The Physiological and Perceptual Responses of Lower Limb Loading in Cycling

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Attestation of Authorship

"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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Ethical Approval

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Abstract

The use of sport-specific training is crucial to enhance performance in professional road cycling, where the competition between the top riders is incredibly close. To achieve specific physiological adaptations, training programmes are developed to stress the physiology in a sport specific manner. In the sport of endurance cycling, this means targeting and overloading the working muscles and the physiology used during a race. One training technique that has found been found to induce specific kinematic and kinetic adaptations in other sports is functional resistance training (FRT). FRT involves applying a load to the body while performing sport-specific movements to induce overload and performance in those movements (Macadam et al., 2016). However, to be able to use FRT in practice requires an understanding of the physiological effects of FRT in the endurance sport of cycling, which previously has not been widely researched. Furthermore, no study has researched the use of FRT in a simulated 'real-world' uphill cycling environment. The objective of this thesis was to extend the current body of knowledge on the use of functional resistance training using limb loading (LL) in cycling. This thesis had two aims, answered in two studies. Firstly, to determine the acute physiological effects of LL in cycling. Secondly, to determine how LL alters physiological responses to cycling at various cycling gradients, and do responses differ when compared to adding load to the bicycle (B_{load}).

In Study One participants performed 5 submaximal exercise bouts for 5 minutes at first ventilatory threshold (VT_1) under different LL conditions (1/3 of total added load on calf; 2/3 of total added load on thigh, at 0, 2%, 4%, 6% and 8% body weight (BW)) on a stationary cycling ergometer. Physiological measures of oxygen consumption (VO_2), heart rate (HR) and blood lactate (BLa) were recorded for each loading condition throughout the submaximal bouts. Pedal force measurements (PFM), and perceptual measures of rating of perceived exertion (RPE), "Comfort" and "Pain" were also recorded. LL was found to have *trivial* or *unclear* effects on physiological measures. Cycling efficiency decreased and VO_2 increased with a negative linear relationship ($r = -0.97 \pm 0.05$), despite only *trivial* effect sizes established for the relationship between added load and VO_2. This was despite the exercise being perceptually harder with every 1% added BW ($r = 0.94 \pm 0.09$)) (RPE: 2% = *small* (effect size (ES) ± 90% confidence limit (CL)) (0.24 ± 0.25); 4% = *trivial*; 6% and 8% = *moderate* (6% = 0.67 ± 0.28; 8% = 0.85 ± 0.38)), more "uncomfortable" ($r = 0.89 \pm 0.17$)) ("Comfort": 2% and 4% =

unclear; 6% = *moderate* (0.82 ± 0.64); 8% = *large* (1.31 ± 0.90)), and more "painful" (r = 0.89 ± 0.17)) ("Pain": 2% = *trivial*; 4% = *unclear*; 6% = *small* (0.57 ± 0.46); 8% = *moderate* (0.80 ± 0.62) compared to baseline. Consequently, it was deemed that LL did not have any physiological effect on submaximal cycling. Despite no physiological benefit found from using LL in submaximal cycling, if LL were to be used in practice, 2% and 4% BW would be the most appropriate due to their limited impact on "Comfort", "Pain", RPE and efficiency.

In Study Two, participants completed three separate testing sessions each consisting of 4 x 5-minute exercise bouts at different gradients (2%, 4% 6% and 8%), under different loading conditions (no added load, LL and B_{load}). Physiological measures of VO_2, HR and BLa were recorded throughout for each loading condition, alongside perceptual measures of RPE, "Comfort" and "Pain". HR had a *small* effect (ES ± 90%CL: -0.33 ± 0.49) using B_{load} at 8% gradient but *unclear* for LL. The remaining HR responses at different gradients for LL and B_{load} were *trivial* (LL: 6%; B_{load}: 4%) or *unclear* (LL: 2%, and 4%; B_{load}: 2% and 6%). VO_2 had a small effect at 2% (0.28 ± 0.36), 4% (-0.27 ± 0.38) and 6% (0.24 ± 0.22). Whereas, B_{load} only induced a *small* (0.26 ± 0.32) effect at 6% gradient, with *unclear* effects at 2% and 4% gradients. *Trivial* effects were seen at 8% gradients for both LL and B_{load}. B_{load} did not induce any effects in BLa at any of the gradients. Perceptually, LL induced a *moderate* (0.60 ± 0.55) effect at 4% gradient for RPE, whereas B_{load} only induced a *small* (0.53 ± 0.47) response at 4% gradient. At 2% gradient the RPE effect for B_{load} was *trivial*, whereas for LL the effect was *unclear*. The effects for both LL and B_{load} at 6% and 8% gradients were *unclear*. As a result, LL was found to induce greater metabolic overload at 2% and 6% gradients and to induce greater sport-specific overload than B_{load}.

Collectively the studies in this thesis demonstrate that application of LL results in trivial effects on physiological overload during cycling. However, at specific gradients some form of physiological overload was observed (VO_2 and BLa at 2% and 6% gradients), which is worthy of further consideration. This thesis has extended the limited current body of knowledge on the physiological and perceptual effects of LL, and will help to inform practitioners, coaches and athletes of its use in cycling. Additionally, it will help to guide and target future research on sport-specific overload in endurance cycling.

Chapter One: Introduction

1.1 Background

Endurance cycling is popularised across a vast variety of individuals as it provides a modality for elite performance, age group event endeavours through to recreational activities. As a result, different mechanisms have been employed to provide training stimulus dependant on the individual and targeted event or goal. To be competitive as a professional road cyclist (PRC) training is required to consist of high training volumes, durations and intensities over thousands of kilometres (Faria, Parker, & Faria, 2005). Cyclists are well known for spending thousands of hours on a bicycle during a calendar year (Faria et al., 2005), however, what is less known is the science behind the sport-specific resistance training that is prevalent in most cyclist training programmes (hill climbing and over-gearing intervals) due to limited literature. The PRC group has been known to avoid traditional resistance training through the stigma around increasing body mass and becoming 'sluggish' and heavy for racing (Yamamoto et al., 2010). Accordingly, techniques are required to incorporate resistance training in a sport-specific manner. One modality that has gained traction in running, sprinting and jumping sports is functional resistance training (FRT) (Couture et al., 2018; Cronin, Hansen, Kawamori, & McNair, 2008; Cross, Brughelli, & Cronin, 2014; Dolcetti, Cronin, Macadam, & Feser, 2018; Macadam, Simperingham, & Cronin, 2018; Macadam, Simperingham, Cronin, Couture, & Evison, 2017; Rusko & Bosco, 1987). However, to date, very little research has been completed in the use of FRT in the sport of cycling.

FRT involves applying a load to specific body parts, allowing an athlete to perform sport-specific movements under resistance to increase power output (PO) and performance in those movements (Macadam et al., 2016). Benefits of FRT have been found in running to improve maximal oxygen consumption (Rusko & Bosco, 1987) and running time (Cureton & Sparling, 1980). In sprinting, effects have been seen in changes to flight time and contact time (Cross et al., 2014; Macadam et al., 2018; Simperingham & Cronin, 2014) and sprint time (Cronin et al., 2008), as a result of using different modalities of FRT. In jumping, there have been improvements in performance by performing a dynamic warm-up using FRT (Thompsen, Kackley, Palumbo, & Faigenbaum, 2007). While research is in its infancy, and loading technique has differed, FRT has a demonstrated ability to induce sport-specific overload. The technology used for FRT has developed over recent years and now allows for more targeted load placement. As a result, there are now opportunities to experiment with FRT in sports where previously it would have been impractical.

In the sport of cycling, FRT may offer a novel approach to include resistance training without reducing a cyclist's time spent on the bicycle. In cycling, where the race demands are heavy, and the margins between winning and losing are so narrow, it is essential that the training performed be targeted in a specific manner. Given the principles of specificity and overload, the placement of a load on the limbs, as well as loading magnitude, are essential areas for consideration. Therefore, it could be considered that the most optimal and sport-specific form of overload, would be to apply load to the working muscles, in particular the lower limbs of a cyclist. However, research in FRT in cycling is limited. One study examined effects of the muscular activity when load was added to the thigh, with no physiological variables examined (Baum & Li, 2003). While another study investigated the metabolic effects of FRT using weighted vests, the study utilised standing cycling and the weight was placed on the trunk, not the working lower limbs (Carriker, Mclean, & Mccormick, 2013). To be able to use FRT in practice it is important to understand the physiological effects of limb loading (LL) with an approach that investigates FRT in the most applied manner for endurance cyclists. As such, it is also unknown whether FRT would deliver any advantage to cyclists over their regular training. Additionally, it is unknown if adding load to the moving limbs whilst cycling adds specific advantages compared to loading a bicycle itself.

To the best of the researcher's knowledge, no previous research has investigated the effects of FRT in this area of cycling. Therefore, research is required to first investigate the acute physiological and perceptual responses of LL in trained cyclists using different load quantities in a controlled laboratory on a cycling ergometer. And second, investigation is required to understand the physiological effects of LL in a practical sense through simulated 'real-world' gradient cycling in comparison to external bicycle loading. It is hoped that such information will help to extend the current body of knowledge on LL in cycling, and provide practical advice for using LL as a form of FRT.

1.2 Study aims

The objective of this thesis is to extend the current body of knowledge on the use of functional resistance training and to investigate the acute physiological effects of LL in cycling. The aim of this thesis is therefore to answer the following research questions:

Research questions:

1. What are the acute physiological and perceptual responses of LL in cycling?
2. How does LL alter physiological and perceptual responses to cycling at various cycling gradients, and does the weighting of the LL give additional benefits to other methods of external loading (e.g. bicycle loading)?

1.3 Study hypotheses

It is hypothesised that:

1. When added load increases in percentage BW, the physiological and perceptual responses of carrying that load will increase.
2. LL will be a more optimal method of sport-specific overload at different gradients than weighting the bicycle, through increased physiological overload due to wearing the load on the working muscles.

1.4 Thesis organisation

This thesis will be performed in two parts; the first will examine question one to understand the acute physiological and perceptual responses of added lower body load in cycling. The second will examine the acute physiological and perceptual responses of LL in comparison to weighting the bicycle (B_{load}) when simulating ‘real-world’ uphill cycling in a controlled laboratory environment. Both experimental studies will utilise a randomised, crossover design.

This thesis follows Pathway One, as outlined in the AUT Postgraduate Handbook (2019). The layout of this thesis includes an introduction, literature review, research methodologies, results, discussions and an overall discussion and conclusion. Figure 1.1 demonstrates the layout of this thesis. The aim of Study One is to answer Research

Question 1: What are the acute physiological and perceptual responses of LL in cycling? The aim of Study Two is to answer Research Question 2: How does LL alter physiological and perceptual responses to cycling at various cycling gradients, and do responses differ compared to adding weight to the bicycle?

