that $\dot{V}O_2max$, RE and v$\dot{V}O_2max$ are all highly correlated (r = -0.90, 0.81 and -0.97 respectively) to 16 km running performance which has also been used to extrapolate a physiologically fastest possible marathon time (Joyner, 1991). McLaughlin and colleagues found little variation in %$\dot{V}O_2max$ at $\dot{V}T_2$ and suggested that the individual variation in performance was due to differences in $\dot{V}O_2max$ and RE, which are variables used to calculate v$\dot{V}O_2max$. They also noted that unsurprisingly, v$\dot{V}O_2max$ was the best predictor of running performance as this accounts for both a large aerobic capacity and an efficient running technique. Each of these important determinants is now discussed in detail below.

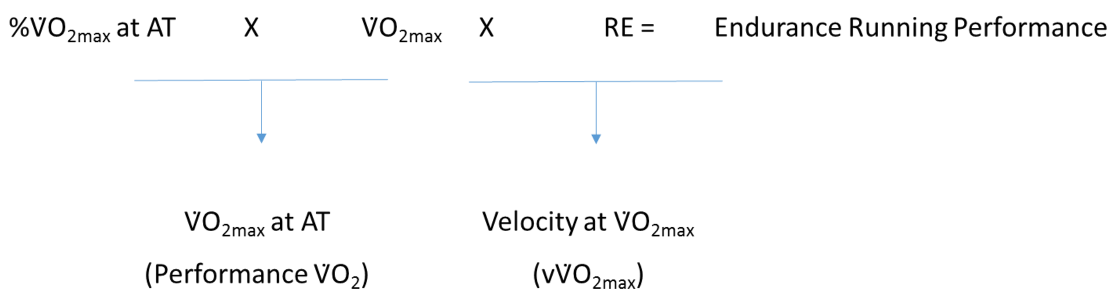

Figure 2: Model for predicting endurance running performance based on physiological variables (McLaughlin et al., 2010).

Key: $\dot{V}O_2max$ = maximum oxygen consumption, v$\dot{V}O_2max$ = running velocity at $\dot{V}O_2max$, %$\dot{V}O_2max$ at AT = percentage of $\dot{V}O_2max$ at anaerobic threshold ($\dot{V}T_2$), RE = Running economy.

Maximal Oxygen Uptake

Maximal oxygen uptake is the maximum volume of oxygen that can be ventilated, delivered and used by the body's cells at sea level (Kenney, Wilmore & Costill, 2015) and sets the upper limit for an individual's aerobic capacity. A high $\dot{V}O_2max$ is a requirement for elite endurance running performance, as a greater capacity to uptake oxygen allows an increase in ATP metabolism via oxidative phosphorylation (Legaz-Arrese et al., 2007). Maximal oxygen uptake is influenced by the availability of oxygen, the use of carbohydrate and fats as fuel, as well as mitochondrial size and density (Coyle, 1999). To increase substrate delivery and utilisation, both central and peripheral adaptations need to be considered when designing training programmes (Jones & Carter, 2000). Enhanced haemoglobin concentrations in blood, capillary size and density, stroke volume and cardiac output (Coyle, 1999), characteristics of muscle fibre type and mitochondrial enzyme activity (Holloszy & Coyle, 1984) are the mechanisms associated with increased aerobic ability. An individual's $\dot{V}O_2max$ does have a genetic ceiling and at elite levels there are differences in $\dot{V}O_2max$ values (see Table 1), indicating that other factors influence elite endurance performance (Tjelta & Shalfawi, 2016).

Table 1: Variation in $\dot{V}O_2max$ and endurance running performance (Noakes, 2003).

Athlete	Country	Major performance	$\dot{V}O2max$
Steve Prefontaine	USA	03:54.6 1 mile	84 $mL \cdot kg^{-1} \cdot min^{-1}$
Craig Virgin	USA	2:10:26 marathon	81 $mL \cdot kg^{-1} \cdot min^{-1}$
Joan Benoit	USA	2:24:52 marathon	78 $mL \cdot kg^{-1} \cdot min^{-1}$
Alberto Salazar	USA	2:08:13 marathon	76 $mL \cdot kg^{-1} \cdot min^{-1}$
Cavin Woodward	U.K	2:19:50 marathon	74 $mL \cdot kg^{-1} \cdot min^{-1}$
Grete Waitz	Norway	2:25:29 marathon	73 $mL \cdot kg^{-1} \cdot min^{-1}$
Frank Shorter	USA	2:10:30 marathon	71 $mL \cdot kg^{-1} \cdot min^{-1}$
Derek Clayton	Australia	2:08:34 marathon	69 $mL \cdot kg^{-1} \cdot min^{-1}$

Fractional Utilisation of Maximal Oxygen Uptake at the Second Ventilatory Threshold.

As exercise intensity increases, pathways to synthesise adenosine triphosphate (ATP) merge from aerobic to anaerobic. When there is not enough oxygen present for oxidative phosphorylation, glycolysis is relied on to produce ATP which in turn produces lactate (Midgley, McNaughton, & Jones, 2007). During incremental exercise, the aerobic threshold marks the first increase in blood lactate, ending with the anaerobic threshold which corresponds to the maximal lactate steady state before La accumulation exceeds clearance (Kindermann, Simon, & Keul, 1979; McLaughlin, et al., 2007) (see Figure 3). Changes in ventilatory measurements during incremental exercise have been shown to correspond to the aerobic ($\dot{V}T_1$) and anaerobic ($\dot{V}T_2$) thresholds and are associated with simultaneous changes in blood lactate (Lucía, Sánchez, Carvajal, & Chicharro, 1999).

In a trained state, higher workloads are possible before a disproportionate increase in blood lactate occurs (see Figure 4). Similarly, when comparing two homogenous endurance athletes in terms of $\dot{V}O_2$max, the athlete who can perform at higher workloads at this transition point will likely be the better performer. This is attributable to a reduction in the amount of La produced and an increase in the aerobic systems ability to clear La production through greater skeletal muscle enzyme activity and metabolic substrate (Bergman et al., 1999). Because endurance events are not run at a maximal intensity, the capacity for an athlete to maintain a higher workload at these thresholds explains some of the variation in $\dot{V}O_2$max values among elite endurance runners (Bassett, & Howley, 2000; Impellizzeri, Marcora, Rampinini, Mognoni, & Sassi, 2005; Tjelta & Shalfawi, 2016). A marathon is typically run at 80-85% of a runners $\dot{V}O_2$max for the duration of a race (Bassett & Howley, 2000). Because it is not practical to measure an individual's %$\dot{V}O_2$max during competition, laboratory-based tests are generally used instead by calculating %$\dot{V}O_2$max at the running velocity capable at $\dot{V}T_2$ (v$\dot{V}T_2$) (Tjelta & Shalfawi, 2016). There is a close correlation between %$\dot{V}O_2$max during competition and %$\dot{V}O_2$max at v$\dot{V}T_2$ measured in a laboratory (Joyner, 1991). Accordingly, v$\dot{V}T_2$ is a good predictor of endurance performance, with assessments of this threshold often used to establish %$\dot{V}O_2$max (McLaughlin, et al., 2010; Impellizzeri et al., 2005).

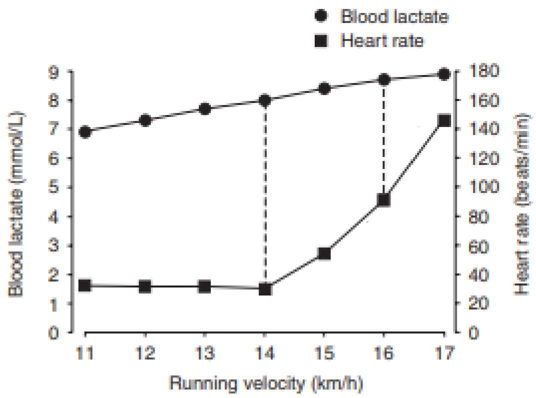

Figure 3: Blood La and HR responses of a competitive club runner during an incremental exercise test (Midgley, McNaughton, & Jones, 2007, p. 875).

Key: First dotted line: Aerobic threshold ($\dot{V}T_1$), second dotted line: Anaerobic threshold ($\dot{V}T_2$).

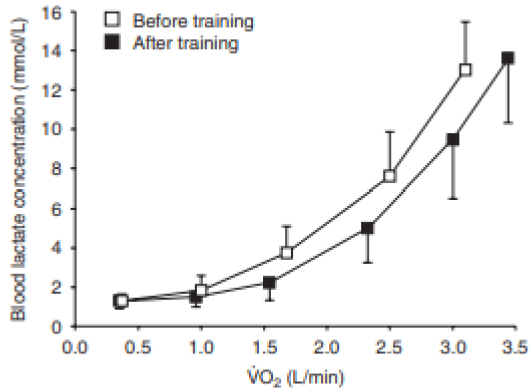

Figure 4: A downward and rightward shift of the mean blood La curve of ten male students in response to 16-weeks of physical training (Midgley, McNaughton, & Jones, 2007, p.868).

Running Economy

Running economy is the metabolic cost of running at a given velocity (Daniels, 1985; Hoogkamer, Kipp, Spiering, & Kram, 2016; Saunders, Pyne, Telford, & Hawley, 2004) and for the purposes of this review will be defined by measures of $\dot{V}O_2$ at submaximal running speeds (Saunders et al., 2004; Tartaruga et al., 2012). An efficient runner can perform more work whilst expending less energy (Daniels, 1985). This dynamic concept is influenced by various physiological (Martin, Doggart, & Whyte, 2001) and biomechanical (Tartaruga et al., 2012) factors which are extensively outlined in a review by Saunders, et al., (2004). Morgan and colleagues (1995) found that %$\dot{V}O_2$max values among elite and untrained runners varied by 47%, while RE differed by only 10%. However, they also made comment that a 1% reduction in aerobic effort at a given running velocity could potentially translate to a 1-minute improvement in marathon running performance at an elite level. The physiological variables that have been identified to affect RE include fluctuations in HR, ventilation, core temperature and La production (Saunders et al., 2004). All of which can be influenced by exercise, the environmental (Martin et al., 2001) and psychological conditions (Thomas, Fernhall, & Granat, 1999; Williams, Krahenbuhl, & Morgan, 1991). The body attempts to maintain homeostasis by synthesising ATP, metabolising and buffering by-products, removing wastes created through the aerobic and anaerobic pathways and efficiently managing thermoregulation (Beneke & Hütler, 2005; MacDougall, Reddan, Layton, & Dempsey, 1974). It is the body's ability to manage these components that are enhanced by endurance training and influence performance (Thomas et al., 1999). Improving a runner's RE limits impacts on homeostasis, slows down the use of muscle glycogen and ultimately prolongs the onset of fatigue (Holloszy & Coyle, 1984).

Force production capabilities

Knuttgen and Kraemer (1987) describe strength as being the maximal amount of force that a muscle or muscle group can generate at a specific velocity. The physiological components that influence the expression of force production includes neural and skeletal muscle factors (Baechle & Earle, 2008; McArdle, Katch, & Katch, 2010; Verkhoshansky & Siff, 2009). The neural adaptions that increase muscular strength include the level of motor unit recruitment, motor unit firing frequency, synchronisation, the decrease in the influence of neural inhibitory reflexes and finally the Golgi tendon organs (Mrówczyński & Lochyński, 2014). These adaptations are considered either intermuscular (interaction between muscles that control or generate force for a movement) or intramuscular (neural adaptations that are specific to an individual muscle) (Paavolainen, Nummela, & Rusko, 2000). In a review by Alcaraz-Ibañez and Rodríguez-Pérez (2018) it is discussed that some of the improvements in RE in previously resistance trained endurance runners can be attributable to greater intermuscular coordination. Accordingly, this neural adaptation emphasises the importance of training specificity. In that increases in coordination allows a muscle group to apply any newly gained force producing capabilities effectively in the required movement pattern at the appropriate velocity (Young, 2006). The factors that contribute to force production capabilities are also highly complex, with the adaptations to training being very specific. Verkhoshansky and Siff (2009) discuss a mechanical model that represents both a contractile component (CC) and non-contractile component of the muscle complex (see Figure 5). The CC represents the mechanical force producing capabilities of skeletal muscle and is influenced by cross-sectional area, the interaction of the actin and myosin filaments, arrangement of muscle fibres, muscle fibre type distribution and muscle length (Baechle & Earle, 2008). While the non-contractile component, represented by the series elastic component (SEC) and parallel elastic component (PEC), describes the elastic stored potential energy of the muscle complex. The elastic properties within a muscle fibre (sarcolemma and titin) (Kollár, Szatmári, Grama, & Kellermayer, 2010) and surrounding connective tissues (endomysium, perimysium and epimysium) are represented by the PEC, while the elastic properties of the musculotendinous unit are represented by the SEC (Verkhoshansky & Siff, 2009). Importantly, endurance runners exhibit enhanced portions of Type IIA muscle fibres compared to Type II muscle fibres. This decreases fatigability while maintaining force production properties of the CC of skeletal muscle (Aagaard & Andersen, 2010; Billat et al., 2003). A more efficient utilisation of the stored elastic energy in the musculotendinous unit assists in the reduction of muscle activation needed during each stride, thereby reducing the metabolic cost of running. Subsequently this can result in an increase in pace and time to exhaustion (Dumke, Pfaffenroth, McBride, & McCauley, 2010; Rønnestad & Mujika, 2014).

In terms of adaptation patterns, Mrówczyński and Lochyński (2014) discuss two stages of strength training. The first 2-3 weeks bring about increases in the excitability of skeletal muscle while 4-5 weeks after the onset of training, morphological adaptations begin to influence force producing capabilities. This shows that force production capabilities can be improved through both neural and skeletal muscle adaptations in a short time period. However, for the reasons outlined above similar movement patterns and training velocities need to be considered to ensure that adaptations in strength are transferred to performance (Young, 2006).

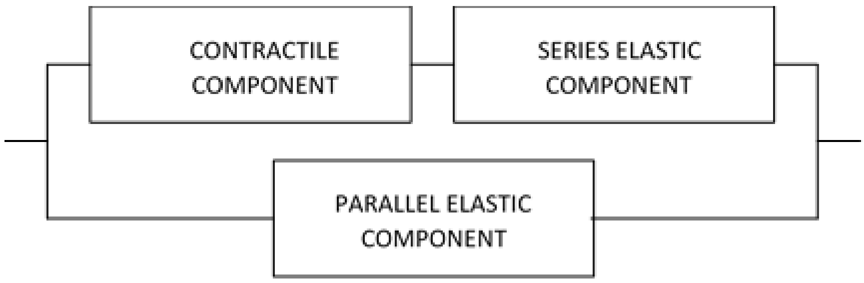

Figure 5: A simple mechanical model of the muscle complex (Verkhoshansky & Siff, 2009, p. 41).

Training Methods

A firm understanding of the determinants of endurance running performance allows training plans to be programmed that elicit the required change in performance. For an individual to improve endurance performance, training methods to encourage central (greater maximal cardiac output) and peripheral (greater arterial-venous oxygen difference) adaptations need to be utilised (Murias, Kowalchuk, & Paterson, 2010). These adaptations are a combination of muscular, metabolic, cardiovascular and pulmonary adaptation to endurance and resistance training (RT). The manipulation of frequency, intensity, time and type of training (FITT principle) are the components that will contribute to the acute decrease (fatigue) or chronic increase (fitness) in performance (Foster et al., 2015; Hawley & Stepto, 2001). In terms of training frequency, this remains relatively consistent with elite and sub-elite endurance runners typically performing between 10-14 training sessions each week (Viru, 1984).

Seiler and Kjerland, (2006) discuss two different training models to describe the intensity and duration distribution of elite endurance runners. The threshold-training model depicts majority of training performed at higher intensities at or above the second ventilatory threshold ($\dot{V}T_2$) for shorter durations. Conversely, the polarised training model has been shown to be common practice among elite endurance runners, in which long slow distance (LSD) training at lower intensities ($< \dot{V}T_2$) make up the bulk of individuals training volume (75%), with shorter, higher intensity bouts ($> \dot{V}T_2$) of effort making up the remainder (25%) of the programme volume. Long slow distance training describes a training load that incorporates high mileage at a relatively moderate running pace $\leq \dot{V}T_1$ (Wells & Pate, 1988). In support of the polarised training model, Esteve-Lanao, Foster, Seiler, and Lucia (2007) found that competitive endurance runners who dedicated 80% of their training load to LSD training had significantly greater improvements in performance then runners who spent more time training at AT. It has been suggested that LSD training is the most effective way for improving RE and that runners naturally adopt the most efficient running form at speeds at which they train (Morgan et al., 1994). However, there is some conjecture as to if simply further increasing the volume of LSD training as a form of progressive overload while controlling for intensity is effective at enhancing $\%\dot{V}O_2max$ in well trained runners (Laursen & Jenkins, 2002; Midgley et al., 2007).

Conversely, in the threshold-training model, LSD training is programmed together with high-intensity training closer to AT or $\dot{V}T_2$ for continuous shorter periods (Tempo Training) (Weltman et al., 1992) or well above $\dot{V}T_2$ for very short periods of time with short recovery periods (High Intensity Interval Training (HIIT)) (García-Pinillos, Soto-Hermoso, & Latorre-Román, 2017). Tempo training encourages more peripheral adaptations, specifically the respiratory control in skeletal muscle through increases in mitochondrial size and number and enzyme activity as a strategy for improving AT (Laursen, 2010; Midgley et al., 2007). The value of HIIT training discussed by García-Pinillos and colleagues (2017) is that when programmed concurrently with LSD training allows higher average intensities at lower weekly training volumes as an injury prevention strategy and for inducing muscular and metabolic adaptations.