Pathway One was selected as the most appropriate thesis structure for this project, as Study Two is a follow-on investigation from Study One. Due to utilising Pathway One for this thesis, there is some repetition throughout.

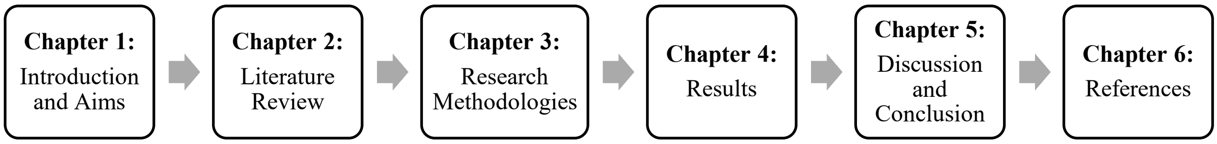


Figure 1.1 Thesis outline and structure

1.5 Significance of thesis

Resistance training has long been reputed for its beneficial physiological responses and improvements to strength, power, hypertrophy and endurance. Sport-specific overload as a form of resistance training is important in the endurance sport of cycling where typical resistance training is often dismissed in favour of spending time on the bicycle. If LL is established as a means to apply overload with beneficial physiological adaptations without jeopardising endurance training time, or negatively impacting performance, the acceptance of cyclists performing resistance training may increase. The current body of research on FRT in endurance sports is limited, and the physiological effects of LL are not well understood. Therefore, it is hoped that this thesis will help to inform practice of applying sport-specific overload through understanding the acute physiological and perceptual responses of LL, and to understand the optimal method of sport-specific overload when comparing weighted limbs to weighted bicycles. The findings from this thesis will help to inform the use of sport-specific overload for training purposes, and the responses of LL in simulated 'real-world' cycling.

Chapter Two: Literature Review

Functional resistance training as a means of applying sport-specific overload in endurance cycling: A review of the literature

2.1 Introduction

Cycling has been a widespread mode of transportation and exercise for many years across all levels of sporting endeavours and ages. From youth competing in organised cycling events, to recreational riders who cycle for health and enjoyment, to competitive athletes who compete at the Olympics and for million-dollar contracts with professional cycling teams. Cycling has long been popularised by its low-impact but physiologically demanding nature. One of the main magnetisms to the sport is the number of different modalities on offer enticing individuals of all different backgrounds and interests. Whether it's stochastic in nature with intermittent high-intensity bursts in the likes of mountain biking and BMX, to the speed and power of sprint track cycling, to the continuous paced efforts of a road time trial, or the endurance nature of cycling in a leg of a triathlon or Ironman event. The variety of cycling events require different physiological demands and mechanical make-ups from the athletes who compete in them.

To understand the physiology and demands of cycling, it is important to focus on each discipline individually. One of the largest disciplines is endurance cycling. Within endurance cycling there still remains an array of types of athletes and energetic demands independent of the targeted event. To cycle competitively in a road race an individual requires both highly developed aerobic (with oxygen) and anaerobic (without oxygen) energy systems (Faria et al., 2005). A typical road race can last for 1 – 5 hours in duration (Faria et al., 2005). Many events however, are multi-stage, where riders are required to tolerate and perform over consecutive days with minimum recovery days between (Faria et al., 2005). The physical demands of a multi-stage tour requires cyclists to generate high power outputs in starts, hill climbs, overtaking and sprint finishes as well as the endurance to perform day-in-day-out on long flat stages (Abbiss & Laursen, 2005; Faria et al., 2005; Lucia, Hoyos, & Chicharro, 2001). Additionally, cyclists often encounter uncontrollable variables including weather conditions (wind, rain, heat and freezing temperatures), altitude, and team tactics which can impact performance (Lucia et al., 2001). To be able to cope with the demands of endurance cycling, individuals are required to be both durable and robust athletes. On long flat stages, cyclists spend large amounts of time in packs to conserve energy by reducing the impact of air resistance (Lucia et al., 2001). By doing so the energy requirements of the race can be reduced by 39% (McCole, Claney, Conte, Anderson, & Hagberg, 1990). However, even with drafting, data from the Tour de France and Vuelta a Espana demonstrate that professional cycling is a high-intensity, long-duration sport with cyclists spending ~90 minutes on flat stages and ~123 minutes in mountain stages above 70% maximal oxygen consumption (VO_2max) (Fernandez-Garcia, Perez-Landaluce, Rodriguez-Alonso, & Terrados, 2000) demonstrating that training an endurance cyclist to cope with tour demands requires careful consideration.

2.2 The physiology of endurance cycling

The characteristics of PRC vary. In a typical professional team the average age is ~26 years old (n = 24), ranging from new incomers ~20 years old to experienced riders ~33 years old (Mujika & Padilla, 2001). Anthropometric variables also cross a continuum with the average height 180cm (range 160 – 190cm), average body mass 69kgs (range 53 – 80kgs) and with low percentage body mass averaging around 8% (range 6.5 – 8%) (Mujika & Padilla, 2001).

In one season a PRC covers between 25,000 to 35,000km in training and competition (Mujika & Padilla, 2001). One characteristic that stands out more than most is their high aerobic capacity, as demonstrated through their VO_{2max} (average 78.8 ml/kg/min (range 69.7 – 84.8 ml/kg/min)) and maximal power outputs (Wmax) (average 439 W (range 349 -525 W)) (Lucia et al., 2001; Lucía, Hoyos, Pérez, & Chicharro, 2000; Mujika & Padilla, 2001). Although large VO_2 values are often found in PRC, their well-trained amateur counterparts often exhibit similar VO_2 values (Lucía, Hoyos, Santalla, Pérez, & Chicarro, 2002). As such, it has been suggested that VO_2 may not be a determining performance factor for PRC and instead gross-mechanical efficiency (GME), and cycling economy (CE) may be larger determinants if high VO_2 values are still present (Lucía, Hoyos, Pérez, Santalla, & Chicharro, 2002). Mechanical efficiency is described as the ratio between mechanical effort and the energy required to perform the effort, while the economy is described as the ratio between power output and VO_2 (Chavarren & Calbet, 1999). It has been established that in PRC, GME and CE are inversely correlated with VO_{2max} (in both relative and absolute values) and that in cycling a low VO_2 may be compensated for with a high GME or CE (Lucía et al., 2002). In general, efficiency in cycling is measured through a whole body assessment of VO_2 which examines the oxygen consumed by the respiratory and heart muscles, as well as the oxygen required for the muscular contractions during pedalling (Chavarren & Calbet, 1999). It has been found that the changes in oxygen consumption in the exercising legs, closely reflects the VO_2 cost of the metabolic cardiovascular and pulmonary support systems (Poole, Gaesser, Hogan, Knight, & Wagner, 1992).

In PRC a significant difference has been found with ventilatory threshold 1 (VT_1) and ventilatory threshold 2 (VT_2) occurring at higher power outputs ($p < 0.001$) when compared to amateurs (Lucía, Pardo, Durantez, Hoyos & Chicarro, 1998). When referring to lactate rather than ventilatory thresholds, PRC second lactate threshold (LT_2) is typically established ~90% of a PRC VO_{2max} (Padilla, Mujika, Cuesta, & Goiriena, 1999). It has been established that PRC typically express a unique breathing pattern which may be a result of their training demands (Lucía, Carvajal, Calderón, Alfonso, & Chicharro, 1999). The unique breathing pattern observed in the PRC shows that exhalation time is longer than their inhalation time at all exercise intensities compared to amateur cyclists despite no differences in cycling posture (Lucía et al., 1999). However, this doesn't determine why they have an ability to sustain such large workloads (~90% VO_{2max}) over long durations (~60 minutes), with the slow motor units having a high resistance to fatigue (Lucia et al., 2002; Lucía, Hoyos, Carvajal & Chicharro, 1999).

2.3 Endurance cycling

2.3.1 Modalities of training

To achieve success in PRC, training is required to consist of high training volumes, durations and intensities over thousands of kilometres (Faria et al., 2005). It has been suggested that there are three main components in endurance cycling that determines inter-individual difference in performance, these are CE, VO_{2max} and lactate threshold

(LT) (Sunde et al., 2010). Accordingly, a PRC training is required to target these three particular areas. Elite endurance athletes have employed a polarised training model throughout certain phases of a season (Stoggl & Sperlich, 2015), allowing them to optimise their performance in those three particular areas. Polarised training is characterised by high volumes of low-intensity (below the first ventilatory or lactate threshold) training interspersed with high-intensity training, often quantified as 80:20 or, 75-80% of training performed at a low-intensity, 5% of training spent at threshold intensity, and 15-20% at high-intensity (above the second ventilatory or lactate threshold) (Muñoz, Seiler, Bautista, España, & Esteve-Lanao, 2013; Stoggl & Sperlich, 2015). Low-intensity training is recognised in cycling through long-slow-distance (LSD) rides typically performed on a weekend in amateurs. As is common practice in distance running, LSD endurance training involves a relatively high duration of moderate pace cycling (below first ventilatory or lactate threshold) (Midgley, McNaughton, & Jones, 2007). It has been thought that endurance training may be a factor that allows PRC to withstand high absolute work-rates over prolonged periods while sustaining steady-state blood lactate levels (Hawley & Stepto, 2001). Training at a prolonged moderate-intensity pace over a sustained period is thought to improve skeletal muscle oxidative consumption and capacity during similar exercise bouts, enhancing endurance capabilities (Burgomaster et al., 2008).

LSD training has been widely researched in endurance running. Research in endurance running has suggested that LSD training has been effective in improving runners lactate threshold and aerobic capacity due to the high-volumes of sub-threshold training that they perform (Midgley et al., 2007). The improvement in running economy is thought to be as a result of the skeletal muscle mitochondria adapting and morphing its functionality to utilise less oxygen in each mitochondrial respiratory chain for a set-running speed (Saunders, Pyne, Telford, & Hawley, 2004). Conversely, an eight-week training study looking into the differences between LSD and aerobic high-intensity interval training found no significant change in lactate threshold when expressed as $\%VO_{2max}$ (Helgerud et al., 2007). Suggestions have been made that LSD training can improve running economy, however, to date no training intervention study has been able to support this assumption. Instead, it is considered that cumulative distance covered by a runner over many training years is the more critically important factor to improving running economy, not increasing acute training volume per se (Midgley et al., 2007).

The effects of LSD training to improve VO_{2max} has been investigated in comparison to high-aerobic intensity endurance training, where LSD training was found to not be as effective in improving maximal oxygen consumption levels over an eight-week training period (Helgerud et al., 2007). The variations in VO_{2max} corresponded with changes in stroke volume post-training, with the high-aerobic intensity interval group seeing improvements in both stroke volume and VO_{2max}, indicating that there is a dependence between the two parameters (Helgerud et al., 2007).