Resistance Training

Many runners also use resistance training (RT) to improve running performance be it by indirectly improving RE, muscular power capabilities of running performance (Alcaraz-Ibañez & Rodríguez-Pérez, 2018). Concurrent training, in the context of the endurance athlete can be described as the simultaneous development of multiple disciplines. Specifically, aerobic and anaerobic development (enhanced endurance qualities) alongside strength development (enhance force production qualities) (Wilson et al., 2012). A recent review by Alcaraz-Ibañez and Rodríguez-Pérez (2018) concluded that concurrent resistance and endurance training could improve RE and performance in distances between 1500 and 10000m without increasing body mass (BM), decreasing capillary density or negatively affecting muscle fibre composition. These improvements have been seen in as early as four (Skovgaard et al., 2014) to six (Ramírez-Campillo et al., 2014) weeks of implementing RT into an endurance programme.

Resistance training used by endurance athletes has been identified in the literature as maximal strength (MS), explosive strength (ES) and reactive strength (RS) (Alcaraz-Ibañez & Rodríguez-Pérez, 2018; Beattie, Kenny, Lyons, & Carson, 2014). It is challenging to compare the specific effects of RT on the differing determinants of endurance performance with varying training designs. However, it seems that this is best achieved when targeting MS and RS (Berryman, Maurel, & Bosquet, 2010). Based on Docherty and Sporer's (2000) proposed model for examining the interference phenomenon, adaptations from MS and RS training will target the neural system, while training for aerobic power will target peripheral adaptations. This limits the interference between training modes and reduces risk of overtraining of either system. By also considering specificity towards the running movement, traditional RT may not efficienly carry any adaptation in strength to performance (Young, 2006). If RT could be implemented into a training program that limited interference and increased specificity, then we can postulate this may be a superior method of improving endurance running performance.

Maximal Strength

Maximal strength training aimed at improving determinants of endurance running performance has been described by using loads > 80% RM at ≤ 8 repetitions. In trained master's endurance runners, 6-weeks of MS training (85-95% 1RM, 4 x 3-4) has shown a significant 6.1% improvement in RE at marathon pace with no significant change in traditional; RT (70% 1RM, 3x10) or control groups (Piacentini et al., 2013). Similarly, in well-trained triathletes, MS training (>90% 1RM, 3-5 x 3-5) over 14-weeks showed a decrease in the energy cost of running while maintain hopping power, whereas an endurance only training group showed no change in RE and lost hopping power (Millet, Jaouen, Borrani, & Candau, 2002). Conversely, MS training over 8-weeks with recreationally trained marathon and long-distance runners had no transfer over to RE at submaximal (7-9 $km \cdot h^{-1}$) running speeds (Damasceno et al., 2015; Ferrauti, Bergermann, & Fernandez-Fernandez, 2010). However, all studies found that MS training could elicit significant improvements in MS with no significant changes in anthropometric data; two studies found no changes in $\dot{V}O_2max$ (Damasceno et al., 2015; Ferrauti et al., 2010) and one study found significant improvements in peak treadmill running velocity and 10000m running performance (Damasceno et al., 2015). Millet and colleagues (2002) proposed that an increase in MS could decrease relative peak tension at each cycle, while also maintaining hopping power which is correlated to leg stiffness and endurance performance. Damasceno and colleagues (2015) suggest that improvements in MS can reduce the negative outcomes of fatigue especially during the final stages of a competitive race. This contributed to improved overall endurance performance, as they noted faster running speeds in the final laps of a time trial. These studies all attribute MS gains to improvements in neural factors, however, it seems unclear as to if this transfers to RE and running performance at submaximal velocities. Importantly, RE is specific to event distance, therefore, as the reviewed studies used differing protocols to measure RE, it is difficult to draw conclusive conclusions on the effect of MS training on RE.

Explosive Strength

Explosive strength (ES) training aimed at improving endurance running performance has been described as using light loads < 80% 1RM, performed at high speed, generating maximal power output e.g. Olympic and ballistic lifting (Alcaraz-Ibañez & Rodríguez-Pérez, 2018; Wilson, Newton, Murphy, & Humphries, 1993). There is limited research on concurrent ES and endurance training. In a comparison of the effectiveness of concurrent ES and concurrent RS training, researchers found a 4% decrease in the energy cost of running and greater peak force production in the ES training group. However, a greater decrease was seen in the RS group of 7% with no change in peak power output (Berryman et al., 2010). The researchers suggest that the smaller improvements in the energy cost of running could be due to not prescribing enough of a stimulus based on the dose response relationship, as only one ES training session per week was implemented. This is under current recommendation for strength training (Rhea, Alvar, Burkett, & Ball, 2003). Furthermore, maximal power output may not be a major determinant of the energy cost of running. Paavolainen and colleagues (1999) prescribed a variety of sport specific resistance training methods including sprinting, loaded jumping and plyometrics over 9-weeks and found RE improved by 8% with no change in $\dot{V}O_2max$. The researchers suggested the mechanisms for improvement were due to a greater net excitation of motor neurons and decreased inhibitory input. As some RS was included in this training protocol and with a small number of longitudinal ES training studies using endurance trained runners, it is difficult to determine exactly what impact explosive training only has on endurance performance.

Table 2: Concurrent maximal strength and endurance training.

Study	Subjects	Training	Variables Measured	Findings
Piacentini et al., (2013)	16 trained masters endurance runners (12 males, 4 females) were randomly assigned to a MS training (n = 6, 44.2 ± 3.9 years), traditional strength training (n = 5, 44.8 ± 4.4 years) or endurance training only (n = 5, 43.2 ± 7.9 years)	6-week training intervention. MS program (4 x 3-4, 85-90% 1RM) Traditional strength program, (3x10, 70% 1RM) Both resistance training groups performed a balanced programme of upper and lower body compound exercises	Estimated 1RM on leg press Squat jump Counter movement jump RE Body composition	MS training group sore significant increases in 1RM (16.34%) and RE (6.1%) with no differences in other groups No significant changes in any other measured variables with body composition remaining unchanged in all groups
Millet et al., (2002)	15 well trained triathletes were randomly assigned to a MS training (n=7, 24.3 ± 5.2 years) or endurance training only (n=8, 21.4 ± 2.1)	14-week training intervention MS programme, 2x per week (3-5 x 3-5, 90%1RM) targeting lower limb muscle groups	Measures of $\dot{V}O_2$ kinetics Running economy Lower-limb stiffness Maximal concentric strength	No changes in $\dot{V}O_2$ kinetics for either group MS training group saw significantly greater MS, RE and leg stiffness Endurance training only group saw no change in and decreases in hopping power Endurance training only
Ferrauti et al., (2010)	22 recreational runners (15 males, 7 females, 40 ± 11.4 years) were randomly assigned to a MS training (n = 11) or endurance	8-week training intervention 1 x MS session per week (4 x 3-5RM) targeting motor unit recruitment patterns of leg muscles 1x Endurance strength session per week (3 x 20-25RM)	BM and peak torque Endurance capacity RE Running coordination	No change in BM, stride length and stride frequency or RE Improved leg strength

	training only (n = 11)	targeting core endurance musculature		
Damasceno et al., (2015)	18 male recreational long-distance runners were randomly assigned to a strength training (n = 9, 34 ± 7.7 years) or control (n = 9, 32.9 ± 9.2 years)	8-week training intervention 2x strength training sessions per week, sessions increased in load intensity from 3 x 8-10RM in the first two weeks to 3 x 3-5RM in the final two weeks targeting the lower body extensor muscles	$\dot{V}O_2$max, RE and 10 km time trial 1RM strength and ES	No change in $\dot{V}O_2$max or RE in either group Strength training group improved 10 km time trial time, discussed that this was due to improved neuromuscular characteristics

Table 3: Concurrent explosive strength and endurance training.

Study	**Subjects**	**Training**	**Variables Measured**	**Findings**
Berryman et al., (2010)	28 moderately to well-trained male runners were randomly assigned to an explosive training (n = 12, 32 ± 7 years), plyometric training (n = 11, 29 ± 8 years) or control (n = 5, 29 + 11)	8-week training intervention 1x strength training session per week ES performed concentric only semi squats 3-6 x 8 Plyometric strength performed drop jumps (20, 40, 60 cm) 3-6 x 8	$\dot{V}O_2$max, peak treadmill speed and RE 3000m time trial Peak vertical jump height	Both training interventions improved RE, greater improvements seen in plyometric group Peak jump height velocity improved in both groups All groups improved 3000m performance

Paavolainen et al., (1999)	18 elite male cross-country runners were randomly assigned to an ES (n = 10, 23 ± 8 years) or control (n = 8, 24 ± 5)	9-week training intervention ES training sessions included sprints (5–10 x20–100 m), jumping exercises, leg-press and knee extensor-flexor exercises with low loads maximal movement velocities 30–200 contractions/training session and 5–20 repetitions/set 0 - 40% 1RM	5 km time trial $\dot{V}O_2max$, RE 20m sprint 5-jump test	Improved 5 km time trial and RE with no improvements in $\dot{V}O_2max$ 20m sprint and 5-jump test improved in ES training group and decreased in control group

Table 4: Concurrent reactive strength and endurance training.

Study	Subjects	Training	Variables Measured	Findings
Spurrs et al., (2003)	17 male distance runners (25 ± 4 years) were randomly assigned to a concurrent running and plyometric training (n = 8) or control group (n = 9)	6-week training intervention Plyometric training group performed 2 x plyometric sessions per week for the first three weeks and then 3 x plyometric training sessions for the final three weeks Exercises included a series of hops, bounds and jumps in the vertical and horizontal plane	Musculotendinous stiffness Maximum isometric force Rate of force development 5 bound distance test Countermovement jump RE $\dot{V}O2max$ La threshold 3 km time trial	Experimental group showed significant improvements in 3km time trial (2.7%) and RE at all tested velocities with no changes in $\dot{V}O2max$ or La threshold Musculotendinous stiffness, 5 bound distance test and countermovement jump also significantly increased No significant changes were observed in any of the control group measures

Ramírez-Campillo et al., (2014)	36 highly competitive middle and long-distance runners (25 ± 4 years) were randomly assigned to a control (n = 12 males, 6 females) and experimental ES training group (n = 10 males, 8 females)	6-weeks of ES training 2 x 30-minute sessions per week	Drop jump height (20 and 40 cm) Countermovement jump 20m Sprint time 2.4 km time trial	Control group showed no significant changes in any performance measures Experimental group had significant reductions in 2.4 km time trial times (-3.9%) and 20 m sprint times (-2.3%), with increases in countermovement jump, depth jump 20 and 40 cm (8.9%, 12.7% and 16.7% respectively)
Saunders et al., (2006)	15 highly trained male distance runners were randomly assigned to a control (n = 8, 24.9 ± 3.2 years) or plyometric training group (n = 23.4 ± 3.2 years)	9-week training intervention Plyometric training group in addition to their normal training completed 3 x 30minute plyometric sessions	RE $\dot{V}O_2max$ Muscle power measuring ground reaction forces	Compared to control, experimental group improved RE at 18 km▪h^{-1} (4.1% p = 0.02) but not at 14 km▪h^{-1} or 16 km▪h^{-1} Experimental group also had higher average power outputs during 5-jump plyometric test (15% p = 0.11) No significant differences were seen an any metabolic measures
Berryman et al., (2010)	28 moderately to well-trained male runners were randomly assigned to an explosive training (n = 12, 32 ± 7 years), plyometric training (n = 11, 29 ± 8 years) or control (n = 5, 29 + 11)	8-week training intervention 1x strength training session per week ES performed concentric only semi squats 3-6 x 8 Plyometric strength performed drop jumps (20, 40, 60 cm) 3-6 x 8	$\dot{V}O_2max$, peak treadmill speed and RE 3000m time trial Peak vertical jump height	Both training interventions improved RE, greater improvements seen in plyometric group Peak jump height velocity improved in both groups All groups improved 3000m performance

Reactive Strength

Reactive strength training uses body weight or light load, rapid and repetitive movements with minimal floor contact e.g. plyometrics, depth jumps and bounding (Alcaraz-Ibañez & Rodríguez-Pérez, 2018). After 6-weeks of concurrent high intensity RS training 2-3 times per week with regular endurance training, resulted in significant improvements in performance trials (2.4 km, 3 km and 20 m) and RS qualities (depth jump, counter movement jump and five jump plyometric test) compared to endurance training only in competitive and endurance trained runners (Ramírez-Campillo et al., 2014; Spurrs, Murphy, & Watsford, 2003). Similarly, 9-weeks of incorporating 3 x 30-minute of RS training sessions into an endurance training programme has significantly improved RE (4.1%) at 18 km▪h^{-1} and greater RS qualities (five-jump plyometric test) with no change in cardiorespiratory measures or $\dot{V}O_2$max in highly trained endurance runners (Saunders, Telford, Pyne, & Peltola, 2006). Reactive strength training has also been shown to improve RE to a greater extent than concurrent ES training (4% vs. 7%) in moderately to well-trained endurance runners (Berryman et al., 2010).

The mechanisms leading to improvements in RE, endurance performance and power producing qualities, with no change in cardiorespiratory measures ($\dot{V}O_2$max or AT) or body composition, has been suggested through increases in tendon stiffness (Spurrs et al., 2003) and better use of stored elastic energy (Saunders et al., 2006). However, Berryman and colleagues (2010) were unable to find a correlation between vertical jump height and RE, therefore strength training activities which allow specificity of training to be adhered to while giving options to overload the reactive qualities of the musculotendinous unit would likely be advantageous.

Wearable Resistance

The exponential growth in modern technology and the level of competitiveness in elite sport continues to push boundaries in training methods, tools, and equipment to enhance human performance. This also widens the scope of applied research opportunities to ensure efficient prescription by strength and conditioning staff, coaches and athletes into practice (Hrysomallis, 2012). Within the 'principles of training', the principle of specificity is a key consideration in training program design. Indeed, innovative WRT is allowing previously non-specific strength orientated movements to become more specific to the running movement. Wearable resistance is explained by an external load being applied to the areas of the body that are in motion (Macadam, Cronin, & Simperingham, 2017). As a training tool, WRT is very much in its infancy, and its current research with endurance runners is limited. Specific programming guidelines such as loading recommendations and body orientation of load to stimulate the desired training effect are unclear. A current systematic review by Macadam and colleagues (2017) extensively outlines the current knowledge regarding acute and longitudinal metabolic, kinetic and kinematic effects of various methods of WRT on walking, running, sprinting and jumping movements. Accordingly, this literature review will direct focus to the metabolic effects of WRT on submaximal locomotion to help guide and justify research methodology.

Metabolic Cost of Running

Mechanically, human running has been described as using a spring-mass model in which the legs act like a spring and utilise stored elastic energy in the support leg with stiffness relating to peak ground reaction forces and the change in stance phase leg length (Dalleau et al., 1998; Silder et al., 2015). Being able to efficiently store and use elastic energy of the SEC is an important component of RE, with estimates indicating that RE could be 30–40% greater due to the force contributions from stored and released elastic energy (Cavagna, Saibene, & Margaria, 1964). The complex nature of running comprises many components that compound the metabolic cost such as supporting the weight of the body vertically, braking and accelerating the bodies center of mass horizontally, swinging the legs about the hip, and swinging the arms (Ackerman & Seipel, 2016). It is suggested that supporting body weight contributes 66-71% of the metabolic cost to run (Ackerman & Seipel, 2016; Teunissen, Grabowski, & Kram, 2007) with 29-39% as the metabolic cost to propel the body horizontally by swinging the arms and legs (Ackerman & Seipel, 2016; Chang & Kram, 1999).

Metabolic Cost of Trunk Loading

Wearable resistance technology to increase exercise intensity has been investigated by Puthoff, Darter, Nielsen and Yack (2006). This study investigated how incorporating a loaded vest (10, 15 and 20%BM) would increase the metabolic demands of walking. Each loading parameter over five different walking speeds was measured. Compared to unloaded trials, greater increases in metabolic costs were expressed at higher walking speeds across all loads. These findings suggest that loading the trunk under 10%BM in endurance runners could potentially produce greater metabolic costs then unloaded, due to the faster training velocities. It was also noted that there was no significant increase in the metabolic cost when load increased from 10-15%BM, however, this cost did become significant at 20%BM. Accordingly, it was concluded that trunk loading during walking requires greater loading increments to see a significant effect. Speed of movement also plays a vital role in the metabolic cost of loaded walking. However, the sensitivity of loading increments in trained endurance runners is unclear and is likely more sensitive due to the higher training velocities. The researchers did find that using a weighted vest during treadmill walking could generate metabolic costs that were similar to walking at higher speeds un-loaded. In addition, the ground reaction forces of weighted walking (20%BM) were similar to running. As such, WRT could be implemented in a running programme to generate the same metabolic stress over shorter durations of exercise. Accordingly, this may suit runners who may have restricted training time or who want to overload the musculotendinous unit to improve RE. Guidelines to best prescribe such a stimulus is not presently know.

Higher metabolic demands during submaximal running with trunk loading (5, 10 and 15%BM) compared to unloaded running have been observed, with significant decreases in maximal treadmill run time, total distance covered in a 12-minute run test and $\dot{V}O_2$max (an average of 35s, 89m and 2.4ml respectively for every 5% increase in BM) (Cureton et al., 1978). Running technique was also altered, with 10, 20, and 30%BM resulting in runners assuming a crouched position with a concomitant increase in leg stiffness. This required an increase in hip, knee and ankle flexion to absorb the additional load (Silder et al., 2015). This suggests that some of the increases in metabolic demands at high loading may be due to the technique compensation needed to run with the additional load. This therefore strengthens the justification for the use of smaller load increments < 5%BM during steady-state running to help ensure that if any induced increases in metabolic demands are due to greater force production through a natural running technique and not due to compensation of technique changes. In comparison to Cureton and colleauges (1978), non-significant increases (0.1 - 0.3%) in $\dot{V}O_2$ were found by Cooke and colleagues (1991) using trunk loads of 5 and 10%BM suggesting that < 5%BM may not be enough to trigger a high enough metabolic cost to improve $\dot{V}O_2$ kinetics more so than running un-loaded. It is unknown if this would be the same for force production capabilities off the ground. Only one study has looked at longitudinal effects of trunk loading on endurance runners. Rusko and Bosco (1987) divided 24-endurance athletes into a control and experimental group. The experimental group was vest loaded with 9 to 10%BM morning to evening including either every or alternate training sessions over a 4-week period. They observed significant increases in blood La (20.7%), $\dot{V}O_2$ during submaximal running and a significant decrease running velocity at $\dot{V}T_1$ (9.4%) during a short maximal run to exhaustion. Participants who wore the additional load during every

Table 5: Metabolic cost of trunk loading.

Study	Subjects	Loading Scheme	Variables Measured	Findings
Puthoff et al., (2006)	7 females and 3 males (23.4 ± 1.7 years) able to walk for 20 minutes up to a speed of 1.79 m▪s-1	Subjects performed a standardised walking test with 4-minute stages at 0.89, 1.12, 1.34, 1.56 and 1.79 m▪s-1 on a treadmill This was repeated over four different loading schemes of 0, 10, 15 and 20%BM	Oxygen consumption $\dot{V}O2$ HR was measured to determine relative exercise intensity	A curvilinear relationship between walking speed and $\dot{V}O_2$ An upward shift in the trend line as load increased Similar trends for relative exercise intensity
Cureton et al., (1978)	4 trained males and 2 trained females (26.2 ± 3.5 years)	0, 5, 10 and 15%BM	Subjects performed a progressive treadmill stress test and 12-minute run over all four loads	An increase of an extra 5%BM lead to an average decrease in $\dot{V}O_2$max of 2.4ml, maximal treadmill running time by 35seconds and 12-minute run distance by 89 meters
Cooke et al., (1991)	16 male subjects (8 children, 11.9 ± 1.0 years and 8 adults 21.3 ± 2.3 years)	5 and 10%BM at 2.67, 3.11, 3.56 and 4.0ms-1	Oxygen consumption $\dot{V}O2$	No significant increase in $\dot{V}O_2$ response in either condition

Rusko et al., (1987)	24 trained endurance athletes (12 runners and 12 cross-country skiers) were randomly assigned to an experimental group (runners: n = 6, 23.6 ± 2.7 years; skiers: n = 6, 26.5 ± 2.6 years) or control group (runners: n = 6, 23.8 ± 1.9 years; skiers: n = 6, 25.7 ± 3.2 years)	9-10%BM worn every day from morning to evening for 4-weeks including every (n =6) or every other (n = 6) training session	RE La threshold Run test until exhaustion Vertical velocity up stairs	Control group had a lower blood La concentration during submaximal running Experimental group had a lower 2mmol La threshold and higher blood La concentration after a short running test to failure Runners who wore load for all training sessions, decreased 2mmol La threshold, greater running time to exhaustion, improved vertical running velocity and higher submaximal $\dot{V}O_2$

training session also improved running time to exhaustion and improved vertical velocity when running upstairs. The researchers concluded that the added load increased anaerobic metabolism through greater recruitment and adaptation of the fast twitch muscle fibres which may have a negative effect on events of a marathon distance or further. The longitudinal effects of WRT endurance runners is virtually unknown.

Metabolic Cost of Limb Loading

Limb loading (0.3 - 8.5%BM) has shown increases in metabolic demand compared to unloaded walking and running (Claremont & Hall, 1988; Martin, 1985; Jones, Toner, Daniels, & Knapik, 1984; Soule & Goldman, 1969). This was indicated by increases in $\dot{V}O_2$, HR, energy workload and energy cost with metabolic demands being greater with lower body loading, and the demands increasing as comparable load is moved more distal on the lower limb. Walking for 20-minutes with hands weighted at 4 and 7 kg at 5.6km▪h^{-1} increased oxygen consumption 1.9 times greater than un-loaded trials and as much as 6.3 times greater when feet were loaded with 6 kg under the same condition (Soule & Goldman, 1969). This equating to an 8.6% increase in energy cost per kg of load added to the feet. Recently, Simperingham and Cronin (2014) found that loading the upper body with 5%BM did not alter sprinting speed over 25-meters, however, when this same load was attached to the lower limbs a significant reduction in sprint speed was noted at distances above 10-meters. This was magnified as the distance covered was increased (-2.4 to -4.2%). These observations suggest that moving constant load away from the point of rotation of the hip may increase angular inertia, requiring more force to accelerate and decelerate the loaded limb during locomotion. These two studies suggest that the impact on metabolic cost and performance of lower body limb loading on sprinting and walking is greater compared to upper body limb loading with the same loads. However, it is unclear as to how the addition of upper body limb loading impacts the metabolic demands on endurance running at submaximal speeds. Jones and colleagues (1984) used running speeds of 8.7, 10.5 and 12.1 km▪h^{-1} and weighted shoes of 1.77 kg and found an increase in oxygen cost of up to 6.3% compared to running in normal athletic shoes (0.16 ± 0.13 kg). This equated to a 4.5% increase in energy cost per kg of additional load to the feet. Martin (1985) found that adding 0.25 (0.7%BM) and 0.5 kg (1.4%BM) to each thigh at a running velocity of 12 km▪h^{-1} increased oxygen consumption by 1.7 and 3.5% respectively. Oxygen cost almost doubled (3.3 and 7.5% respectively) when the same load was added to the ankles. The researchers noted that HR increases were consistent with increases in oxygen consumption but also noted that HR was less sensitive

Table 6: Metabolic cost of limb loading.

Study	Subjects	Loading Scheme	Variables Measured	Findings
Claremont et al. (1988)	5 males and 3 females (42 ± 8.37 years)	30-minute treadmill runs over four days with each loading condition randomly assigned Un-loaded Hand weights (Females 0.45 kg each, Males 0.9 kg each) Ankle weights (0.4 kg each) Hand and ankle weights	Oxygen consumption $\dot{V}O_2$ HR	Highest metabolic cost during fully loaded trial, energy expenditure increases ranged from 5-8% across all loading schemes
Martin, (1985)	15 male long-distance runners (29.3 ± 8.2 years)	No load 0.25 kg each thigh 0.25 kg each foot 0.50 kg each thigh 0.50 kg each foot 8minutes of running at 12 km-h-1 at each load	Oxygen consumption $\dot{V}O_2$ HR	7.2% increase in oxygen consumption during foot loading, almost double that of thigh loading
Jones et al, (1984)	14 male subjects (6 trained, 30.5 ± 4.3 years; 8 un-trained, 30.4, 3.5 years)	Running shoe (0.616 kg per pair) Running shoe plus weight (1.776 kg per pair) Over three running speeds (8.9, 10.5 and 12.1 km-h-1)	Oxygen consumption $\dot{V}O_2$ HR	Oxygen consumption was significantly higher (5.9 - 10.2%) in boots at all speeds except the slowest walk

Soule et al (1969)	10 male subjects (20 -23 years)	No load 4 kg each hand 7 kg each hand 6 kg on each foot 14 kg on the head Over three walking speeds (4.0, 4.8 and 5.6 km-h-1) for 20minutes each	Oxygen consumption $\dot{V}O_2$	Head loading 1.2 times greater than un-loaded at all speeds Hand loading (4 and 7 kg) 1.9 times greater at 5.6 km-h-1 and at slower speeds 1.9 times greater at 7 kg and 1.4 times greater at 4 kg Feet loading 4.2 times greater at 4 km-h-1, 5.8 times greater at 4.8 km-h-1 and 6.3 times greater at 5.6 km-h-1

to lower extremity loading (Martin, 1985). Interestingly, all temporal and kinematic variables (stride length, single leg support time, swing time, flight time, peak height and velocity of the ankle and vertical displacement of the hip) exhibited no significant changes over both loads on the thigh. However, when 0.5 kg was added on the ankle significant but modest increases in stride length (1.4 cm), swing time (9 $m \cdot s^{-1}$), and flight time (6 $m \cdot s^{-1}$) and a decrease in peak velocity of the ankle (0.23 $m \cdot s^{-1}$) were seen. It was concluded that running form was not altered by the loads used in their study (Martin, 1985). This is similar to recent findings in sprinters who added 3%BM to both anterior and posterior aspects of their lower limbs and did not negatively impact sprinting technique over 20m (Macadam et al, 2017). Claremont and Hall (1988) used ankle weights to load runners at 0.45 kg and found a significant 4.3% increase in $\dot{V}O_2$ over self-selected running velocities and recorded no significant changes in kinematic data measured. Runners did comment on having ankle tightness which may have impacted joint range of motion and some increases in metabolic cost due to discomfort.

Rationale

Currently there is only a small volume of research on WRT to be able to fully understand the metabolic costs of submaximal running in endurance runners and even less exploring WRT as a potential training tool for improving endurance running performance. Studies have shown that trunk loading requires greater loading (loads > 5%BM) then limb loading to elicit a metabolic response (Cooke et al., 1991; Cureton et al., 1978). Furthermore, there is a curvilinear relationship between trunk loading and running velocity, with greater running velocities eliciting exponential metabolic responses to load (Puthoff et al., 2006). Lower body loading has a greater metabolic response than upper body loading (Soule & Goldman, 1969) and the further load moves distally on the lower limb the greater the metabolic response (Martin, 1985). Also, lower body loading of less than 1.4%BM does not seem to alter the natural running gait (Claremont & Hall, 1988; Martin, 1985). Majority of the research that has been collected on the metabolic cost of using WRT is outdated and methods for applying external load cumbersome. Available data is not specific to endurance runners and even more so trained endurance runners. It is also unknown how greater loads on the lower limbs impacts running biomechanics. The metabolic cost of limb loading on areas other than the foot, thigh and hands is not present and there is a need for further research. It is unclear as to how different loading positions change the impact of oxygen cost on running, how smaller incremental loads will impact oxygen cost and what this relationship looks like. These variables need further investigation to help guide how WRT might best be used as a training tool to improve endurance running performance and to understand the physiological mechanisms of any potential adaptation.

The Exogen^{TM} exoskeleton technology by Lila^{TM} is a compressive garment that is designed to allow small weights (50-200grams) to be applied to all areas of the body for site-specific loading. This technology provides limited movement restriction, increasing training specificity allowing for sensitive progressive overload and a greater scope for loading parameters. Thus, effective programming is only limited by the imagination and level of knowledge in human performance and interpretation of current research by the practitioner. The aim of this thesis is to give a clearer insight into the acute metabolic effects of WRT on both the PLL and DLL during submaximal running. It is hoped that this information will assist practitioners and athletes in accurately programming this type of technology into their training regimes and to guide future research.

CHAPTER THREE – RESEARCH METHODOLOGIES

Methods – Study One

Experimental Approach

This experimental research used a randomised, crossover design to quantify the metabolic demands of submaximal running using WRT to load the PLL in trained endurance runners. This design was appropriate as each submaximal running trial had no chronic training effect on the runners over the research period and sufficient time for washout between each trial. Randomising the load order for each trial will help reduce any bias when considering for order effect of loading increments. A comparison of means for all loads was possible for each participant, reducing the between individual variability and strengthening the integrity of the study.

Participants

2 female and 18 male endurance trained runners were recruited for the current study (see Table 7). All runners had no history of any major health issues 12 months prior to commencement of the study, had completed a minimum of one-half marathon distance in the last 12 months, were actively endurance run training at the onset of the study and had a minimum $\dot{V}O_2max$ of 50 and 40 ml/min/kg for males and females respectively. Height was measured to the nearest 0.1 of a centimetre using a Seca 220 stadiometer and BM was measured to the nearest 0.1 of a kilogram using Seca 220 scales. Skin fold data was collected at five sites (biceps, triceps, subscapularis, iliac crest and supraspinalis) utilising the procedures recommended by Marfell-Jones, Stewart, and De Ridder (2012). Ethical

Table 7: Characteristics and baseline measures of participants (n 20), mean ± SD.

Characteristics		
	age (y)	40.8 ± 8.2
	height (cm)	177.1 ± 7.4
	BM (kg)	75.4 ± 9.2
	sum of 5 skin folds (mm)	43.8 ± 13.7
	$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	59.6 ± 7.9
	maximum HR (bpm)	183.8 ± 8.4
	Predicted 10 km Time	44.3 ± 5.9
	$\dot{V}T_1$ ($km.h^{-1}$)	11.4 ± 1.2
	$\dot{V}T_2$ ($km.h^{-1}$)	14.5 ± 1.5

approval for this study was obtained from the AUT University Ethics Committee. Before testing all participants gave informed consent in writing and completed a pre-exercise health questionnaire (Par-Q). To protect the confidentiality of the participants all data collected is expressed as means (±SD).

Metabolic and Subjective Assessment

All running trials were conducted under stable laboratory conditions on a motorised treadmill (Woodway, Waukesha, Wisconsin, USA) with the gradient set a 1% (Jones & Doust, 1996). Heart rate response data was collected using a HR monitor (Polar A300, China), oxygen consumption data was measured using a carbon dioxide and oxygen analyser (Metalyzer Cortex, Biophysik GmbH, Leipzig, Germany), which was calibrated before each testing session according to the manufacturers specifications. All capillary samples were drawn from the preferred finger of the runner and La accumulation was measured using a blood La analyser (La Pro 2, Shiga, Japan). Subjective data was measured by way of rate of perceived exertion (RPE) using a modified BORG 10-point scale (Seiler & Kjerland, 2006).

Wearable Resistance Participant Loading

Each loaded trial required participants to wear a pair of compression shorts with associated loads (Lila™, Exogen™, Wilayah Persekutuan Kuala Lumpur, Malaysia). Weighted panels were in either 100 or 200g increments and total load for each trial was rounded to the nearest 100g. Loading scheme started with the first weight being added horizontally, anterior and most distal with the head of the weight facing medial on the limb followed by posterior and most distal with the head of the second weight facing lateral. Weights then alternated in this fashion with each load facing the opposite direction to the one directly below, stacked distal to proximal (see Figures 6-8).

Testing Procedures

For each participant the study was conducted over a maximum of 15 days. This included one familiarisation session and three testing sessions (see Figure 9) under laboratory conditions. The purpose of the familiarisation session was to allow each runner to become accustomed to treadmill running while wearing both the compression shorts and all metabolic measuring equipment. Participants completed a self-paced run for 20-minutes followed by a 10-minute recovery. During this time the graded exercise test (GXT) protocol was discussed and a HR monitor and gas mask fitted. Participants then completed a further 10-minute run including following enough of the GXT incremental

Figure 6: Example of proximal lower limb loading pattern (1%BM) for a 70 kg runner.

Figure 7: Example of proximal lower limb loading pattern (3%BM) for a 70 kg runner.

Figure 8: Example of proximal lower limb loading pattern (5%BM) for a 70 kg runner.

protocol to feel comfortable with the procedures, no data was collected. Participants were instructed to refrain from training on the day of testing session one and to avoid any strenuous training sessions 24 hours prior.

Testing session one occurred within seven days of completing the familiarisation session. The purpose was to generate a $\dot{V}O_2$ response profile to graded exercise to establish $\dot{V}T_1$, $\dot{V}T_2$ and $\dot{V}O_2max$. Participants completed a self-paced 20-minute warm-up on a treadmill and were given a recovery period of 10-minutes prior to the commencement of the GXT. Starting speed was maintained for 1-minute followed by an increase of 0.5 $km.h^{-1}$ every 30-seconds until voluntary exhaustion (Mann et al., 2014). Starting speed was adjusted on an individual basis to ensure volitional exhaustion at 8-12 minutes. $\dot{V}O_2$ was tracked continuously at a sampling rate of 0.1Hz, HR and RPE recorded at each speed increment with La being measured immediately post completion of test. Maximum oxygen consumption was an average over 30-seconds and was considered to be achieved if any one of the following criteria were met: a plateau in $\dot{V}O_2$ was reached despite an increase in workload, a respiratory exchange ratio (RER) > 1.15 was observed, a HR within five beats of age predicted maximum (220-AGE) was reached or a peak exercise blood La concentration > 8mmol/L was achieved (Scharhag-Rosenberger, Carlsohn, Cassel, Mayer, & Scharhag, 2011). Testing sessions two and three included all submaximal running trials to measure metabolic and subjective responses while un-loaded and loaded. Testing session two occurred within 2-5 days of testing session one and testing session three occurred within 2-3 days of testing session two to ensure no fatigue between all three sessions (Barnett, 2006). Participants were asked to keep a food and exercise diary 24-hours prior to the commencement of testing session two. This was to ensure these variables were kept consistent prior to coming in for testing session three. Similar to testing session one, participants were also instructed to refrain from training on both days of submaximal testing and to avoid any strenuous training sessions 24 hours prior to either session. Testing session two included three randomly selected wearable loads and testing session three included the final three randomly selected wearable loads (0, 1, 2, 3, 4, and 5%BM). Load order was different for each runner. At the start of both testing session two and three an 8-minute warm up set

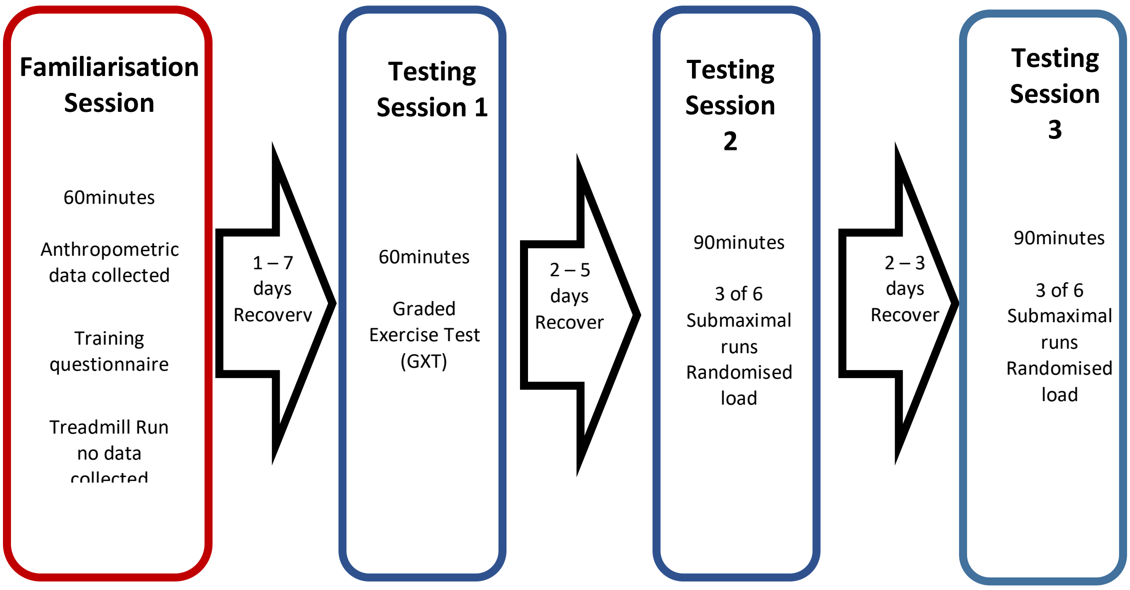

Figure 9: Structure of study one.

at a running speed equivalent to $\dot{V}T_1$ was completed followed by a 10-minute recovery. Each submaximal running trial lasted 8-minutes with 10-minutes seated recovery between each subsequent trial. Oxygen cost and HR were tracked for 2-minutes prior to each trial starting, for the 8-minutes of each trial (final 2-minutes used for analysis) and for 2-minutes post trial. Rate of perceived exertion and La was recorded immediately post completion of each 8-minute trial.