An alternative mode of training employed by cyclists is high-intensity interval training (HIIT). HIIT training has grown in popularity through its touted abilities to improve performance through developing metabolic and cardiorespiratory functions (Buchheit & Laursen, 2013a). HIIT can be performed through long and short intervals. Long intervals (> 60 seconds) typically accrue 30 – 60 minutes above the anaerobic threshold training zone (Zone 4, when using the Norwegian Olympic Federation Five-Zone Intensity Scale) with 2 – 4 minute recovery periods (Buchheit & Laursen, 2013a; Seiler, 2010). Long intervals enable a greater time spent training at levels close to VO_{2max} than shorter (15 – 30 seconds) intervals and allow athletes to reach higher stroke volumes while maximally stressing oxygen transportation and utilisation structures during the work and rest intervals (Buchheit & Laursen, 2013a). Exercise performed at intensities near VO_{2max} recruit large motor units (type II muscle fibres) resulting in the signalling of myocardium enlargement and muscle fibre adaptation (Buchheit & Laursen, 2013a). In turn, this may lead to improved cardiopulmonary function when compared to short supramaximal intervals and therefore the most effective stimulus for improving VO_{2max} (Buchheit & Laursen, 2013a; Helgerud et al., 2007). Research in recreational cyclists demonstrated that accumulating 32 minutes of exercise at 90% of maximum HR can improve maximal and submaximal performance indicators (ventilation peak, VO_{2peak}, peak power and power at 4mmol/L blood lactate), suggesting that accumulative duration of interval sessions and exercise intensity act concurrently for physiological adaptations (Buchheit & Laursen, 2013a, 2013b; Seiler, 2010). Additionally, it has been found that long-duration intervals can improve time-trial performance in endurance-trained cyclists after a 6-week training block when incorporated alongside a cyclist's typical aerobic training (Stepto, Hawley, Dennis, & Hopkins, 1999).

Short-duration ‘sprint’ HIIT of supramaximal work intervals (e.g. 15 – 30 seconds), with more extended recovery periods (e.g. >45 seconds), is known as sprint interval training (SIT) (Buchheit & Laursen, 2013a). Time at VO_{2max} is not typically ascertained on the first few short duration intervals but can be reached on subsequent intervals, however, short-duration HIIT does easily stress the metabolic and neuromuscular systems, enabling the ability to increase VO_{2max}, power outputs and repeat-sprint ability (Buchheit & Laursen, 2013a). One of the benefits of SIT is the ability to perform at high intensities with relatively low blood lactate levels (Buchheit & Laursen, 2013b). Lactate levels are typically lower in SIT than HIIT due to the short exercise bursts relying predominantly on stored oxygen (Buchheit & Laursen, 2013b). In the initial phase of SIT, oxygen bound to myoglobin stores delivers the oxygen requirements before the circulatory and respiratory systems are encouraged to meet the oxygen demands (Buchheit & Laursen, 2013b). As a result SIT can be performed for up to 30 minutes before a trained individual fatigues (Buchheit & Laursen, 2013b). SIT elicits higher work intensities than longer intervals requiring a greater relative force development per muscle fibre and firing-rate, resulting in a greater neuromuscular load from SIT. In order to respond well to an increase in training intensity, it is understood that cyclists need a well-established endurance base to tolerate the high training load without risk of adverse outcomes (Seiler, 2010). Periodising a cyclist’s training programme and incorporating ~2 HIIT sessions a week alongside endurance training is thought to be critical for a PRC to ensure that they are targeting all energy systems during training.

2.3.2 Modalities of resistance training

2.3.2.1 Traditional strength training

Resistance training is known to elicit physiological adaptations and improve performance. Cyclists, however, have been known and are often stereotyped to avoid traditional resistance training through the stigma and concern of increasing lean body mass, which can have a detrimental impact on performance related demands such as hill climbing (Yamamoto et al., 2010). However, well planned concurrent endurance and strength training programmes can improve performance (Bell, Syrotuik, Socha, Maclean, & Quinney, 1997; Chtara et al., 2005; Hoff & Helgerud, 2004; McCarthy, Pozniak, & Agre, 2002; Sale, MacDougall, Acobs, & Garner, 1990). As the physiological responses in strength and endurance training are dependent on separate biological processes, it is possible that strength and endurance can both be targeted without inhibiting one another, provided that there is sufficient recovery in between (Hoff & Helgerud, 2004).

Research has demonstrated that after an eight-week maximal strength training programme (smith machine half squats: 4 sets x 4 repetitions maximum (RM)) significantly improved CE, time to exhaustion (TTE), and work efficiency at maximal aerobic power (Sunde et al., 2010). The improvements were made without impacting on the body weight of the competitive road cyclists, despite a decrease in total weekly cycling training to allow for the strength training to be completed (Sunde et al., 2010). Other studies in untrained cyclists have seen performance improvements following maximal strength training programmes. Following an eight-week leg strength programme (4 sets x 5 repetitions at 85% 1 repetition max (RM)) significant improvements were seen in peak power and cycling economy in previously untrained men (Loveless, Weber, Haseler, & Schneider, 2005). In trained cyclists performing a 10-week strength training programme (squats, leg extensions, knee flexions and toe raises) found that cycling time to exhaustion at 80% VO_{2max} increased significantly ($p = <0.05$) (Hickson, Dvorak, Gorostiaga, Kurowski, & Foster, 1988). However, other studies have shown differing outcomes from strength training. One study found no improvement to cycling performance after a 12 week resistance training intervention (5 sets to failure (2 – 8 RM) parallel squats) (Bishop, Jenkins, MacKinnon, McEniery & Carey, 1999). However, this study utilised a wide age range (18 – 42 years) of female trained endurance cyclists. With the different responses that males and females experience from strength training as a result of their differing muscle fibre areas and hormone levels there may be potential that trained male cyclists may have responded differently to the same intervention. Where Bishop et al., (1999) utilised one exercise for the training intervention (parallel squats) over 12 weeks, with no performance change found. Sunde et al., (2010) used one similar exercise (smith machine half squats) over 10 weeks with trained competitive male riders, and found performance and strength improvements. Likewise, Loveless et al., (2005) used 1RM squats over 8 weeks and found performance improvements in untrained men.

It has been shown that concurrent strength training can improve determinants of cycling performance when utilising different styles of resistance training with the likes of

Olympic lifts, heavier weights with low repetitions and plyometrics (Yamamoto et al., 2010). However, there is still scepticism around whether the performance improvements would be of benefit or whether well-trained cyclists could even get benefits that cross-over into their race demands (Hawley & Stepto, 2001). The majority of training studies have used 'trained' cyclists (Hickson et al., 1988; Sunde et al., 2010), or untrained participants (Campos et al., 2002; Hickson, Rosenkoetter, & Brown, 1980; Loveless et al., 2005) however, no study has examined the effects of a strength training intervention on elite cyclists.

2.3.2.2 Sport-specific resistance training

Sport-specific training is crucial to enhance performance as margins between winning and losing in professional and high-performance sport are becoming seemingly narrower. Specificity is a fundamental principle of training, where an athlete's prescribed exercise in training is purposeful to match the requirements of their sport (Young, 2006). Training specificity is fundamental in an athletes programme for improving performance and achieving optimal adaptations (Reilly, Morris, & Whyte, 2009). From a physiological standpoint, training programmes are required to stress the physiology that is required to perform in a particular manner to achieve specific training adaptations known as 'specific adaptations to imposed demands' or SAID (Mathews & Fox, 1976; Reilly et al., 2009). Three mechanisms of specificity required to be taken into consideration to stress the physiological systems connected with performance in an optimal manner are: (i) the muscle group, (ii) the energy system, and (iii) the skill required for the sport (Reilly et al., 2009). As a result of the specificity principle of training, researchers, coaches and athletes have sought methods to include non-traditional resistance training into their programmes as a form of conditioning. Two such modes of sport-specific training are hill climbing interval training and over gearing (high/low cadence) training.

<u>Hill climbing:</u>

Cyclists have utilised hill climbing as a form of sport-specific interval training, where cyclists will perform repeated efforts up-hill, utilising the down-hill, or horizontal gradients as a recovery bout. It is believed that hill climbing not only practises the skill required in a road race, but also targets the physiology that is required to perform the task. Research has found that PRC who specialise in hill climbing have higher anaerobic capacities and maximal lactate levels than flatter stage specialists (Lucia et al., 2000). This can be explained through their incredible tolerance to lactic acidosis and buffering capacity which allows hill specialists to tolerate repeat bouts of high intensity efforts throughout mountain stages (Lucia et al., 2001, 2000). During such stages hill specialists have been reported to have a natural ability to switch between an already demanding pace to an even harder pace (Lucia et al., 2000). Therefore, training in the exact skill required during a race is believed to be an optimal method of acquiring the adaptations required to perform. However, research to date is limited on the effects of hill climbing as a training stimulus (Table 2.1). One study found hill climbing improved performance during a graded exercise test and increased power output during uphill cycling on a treadmill (Nimmerichter, Eston, Bachl, & Williams, 2011). The same study also found that higher power outputs are exerted when on an uphill gradient compared to flat 20 min time-trials in trained road cyclists (Nimmerichter et al., 2011). Research has hypothesised that interval training performed in the similar fashion of the physical demands required by cyclists (either uphill or on flat surfaces) could increase performance capacity in flat and uphill stages of a road race (Nimmerichter et al., 2011). However, research in the 'real-world' training environment of hill climbing is limited. This is potentially a result of the difficulties and uncertainties of the acquired measures when carrying out research in the environment. Despite research being in its infancy on the effects of hill climbing training, it remains a popular mode of training among cyclists, perhaps due to its sport-specific nature.

Over-gearing:

It is well believed that high-intensity-interval training is beneficial for endurance performance (Buchheit & Laursen, 2013a), however, the performance effects of traditional resistance training are less decisive (Paton & Hopkins, 2005). Cyclists have been known to vary their pedal cadence in training sessions in a belief that it may produce a beneficial training response (Paton, Hopkins, & Cook, 2009). However, research to date on over-gearing as a specific modality is limited (Table 2.1). One study found that training at a lower cadence produced greater power benefits at 4mmol/L blood lactate (10.6 ± 8.0% change) than training at a higher cadence (3.3 ± 6.2% change) (Paton et al., 2009). Another study found that after using maximal sprints at 60 – 70 revolutions per minute, mean power and peak power improved by 6.7% – 8.7% with "almost certain" (> 99.3% chances) substantial changes of improvement, with oxygen cost and lactate-profile power having "likely" (>83% chances) substantial changes when compared to a control group doing normal cycling training (Paton & Hopkins, 2005). Mechanistically, over-gearing has been speculated to improve cycling efficiency through increasing the firing frequency of motor units, and in-turn increasing the rate of force production and peak muscle forces (Paton & Hopkins, 2005). Utilising over-gearing as a training tool is particularly useful for road racing and time-trials where repeat high-intensity, short-duration efforts are required (Lucia et al., 2001; Paton & Hopkins, 2005). While research is in its infancy, over-gearing seems to be a possible option for cyclists wishing to apply sport-specific resistance to their training plans.

Table 2.1 Sport-specific methods of resistance training.

Study	Participants (sex and mean ± SD age, height and mass)	Training Method	Measures	Pre-training results/ Control Group	Post training results	Acute/Longitudinal
Hill Climbing						
Nimmerichter et al., 2011	18 well-trained male cyclists Int$_{60}$ (n = 6): 30 ± 6.8 years, 179 ± 3.2 cm, 70.9 ± 6.4 kg. Int$_{100}$ (n = 6): 31 ± 6.9 years, 177 ± 4.8 cm, 71.5 ± 5.0 kg. Con (n = 5) 33 ± 5.1 years, 182 ± 7.0 cm, 75.4 ± 4.2 kg.	4 weeks with 2 interval training sessions a week (control = no interval training sessions). Int$_{60}$: 6 x 5 min intervals @ RCP Power at ~7% gradient & 60 RPM. Int$_{100}$: 6 x 5 min intervals @ RCP Power at ~0% gradient & 100 RPM	GXT 2 x 20 minute time trials on TT$_{flat}$ or TT$_{hill}$	GXT: VO$_{2max}$ (ml/kg/min): Int$_{60}$ = 61.1 ± 5.0 Int$_{100}$ = 58.8 ± 6.0 Con = 55.4 ± 4.3 Time Trials: HR (bpm) TT$_{flat}$: Int$_{60}$ = 178 ± 15 Int$_{100}$ = 174 ± 7 Con = 174 ± 10 TT$_{hill}$: Int$_{60}$ = 180 ± 8 Int$_{100}$ = 177 ± 7 Con = 177 ± 10 BLa (mmol/L) TT$_{flat}$: Int$_{60}$ = 9.7 ± 2.5 Int$_{100}$ = 8.1 ± 2.3 Con = 8.4 ± 0.9 TT$_{hill}$: Int$_{60}$ = 10.0 ± 2.7 Int$_{100}$ = 9.2 ± 2.3 Con = 9.1 ± 2.7	GXT: VO$_{2max}$ (ml/kg/min): Int$_{60}$ = ↔ Int$_{100}$ = ↔ Con = ↔ Time Trials: HR (bpm) TT$_{flat}$: Int$_{60}$ = ↑ Int$_{100}$ = ↔ Con = ↓ TT$_{hill}$: Int$_{60}$ = ↔ Int$_{100}$ = ↔ Con = ↔ BLa (mmol/L) TT$_{flat}$: Int$_{60}$ = ↔ Int$_{100}$ = ↔ Con = ↓ TT$_{hill}$: Int$_{60}$ = ↑ Int$_{100}$ = ↔ Con = ↑	Longitudinal

Over-gearing Intervals						
Paton & Hopkins, 2005	20 well-trained male cyclists. EG (n = 9): 24.6 ± 5.7 years, 180 ± 0.05 cm, 74.7 ± 7.1 kg CG (n = 9): 29.2 ± 8.4 years, 181 ± 0.06 cm, 77.5 ± 8.1 kg	EG: 30 minute sessions 2-3 days/week: 3 sets of 20 single leg jumps & 3 sets of 5 x 30 second max cycling efforts @ 60-70 RPM CG: Normal training	Mean power in a 1km & 4km time trial Lactate-profile power (LPP) Oxygen cost	CG: 1km MP: 0% change 4km MP: 0.3% change LPP: 1.7 % change Oxygen cost: -0.2 % change	EG: 1km MP: ↑ 4km MP: ↑ LPP: ↑ Oxygen cost: ↓	Longitudinal
Paton, et al., 2009	18 well trained male cyclists. LC (n = 9) 26.8 ± 7.4 years, 81.1 ± 7.7 kg. HC (n = 9) 24.9 ± 6.2 years, 81.2 ± 5.5 kg	LC: 8 x 30 minute sessions 2 days/week: 3 sets of 20 single leg jumps & 3 sets of 5 x 30 second max cycling efforts @ 60-70 RPM with 30 second RI HC: 8 x 30 minute sessions 2 days/week: 3 sets of 20 single leg jumps & 3 sets of 5 x 30 second max cycling efforts @ 60-70 RPM with 30 second RI CG: Normal training	60 second mean power Power at 4 mmol/L VO_{2max}	HC (% change in measure): 60 second mean power: 3.0 ± 6.4 Power at 4 mmol/L: 3.3 ± 6.2 VO_{2max}: 1.1 ± 5.6	LC (% change in measure): 60 second mean power: 5.6 ± 5.3 Power at 4 mmol/L: 10.6 ± 8.0 VO_{2max}: 4.5 ± 3.9	Longitudinal

↑ = increased significantly; ↓ = decreased/reduced significantly; ↔ no change

Int_{60} = low cadence group (60 revolutions per minute); Int_{100} = high cadence group (100 revolutions per minute); RCP = respiratory compensation point; RPM = revolutions per minute; GXT = incremental graded exercise test; TT_{flat} = time trial on flat road; TT_{hill} = time trial on uphill road; P_{max} = maximum power output (W); VO_{2max} = maximal oxygen consumption (ml/min/kg) VT = Ventilatory threshold (ml/kg/min); BLa = blood lactate concentration; HR = heart rate (bpm); RPE = rate of perceived exertion; EG = experimental group; CG = control group; MP = mean power; LC = low cadence; HC = high cadence; RI = recovery interval; VO_{2max} = maximal oxygen consumption

2.4 Functional resistance training

Resistance training is required to target the performance characteristics of active skeletal muscles. In circumstances where muscle endurance, power or strength are inadequate to perform the demands of the sport, the targeted muscle groups can be isolated in training (Reilly et al., 2009). Alongside targeting the specific muscle groups, resistance training can focus on the specific type of movement (isometric, concentric or eccentric), the range of motion, velocity and joint angle required to optimise performance improvements for a particular sport (Reilly et al., 2009). A means of targeted resistance training is FRT. FRT has been found to provide a technique of applying overload in a sport-specific manner (Macadam, Cronin, & Simperingham, 2016). FRT involves applying a load to specific body parts, allowing an athlete to perform sport-specific movements at an additional load to increase power output and performance in those actions (Macadam et al., 2016, 2018; Simperingham & Cronin, 2014). A proposed benefit of FRT is that it can be done without negatively affecting the mechanics of the movement and unlike traditional resistance training, can be performed within the context of sport (sprinting and running) (Cronin et al., 2008; Macadam et al., 2016, 2018; Simperingham, Cronin, & Pearson, 2015). FRT provides added resistance to regular training and may optimise training adaptations through a more significant stimulus/stress applied to the working muscles (Hrysomallis., 2012). FRT has previously been researched in daily activities, walking/stair climbing programmes, and sprint and power-based sports as a practical means for incorporating specificity and progressive overload into training programmes. Some studies have recorded improvements to strength, power, endurance, balance and bone mineral density (Campos et al., 2002; Hickson et al., 1988; Sunde et al., 2010), while others have reported no benefits to these factors that influence performance (Puthoff, Darter, Nielsen, & Yack, 2006). Research in FRT is still in its early stages with very little research carried out in endurance sport and cycling.

2.4.1 Functional resistance training in other sporting disciplines

The research on the practicality of FRT has been carried out in sports such as running, sprinting and jumping. While still in its infancy, these researchers have focused on the kinematic and kinetic effects of using FRT within the specific modality (Table 2.2). These studies are examined in further detail below:

Running:

Load magnitude and orientation of FRT has been explored in running locomotion across a variety of variables. Table 2.2 shows that the majority of studies have focused on trunk loading with 0 – 15% added BW worn during submaximal exercise bouts (Couture et al., 2018; Cureton et al., 1978; Cureton & Sparling, 1980). Only one study examined LL, utilising relatively small loads (1, 3 & 5% added BW) in comparison to the quantities applied to the trunk (5 – 10% added BW) (Couture et al., 2018). However, when examining flight time, contact time, step frequency and step length no significant changes were found when using LL in comparison to the unloaded trials (Couture et al., 2018).

Rusko & Bosco (1987) examined the effects on runners wearing a weighted vest all day (9-10% BW) from morning to evening throughout their regular training and daily tasks over a four-week period. It was found that wearing weighted vests increased anaerobic metabolism in the lower limbs and during submaximal and maximal running ($p < 0.05$), and VO_2 increased during maximal running ($p < 0.001$) (Rusko & Bosco, 1987). However, the practicality of utilising FRT all day would be questionable for elite athletes.

The magnitude of weight added varied from none to little, to medium to large across all studies. Rusko & Bosco (1987) only investigated 9-10% of additional BW with weighted vests. Whereas Cureton and Sparling (1980) arguably had the most interesting technique for adding load, where the male participants percentage of added load was calculated by pairing the male with a female participant to bring the male up to the same percentage of added BW of his paired female. Run time did improve in the added load trials by an average of 1.2 minutes longer until volitional exhaustion (Cureton & Sparling, 1980). While the purpose of this study was to determine the extent of the metabolic and performance differences between female and male runners, it was also one of the first studies that applied added load to participants. Arguably this helped to spark the idea of FRT as a tool to enhance performance (Cureton & Sparling, 1980). In recent years the technology used to add load has developed, making the options and abilities for practical use of FRT to be rather different than in the earlier research. Couture et al., (2018) examined a full range from 0, 1, 3, 5, & 10 % added BW using the newer Lila™ Exogen™ EXO-skeleton suit (Kuala Lumpur, Malaysia) technology, whereas Cureton et al., (1978) also examined a range of added load (0, 5, 10 & 15% added BW) using the older weighted vests. Further research is required to fully understand the effects of FRT in running, in particular, longitudinal training studies.