Statistical Analysis

Descriptive statistics including means and standard deviations were calculated for each measure. The statistical aim of this study was to make an inference about the impact on metabolic stress of submaximal running while wearing load, which requires determining the magnitude of an outcome. The traditional sample size estimation and hypothesis testing approach was not appropriate for this study design (Hopkins, Marshall, Batterham, & Hanin, 2009). Accordingly, inferential statistics were used to examine the qualitative meaning of the observed changes in metabolic cost ($\dot{V}O_2$, HR, La) and perception (RPE) of submaximal running with load compared to unloaded. Collected data was presented as the mean value for each with reported effect sizes and percent differences at 90% CI.

The smallest worthwhile change was used to determine if any observed changes were considered trivial, possible or likely including the magnitude of each change, calculated as a change in score standardised to 0.2 of the between subject SD from the unloaded condition (Cohen, 1992). The qualitative probabilities were defined by the scale < 0.5% *most likely trivial increase*, < 5% *very likely trivial increase*, < 25% *likely trivial increase*, 25-75% *possible small increase*, > 75% *likely moderate increase*, > 95% *very likely large increase*, > 99.5% *most likely very large increase* and the outcome was deemed *unclear* where the 5 and 90% CI of the mean change overlapped both the positive and negative outcomes (Hopkins et al., 2009). To help quantify the metabolic cost of wearing load based on relative exercise intensity and duration, HR was used to extrapolate a training load score (TLS) for each load (Training Peaks, (2012) for 10-minutes of running (see Figure 10). To understand the relationship between metabolic variables ($\dot{V}O_2$, HR and TLS) and load, a scatterplot was created in excel to establish a linear equation and R^2 value for each variable.

$$\text{TLS} = (\text{sec x HR x IF}) / (\dot{V}T_2 \text{ x } 3600) \text{ x } 100$$

$$\text{IF (impact factor)} = \text{HR} / \dot{V}T_2$$

Figure 10: Formula used for calculating Training Load Score (Training Stress Score (TSS) from Training Peaks, 2012).

Key: TLS: Training load score, HR: Heart rate (average heart rate during exercise), IF: Impact factor, $\dot{V}T_2$: Second ventilatory threshold (point at which lactate accumulation exceeds clearance).

Methods – Study Two

Participants

Four female and 11 male endurance trained runners were recruited for the current study (see Table 8). All runners had no history of any major health issues 12 months prior to commencement of the study, had completed a minimum of one-half marathon distance in the last 12 months, were actively endurance run training at the onset of the study and had a minimum $\dot{V}O_2max$ of 50 and 40 ml/min/kg for males and females respectively. Height was measured to the nearest 0.1 of a centimetre using a Seca 220 stadiometer and BM was measured to the nearest 0.1 of a kilogram using Seca 220 scales. Skin fold data was collected at five sites (biceps, triceps, subscapularis, iliac crest and supraspinalis) utilising the procedures recommended by Marfell-Jones and colleagues (2012). Ethical approval for this study was obtained from the AUT University Ethics Committee. Before testing all participants gave informed consent in writing and completed a pre-exercise health questionnaire (Par-Q). To protect the confidentiality of the participants all data collected is expressed as means (±SD).

Table 8: Characteristics and baseline measures of participants (n 15), mean ± SD

Characteristics		
	age (y)	37.8 ± 6.4
	height (cm)	177.2 ± 6.2
	BM (kg)	72.5 ± 9.8
	sum of 5 skin folds (mm)	41.1 ± 17.4
	$\dot{V}O_2max$ (ml·kg^{-1}·min^{-1})	58.9 ± 7.4
	maximum HR (bpm)	184.1 ± 6.5
	Predicted 10 km Time	45.7 ± 5.8
	$\dot{V}T_1$	11.3 ± 1.1
	$\dot{V}T_2$	14.3 ± 1.6

Metabolic and Subjective Assessment

All running trials were conducted under stable laboratory conditions on a motorised treadmill (Woodway, Waukesha, Wisconsin, USA) with the gradient set a 1% (Jones, & Doust, 1996). Heart rate response data was collected using a HR monitor (Polar A300, China), oxygen consumption data was measured using a carbon dioxide and oxygen analyser (Metalyzer Cortex, Biophysik GmbH, Leipzig, Germany), which was calibrated before each testing session according to the manufacturers specifications. All capillary samples were drawn from the preferred finger of the runner and La accumulation was measured using a blood La analyser (La Pro 2, Shiga, Japan). Subjective data was measured by way of RPE using a modified BORG 10-point scale (Seiler & Kjerland, 2006).

Wearable Resistance Participant Loading

Each loaded trial required participants to wear a pair of compression calf sleeves with associated loads (Lila™, Exogen™, Wilayah Persekutuan Kuala Lumpur, Malaysia). Weighted panels were in either 50, 100 or 200g increments and total load for each trial was rounded to the nearest 50g. Loading scheme always started with the first weight being added horizontally, lateral and most distal with the head of the weight facing anterior on the limb followed by medial and most distal with the head of the second weight facing posterior. Weights then alternated in this fashion with each load facing the opposite direction to the one directly below, stacked distal to proximal (see Figures 11-13).

Testing Procedures

For each participant the study was conducted over a maximum of 15 days. Including one familiarisation session and three testing sessions (see Figure 14) under laboratory conditions. The purpose of the familiarisation session was to allow each runner to become accustomed to treadmill running while wearing both the compressive calf sleeves and all metabolic measuring equipment. Participants completed a self-paced run for 20-minutes followed by a 10-minute recovery. During this time the GXT protocol was discussed and a HR monitor and gas mask fitted. Participants then completed a further 10-minute run including following enough of the GXT incremental protocol to feel comfortable with the procedures, no data was collected. At the completion of the familiarisation session, participants were instructed to refrain from training on the day of testing session one and to avoid any strenuous training sessions 24 hours prior. Testing session one occurred within seven days of completing the familiarisation session. The purpose of session one was to generate a $\dot{V}O_2$ response profile to graded exercise to establish $\dot{V}T_1$, $\dot{V}T_2$ and $\dot{V}O_2max$. Participants completed a self-paced 20-minute warm-up on a treadmill and were given a recovery period of 10-minutes prior to the commencement of the GXT. Starting speed was maintained for 1-minute followed by an increase of 0.5 $km \cdot h^{-1}$ every 30-seconds until voluntary exhaustion (Mann et al., 2014). Starting speed was adjusted on an individual basis to ensure volitional exhaustion at 8-12 minutes. Oxygen consumption was tracked continuously at a sampling rate of 0.1Hz, HR and RPE recorded at each speed increment with La being measured immediately post completion of test. $\dot{V}O_2max$ was an average over 30-seconds and was considered to be achieved if any one of the following criteria were met: a plateau in $\dot{V}O_2$ was reached despite an increase in workload, a respiratory exchange ratio (RER) > 1.15 was observed, a HR within five beats of age predicted maximum (220-AGE) was reached or a peak exercise blood La concentration > 8mmol/L was achieved (Scharhag-Rosenberger, Carlsohn, Cassel, Mayer, & Scharhag, 2011). Testing sessions two and three included all submaximal running trials to measure metabolic and subjective responses while un-loaded and loaded. Testing session two occurred within 2-5 days of testing session one and testing session three occurred within 2-3 days of testing session two to ensure no fatigue between all three sessions (Barnett, 2006). Participants were asked to keep a food and exercise diary 24-hours prior to the

Figure 11: Example of distal lower limb loading pattern (0.5%BM) for a 70 kg runner.

Figure 12: Example of distal lower limb loading pattern (1.5%BM) for a 70 kg runner.

Figure 13: Example of distal lower limb loading pattern (2.5%BM) for a 70 kg runner.

commencement of testing session two. This was to ensure these variables were kept consistent prior to coming in for testing session three. Similar to testing session one, participants were also instructed to refrain from training on both days of submaximal testing and to avoid any strenuous training sessions 24 hours prior to either session. Testing session two included four randomly selected wearable loads and testing session three included the final three randomly selected wearable loads (0, 0.5, 1, 1.5, 2, 2.5 and 3%BM), load order was different for each runner. At the start of both testing session two and three an 8-minute warm up set at a running speed equivalent to $\dot{V}T_1$ was completed followed by a 10-minute recovery. Each submaximal running trial lasted 5-minutes with 10-minutes seated recovery between each subsequent trial. Oxygen consumption and HR were tracked for 2-minutes prior to each trial starting, for the 5-minutes of each trial (final 2-minutes used for analysis) and for 2-minutes post trial. Rate of perceived exertion and La was recorded immediately post completion of each 5-minute trial.

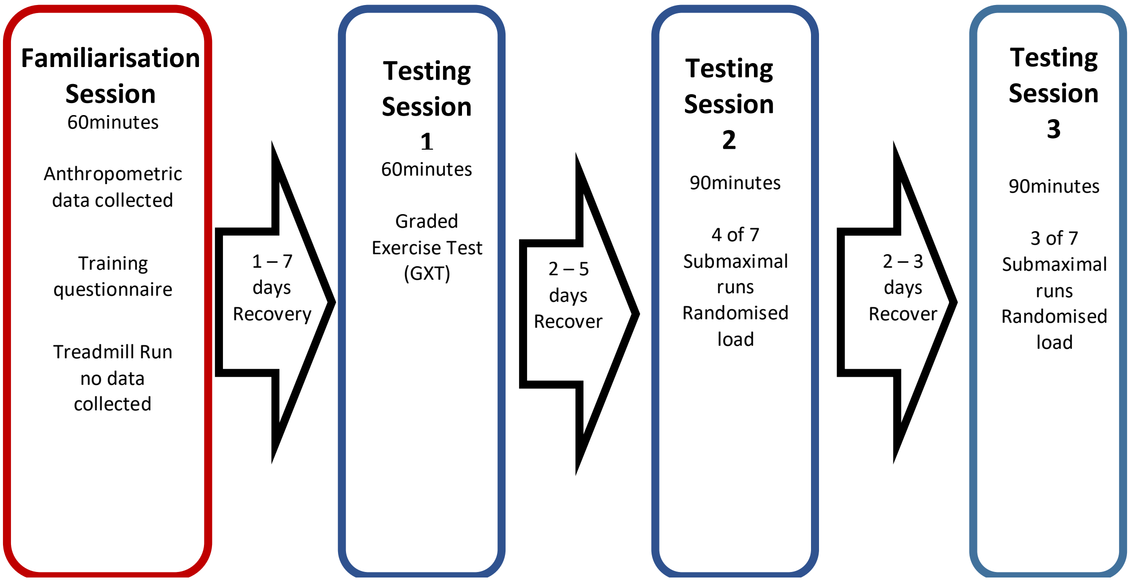

Figure 14: Structure of study two.

Statistical Analysis

Descriptive statistics including means and standard deviations were calculated for each measure. The statistical aim of this study was to make an inference about the impact on metabolic stress of submaximal running while wearing load, which requires determining the magnitude of an outcome. The traditional sample size estimation and hypothesis testing approach was not appropriate for this study design (Hopkins et al., 2009). Accordingly, inferential statistics were used to examine the qualitative meaning of the observed changes in metabolic cost ($\dot{V}O2$, HR, La) and perception (RPE) of submaximal running with load compared to unloaded. Collected data was presented as the mean value for each with reported effect sizes and percent differences at 90% CI.

The smallest worthwhile change was used to determine if any observed changes were considered trivial, possible or likely including the magnitude of each change, calculated as a change in score standardised to 0.2 of the between subject SD from the unloaded condition (Cohen, 1992). The qualitative probabilities were defined by the scale < 0.5% *most likely trivial increase*, < 5% *very likely trivial increase*, < 25% *likely trivial increase*, 25-75% *possible small increase*, > 75% *likely moderate increase*, > 95% *very likely large increase*, > 99.5% *most likely very large increase* and the outcome was deemed *unclear* where the 5 and 90% CI of the mean change overlapped both the positive and negative outcomes (Hopkins et al., 2009). To help quantify the metabolic cost of wearing load based on relative exercise intensity and duration, HR was used to extrapolate a Training Load Score (TLS) for each load (Training Peaks, (2012) for 10-minutes of running (see Figure 15). To understand the relationship between metabolic variables ($\dot{V}O_2$, HR and TLS) and load, a scatterplot was created in excel to establish a linear equation and R^2 value for each variable.

$$TLS = (sec \times HR \times IF) / (\dot{V}T_2 \times 3600) \times 100$$

$$IF \text{ (impact factor)} = HR / \dot{V}T_2$$

Figure 15: Formula used for calculating Training Load Score (Training Stress Score (TSS) from Training Peaks, 2012).

Key: TLS: Training load score, HR: Heart rate (average heart rate during exercise), IF: Impact factor, $\dot{V}T_2$: Second ventilatory threshold (point at which lactate accumulation exceeds clearance).

CHAPTER FOUR- RESULTS

Results – Study One

Metabolic responses

Table 9 contains the means, standard deviations and custom effects as standardised units (ES ± 90%CI) for the acute oxygen responses for all loading conditions. The mean oxygen cost of submaximal running at 1%BM was 3.67L (± 0.59) with an increase of 1.7% (±0.01), however resulted in a *likely trivial increase* (0.13 ± 0.08). Similarly, a *very likely trivial increase* at 2%BM (0.06 ± 0.7) with a mean oxygen consumption of 3.73L (± 0.62) and 2.4% (±0.01) increase. Both 3 and 4%BM reported *likely moderate increase* (0.24 ± 0.07 and 0.29 ± 0.09 respectively), with mean oxygen consumption values of 3.80L (± 0.62) and 3.84L (± 0.64) respectively, and 4.3 (±0.01) and 5.4% (±0.02) increases respectively. 5%BM saw a *most likely very large increase* (0.43 ± 0.07) at 3.94L (± 0.66) mean oxygen cost and an 8.1% (±0.01) increase. Figure 16 contains the percentage change in oxygen response from unloaded to loaded (± 90% CI). Linear regression was carried out and showed a positive relationship (R^2 = 0.96) representing an additional 1.59% (±0.62%) increase in oxygen consumption for every 1%BM of additional load.

Table 9: Acute oxygen responses to light wearable resistance on the proximal lower limbs**.**

Training Load (%BM)	Mean $\dot{V}O_2$ (L)	Effect Size (± 90% CI) as Standardised Units	Rating
0%	3.64 (± 0.57)		
1%	3.67 (± 0.59)	0.13 (0.06; 0.21)	(7/93/0) *likely trivial increase*
2%	3.73 (± 0.62)	0.13 (0.07; 0.19)	(3/97/0) *very likely trivial increase*
3%	3.80 (± 0.62)	0.24 (0.17; 0.3)	(84/16/0) *likely moderate increase*
4%	3.84 (± 0.64)	0.29 (0.2; 0.38)	(94/6/0) *likely moderate increase*
5%	3.94 (± 0.66)	0.43 (0.37; 0.5)	(100/0/0) *most likely very large increase*

Abbreviations: CI, Confidence interval
*Values are mean $\dot{V}O_2$ collected over the final 2-minute period of 8-minutes of submaximal treadmill running at first ventilatory threshold

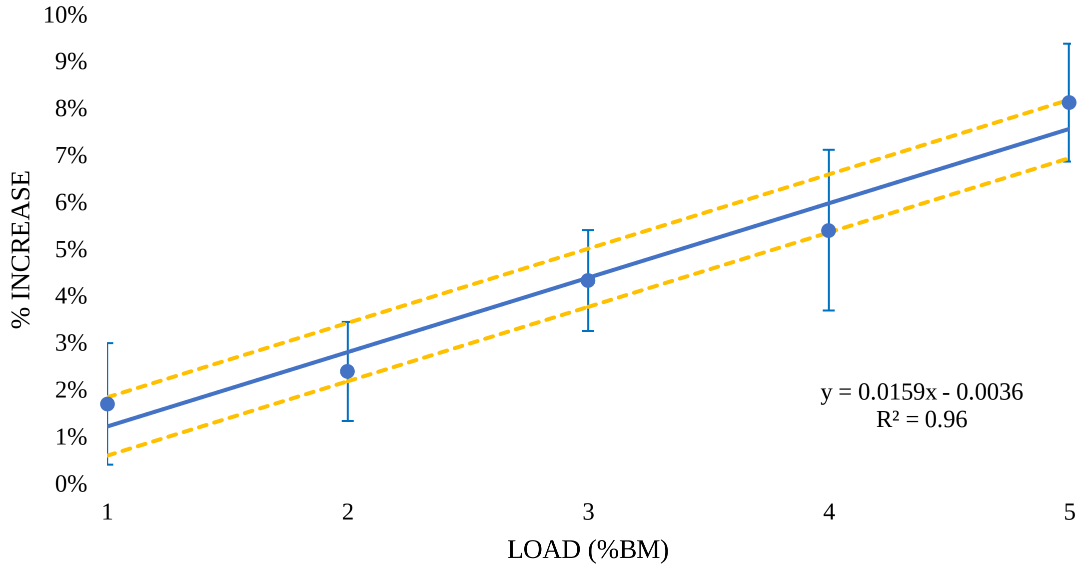

Figure 16: Acute oxygen responses to light wearable resistance on the proximal lower limbs (±90%CI).