Sprinting:

Like running, research in sprinting has examined FRT across different magnitudes and orientations (Table 2.2). The locations examined using FRT include LL (Macadam et al., 2018), trunk loading (Cross et al., 2014), a combination of limb and trunk loading (Simperingham & Cronin, 2014), and a combination of trunk loading and weighted sled towing (Clark, Stearne, Walts, & Miller, 2010; Cronin et al., 2008). The magnitude of the amount of weight added varied from none/little, to medium to large, similar to the trials in running. Macadam et al., (2018) used the smallest amount of added load (~2% added BW), which is logical as the study also applied the load to the smallest body part (forearms (~1% added BW to each forearm)). Several studies used the torso as a way to add higher loads (5, 10, 15, 18.5 & 20% added BW) rather than the smaller amounts that are necessary when only applying load to the limbs (Clark et al., 2010; Cronin et al., 2008; Simperingham & Cronin, 2014). Cross et al., (2014) used set added kilogram amounts (9kg & 18kg weighted vests) rather than a percentage of BW across all participants which does not take into account the individual differences in participant's BW across participants and may influence study outcomes. For example, if a sport team were to apply the same amount of weight across all members it would be difficult to quantify the effects, and whether it is a useful training stimulus as the load would feel easier to carry for some and have less impact on measures such as power output, contact time and sprint time than it would on others. More longitudinal studies would be required to fully understand the effects of FRT in sprinting. Two studies investigated the effects of sled towing in comparison to weighted vests and found confounding results, however, differing magnitudes of loading and sprint protocols were employed so direct comparisons cannot be made. Cronin et al., (2008) found that sprint time increased by 5.7 – 19.8% in both weighted vest and weighted sled conditions, whereas Clark et al., (2010) found no difference in sprint performance in either of the weighted trials when compared to non-weighted trials. Further exploration in the use of FRT is required to be able to standardise protocols, measurements and expected performance outcomes.

Jumping:

Macadam, Simperingham, Cronin, Couture, & Evison (2017) examined the acute effects of wearing weighted vests under different percentages of added BW (3 and 6%) on the upper and lower body during counter-movement jumps (CMJ), drop jumps, (DJ) and pogo jumps (PJ). The study found that jump height and relative peak power decreased across all loading patterns ($p < 0.05$) in trained participants which is not unexpected when adding load and trying to jump (Macadam et al., 2017). A training study looking into the effects of longitudinal use of FRT during training to improve performance would prove beneficial to understand if the added load over time improves the ability to generate power and thereby jump height. Conversely, Thompsen, Kackley, Palumbo, & Faigenbaum, (2007) used added load during a dynamic warm-up in comparison to an unweighted dynamic warm-up and a static-stretch warm-up. It was found through adding load to a normal dynamic warm-up, both vertical jump height and long jump distance significantly improved ($p < 0.05$) when compared to the other two protocols. The added load used during the dynamic warm-up was worn on the torso which raises the question of 'where is the ideal placement for load to be added?' The study by Macadam et al., (2017) utilised both upper body (torso) and lower body (LL). Additionally Macadam et al., (2017) used 3 & 6% added BW for jumping, in comparison to Thompsen et al., (2007) who used 10% added BW for activation. Both Macadam et al., (2017) and Thompsen et al., (2007) used 'sport active' participants for their acute studies. It would be interesting to see if trained athletes from team sports (e.g. basketball) or individual sports (etc. high jump, long jump) would elicit the same responses as those who are not used to jumping for performance outcomes.

The use of FRT as a primer for performance is something that demonstrates a potential area of further research through its post-activation potentiation abilities (PAP) (Barnes, Hopkins, McGuigan, & Kilding, 2015). A greater understanding of the opportunities to improve jump performance through the use of FRT is required, and may have potential through both training and warm-up (PAP) purposes. Additionally, understanding the placement and loading amounts is something that requires further exploration.

Table 2.2 Use of functional resistance training in other sports (running, sprinting and jumping)

Study	Participants (sex and mean ± SD age, height and mass)	Methods	Load Placement and Amount	Measurement Variables	Pre Results (pre – testing or unloaded)	Post Results (post-testing or loaded)
Running						
Couture et al., (2018)	12 trained male runners (28.17 ± 7.35 years, 178.90 ± 8.06 cm, 70.83 ± 9.54 kg)	8 x 2 min running bouts (14km/h) either loaded (bout 2 – 7) or unloaded (bouts 1 & 8)	Loaded bouts were randomised as: UB 5% BW, LB 1%, 3%, 5% BW, 5% & 10% WB	Flight time Contact time Step length Step frequency	Unloaded (1): FT: 142.00 ± 12.08 CT: 207.42 ±12.15 SF: 172.13 ± 8.44 SL: 136.28 ± 6.7	LB 1% (2): ↔ FT, CT, SF & SL LB 3% (3): ↔ FT, CT, SF & SL LB 5% (4): ↔ FT, CT, SF & SL UB 5% (5): ↑ FT & CT (*2) ↔ SF & SL WB 5% (6): ↔ FT, CT, SF & SL WB 10% (7): FT: ↑ (*2,3,4,5) CT: ↑ (*1,2,3,4,5) ↔ SF & SL
Rusko & Bosco (1987)	24 well trained runners (n = 12) (23.6 ± 2.7 years, 177.6 ± 10.1 cm, 66.1 ± 11.2 kg) and cross-country skiers (n = 12 (1 female)) (26.5 ± 2.6 years, 174.2 ± 6.8 cm, 66.4 ± 9.2 kg)	Followed usual training regime and wore a weighted vest (9-10% BW) for 4 weeks (morning – evening). Skiers also wore it for every training session and runners wore it for 3 – 5 training sessions/week. Control group wore no vest.	9 – 10 % BW weighted vest worn over the trunk	LRT (VO_2) SRT (MAP) Running at 15km/h	LRT: VO_2: 45.8 ± 3.2 BLa: 1.5 ± 0.4 SRT: ExT: 59.6 ± 27.0 s BLa: 12.6 ± 3.0 Running at 15km/h: VO_2: 51.6 ± 3.6 BLa: 2.3 ± 1.1	LRT: VO_2: ↔ BLa: ↑ SRT: ExT: ↔ BLa: ↑ Running at 15km/h: VO_2: ↑ BLa: ↑

Cureton & Sparling (1980)	20 trained runners (10 males/10 females) (males: 26.4 ± 4.9 years, 178.7 ± 6.7 cm, 70.8 ± 8.1 kg / females: 25.8 ± 4.6 years, 160.4 ± 6.9 cm, 50.6 ± 8.1 kg)	Men were paired with women and performed two tests. The men did the tests twice, 1st as NW, and the second as AW	The AW condition was calculated to bring the male up to the same % excess weight of his paired female	Submaximal Treadmill Running	NW: V_E: 53.4 ± 8.7 VO_2 FFW: 42.4 ± 3.7 HR: 143 ± 6 Run Time: 15.6 ± 1.4 min	AW: V_E: ↔ VO_2: ↔ HR: ↔ Run Time: ↑
Cureton et al., (1978)	6 trained runners (4 males/ 2 females) (20 - 30 years, 163.7 - 191.5 cm, 53.2 - 79.4 kg)	Participants did 2 tests once a week for 4 weeks under 4 different conditions (NW, 5% BW, 10% BW & 15% BW)	0, 5, 10 & 15% BW to trunk	Submaximal treadmill running 12 min running performance	0%: V_E: 105.3 ± 19.3 VO_2 (l/min): 3.61 ± 0.82 HR: 194 ± 8	5%: V_E: ↔ VO_2 (l/min): ↔ HR: ↔ 10%: V_E: ↔ VO_2 (l/min): ↔ HR: ↔ 15%: V_E: ↔ VO_2 (l/min): ↔ HR: ↔
Sprinting						
Macadam et al., (2018)	22 amateur male rugby union players (19.4 ± 0.5 years, 180.4 ± 7.2 cm, 97.0 ± 4.8 kg)	2 x 20 metre maximum effort sprints (1 repetition unloaded, the other loaded)	~2% BW evenly distributed on forearms (~1% BW on each forearm)	Flight time Contact time Step length Step frequency	FT: 0.050 ± 0.008 CT: 0.197 ± 0.018 SL: 4.03 ± 0.25 SF 4.03 ± 0.25	↑ FT, CT, SF & SL
Simperingham & Cronin (2014)	8 trained team sport males (29.2 ± 3.8 years, 177.1 ± 7.5 cm, 81.8 ± 9.7 kg)	4 sets of 2 maximal effort 6 second sprints unloaded, loaded on UB and loaded on LB.	5% BW worn in a randomised order on either the UB (anterior and posterior torso), or LB (anterior and posterior thigh) and distributed evenly	Peak Velocity: AP & MVP CT: AP & MVP FT: AP & MVP	Unloaded *Peak velocity* AP: 5.24 ± 0.48 MVP: 5.33 ± 0.43 *CT* AP: 184 ± 12 MVP: 170 ± 11 *FT* AP: 40 ± 15 MVP: 51 ± 13	5%UB *Peak velocity* AP: ↔ MVP: ↔ *CT* AP: ↑ MVP: ↑ *FT* AP: ↑ MVP: ↔

						10%UB *Peak velocity* AP: ↓ MVP: ↓ *CT* AP: ↑ MVP: ↑ *FT* AP: ↓ MVP: ↑
Cross et al., (2014)	13 active subjects (gender not specified) (22.9 ± 3.3 years, 179.1 ± 6.6 cm, 82.5 ± 8.4 kg)	3 x 6 second maximal sprints under three different conditions (NW, 9kg vest and 18kg vest)	9 kg & 18 kg vests worn on the torso	Peak Velocity: CT: AP & MVP FT: AP & MVP	Unloaded *Peak velocity:* 5.86 ± 0.54 *CT* AP: 222 ± 1.8 MVP: 169 ± 7.9 *FT* AP: 45 ± 10 MVP: 69 ± 14	9kg vest *Peak velocity:* ↑ *CT* AP: ↔ MVP: ↑ *FT* AP: ↔ MVP: ↑ 18kg vest *Peak velocity:* ↑ *CT* AP: ↔ MVP: ↑ *FT* AP: ↑ MVP: ↑
Clark et al., (2010)	20 NCAA Division 3 lacrosse players (NW (n = 7): 19.92 ± 1.05 years, 178.53 ± 6.64 cm, 81.78 ± 8.07 kg/ WS (n = 7): 19.73 ± 1.01 years, 181.15 ± 6.84 cm, 87.9 ± 17.3	13 x 60 minute sprint training sessions over 7 weeks under their 3 different loading conditions (with exception for the last 2 sprints of every session)	NW WS = 10 % BW WV = 18.5 % BW worn over the torso	3 x maximum effort 54.9 m sprints	NW Time (s): 4.373 ± 0.142 AV (m/s): 8.372 ± 0.267 WS	NW Time (s): ↔ AV (m/s): ↔ WS Time (s): ↔ AV (m/s): ↔

	kg/ WV (n = 6): 19.79 ± 0.92 years, 182.25 ± 8.36 cm, 79.15 ± 5.26 kg)				Time (s): 4.453 ± 0.212 AV (m/s): 8.230 ± 0.395 <u>WV</u> Time (s): 4.410 ± 0.215 AV (m/s): 8.311 ± 0.415	<u>WV</u> Time (s): ↔ AV (m/s): ↔
Cronin et al., (2008)	20 trained subjects (16 males, 4 females) (19.9 ± 2.2 years, 176 ± 8 cm, 76.5 ± 10.7 kg)	30 m sprints under 3 different conditions (NW, WS & WV). Each subject performed 1 sprint per condition (total 5 sprints)	No weight WS = 15 & 20 % BW WV = 15 & 20 % BW worn over the torso	Sprint times for 20 & 30 m	Exact times not published	Sprint time ↑ Exact times not published. Sprint time increased 7.5 to 19.8% in both weighted conditions
Jumping						
Macadam et al., (2017)	20 sport active (10 males & 10 females) subjects (27.8 ± 3.8 years, 174 ± 7.8 cm, 70.2 ± 12.2 kg)	Performed a CMJ, DJ, & PJ under different weighted conditions	No weight 3 % BW UB (anterior and posterior trunk) 3 % BW LB (anterior and posterior trunk) 6 % BW UB (2/3 thigh & 1/3 calf – anterior and posterior) 6 % BW LB (2/3 thigh & 1/3 calf – anterior and posterior)	JH RPP	<u>NW:</u> JH: 32.0 ± 7.6 RPP: 44.2 ± 8.6	<u>3% BW UB:</u> JH: ↓ RPP: ↓ <u>3% BW LB:</u> JH: ↓ RPP: ↓ <u>6% BW UB:</u> JH: ↓ RPP: ↓ <u>6% BW LB:</u> JH: ↓ RPP: ↓
(Thompsen et al., (2007)	16 sport active females (19.7 ± 1.4 years, 166 ± 11 cm, 67 ± 11 kg)	Warm-up in preparation for jumps. Warm-ups were under 3 different conditions	10 % BW worn on the torso	Vertical Jump Long Jump	1) <u>Cycling and static stretching:</u> Vertical Jump ↔ Long Jump ↔	3) <u>Dynamic Exercise with WV</u> Vertical Jump ↑ Long Jump ↑

1) moderate cycling & static stretching 2) dynamic exercise 3) dynamic exercise with a weighted vest	2) <u>Dynamic Exercise</u> Vertical Jump ↑* Long Jump ↑*

↑ = increased significantly; ↓ = decreased/reduced significantly; ↔ no change
BW = added body weight; VO_2: maximal oxygen consumption (ml/kg/min); LRT = long running test; SRT = short running test; MAP = maximal aerobic performance ; BLa = blood lactate concentration (mmol/L); ExT = exhaustion time; NW = no weight added; AW = added excess weight; V_E = ventilatory equivalent ($l.min^{-1}$); FFW = fat free weight; HR = heart rate (bpm); CMJ = countermovement jump; UB = upper body; LB = lower body; AP = acceleration phase; MVP = maximum velocity phase; CT = contact time (m/s); FT = flight time (m/s); SF = step frequency (step/min); SL = step length (cm); WS = weighted sled; WV = weighted vest; DJ = drop jump; PJ = pogo jump; JH = jump height (cm); RPP = relative peak power (W/kg); WB = whole body; AV = average velocity

The technology used in FRT has advanced over recent years from weighted belts and sled towing to weighted compression vests and bodysuits (e.g. Lila™ Exogen™ EXO-skeleton suit (Kuala Lumpur, Malaysia)). The latter offers greater specificity and customisations of load placements and amounts (Macadam et al., 2016). As technology has advanced, it may now be possible for FRT to be used in sports that have typically not been researched. Such advancements allow for a more specific movement within the context of the sport that could not previously be achieved.

2.4.2 Functional resistance training in cycling

As discussed earlier, FRT in sport is in its infancy, and it is no different when it comes to the use of FRT in cycling. Table 2.3 demonstrates that lack of research on FRT in cycling. To the best of the researcher's knowledge, only two acute studies have researched this area, using very different protocols, measures, loading amounts and locations. Baum & Li, (2003), utilised LL with relatively small loads to examine the effects of FRT on inertia and muscle activity frequencies under different loads (0, 0.5, 1, 1.5 and 2kgs). The study found that mean peak electromyography (EMG) activity increased significantly in both biceps femoris and tibialis anterior in a linear fashion across all loads, but not in the remaining sites measured. Moreover, higher loads impacted on the coordination and timing of the antagonist muscles used during each full pedal stroke (Baum & Li, 2003). In practical terms, these findings indicate that adding load to a cyclist's lower limbs can alter the mechanics of cycling and requires careful consideration not to incur injury or promote undesirable technique. Alternatively, adding load through the use of FRT in cycling could be used if applied in a specific manner to potentially train parts of the body that have an imbalance or muscular deficiency, to overcome the deficit or strengthen parts of the limb that require attention.

Further research is required to understand the impact of FRT in cycling and its impact on muscle mechanics. Carriker, Mclean, & Mccormick (2013) explored the physiological impact of adding load to the torso during standing cycling (5, 10 & 15% added BW). The two heaviest conditions (10 & 15% added BW) saw significant increases in RPE and 15% added BW increased kilocalorie expenditure during standing cycling (Carriker et al., 2013). Regarding energy expenditure, cycling with 15% added BW is more beneficial than cycling at the same power output with no added BW which could easily be incorporated into training programmes. The two studies investigate different acute responses, utilising different methods, subject populations, magnitudes and orientations for loading of FRT. It is therefore difficult to make assumptions on the effects of adding load for the purposes of FRT as a longitudinal training study. Further research is warranted in cycling, particularly with an endurance focus in order to understand the practicalities of using FRT to enhance performance.

Table 2.3 Functional resistance training in cycling

Study	Participants (sex and mean ± SD age, height and mass) and training status	Methods	Load Placement and Amount	Measurement Variables	Results	Acute/ Chronic
Baum & Li (2003)	16 recreational male cyclists, (23 ± 5 years, 180cm ± 2, 85 ± 10kg)	Cycling at 250 W on a stationary cycling ergometer. Duration unspecified.	0, 0.5, 1.0, 1.5, and 2.0 kg attached to the distal end of the thigh	EMG: GM, RF, BF, VL, TA, GAS & SOL	Mean peak of EMG activity per cycle across loads (%) 0 kg load: BF & TA ↑ GM, RF,VL, GAS & SOL ↔ 0.5 kg load: BF & TA ↑ GM, RF,VL, GAS & SOL ↔ 1 kg load: BF & TA ↑ GM, RF,VL, GAS & SOL ↔ 1.5 kg load: BF & TA ↑ GM, RF,VL, GAS & SOL ↔ 2.0 kg load: BF & TA ↑ GM, RF,VL, GAS & SOL ↔	Acute
Carriker et al., (2013)	12 recreationally trained female cyclists (40 ± 8 years, 164.8 ± 6.5 cm, 57.33 ± 5.33 kg)	4 minutes of standing cycling at 65% PPO under 4 different loading conditions on a stationary cycling ergometer	Weighted vests with conditions of: No vest, 5%BW, 10%BW, 15%BW	VO_2 HR Kcal RPE	VO_2: ↔ HR: ↔ Kcal: ↑ energy expenditure 15%BW RPE: 10 & 15%BW ↑	Acute

↑ = increased significantly; ↓ = decreased/reduced significantly; ↔ no change
GM = gluteus maximus; RF = rectus femoris; BF = biceps femoris; VL = vastus lateralis; TA = tibialis anterior; GAS = medial gastrocnemius; SOL = soleus; PPO = peak power output; BW = added body weight; VO_2 = oxygen consumption; HR = heart rate; Kcal = kilocalorie expenditure; RPE = rate of perceived exertion

2.5 Future Directions

Recent developments in the technology used to apply FRT allows for more specific load placement and quantities. However, given the principles of specificity and overload, the placement of the load on the limbs, as well as loading magnitude, is an essential area of consideration. However, there seem to conflicting opinions and differences in study methodology around load quantities and orientations. One area of agreement is that loads worn on the trunk can be more substantial (5 – 65 % BM), compared to loads worn on the limbs (<10 % BM), and that the distal ends of the body segment were preferable for load placements due to the amount of muscle activity that can be increased (Macadam et al., 2016). The current literature in FRT has employed different loading patterns, load amounts, training status of participants, research design and duration for investigations across sprinting, running and jumping (Macadam et al., 2016; Puthoff et al., 2006). However, little research has investigated the effects of FRT in endurance sport, particularly cycling.

In the sport of cycling, resistance is typically added in training sessions through over-gearing intervals and hill climbing. However, resistance is never added to the moving limbs of the cyclist. It is unknown whether FRT would deliver any advantage to cyclists over their regular training and prove to be beneficial. Additionally, unlike sprinting where sled-towing has been utilised, it is unknown about the effects of adding load to the bicycle comparatively to adding load to the moving limbs of the cyclist themselves. To the best of the researcher's knowledge, there is no research to date which investigates the effects of FRT in this area. Therefore, this thesis aims to investigate the physiological and perceptual responses of limb loading (LL) in trained cyclists using different load quantities in laboratory controlled stationary cycling, and the practical applications of LL through simulated 'real-world' uphill cycling in comparison to loading the bicycle.