Table 10 contains the means, standard deviations and custom effects as standardised units (ES ± 90%CI) for the acute HR responses for all loading conditions. The mean HR response to submaximal running with a load of 1%BM was 158 bpm (± 13.42), with a 0.4% (±0.01) increase and resulted in a *very likely trivial increase* (0.05 ± 0.11). *Possible small increase* at 2 and 3%BM (0.17 ± 0.15 and 0.2 ± 0.13 respectively), with mean values of 159.50 (± 13.42) and 160 bpm (± 12.35) respectively with 1.5 (±0.01) and 1.8% (±0.01) increases respectively. A mean HR response of 162 bpm (± 11.99) and 2.9% (±0.01) increase at 4%BM reporting a *likely moderate increase* (0.32 ± 0.16). At 5%BM a *very likely large increase* (0.33 ± 0.12) with a mean HR response of 162 bpm (± 11.36) and 2.9% (±0.01) increase. Figure 17 contains the percentage change in HR response from unloaded to loaded (± 90% CI). Linear regression was carried out and showed a positive relationship ($R^2 = 0.94$) representing an additional 0.63% (±0.32) increase in HR response for every 1%BM of additional load. Figure 18 represents the relationship between the TLS extrapolated from the HR data for the equivalent of 10-minutes of running at $\dot{V}T_1$ and load. The regression equation showed a positive linear relationship ($R^2 = 0.96$) representing an additional 0.17(±0.06) of internal training stress for every 1%BM of additional load for 10 minutes of running.

Table 10: Acute HR responses to light wearable resistance on the proximal lower limbs.

Training load (%BM)	Mean HR (bpm)	Effect Size (± 90% CI) as Standardised Units	Rating
0%	157.25 (± 12.70)		
1%	157.95 (± 13.42)	0.05 (-0.07; 0.16)	(2/98/0) *very likely trivial increase*
2%	159.53 (± 13.42)	0.17 (0.02; 0.31)	(36/64/0) *possible small increase*
3%	159.98 (± 12.35)	0.2 (0.07; 0.33)	(49/51/0) *possible small increase*
4%	161.58 (± 11.99)	0.32 (0.16; 0.47)	(90/10/0) *likely moderate increase*
5%	161.69 (± 11.36)	0.33 (0.21; 0.45)	(96/4/0) *very likely large increase*

Abbreviations: CI, Confidence interval
*Values are mean HR collected over the final 2-minute period of 8-minutes of submaximal treadmill running at first ventilatory threshold

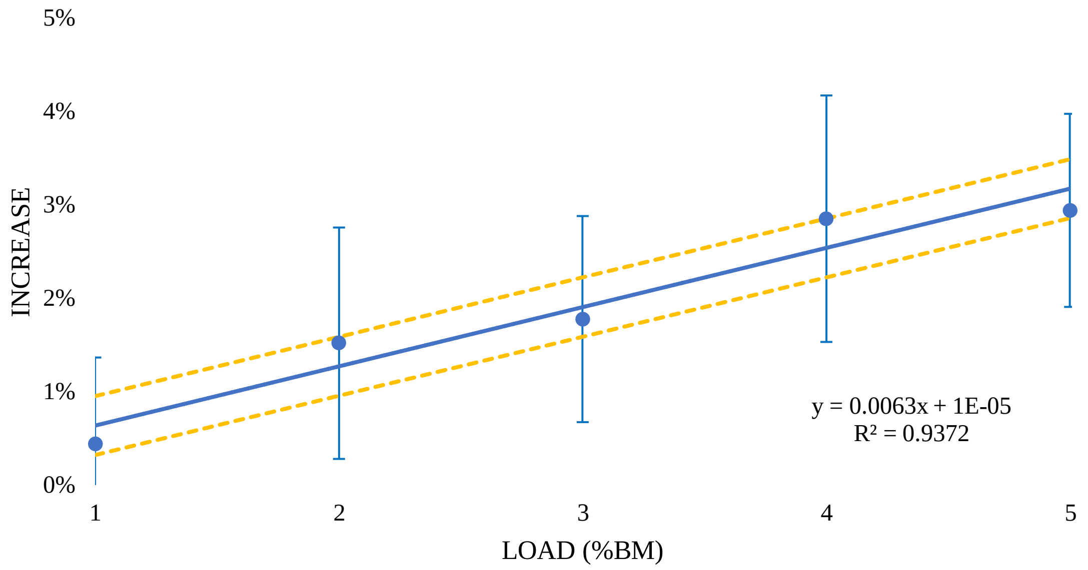

Figure 17: Acute HR responses to light wearable resistance on the proximal lower limbs (±90%CI).

Table 11 contains the means, standard deviations and custom effects as standardised units (ES ± 90%CI) for the acute La responses for all loading conditions. Blood La responses post submaximal running with a load of 1%BM resulted in a mean accumulation of 2.77mmol/L (± 1.90), however, an *unclear* effect with more data needed (0.0 ± 0.28). A *likely trivial increase* at 2%BM (0.08 ± 0.15) with a mean accumulation of 4.83mmol/L (± 2.04) was observed. With loads at 3 and 4%BM reporting *very likely large increases* (0.41 ± 0.18 and 0.42 ± 0.19 respectively) with mean accumulations of 3.27 (± 1.79) and 3.30mmol/L (± 2.03) respectively. Loaded at 5%BM produced a mean accumulation of 3.52mmol/L (± 2.35) and reported a *most likely very large increase* (0.49 ± 0.15).

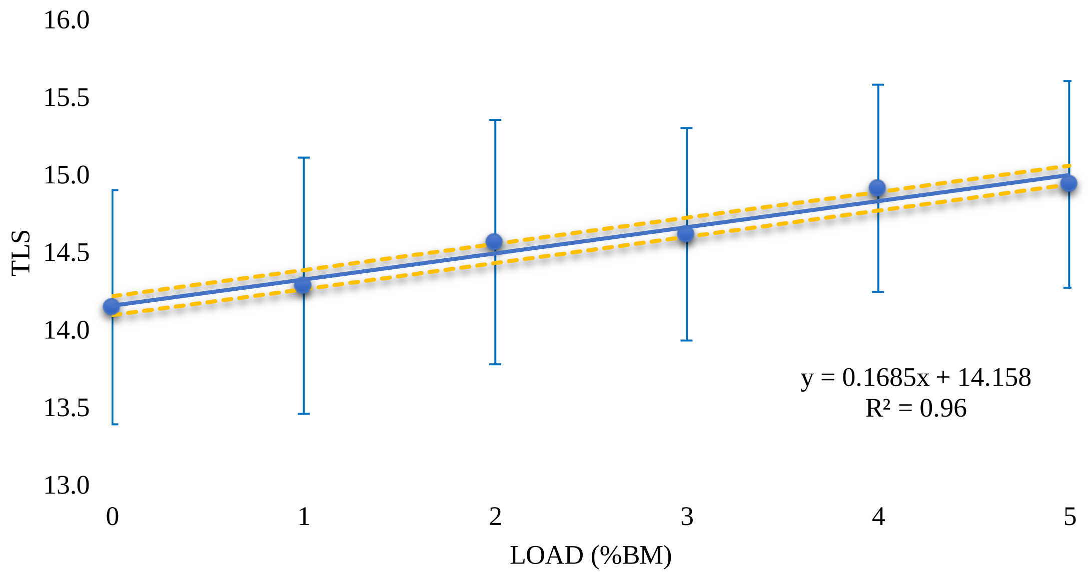

Figure 18: Impact of load on Training Load Score for 10-minutes of running (±90%CI).

Table 11: Acute La responses to light wearable resistance on the proximal lower limbs.

Training load (%BM)	Mean La (mmol/L)	Effect Size (± 90% CI) as Standardised Units	Rating
0%	2.62 (± 1.56)		
1%	2.77 (± 1.90)	0.0 (-0.27; 0.28)	(12/77/11) *unclear effect*
2%	4.83 (± 2.04)	0.08 (-0.07; 0.23)	(10/90/0) *likely trivial increase*
3%	3.27 (± 1.79)	0.41 (0.23; 0.60)	(97/3/0) *very likely large increase*
4%	3.30 (± 2.03)	0.42 (0.23; 0.61)	(97/3/0) *very likely large increase*
5%	3.52 (± 2.35)	0.49 (0.34; 0.63)	(100/0/0) *most likely very large increase*

Abbreviations: CI, Confidence interval
*Values are mean blood La accumulations sampled immediately post 8-minutes of submaximal treadmill running at first ventilatory threshold

Subjective Responses

Table 12 contains the means, standard deviations and custom effects as standardised units (ES ± 90%CI) for the acute RPE responses for all loading conditions. Post submaximal running with a load of 1%BM resulted in a *possible small increase* (0.28 ± 0.25) and mean reported score of 3.35 (± 1.16). A *likely moderate increase* at 2%BM (0.43 ± 0.23) with mean reported score of 3.68 (± 1.44) and a mean reported score of 3.73 (± 1.33) and *very likely large increase* at 3%BM (0.52 ± 0.26). Both 4 and 5%BM reported *most likely very large increases* (0.82 ± 0.29 and 0.86 ± 0.28 respectively) with mean reported scores of 4.20 (± 1.26) and 4.38 (± 1.57) respectively.

Table 12: Acute RPE responses to light wearable resistance on the proximal lower limbs.

Training load (%BM)	Mean Rate of Perceived Exertion (RPE)	Effect Size (± 90% CI) as Standardised Units	Rating
0%	3.08 (± 1.37)		
1%	3.35 (± 1.16)	0.28 (0.03; 0.53)	(70/30/0) *possible small increase*
2%	3.68 (± 1.44)	0.43 (0.19; 0.66)	(95/5/0) *likely moderate increase*
3%	3.73 (± 1.33)	0.52 (0.26; 0.78)	(98/2/0) *very likely large increase*
4%	4.20 (± 1.26)	0.82 (0.53; 1.11)	(100/0/0) *most likely very large increase*
5%	4.38 (± 1.57)	0.86 (0.58; 1.14)	(100/0/0) *most likely very large increase*

Abbreviations: CI, Confidence interval
*Values are mean RPE scores recorded immediately post 8-minutes of submaximal treadmill running at first ventilatory threshold

Results – Study Two

Metabolic responses

Table 13 contains the means, standard deviations and custom effects as standardised units (ES ± 90%CI) for the acute oxygen responses for all loading conditions. The oxygen cost of submaximal running at 0.5%BM resulted in a mean $\dot{V}O_2$ response of 3.28L (± 0.53), a 1.5% (±0.02) increase and reported a *very likely trivial increase* (0.09 ± 0.11). At 1%BM a mean $\dot{V}O_2$ response of 3.36L (± 0.59), a 3.9% (±0.02) increase and a *possible small increase* (0.22 ± 0.12). 1.5 and 2%BM resulted in a mean $\dot{V}O_2$ response of 3.39L (± 0.56) and 3.39L (± 0.53) respectively, with 4.9 (±0.02) and 5.3%BM (±0.02) increases respectively. Both reporting *likely moderate increases* (0.28 ± 0.11 and 0.30 ± 0.10 respectively). 2.5%BM generated a mean $\dot{V}O_2$ response of 3.43L (± 0.59), a 6.9% (±0.02)

Table 13: Acute oxygen responses to light wearable resistance on the distal lower limbs.

Training Load (%BM)	Mean $\dot{V}O_2$ (L)	Effect Size (± 90% CI) as Standardised Units	Rating
0%	3.22 (± 0.48)		
0.5%	3.28 (± 0.53)	0.09 (-0.02; 0.19)	(4/96/0) *very likely trivial increase*
1%	3.36 (± 0.59)	0.22 (0.9; 0.34)	(60/40/0) *possible small increase*
1.5%	3.39 (± 0.56)	0.28 (0.17; 0.39)	88/12/0) *likely moderate increase*
2%	3.39 (± 0.53)	0.3 (0.19; 0.40)	(94/6/0) *likely moderate increase*
2.5%	3.43 (± 0.59)	0.34 (0.22; 0.44)	(97/3/0) *very likely large increase*
3%	3.52 (± 0.54)	0.51 (0.42; 0.60)	(100/0/0) *most likely very large increase*

Abbreviations: CI, Confidence interval
*Values are mean $\dot{V}O_2$ collected over the final 2-minute period of 5-minutes of submaximal treadmill running at first ventilatory threshold

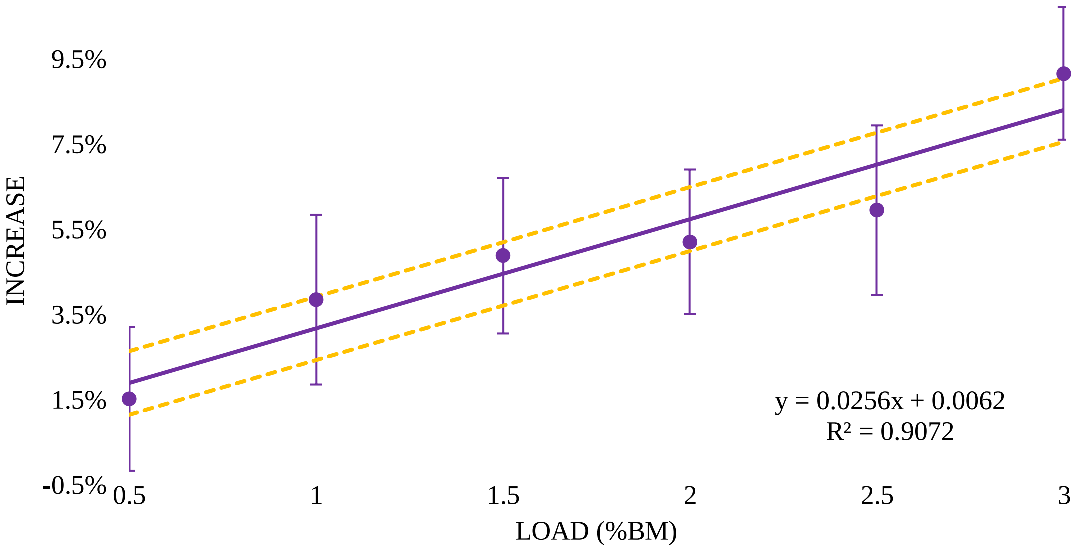

Figure 19: Acute oxygen responses to light wearable resistance on the distal lower limbs (±90%CI).

increase and resulted in a *very likely large increase* (0.34 ± 0.12). While 3%BM generated a mean $\dot{V}O_2$ response of 3.52L (± 0.54), a 9.2% (±0.02) increase and reported a *most likely very large increase* (0.51 ± 0.09). Figure 19 contains the percentage change in oxygen response from unloaded to loaded (± 90% CI). Linear regression was carried out and showed a positive relationship (R^2 = 0.91) representing an additional 2.56% (±0.75) increase in oxygen consumption for every 1%BM of additional load.

Table 14 contains the means, standard deviations and custom effects as standardised units (ES ± 90%CI) for the acute HR responses for all loading conditions. At 0.5%BM a mean HR response of 152 bpm (± 9.09) and 1.0% (±0.01) increase, resulted in a *possible small increase* (0.13 ± 0.20). *Likely moderate increases* at 1 and 1.5%BM (0.30 ± 0.22 and 0.35 ± 0.17 respectively), generating mean HR responses of 154 bpm (± 12.05) and 154 bpm (± 10.63) respectively. With 2.2 (±0.02) and 2.6% (±0.01) increases respectively. 2, 2.5 and 3%BM all reported *most likely very large increases* (0.49 ± 0.17, 0.60 ± 0.16, and 0.62 ± 0.22 respectively) with mean HR responses of 155.53 (± 9.84), 156.67 (± 9.17) and 157 bpm (± 7.95) respectively. This equates to a 3.6 (±0.01), 4.4 (±0.01), and 3.6% (±0.01) increase respectively. Figure 20 contains the percentage change in HR response from unloaded to loaded (± 90% CI). Linear regression showed a positive relationship (R^2 = 0.80) representing an additional 1.16% (±0.52) increase in HR response for every 1%BM of additional load. Figure 21 represents the relationship between the TLS extrapolated from collected HR data for the equivalent of 10-minutes of running at $\dot{V}T_1$

Table 14: Acute HR responses to light wearable resistance on the distal lower limbs.