2.6 Conclusion

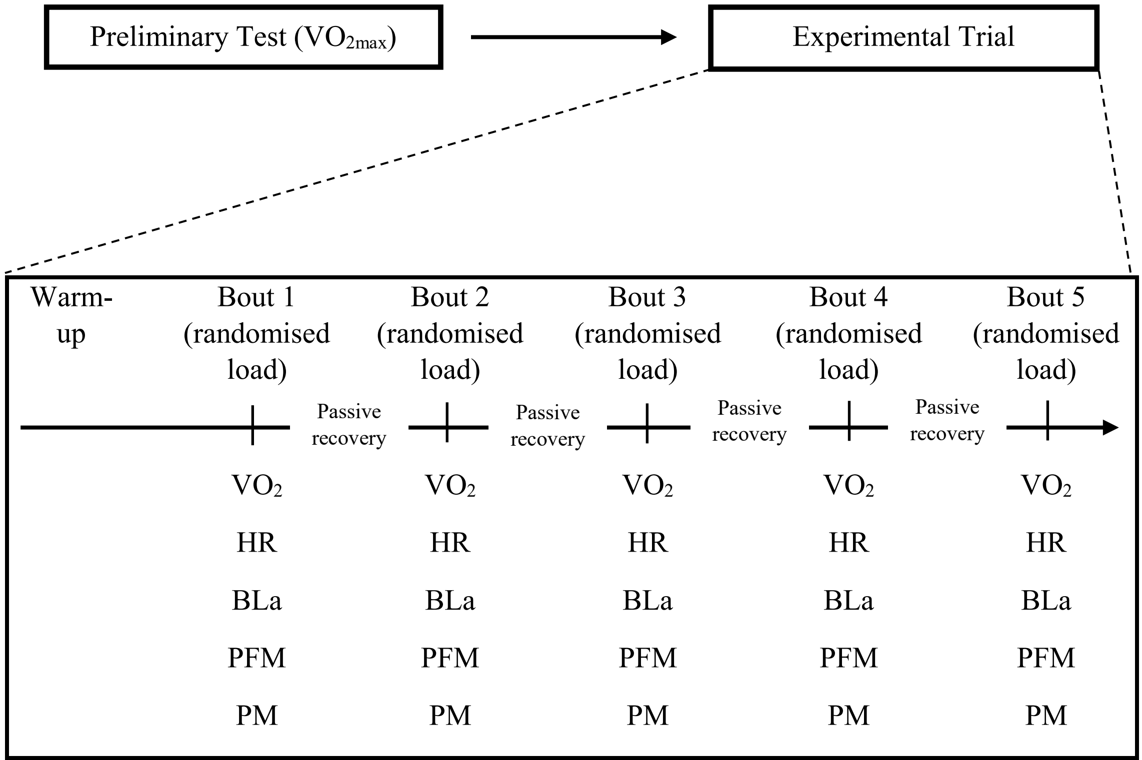
Training a cyclist for the physical demands of endurance cycling requires careful attention. One component of an overall training programme that is often overlooked in favour of spending time on the bike, is resistance training (Yamamoto et al., 2010). Cyclists have implemented hill climbing and over-gearing as a way of incorporating overload into their programmes, however further exploration of ways to incorporate sport-specific overload are required. FRT has been explored in the domains of running, sprinting and jumping for its ability to induce sport-specific overload. The ideology behind FRT and the current literature to date has identified the opportunities and benefits that can come from this sport-specific mode of resistance training. FRT is developing regarding the equipment used to apply overload, and now allows for greater exploration in sporting codes where previously FRT would have been very difficult. The current body of knowledge on FRT has been discussed in this literature review. To date, there is little research in FRT and cycling. Further examination is required to understand the acute physiological effects of LL in cycling, including load amount, adaptations made, whether body or external equipment is the ideal place to add load, and its 'real-world' applicability to riding with the garments over long durations and in repetitive cyclic motions. Understanding the physiological effects of LL may provide a sport-specific and easy way for an athletic population who typically have avoided traditional resistance training an opportunity to incorporate sport-specific overload into their training.

Chapter Three: Research methodologies

Methods: Study One

3.1 Research design

This study used a cross sectional design to determine the acute physiological and perceptual responses of limb loading in cycling. The physiological effects of added load were assessed during a single test session, during which participants completed repeated submaximal LL bouts, varying in load (0, 2, 4, 6 and 8% of added body weight, BW), in random order (Figure 3.1).



Abbreviations: VO_2 = oxygen consumption; HR = heart rate; BLa = blood lactate; PFM = Pedal Force Measurements; PQ = perceptual measures

Figure 3.1 Schematic representation of study design for submaximal ergometer cycling trials.

3.2 Participants

Nine well-trained cyclists (n = 8 males, n = 1 female) volunteered to take part in this study (*Table 3.1*). All participants had more than of 2 years cycling training, were riding at least 150 km/wk and were free from injury, illness or disability at the time of the study.

Participants were informed of any risks and benefits from participating in this study and signed informed consent. Ethical approval was granted for this study from the Auckland University of Technology Ethics Committee (AUTEC) prior to the commencement of data collection. Confidentiality of the participants is protected through displaying all data as means ± standard deviations.

Table 3.1 Participant Characteristics

Variable	Mean ± SD
Sex	8 Males, 1 Female
Age (yrs.)	32.3 ± 7.1
Height (cm)	180.9 ± 8.2
Body Mass (kg)	77.03 ± 5.09
VO_{2max} (ml/kg/min)	57.8 ± 7.3
Max Power Output (W)	347.78 ± 56.96
VT1 Power Output (W)	177 ± 32

Abbreviations: SD = standard deviation; yrs = years; cm = centimetres; kg = kilograms; VO_{2max} = maximal oxygen consumption; W = watts; VT1 = first ventilatory threshold

3.3 Pilot testing

Pilot testing was undertaken to understand the optimal testing protocol for the submaximal trials. The aim of pilot testing was to:

1) Ascertain the practical and comfortable loads to wear whilst cycling for the experimental trial.

2) The duration of the exercise bout for the experimental trial.

3) The recovery period required between exercise bouts.

Three participants volunteered to perform pilot testing (n= 2 males (trained cyclists), n= 1 female (recreationally active)). After trialling different load quantities (0, 4, 5, 6, 8, 10 and 15% added body weight using LL) it was deemed that 8% added body weight would be the maximal amount comfortable to cycle with, and small increments would be more practical and suitable for the experimental trials. Additionally, it was established that 5 minutes of VT_1 cycling was long enough to achieve steady state exercise, and 10 minutes cycling would not provide any further important information. Finally, it was deemed that an adequate controlled recovery period would need to be taken between trials so that participants were not going into the next exercise bout in a fatigued state.

3.4 Preliminary testing

Participants first underwent an incremental step test to exhaustion on a cycle ergometer, (Lode Excalibur Sport, Lode BV, Groningen, Netherlands). Participants performed 4-minute stages, increasing by 30W every 4 minutes until volitional exhaustion. Gas-exchange was measured continuously using a calibrated metabolic cart (TrueOne 2400, Parvo Medics, Sandy, UT) and their maximal oxygen consumption (VO_{2max}) and ventilatory thresholds were determined. A capillary blood lactate sample was determined (Lactate Pro2, Arkray, Amsterdam, Netherlands) from a fingertip sample taken in the last 30 s of every stage until it was determined that anaerobic threshold (defined as the point where the requirements of the exercise cannot be met aerobically, and simultaneously an increase in anaerobic metabolism occurs (~4mmol/L BLa) (Kenney, Wilmore, & Costill, 2012; Lucía, Hoyos, Pérez, & Chicharro, 2000)) had been reached. Data was used to prescribe the optimal intensities for subsequent experimental trials. To ensure the same relative intensity for all participants, power output and optimal cadence of each submaximal cycling bout was set at their individualised VT_1. VT_1 was established as an increase in V_E/VO_2 (V_E = volume of air expired in a minute) without a complementary increase in V_E/VCO_2 (VCO_2 = volume of carbon dioxide produced in a minute) (~ 2mmol/L BLa) (Kenney et al., 2012; Lucía et al., 2000).

3.5 Experimental protocol

Participants wore the Lila™ Exogen™ EXO-skeleton suit (Kuala Lumpur, Malaysia) on their lower limbs and undertook 5 x 5 minutes of submaximal cycling on the Lode Excalibur Sport (Lode BV, Groningen, The Netherlands) cycling ergometer wearing 0%, 2%, 4%, 6% and 8% of added BW in a randomised order after performing a standardised warm-up at an intensity of 60% peak PO following that of Atkinson, Todd, Reilly, & Waterhouse (2005). The cycling ergometer was configured to participants saddle position, handle bar position and crank length and participants wore their own cycling shoes and shorts. The protocol followed that of Macadam, Cronin, & Simperingham (2017) where the added body load was evenly placed on the distal ends of the lower limbs with 2/3 of the total load on the thigh and 1/3 on the calf. Participants were not told the percentage of added BW they were wearing for the exercise bouts. Participants had 15 minutes passive recovery between each 5-minute exercise bout, where the loads were changed in the first 3 minutes. The following 10 minutes were seated passive recovery where participants could drink water (ad libitum) before the final 2 minutes where the participants repositioned for the next exercise bout. Before and during each bout a range of measures were determined.

3.5.1 Submaximal LL Measures

Oxygen Consumption (VO_2)

Resting oxygen uptake (ml/kg/min) was measured (TrueOne 2400, Parvo Medics, Sandy, UT) for one minute prior to starting each five minute exercise bout and continued throughout each bout. Each exercise bout for the varying loads were recorded and saved separately. VO_2 was averaged over the final two minutes of the exercise bout for each participant.

Heart Rate (HR)

Heart rate (HR) (beats per minute (bpm) data was recorded and saved for each exercise bout using Polar Heart Rate Monitor CS800RX (Polar Electro Oy, Kempele, Finland). The Polar HR monitors were set to average HR over a 15 second period. The HR data was then analysed retrospectively via Polar ProTrainer 5 software (Version 5.42.2, Polar Electro Oy, Kempele, Finland). HR was averaged over the last two minutes of each exercise bout.

Blood Lactate (BLa)

BLa (mmol/L) was taken in the final 30 seconds of the exercise bout using Lactate Pro 2 (Arkray, Amsterdam, Netherlands). BLa was grouped for each added load amount.

Pedal Force Measurements (PFM)

The cycling ergometer Lode Excalibur Sport with Pedal Force Measurement (Lode BV, Groningen, Netherlands) recorded PFM throughout each five-minute exercise bout. The cycling ergometer was calibrated before each testing session. PFM were used to establish efficiency and power outputs.

Perceptual Measures

Perceptual ratings were recorded in the final 30 seconds of the exercise bout. Perceptual ratings were used to understand the sensations the participants were feeling in relation to the exercise they were performing. RPE has been validated to closely correlate with measures of physiological stress such as VO_2, HR, and PO (Borg, 1990; Faulkner & Eston, 2007). Participants were familiarised with RPE, Pain and Comfort prior to the commencement of the sub-maximal trials.

Rate of Perceived Exertion (RPE):

Rate of Perceived Exertion Scale (RPE): BORG 6 – 20 scale (Borg, 1990).

Pain Scale:

Pain Intensity: Pain Scale (0 – 10 Scale; No pain – Worst Pain Possible).

Comfort Scale:

Comfort Scale (1 (comfortable) – 10 (extremely uncomfortable)).