Training Load (%BM)	Mean HR (bpm)	Effect Size (± 90% CI) as Standardised Units	Rating
0%	150.18 (± 10.17)		
0.5%	151.57 (± 9.09)	0.13 (-0.06; 0.33)	(28/71/1) *possible small increase*
1%	153.52 (± 12.05)	0.30 (0.8; 0.52)	(78/22/0) *likely moderate increase*
1.5%	154.06 (± 10.63)	0.35 (0.19; 0.52)	(94/6/0) *likely moderate increase*
2%	155.53 (± 9.84)	0.49 (0.32; 0.67)	(100/0/0) *most likely very large increase*
2.5%	156.67 (± 9.17)	0.60 (0.44; 0.76)	(100/0/0) *most likely very large increase*
3%	156.80 (± 7.95)	0.62 (0.4; 0.84)	(100/0/0) *most likely very large increase*

Abbreviations: CI, Confidence interval
*Values are mean HR collected over the final 2-minute period of 5-minutes of submaximal treadmill running at first ventilatory threshold

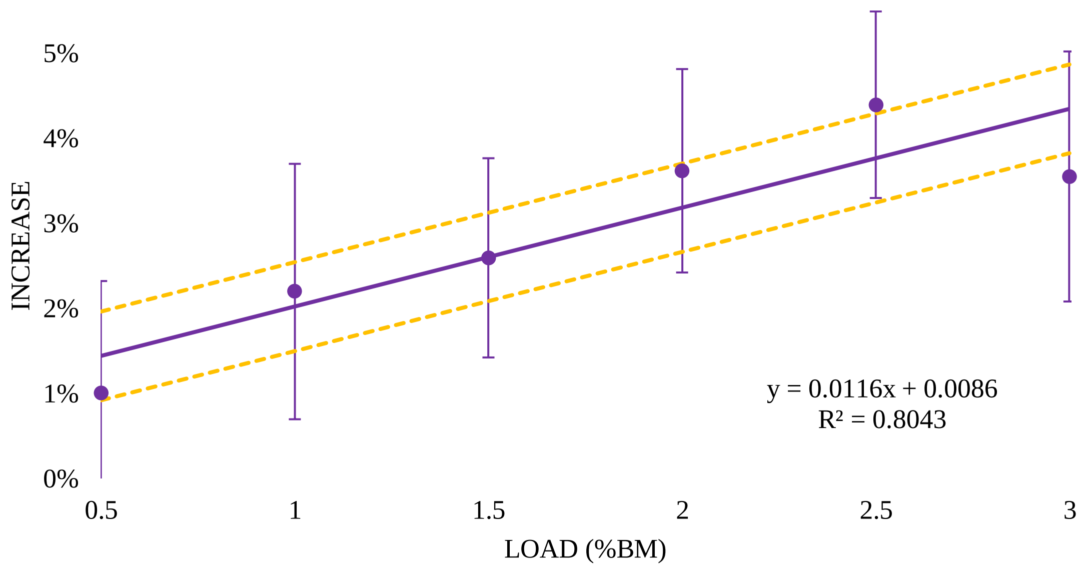

Figure 20: Acute HR responses to light wearable resistance on the distal lower limbs (±90%CI).

and load. The regression equation showed a positive linear relationship (R^2 = 0.97) representing an additional 0.39(±0.06) of internal training stress for every 1%BM of additional load. Table 15 contains the means, standard deviations and custom effects as standardised units (ES ± 90%CI) for the acute La responses for all loading conditions. Post submaximal running with a load of 0.5%BM produced a mean La response of 2.29mmol/L (± 0.89) and resulted in a *likely moderate increase* (0.49 ± 0.46). 1%BM produced a mean La response of 2.35mmol/L (±1.11) and resulted in a *very likely large increase* (0.63 ± 0.40).

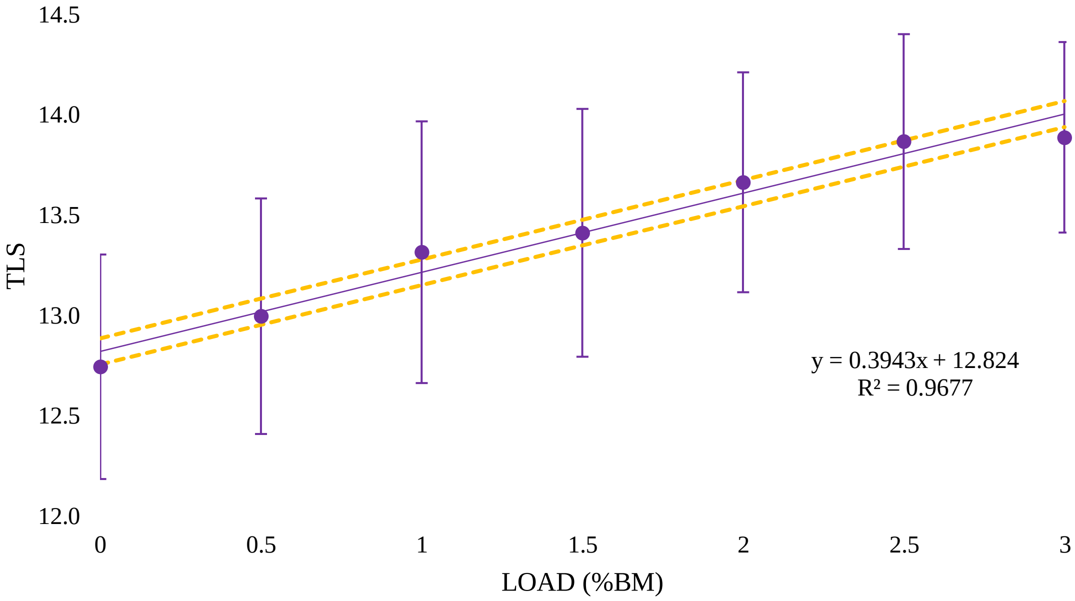

Figure 21: Impact of load on Training Load Score for 10-minutes of running (±90%CI).

Both 1.5 and 2%BM resulted in *likely moderate increases* (0.45 ± 0.48 and 0.65 ± 0.53 respectively) and produced a mean La response of 2.37 (± 1.11) and 2.44mmol/L (± 0.95) respectively. At 2.5 and 3%BM a mean La response of 2.61 (± 0.66) and 2.83mmmol/L (± 1.22) respectively reporting *most likely very large increases* (0.96 ± 0.44 and 1.05 ± 0.45 respectively).

Table 15: Acute La responses to light wearable resistance on the distal lower limbs.

Training Load (%BM)	Mean La (mmol/L)	Effect Size (± 90% CI) as Standardised Units	Rating
0%	1.89 (± 0.60)		
0.5%	2.29 (± 0.89)	0.49 (0.3; 0.95)	(86/13/1) *likely moderate increase*
1%	2.35 (± 0.72)	0.63 (0.22; 1.03)	(96/4/0) *very likely large increase*
1.5%	2.37 (± 1.11)	0.45 (-0.03; 0.93)	(82/16/2) *likely moderate increase*
2%	2.44 (± 0.95)	0.65 (0.12; 1.19)	(92/7/1) *likely moderate increase*
2.5%	2.61 (± 0.66)	0.96 (0.52; 1.39)	(100/0/0) *most likely very large increase*
3%	2.83 (± 1.22)	1.05 (0.6; 1.51)	(100/0/0) *most likely very large increase*

Abbreviations: CI, Confidence interval
*Values are mean blood La accumulations sampled immediately post 5-minutes of submaximal treadmill running at first ventilatory threshold

Subjective Responses

Table 16 contains the means, standard deviations and custom effects as standardised units (ES ± 90%CI) for the acute RPE responses for all loading conditions. With a load of 0.5%BM a mean RPE response of 3.03 (± 1.22) was observed, resulting in a *likely moderate increase* (0.40 ± 0.33). Both 1 and 1.5%BM resulted in *very likely large increases* (0.63 ± 0.28 and 0.73 ± 0.38 respectively) and produced mean RPE responses of 3.27 (± 1.07) and 3.40 (± 1.02) respectively. At 2, 2.5 and 3%BM, *most likely very large increases* were reported (1.11 ± 0.33, 1.30 ± 0.25 and 1.38 ± 0.40 respectively), generating mean RPE responses of 4.0 (± 1.28), 4.3 (± 1.15) and 4.53 (± 1.59) respectively.

Table 16: Acute RPE responses to light wearable resistance on the distal lower limbs.

Training Load (%BM)	Mean Rate of Perceived Exertion (RPE)	Effect Size (± 90% CI) as Standardised Units	Rating
0%	2.53 (± 0.88)		
0.5%	3.03 (± 1.22)	0.40 (0.07; 0.72)	(85/15/0) *likely moderate increase*
1%	3.27 (± 1.07)	0.63 (0.35; 0.90)	(99/1/0) *very likely large increase*
1.5%	3.40 (± 1.02)	0.73 (0.35; 1.11)	(99/1/0) *very likely large increase*
2%	4.00 (± 1.28)	1.11 (0.78; 1.43)	(100/0/0) *most likely very large increase*
2.5%	4.30 (± 1.15)	1.30 (1.05; 1.55)	(100/0/0) *most likely very large increase*
3%	4.53 (± 1.59)	1.38 (0.98; 1.79)	(100/0/0) *most likely very large increase*

Abbreviations: CI, Confidence interval
*Values are mean RPE scores recorded immediately post 5-minutes of submaximal treadmill running at first ventilatory threshold

CHAPTER FIVE – DISCUSSION OF THESIS FINDINGS

Introduction

The purpose of this thesis was to investigate how utilising the Exogen™ exoskeleton technology by Lila™ to load the PLL and DLL impacts the acute metabolic ($\dot{V}O_2$, HR and lactate) responses to submaximal running in endurance trained runners. It is hoped that such information will give practitioners and athletes information to help effectively integrate this technology into their training regimes. The metabolic data collected in the current thesis agrees with data previously reported, showing that lower body limb loading during locomotion can increase metabolic cost compared to un-loaded (Claremont & Hall, 1988; Jones et al., 1984; Martin, 1985; Soule & Goldman, 1969) and that a greater metabolic response is expected when comparative load is moved more distal (Martin, 1985). Most research in the area of locomotion with loaded limbs has focused on comparing unloaded conditions with loaded feet only (Jones et al., 1984), with loaded feet, hands and a combination of both, (Claremont & Hall, 1988) and with loaded feet, hands and head (Soule & Goldman, 1969). Martin (1985) is the only other study to compare loading of the PLL and DLL with un-loaded conditions over more than one load.

Study One

Discussion

The aim of study one was to understand the acute metabolic effects of PLL loading during submaximal running in endurance trained runners. It is hoped that such information will give practitioners and athletes information to help effectively integrate this technology into their training regimes. It was found that for every 1%BM of additional load there is an expected 1.59 (±0.62) and 0.63% (±0.32) increase in $\dot{V}O_2$ and HR response respectively. Proximal limb loading of at least 3%BM was needed to have a *likely moderate increase* (0.24 ± 0.07) in $\dot{V}O_2$ response, with a *most likely very large increase* (0.43 ± 0.07) at 5%BM. Loading of at least 2%BM was needed to have a *possible small increase* (0.17 ± 0.15) in HR response, with a *very likely large increase* (0.33 ± 0.12) at 5%BM. This resulted in a predicted 0.17 (±0.06) increase of internal stress for every 1%BM of additional load for 10-minutes of running at a speed equivalent to $\dot{V}T_1$.

The $\dot{V}O_2$ and HR data collected in this study agrees with data previously reported, showing that limb loading during locomotion can increase metabolic cost compared to un-loaded (Claremont & Hall, 1988; Jones et al., 1984; Martin, 1985; Soule & Goldman, 1969), however, these studies have all investigated DLL loading (feet). Martin (1985) is the only other study to use PLL loading. They reported an increase in oxygen consumption of 1.7 and 3.5% when the equivalent of 0.69 and 1.39%BM respectively was added to the thighs of highly trained male distance runners at a running speed of 12 km▪h^{-1}, with increases in $\dot{V}O_2$ response to load reaching statistical significance (p<.05). For an additional load of 1, 2, 3, 4, and 5%BM an increase in $\dot{V}O_2$ of 1.7 (±0.01), 2.4 (±0.01), 4.3 (±0.01), 5.4 (±0.02) and 8.1% (±0.01) was found respectively. Comparatively, an increase in $\dot{V}O_2$ of 1.59% (±0.62%) for every 1%BM (equivalent to 0.75 kg when extrapolated from the mean weight of our participants) of additional load was also observed. Accordingly, the increase in cost is slightly less compared to the findings of Martin (1985). The statistical method used in the current study (inferential based analysis), demonstrated that PLL loading of at least 3%BM was needed to have a *likely moderate increase* (0.24 ± 0.07). Martin (1985) produced statistically significant increases in oxygen consumption at loads lower than 3%BM on the thighs, however, they did not report any effect sizes to establish the magnitude of this change.

In terms of HR responses, Martin (1985) only reported on mean values but showed a similar trend to that of $\dot{V}O_2$ in that HR increased slightly with additional load to the thighs. These changes, however, did not reach statistical significance and the researchers suggested that HR is a less sensitive measure of thigh loading under 1.39%BM. Comparatively, we reported an increase in HR of 0.63% (±0.32) for every 1%BM (equivalent to 0.75 kg when extrapolated from the mean weight of our participants) of additional load, which is less than half that of $\dot{V}O_2$ (1.59%) for the same load. Inferential based analysis demonstrated that PLL loading of at least 2%BM was needed to have a *possible small increase* (0.17 ± 0.15) in HR response with 1%BM reporting a *very likely trivial increase* (0.05 ± 0.11). Using the HR data collected, a TLS (Training Peaks, 2012) was extrapolated to help quantify the amount of internal stress each loaded trial would have over a 10-minute running period. Based on the linear regression equation produced for TLS plotted against load, for every 1%BM of additional load there is an extra 0.17(±0.06) increase in internal stress.

Conclusion

In summary, the current findings suggest that evenly loading the anterior and posterior aspect of the PLL while running at a speed equivalent to $\dot{V}T_1$ will elicit an increase in metabolic response compared to un-loaded conditions. There is an expected increase in $\dot{V}O_2$ and HR response of 1.59 (±0.62) and 0.63% (±0.32) respectively for every 1%BM of additional load and an increase in exercise stress of 0.17 (±0.06) for the equivalent of 10-minutes of running for every 1%BM of additional load. However, loads of at least 3 and 2%BM are needed to see substantial increases in $\dot{V}O_2$ and HR responses respectively.

The data collected from the current study gives some evidence for guiding minimal loading thresholds and helps quantify the potential increase in both $\dot{V}O_2$ and HR responses to PLL loading during short-term submaximal running. However, this evidence is based only on 8-minutes of running and the effects of longer duration loaded running under these conditions are still unknown. It also gives means for quantifying an expected TLS for loaded submaximal running for a given duration.

Study Two

Discussion

The aim of the current study was to understand the acute metabolic effects of DLL loading during submaximal running in endurance trained runners. It is hoped that such information will give practitioners and athletes information to help effectively integrate this technology into their training regimes. It was found that for every 1%BM of additional load there is an expected 2.56 (±0.75) and 1.16% (±0.52) increase in $\dot{V}O_2$ and HR response respectively. Inferential based analysis demonstrated that loading of at least 1%BM was needed to have a *possible small increase* (0.22 ± 0.12) in $\dot{V}O_2$ response, with a *most likely very large increase* (0.51 ± 0.09) at 3%BM. The smallest loaded trial (0.5%BM) was enough to have a *possible small increase* (0.13 ± 0.20) in HR response. A TLS from the collected HR data was able to be extrapolated to establish the impact that additional load would have on a training session. This resulted of a predicted 0.39 (±0.06) increase in internal stress for every 1%BM of additional load for 10-minutes of loaded running at a speed equivalent to $\dot{V}T_1$.

The $\dot{V}O_2$ and HR data collected in this study agrees with data previously reported, showing that limb loading during locomotion can increase metabolic cost compared to un-loaded (Claremont & Hall, 1988; Jones et al., 1984; Martin, 1985; Soule & Goldman, 1969). Soule and Goldman, (1969) reported the greatest increase in energy expenditure per kg of load added of 8.6% at walking speeds up to 5.6 km▪h^{-1} in military personal. Jones and colleagues (1984) reporting an equivalent of a 4.5% increase in oxygen consumption per kg of load at a running speed of 12 km▪h^{-1} in trained and un-trained individuals. Claremont and Hall (1988) reporting a 5.4% increase in energy expenditure per kg of load at self-selected running speeds up to 13.6 km▪h^{-1} in moderately trained endurance runners and Martin (1985) reporting a 3.5% in oxygen consumption when the equivalent of 0.69 and 1.39%BM respectively was added to the feet of highly trained male distance runners at a running speed of 12 km▪h^{-1}. For an additional load of 0.5, 1, 1.5, 2, 2.5 and 3%BM an increase in $\dot{V}O_2$ of 1.5 (±0.02), 3.9 (±0.02), 4.9 (±0.01), 5.2 (±0.02) 6.0 (±0.02) and 9.2% (±0.02) was found respectively. Comparatively, an increase in $\dot{V}O_2$ of 2.56% (±0.75) for every 1%BM (equivalent to 0.725 kg when extrapolated from the mean weight of participants) of additional load was also noted. Accordingly, the increase in cost is less than previously reported, however is to be expected as direct comparisons are difficult to make due to variations in participant demographics and loading variations. Jones and colleagues found that load has a significantly (p<0.5) greater impact on both relative $\dot{V}O_2$ and HR response in less trained individuals, while Martin (1985) has shown that comparative load moved more distal on the lower limb has a significantly (p<0.5) greater impact on the metabolic cost of running. The current study used endurance trained runners wearing unrestrictive calf sleeves which allowed load attachment to spread across the entirety of the DLL, from knee to ankle. Inferential based analysis demonstrated that DLL loading of at least 1%BM was needed to have a *possible small increase* (0.22 ± 0.12) in $\dot{V}O_2$ response with 0.5%BM reporting a *very likely trivial increase* (0.09 ± 0.11).

In terms of HR responses, a similar trend to that of $\dot{V}O_2$ has been reported with slight increases with additional load to the feet, (Jones et al., 1984; Martin, 1985) however, these changes did not reach statistical significance and the researchers suggested that HR is a less sensitive measure of foot loading. Comparatively, the current study reported an increase in HR of 1.16% (±0.52) for every 1%BM (equivalent to 0.725 kg when extrapolated from the mean weight of participants) of additional load, which is less than half that of $\dot{V}O_2$ (2.56%) for the same load. Inferential based analysis demonstrated that the smallest DLL loading of 0.5%BM could produce a *possible small increase* (0.13 ± 0.20) in HR response. Using the HR data collected, a TLS (Training Peaks, 2012) was extrapolated to help quantify the amount of internal stress each loaded trial would have over a 10-minute running period. Based on the linear regression equation produced for TLS plotted against load, for every 1%BM of additional load there is an extra 0.39(±0.06) increase in internal stress.

Conclusion

In summary, the current findings suggest that evenly loading the medial and lateral aspect of the DLL while running at a speed equivalent to $\dot{V}T_1$ will elicit an increase in metabolic response compared to un-loaded conditions. There is an expected increase in $\dot{V}O_2$ and HR response of 2.56 (±0.75) and 1.16% (±0.52) respectively for every 1%BM of additional load and an increase in exercise stress of 0.39(±0.06) for the equivalent of 10-minutes of running for every 1%BM of additional load. A load of at least 1%BM is needed to see substantial increases in $\dot{V}O_2$ responses, however, 0.5%BM can produce substantial increases in HR responses.

The data collected from the current study gives some evidence for guiding minimal loading thresholds and helps quantify the potential increase in both $\dot{V}O_2$ and HR responses to DLL loading during short-term submaximal running. However, this evidence is based only on 5-minutes of running and the effects of longer duration loaded running under these conditions are still unknown It also gives means for quantifying an expected TLS for loaded submaximal running for a given duration.

Proximal vs. Distal Loading Comparisons

Comparative Oxygen Consumption

It was found for an additional load of 1, 2, 3, 4, and 5%BM to the PLL, an increase in $\dot{V}O_2$ response of 1.7 (±0.01), 2.4 (±0.01), 4.3 (±0.01), 5.4 (±0.02) and 8.1% (±0.01) respectively. This equated to an increase of 1.59% (±0.62%) for every 1%BM (equivalent to 0.75 kg when extrapolated from the mean weight of our participants) of additional load. Comparatively (see Figure 22), for an additional load of 0.5, 1, 1.5, 2, 2.5 and 3%BM to the DLL, an increase in $\dot{V}O_2$ response of 1.5 (±0.02), 3.9 (±0.02), 4.9 (±0.01), 5.2 (±0.02) 6.0 (±0.02) and 9.2% (±0.02) respectively. This equated to an increase of 2.56% (±0.75) for every 1%BM (equivalent to 0.725 kg when extrapolated from the mean weight of our participants) of additional load. Unsurprisingly, these results show that loading of the DLL will have a greater impact on oxygen consumption than PLL loading, when comparing equal loads. This impact is almost double, which is in agreement with Martin (1985) who reported significant increases in oxygen consumption of 1.7 and 3.5% (p<0.05) when the equivalent of 0.69 and 1.39%BM respectively was added to the thighs of male distance runners. Similarly, when the same load was added to the feet, oxygen consumption almost doubled with significant increases of 3.3 and 7.2% (p<0.05). Martin (1985) have recorded higher $\dot{V}O_2$ responses for both loading schemes. Moving load away from the hip seems to have greater impacts on metabolic cost, which could explain this difference as loading technology and patterns used were different. The current thesis was able to distribute load over the entirety of the PLL (from hip to knee) and DLL (from knee to ankle), while Martin (1985) applied load using lead shots to fill pockets stitched into to elastic bicycle shorts (59-80% of thigh length) and elastic pockets stitched onto the lateral aspect of each shoe.

Inferential based analysis identified that for PLL loading, at least 3%BM was needed to have a *likely moderate increase* (0.24 ± 0.07) in oxygen consumption, while DLL loading had a *possible small increase* from 1%BM (0.22 ± 0.12). Initially it would seem advantageous to use less load placed more distal to increase metabolic cost as a training tool and inherently decrease mechanical load on the lower body. However, there is not nearly enough literature to determine how the body is affected by either loading pattern. While PLL loading potentially increases inertia about the hip joint, DLL loading potentially increases inertia about both the hip and knee joints. It may be that each loading pattern produces a different stimulus other than just increases in metabolic cost, which may be advantageous or detrimental in the pursuit of improving endurance running performance.

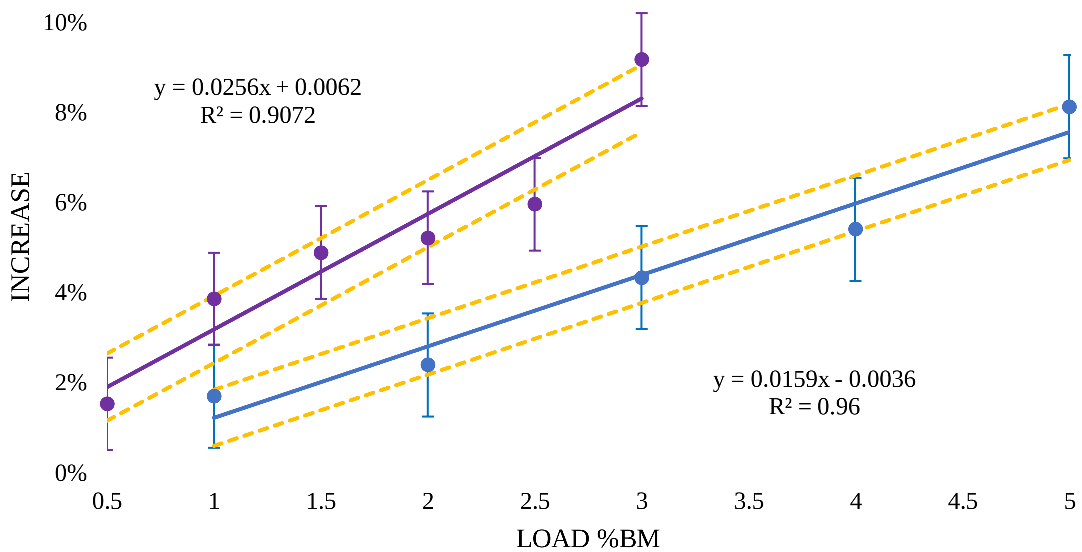

Figure 22: $\dot{V}O_2$ responses to submaximal running with proximal lower limb vs. distal lower limb loading (±90%CI).

Comparative Heart Rate

It was found that for an additional load of 1, 2, 3, 4, and 5%BM to the PLL, an increase in HR response of 0.4 (±0.01), 1.5 (±0.01), 1.8 (±0.01), 2.9 (±0.01) and 2.9% (±0.01) respectively. This equated to an increase of 0.63% (±0.32) for every 1%BM (equivalent to 0.75 kg when extrapolated from the mean weight of our participants) of additional load.

Also, for an additional load of 0.5, 1, 1.5, 2, 2.5 and 3%BM to the DLL, an increase in HR response of 1.0 (±0.01), 2.2 (±0.02), 2.6 (±0.01), 3.6 (±0.01) 4.4 (±0.01) and 3.6% (±0.01) was noted respectively. This equated to an increase of 1.16% (±0.52) for every 1%BM (equivalent to 0.725 kg when extrapolated from the mean weight of participants) of additional load. These results suggest that loading of the DLL will have a greater impact on HR response than PLL loading, when comparing equal loads. This impact more than doubles, which is comparable to the response in oxygen consumption provides additional evidence to support the in metabolic response to PLL and DLL limb loading while running.

Comparative Training Load Estimation

Based on the linear regression equation produced for a TLS generated for 10-minutes of running plotted against load, for every 1%BM of additional load added to the PLL there is an extra 0.17 (±0.06) increase in internal stress. For every 1%BM of additional load added to the DLL there is an extra 0.39 (±0.06) increase in internal stress. This supports the oxygen consumption data collected, strengthening the idea that metabolic cost is more sensitive to DLL loading than PLL loading and comparatively the impact on training load is also double at DLL loading compared with PLL loading. Because this study used relative loads this gives a means to quantify the stress that PLL and DLL loading of 1-5 and 0.5-3%BM respectively will have on every 10-minutes of running at a speed equivalent to $\dot{V}T_1$. In terms of a practical example, if an un-loaded 60-minute training session generated a TLS of 80, then the same session run at the same speed with 3%BM on the PLL or DLL would generate a TLS of 83.06 (0.17x6x3) and 87.02 (0.39x6x3) respectively. This is useful as it gives means to help guide programming WRT into training and assists any future training studies looking at the chronic impact of training with load. However, caution must be used as these calculations are based on short-term submaximal running (5-8 minutes) and the impact of limb loading on the accumulation of peripheral fatigue and physiological demand beyond these durations is unknown.

Comparative Lactate Accumulation

This thesis is the first to report on the acute La responses to submaximal running with load. Inferential based analysis demonstrated that PLL loading of at least 3%BM was needed to have a *very likely large increase* (0.41 ± 0.18) in La response with 1 and 2%BM reporting an *unclear* and *likely trivial increase* (0.0 ± 0.28 and 0.08 ± 0.15 respectively). DLL loading produced a *likely moderate increase* (0.49 ± 0.28) from 0.5%BM with *most likely very large increases* (0.96 ± 0.44 and 1.05 ± 0.45) at 2.5 and 3%BM respectively.

Like oxygen consumption, DLL loading is more sensitive to La production which may indicate that having load impact both the hip and knee joint could potentially influence the contribution of muscle activation differently across these two loading patterns. No loads reported substantial increases in La production above 4mmol/L for either loading pattern, suggesting that the intensity of running at a speed equivalent to $\dot{V}T_1$ with either PLL loading up to 5%BM or DLL loading up to 3%BM will likely remain below the onset of blood lactate accumulation (Sjodin & Jacobs, 1981) or $\dot{V}T_2$. Something to consider is that a curvilinear relationship has been suggested to exist between trunk loading (10-20%BM) and speed on the metabolic cost of walking. Accordingly, vest mass has a greater impact on metabolic cost a higher walking speed (Puthoff et al, 2006). While this relationship has not been investigated on lower limb loading at more than two running speeds, it would seem likely that faster running speeds may have a greater impact on metabolic cost and impact energy system contribution. Limb loading may be more sensitive to running speed even more so than trunk loading considering the need to overcome the increased inertia around the limb created by the additional load.

Comparative Rate of Perceived Exertion

This thesis is also the first to report on any subjective measures. Both PLL and DLL loading produced substantial increases in RPE ratings across all loads compared to un-loaded trials. The highest mean RPE measure for both PLL and DLL loading was a rating of 4.38 (±1.57) (somewhat hard) and 4.53 (±1.59) (somewhat hard) respectively compared to the un-loaded trials. Unsurprisingly, DLL loading has reported greater effects when comparative load is moved to the PLL. The current study found that 1, 2 and 3%BM carried on the PLL produced a *possible small* (0.28 ± 0.25), *likely moderate* (0.43 ± 0.23) and *most likely very large* (0.52 ± 0.26) *increase* in RPE respectively. While the same loads (1, 2 and 3%BM) carried on the DLL reported *very likely large* (0.63 ± 0.28), *most likely very large* (1.11 ± 0.33) and *most likely very large increase* (1.38 ± 0.40) in RPE respectively. Interestingly, when considering the trend in $\dot{V}O_2$ and HR response to loaded running discussed previously, comparatively RPE responses to both loading patterns were similar. It was found that 3, 4 and 5%BM carried on the PLL produced a *very likely large* (0.52 ± 0.26), *most likely very large* (0.82 ± 0.29) and *most likely very large increases* (0.86 ± 0.28) in RPE responses. Similarly, 1.5, 2 and 2.5%BM carried on the DLL produced *very likely large* (0.73 ± 0.38), *most likely very large* (1.11 ± 0.33) and *most likely very large increases* (1.30 ± 0.25) in RPE responses. Therefore, the RPE data collected supports the trend in metabolic responses to load but it also indicates that runners perceived greater loads to be harder and that this response is greater when comparative load is carried further down the shank.

Practical Applications

Based upon the findings of this thesis there exist opportunities to enhance the prescription of wearable resistance within practice:

1. In terms of general exercise prescription, some evidence now exists for guiding minimal loading thresholds for PLL (3%BM) and DLL (1%BM) loading to elicit substantial metabolic responses.
2. The use of the TLS gives means to quantify the training stress that lower limb loading has on submaximal running.
3. Endurance athletes who are restricted in training time may benefit from the additional metabolic response that lower limb loading produces.

Limitations

The authors note and acknowledge the following limitations of the research performed:

1. This thesis may only infer as to the responses found with the repeated application of such loading schemes to short-term submaximal running at a speed equivalent to $\dot{V}T_1$.
2. Due to the subject inclusion criteria (male and female endurance trained runners) the findings of this study may only be applied to this population.
3. Trials were performed under laboratory conditions, which are not directly comparable to the traditional method of training for endurance trained runners.
4. To ensure participants only had to come in for testing over three sessions, the protocols employed meant multiple trials in one session. Load order was randomised for each runner to minimise order effect.

Recommendations

Several areas require further investigation and in doing so will ultimately help guide how WR technology may provide an advantageous training stimulus for endurance runners.

Because moving constant load away from the hip seems to have greater impacts on metabolic cost and sensitivity to load greater the further distal the load there is a need to further investigate how changing loading patterns impacts metabolic cost of running. The Exogen™ exoskeleton by Lila™ has a multitude of loading options that will allow more accurate comparisons to be made. Future research in this area should investigate relative loads of 3-5%BM distributed across other aspects of the PLL such as anterior and posterior only, while DLL loading from 1 – 3%BM distributed across the medial and lateral aspect only. It would also be interesting to investigate the metabolic response to running at loads between 1-5%BM at various loading patterns across the entire lower limb.

It is unclear as to the impact of prolonged running with load on RE. Both Martin (1985) and the current thesis used running durations of only 5 to 8-minute. Claremont and Hall (1988) used running trials of 30-minutes and collected both metabolic data and mechanical work done at multiple stages during each trial, however, they did not report on any differences in variables within any of the trials. Additionally, further information regarding the impact of longer durations of loaded running on RE would be additive to the current body of knowledge.

A philosophy of the Lila™ Exogen™ compression technology as a training tool is that loaded movement is possible with minimal restriction to individual movement pattern. There is some evidence to show limited impact on basic running pattern when loading the feet and thighs. Indeed, both Martin (1985) and Claremont and Hall (1988) measured several kinematic variables and reported only small changes in these variables. Martin (1985) found significant (p<0.05) differences only at maximum loading on the feet (1.0 kg total), including increases in stride length (1.4 cm), swing time (9 $m.s^{-1}$) and flight time (6 $m.s^{-1}$) with all other loading parameters not reaching statistical significance. Claremont and Hall (1988) found no significant differences with loaded feet (0.9 kg total) for any kinematic variables measured. Both studies had conflicting stride length findings however results were either non-significant or change in variable quite small. It is unclear as to how kinematic variables are impacted by DLL loading above 1.39%BM and even less clear about the kinetic impacts. Being able to take an evidence-based approach to programming WR to improve endurance performance, means understanding the relationship between both the metabolic cost of running and the biomechanical changes when loaded. Both components play a pivotal role in the overall determinants of endurance performance and there is scope for future research here, especially with the advancements in three-dimensional biomechanical analysis.

Understanding the metabolic cost of lower body limb loading is useful to help effectively programme and efficiently monitor training load within a periodised plan. However, there is also a need to build an understanding of muscle contribution and ground reaction forces produced by lower body limb loading during submaximal running. Proximal lower limb loading overloads the hip while DLL loading overloads both the hip and knee. It would seem logical to assume that even if metabolic response is similar when half the load from the PLL is moved to the DLL that the impact on the musculoskeletal system would be different. If so, prolonged running under either condition may produce different adaptations. Future research should investigate how mechanical work is affected by loading and how the musculoskeletal system is being impacted by this change ion mechanical work.

What is novel about the current thesis, is the technology used to load the lower limbs allows less restrictive load attachments, whereas earlier research has used varying and often cumbersome methods for attaching load. It has been suggested that some of the increases in metabolic cost of wearing heavy boots is due to the biomechanical limitations and sole stiffness of such foot wear (Jones et al., 1984). In support for this notion, Claremont and Hall (1988) reported that their participants made continual requests to adjust ankle loads during trials. Runners in the current thesis were able wear unrestrictive, familiar running attire with the Lila^{TM} Exogen^{TM} garments, however, observations made from pilot trials revealed that both the compression shorts and calf sleeves need to be worn with no clothing underneath as skin contact limits the chance for the clothing to slip down while loaded. Even so, maximal loading of both the shorts and calf sleeves for some participants still reported slipping while running which made wearing the garments more noticeable. This is however anecdotal, but any future research should include some qualitative data collection, including feedback from users on equipment comfort to help guide future loading patterns and equipment development.

There is very little longitudinal research using external load as a training tool for improving endurance running performance. Building an understanding about how external load impacts the body acutely is important to help guide an evidence-based approach to programming this technology, however, ultimately the potential longitudinal adaptations possible and how these impacts running performance is what is important to the athlete.

Conclusion

In summary, the findings of the current study suggest that all metabolic measures ($\dot{V}O_2$, HR and La) will increase while running with added load and that this increase is greater the more distal constant load is moved. Running at a speed equivalent to $\dot{V}T_1$ with PLL loading will elicit an expected increase in $\dot{V}O_2$ and HR responses of 1.59 (±0.62) and 0.63% (±0.32) respectively for every 1%BM of additional load and there is an expected increase in exercise stress of 0.17(±0.06) for every 1%BM of additional load for 10-minutes of running. Comparatively, these responses almost double when load is moved to the DLL with expected increases in $\dot{V}O_2$ and HR responses of 2.56(±0.75) and 1.16 (±0.52) respectively for every 1%BM of additional load and there is an expected increase in exercise stress of 0.39(±0.06) for every 1%BM of additional load for 10-minutes of running.

There are minimal loading thresholds before substantial metabolic responses are present and these thresholds are smaller the more distal load is added. Loads of at least 3 and 1%BM are needed to see substantial increases in $\dot{V}O_2$ responses when loading the PLL and DLL respectively. Loads of at least 2 and 0.5%BM are needed to see substantial increases in HR responses when loading the PLL and DLL respectively. While loads from 3 and 0.5%BM will elicit substantial increase in La when loading the PLL and DLL respectively. No loads reported substantial increases in La production above 4mmol/L for either loading pattern, suggesting that the intensity of running at a speed equivalent to $\dot{V}T_1$ with either PLL loading up to 5%BM or DLL loading up to 3%BM will likely remain below the onset of blood lactate accumulation or $\dot{V}T_2$.

The data collected from the current thesis gives some evidence for guiding minimal loading thresholds, helps quantify the potential increases in both $\dot{V}O_2$ and HR responses and gives means for quantifying an expected TLS for loaded submaximal running. This information will be useful in both practice and for guiding future research.

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APPENDICES

Appendix 1. Subject information sheet

Participant Information Sheet

Date Information Sheet Produced:

3 May 2017

Project Title

Light Variable Resistance Training^{TM} with Exogen^{TM} Exoskeletons

An Invitation

My name is Allister Field and I am a master's student enrolled at SPRINZ (Sports Performance Research Institute New Zealand) at the AUT Millennium Campus of the Auckland University of Technology (AUT). We are currently conducting a study into the effect on sporting performance of added external weight using a product called an Exogen^{TM} exoskeleton (*see photos below*). Your participation in this study would be greatly valued but is entirely voluntary and you may withdraw at any time prior to the completion of the data collection.

Lila^{TM}, the producer of Exogen^{TM}, will provide Exogen^{TM} suits for use during testing and may provide some grants (e.g. student scholarships) to help fund the research project. The results from the studies will be provided in de-identified form (i.e. without your associated name and personal details) to Lila^{TM} in the form of journal or thesis publications and/or conference presentations. Your consent to participate in this research will be indicated by your signing and dating the consent form. Signing the consent form indicates that you have read and understood this information sheet, freely give your consent to participate, and that there has been no coercion or inducement to participate.

What is the purpose of this research?

The purpose of this research is to analyse the changes in running effort and performance that occur when small amounts of external loading are attached to the body. Exogen™ exoskeletons include shorts, sleeveless tops and upper arm, forearm and calf sleeves to which small (approximately 19 cm long) loads of 50 – 200 g can be attached with Velcro. This research includes two studies which initially aim to quantify the acute metabolic demands that occur when loads are attached to the lower body only (e.g. upper leg, lower leg, front and back) while running and then secondly the chronic changes that occur after a period of several weeks of training with added weight attached to the body while running. We will use relevant tests from a range of options: running performance will be measured by treadmill and over ground running on an athletics track using timing light technology; metabolic tests wearing a face mask to measure gas exchange; blood La measures via blood taken from finger prick samples; heart rate measures taken via wearable heart rate monitors; and body composition measured using skinfold testing with callipers. The research findings will be reported in my master's thesis as well as conference presentation(s) and scientific journal article(s).

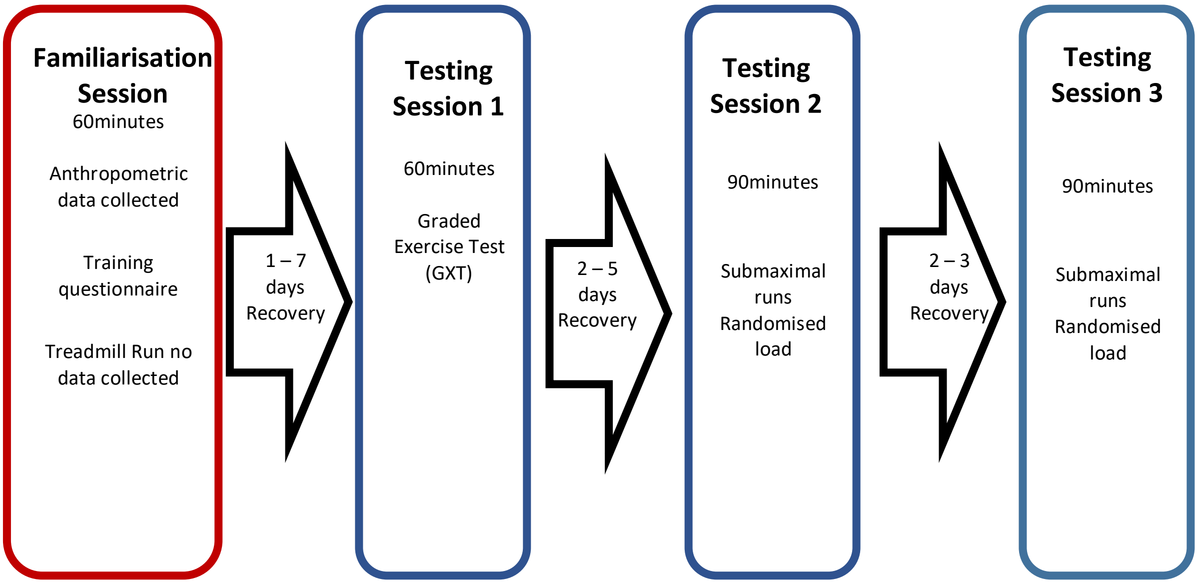
How was I identified and why am I being invited to participate in this research?

To be eligible for either study we require well endurance trained, healthy male or female runners who are injury free and have been regularly training for at least the last 3 months.

You have been identified because you may fit this criterion.

What will happen in this research?

You will be required to complete one meet and greet/ familiarisation session and three testing sessions over a two-week period, at Toi Ohomai, Windermere campus for approximately one hour (session one) and one and a half hours (sessions two and three each). The aim of study is to quantify the metabolic demands of running with load on the legs at submaximal intensities.



You will complete a standardised warm-up prior to all testing and you will have a recovery period of at least 5-minutes before each maximal or submaximal running effort. Following the standardised warm-up, you will complete selected tests from the following list:

- Body composition assessment using skinfold callipers, height and weight
- Submaximal steady state running trial
- Incremental VO2max test
- Blood La

What are the discomforts and risks?

There should be no significant discomforts or risks associated with this testing beyond those experienced during normal endurance run testing and training. You will likely experience some shortness of breath and perhaps some lower body muscular soreness in the 48 hours after each testing session. Both the submaximal steady state running trial and VO2max tests involve blood La measures to be taken via finger prick samples which will involve a small amount of discomfort.

How will these discomforts and risks be alleviated?

You will be requested to not complete any high-intensity training in the 24 hours prior to each testing session and to present to each testing session well hydrated and having not eaten in the 90 minutes prior to the start of testing. You will perform a comprehensive warm-up and cool-down before and after each testing session with a full recovery of at least 10 minutes will be ensured before each maximal and submaximal effort test.

Full disclosure of all testing protocols and measures will be discussed with you before each testing session, all measures will be taken by a qualified team of researchers and every effort made to make you as safe and comfortable as possible.

What are the benefits?

The research findings will inform and improve the effectiveness of athletic training procedures particularly in the areas of endurance running training and performance. As a participant, you can receive a report of the research outcomes and your individual results at the completion of the study. These results can be used to individualise your on-going program decisions. Additionally, if you are involved in an organised club, a summary of your results can be made available to your coach, manager or doctor if you agree to this on the consent form.

Finally, you will be contributing to the attainment of my Master's degree. Without you it wouldn't be possible, so thank you!

What compensation is available for injury or negligence?

In the unlikely event of a physical injury because of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations

How will my privacy be protected?

- We will take several measures to protect your privacy as much as possible and to ensure your personal details remain confidential.
- The data from the project will be coded and held confidentially in secure storage under the responsibility of the principal investigator of the study in accordance with the requirements of the New Zealand Privacy Act (1993).
- All reference to participants will be by code number only in terms of the research publications. Identification information will be stored on a separate file and computer from that containing the actual data.
- De-identified test results (i.e. without your associated name and personal details) may be stored indefinitely in the SPRINZ research database and may be used for similar research studies in the future.
- The findings of this project will be published in scientific journals, at a conference presentation(s) and in a master's thesis, but at no stage will you be identifiable. The results will be presented as averages and not individual responses. Your identifiable test results will only be made available to yourself and your sports coach, manager or doctor (if you agree to this option on the consent form).

What are the costs of participating in this research?

Participating in this research project will not cost you apart from your time, which we greatly thank you for. The total time commitment will be four testing sessions of approximately one and a half hours for the acute study. For the training study, the total time commitment is 6 weeks consisting of two 1-hour performance testing sessions followed by 4 weeks of a prescribed and monitored training programme. You may or may not be required to wear the Exogen exoskeleton with a specified amount of added weight attached depending what group you are allocated followed by a repeat of the performance tests.

What opportunity do I have to consider this invitation?

- Please take the necessary time (up to 2 weeks) you need to consider the invitation to participate in this research.
- It is reiterated that your participation in this research is completely voluntary.
- If you require further information about the research topic, please feel free to contact Dr Daniel Plews (details are at the bottom of this information sheet).
- You may withdraw from the study at any time without there being any adverse consequences of any kind.
- You may ask for a copy of your results at any time and you have the option of requesting a report of the research outcomes at the completion of the study.

How do I agree to participate in this research?

If you agree to participate in this study, please sign and date the consent form at the bottom of this information sheet and return to Allister. I will then contact you to arrange and set up the first familiarisation session which will give you an opportunity ask further questions about the project to ensure it is something that you want to be a part of.

Will I receive feedback on the results of this research?

We will provide a summary via email of your results from the testing and the averages of all participants. If you wish to receive your results, please provide your email on the attached consent form where indicated.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Primary Project Supervisor, Daniel Plews, plews@plewsandprof.com

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, ethics@aut.ac.nz, 921 9999 ext 6038.

Whom do I contact for further information about this research?

Researcher Contact Details:

Allister Field
Toi Ohomai Institute of Technology, Sport and Recreation Department at 70 Windermere Drive, Poike, Tauranga 3112.
allister.field@toiohomai.ac.nz
022 6892847

Project Supervisor Contact Details:

Primary Supervisor

Dr Daniel Plews
Sports Performance Research Institute New Zealand (SPRINZ) at AUT Millennium, Auckland University of Technology, 17 Antares Place, Mairangi Bay, Auckland 0632.
plews@plewsandprof.com

Secondary Supervisor

Dr Nicholas Gill
Sports Performance Research Institute New Zealand (SPRINZ) at AUT Millennium, Auckland University of Technology, 17 Antares Place, Mairangi Bay, Auckland 0632.
nicholas.gill@nzrugby.co.nz

Appendix 2. Subject consent form (Study)

Consent Form

Project title: Light wearable resistance training with Exogen Exoskeletons

Project Supervisors: Dr Daniel Plews

Dr Nicholas Gill

Researcher: Allister Field

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 03/05/2017
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
- ○ I understand that if I withdraw from the study then I will be offered the choice between having any data or tissue that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.
- ○ I understand that the data collected from my test will be used in a master's thesis and will be stored indefinitely on the SPRINZ database and may be used for future studies by SPRINZ approved researchers.
- ○ I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance, or any infection
- ○ I agree to provide blood samples by way of finger prick, to measure blood La levels
- ○ I agree to take part in this research.

I wish to receive a summary of the research findings (please tick one)

Yes○ No○

I wish to receive my individual results at the completion of data collection and made available to my coach / manager / doctor (please tick one)

Yes○ No○

I wish to have any material that contains my blood samples returned to me in accordance with right 7 (9) of the *Code of Health and Disability Services Consumers' Rights* (please tick one):

Yes○ No○

Participant’s name:

……………………………………………………………………………………………………

Participant’s signature:

……………………………………………………………………………………………………

Date :

……………………………………………………………………………………………………

Approved by the Auckland University of Technology Ethics Committee on the 26th June, 2017 AUTEC Reference number 17/172

Note: The Participant should retain a copy of this form.

Appendix 3. Subject consent form (Treadmill Incremental Test)

Participant Consent Form

Testing Procedure: Treadmill Incremental Test (approx. 60-minutes)

Before the start of this session you will have a heart rate monitor and gas mask fitted (this won't be worn until after the warm up). Resting heart rate will be recorded as well as resting blood La levels taken via a finger prick sample.

You will have 20-minutes to run through the same self-paced warm up that was established during the familiarisation session before the test.

After the warm up you will have 5-minutes recovery so that you can be set up on the gas analysis system.

The test is maximal effort, aimed to be completed within 8-12 minutes. Treadmill speed will start at 8km/h for females and 10 km/h for males at a consistent gradient of 1% for 1 minute initially.

At the 1-minute mark your treadmill speed will be increased by 0.5 km/h every 30 seconds until you can no longer keep up with the treadmill speed.

Various measures will be taken from your heart rate monitor and gas analysis while the test is being conducted. Another La measure will be taken immediately after finishing the test.

I have been verbally informed of and fully understand the procedures of the test in which I am to be a participant. I understand the potential risk of participation.

I understand that I may withdraw from testing at any point, without reason or repercussion.

I understand that the data collected from my test will be used in a master's thesis and will be stored indefinitely on the SPRINZ database and may be used for future studies by SPRINZ approved researchers.

I consent to be a participant in this testing procedure at Toi Ohomai Institute of Technology, Windermere Tauranga.

Participant's name:

………………………………………………………………………………………………

Participant's signature:

………………………………………………………………………………………………

Date:

………………………………………………………………………………………………

Approved by the Auckland University of Technology Ethics Committee on type the date on which the final approval was granted AUTEC Reference number type the AUTEC reference number

Note: The Participant should retain a copy of this form.

Appendix 4. Subject consent form (Submaximal Running Trials)

Participant Consent Form

Testing Procedure: Submaximal Running Trials (approx. 90-minutes)

Before the start of this session you will have a pair of Exogen shorts, a heart rate monitor and gas mask fitted, as well as having resting blood La levels taken via a finger prick sample.

You will have 10-minutes to run through a self-paced warm up before the first trial only. This warm up will be recorded so that it can be repeated in subsequent testing sessions.

After the warm up you will have 10-minutes recovery so that you can be set up on the gas analysis system and weight added to your shorts.

This session will involve 3 x running trials that last 8-minutes each, at a continuous pre-determined running velocity of ___________________ km/h, separated by 10minutes of seated recovery

During each trial, various measures will be taken from your heart rate monitor and gas analysis as well as blood La samples at 0, 5 and 10-minutes after each trial.

> *I have been verbally informed of and fully understand the procedures of the test in which I am to be a participant. I understand the potential risk of participation.*
>
> *I understand that I may withdraw from testing at any point, without reason or repercussion.*
>
> *I understand that the data collected from my test will be used in a master's thesis and will be stored indefinitely on the SPRINZ database and may be used for future studies by SPRINZ approved researchers.*
>
> *I consent to be a participant in this testing procedure at Toi Ohomai Institute of Technology, Windermere Tauranga.*

Participant's name: ………………………………………………………………………………

Participant's signature: ………………………………………………………………………………

Date ………………………………………………………………………………

Approved by the Auckland University of Technology Ethics Committee on type the date on which the final approval was granted AUTEC Reference number type the AUTEC reference number

Note: The Participant should retain a copy of this form.

Appendix 5. Ethics approval letter

26 June 2017

Daniel Plews
Faculty of Health and Environmental Sciences

Dear Daniel

Re Ethics Application: **17/172 Light variable resistance training with exogen exoskeletons.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 26 June 2020.

Standard Conditions of Approval

1. A progress report is due annually on the anniversary of the approval date, using form EA2, which is available online through http://www.aut.ac.nz/researchethics.
2. A final report is due at the expiration of the approval period, or, upon completion of project, using form EA3, which is available online through http://www.aut.ac.nz/researchethics.
3. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form: http://www.aut.ac.nz/researchethics.
4. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
5. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.

Please quote the application number and title on all future correspondence related to this project.

AUTEC grants ethical approval only. If you require management approval for access for your research from another institution or organisation then you are responsible for obtaining it. You are reminded that it is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard.

For any enquiries, please contact ethics@aut.ac.nz

Yours sincerely,

Kate O'Connor
Executive Manager
Auckland University of Technology Ethics Committee

Cc: allister.field@hotmail.co.nz

Appendix 6. Pre-exercise health questionnaire and training history

Pre-exercise Health Questionnaire Training History

Personal Information

First Name:

Last Names:

Gender:

Date of Birth:

Age:

Have you had, or do you have?	**YES**	**NO**	**DETAILS**
1. A doctor say that you have a heart condition and that you should only do physical activity recommended by a doctor?			
2. Pain in your chest when you do physical activity?			
3. In the past month, pain in your chest when you were not doing physical activity?			
4. A loss of balance because of dizziness or do you ever lose consciousness?			
5. A bone or joint problem (for example, back knee or hip) that could be made worse by a change in your physical activity?			
6. Prescription drugs for blood pressure or heart condition?			
7. Do you know of <u>any other reason</u> why you should not do physical activity?			

Fitness Background – Provide as much detail as you can

1. **What running events have you completed in the last 12 months?**

2. **Are you training for any events currently? If so what ones?**

3. **How often are you running currently?**

4. **What would your total volume of running be for a typical week?**

5. **What would you estimate your 10km run time at?**

6. **Do you do any other forms of training other than running? If so what?**

7. **What does the structure of your typical training week look like?**

8. **Till now, how long have you been consistently training for?**

Thank you for your time, it is greatly appreciated.

Ali