3.6 Statistical Analysis

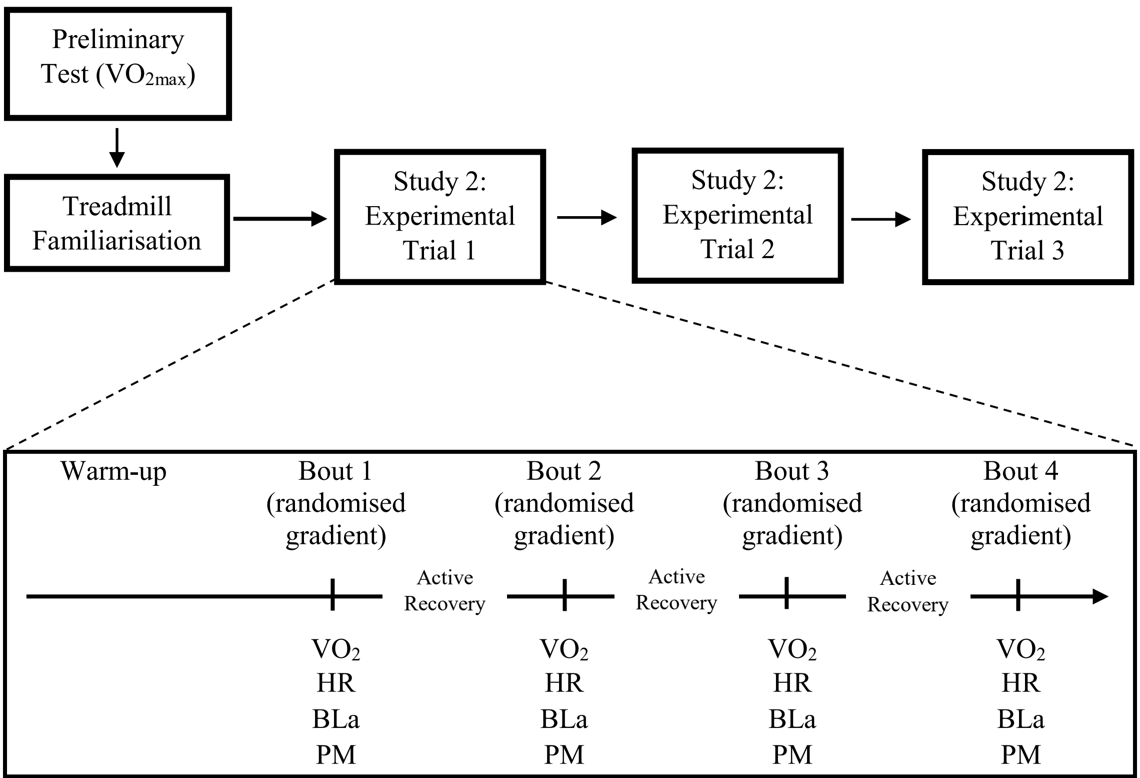
Statistical analysis was performed using descriptive statistics with means ± standard deviations and 90% confidence limits (CL) for each measure in relation to percentage added BW to understand the inference and magnitude of the outcome. The statistical aim for this study was to understand the inference of added load on submaximal cycling, therefore a magnitude-based inference approach was applied.

Qualitative inferences evaluated the magnitude of each effect through the use of a modified statistical spreadsheet (Hopkins, 2018) where standardised custom effects (Effect sizes) and 90% CL were calculated. Standardised differences were quantified qualitatively as follows: <0.2, trivial; >0.2, small; >0.6, moderate; >1.2, large; >2.0, very large (Hopkins, Marshall, Batterham, & Hanin, 2009). Additionally, the percentage chances were evaluated qualitatively as follows: <1%, almost certainly not; >1%, very unlikely, > 5%, unlikely, > 25%, possible, > 75% likely, > 95% very likely, > 99%, almost certain (Hopkins et al., 2009).

Linear regression was used to establish the relationship between each measured variable and added load. The square root of each R^2 was then calculated and used in a modified Hopkins (2007) spreadsheet to establish a Pearson product-moment correlation analysis. Correlations were established using the thresholds: <0.1 (*trivial*), >0.1 (*small*), >0.3 (*moderate*), >0.5 (*large*), >0.7 (*very large*) and >0.9 (*almost perfect*) (Hopkins et al., 2009). The magnitude of correlation was deemed 'unclear' when the 90% confidence limit corresponded small negative and positive values (Hopkins et al., 2009).

3.7 Research design

This study employed a cross sectional design to investigate the acute physiological and perceptual responses of LL in comparison to B_{load} to understand the optimal method of loading to induce physiological sport-specific overload. Participants rode their own road bicycles on a purpose-built treadmill (h/p/cosmos Saturn 300/100r, Japan) (while wearing a harness) at different gradients (2, 4, 6 & 8% gradient) and different loading conditions (no added weight (control), body loaded (using limb loading) (LL) and bike loaded (B_{load}) under laboratory conditions, following familiarisation sessions riding on the treadmill. The added load was the same body weight percentage (4% added BW) throughout the experimental trials whether it was added to the body or bicycle. 4% added BW was identified as the most optimal load in Study One. Participants were weighed at each experimental trial to adjust for weight changes throughout the data collection period. The physiological effects of added load were assessed through physiological measures recorded throughout the testing sessions (Figure 3.2).



Abbreviations: VO_{2max}= maximal oxygen consumption; VO_2 = oxygen consumption; HR = heart rate; BLa = blood lactate; PM = perceptual measures

Figure 3.2 Schematic representation of study design for treadmill cycling trials.

Study Two consisted of 3 independent trials on separate days and was comprised of four, five minute exercise bouts under different loading conditions (no added weight, body loaded, and bike loaded in a randomised order) and different gradients (2, 4, 6, and 8% gradient in a randomised order), following a standardised warm-up. Each experimental trial was comprised of the identical measurements and protocols.

3.8 Participants

Eight well-trained cyclists (n = 7 males, n= 1 female) volunteered to take part in this study (Table 3.2). All participants had more than 2 years cycling training, were riding at least 150 km/wk and were free from injury, illness or disability at the time of the study. Participants were informed of any risks and benefits from participating in this study and signed informed consent prior to the commencement of data collection. Ethical approval was granted for this study from the Auckland University of Technology Ethics Committee (AUTEC) prior to the commencement of data collection. The confidentiality of the participants has been protected through displaying all data as means ± standard deviations.

Table 3.2 Participant Characteristics

Variable	**Mean ± SD**
Sex	7 Males, 1 Female
Age (yrs.)	32.9 ± 7.4
Height (cm)	181.2 ± 8.56
Body Mass (kg)	77.50 ± 5.08
VO_{2max} (ml/kg/min)	54.5 ± 6.1
Max Power Output (W)	321.25 ± 49.70
VT1 Power Output (W)	176 ± 35

Abbreviations: SD = standard deviation; yrs = years; cm = centimetres; kg = kilograms; VO_{2max} = maximal oxygen consumption; W = watts; VT1 = first ventilatory threshold

3.9 Pilot testing

Pilot testing was undertaken to understand the optimal testing protocol and treadmill gradients for Study Two. Power output (PO) was calculated using the formula (Figure 3.3) identified by Coleman, Wiles, Davison, Smith, & Swaine, (2007) as a reliable calculation to estimate the correct treadmill speed for an identified PO. It was identified that treadmill speed should be calculated at VT1 PO for 4% gradient on the treadmill and remain the same speed for the other 3 gradients. This method was chosen due to the speed being too slow if calculated for VT1 PO at 8% for the cyclists to get enough speed to stay moving on the treadmill with correct balance. Additionally, if calculated for VT1 PO at 2% gradient, the speed was too fast for the participants to cycle safely on the belt. Through keeping the speed the same on the treadmill, it was established through pilot testing that at 2% gradient the speed was slightly below VT1. The gradient at 4% equalled VT1 PO, 6% gradient was close to VT2 PO, and 8% gradient meant that most participants would be riding close to VO_{2max} PO. Pilot testing also identified that participants would be able to cycle as they normally would in the environment, while controlling for environmental conditions.

Gain in potential energy (J) = mass × gravity × height (J = [body mass + cycle equipment] × [.8066] × [theoretical height gained])

Power (W) = (gain in potential energy [J] ÷ time [s]) + (rolling resistance)

Abbreviations: J = joules; W = watts; s = seconds

Figure 3.3 Equation to calculate treadmill speed for set power outputs (Coleman et al., 2007).

3.10 Preliminary testing

Participants first underwent an incremental step test to exhaustion on a cycle ergometer, (Lode Excalibur Sport, Lode BV, Groningen, Netherlands). Participants performed 4-minute stages, increasing by 30W every 4 minutes until volitional exhaustion. Gas-exchange was measured continuously using a calibrated metabolic cart (TrueOne 2400, Parvo Medics, Sandy, UT) and their maximal oxygen consumption (VO_{2max}) and ventilatory thresholds were determined. A capillary blood lactate sample was determined (Lactate Pro2, Arkray, Amsterdam, Netherlands) from a fingertip sample taken in the last 30 seconds of every stage until it was determined that anaerobic threshold (defined as the point where the requirements of the exercise cannot be met aerobically, and simultaneously an increase in anaerobic metabolism occurs (~4mmol/L BLa) (Kenney et al., 2012; Lucía, Hoyos, Pérez, & Chicharro, 2000) had been reached.

Data was used to prescribe the optimal intensities for subsequent experimental trials. To ensure the same relative intensity for all participants, power output and optimal cadence of each submaximal cycling bout was set at their individualised VT_1. VT_1 was established as an increase in V_E/VO_2 (V_E = volume of air expired in a minute) without a complementary increase in V_E/VCO_2 (VCO_2 = volume of carbon dioxide produced in a minute) (~ 2mmol/L BLa) (Kenney et al., 2012; Lucía et al., 2000). To ensure the same relative intensity for all participants, power output and optimal cadence of treadmill cycling was calculated for their individualised VT_1 at 4% gradient. The speed then stayed the same for 2%, 6% and 8% gradient.

3.11 Familiarisation

Participants had the opportunity to perform two familiarisation sessions where they rode their bicycle on the treadmill on separate days to data collection sessions. Participants accustomed themselves to riding on the treadmill and practiced starting and stopping at their prescribed speed, as well as riding at different gradients. Once participants felt comfortable with riding on the treadmill, they then familiarised themselves with wearing the head- and mouth-piece required to assess VO_2 (TrueOne 2400, Parvo Medics, Sandy, UT) as well as the protocol required for experimental trials.

3.12 Experimental protocol

The experimental protocol utilised three separate data collection sessions under laboratory conditions (Figure 4.1). The three data collection sessions involved a different loading condition (unloaded (control), limb loading (LL) or bicycle loading (B_{load}) in a randomised order as outlined below, on different treadmill gradients (2%, 4%, 6% and 8% gradient in a randomised order) (h/p/cosmos Saturn 300/100r, Japan) whilst wearing a harness (Figure 3.4). After participants had completed the first loading condition trial the remaining two trials were performed in the same randomised gradient order.

No added load (Control)

Under laboratory conditions participants undertook five minutes of submaximal seated cycling on their own bicycle on the treadmill at different gradients in a randomised order with no added load after performing a 10 minute standardised warm-up (60% peak power output) (Atkinson et al., 2005). Power output was calculated using the formulas identified by Coleman et al., (2007) (Figure 3.3) to estimate the correct treadmill speed for VT1 PO for 4% gradient. Cadence was self-selected to an optimal rate that allowed each participant to safely ride on the treadmill and was kept at a constant pace to avoid surging on the treadmill. Once the optimal cadence was identified the cadence and gearing remained the same for each control condition, LL and B_{load} trials. Participants had 15 minutes' active recovery between trials, where they cycled for 10 minutes below their VT1 (as identified in their preliminary VO_{2max} test) on a stationary cycling ergometer set to their seat and handle bar height and length, and crank length (Lode Excalibur Sport (Lode BV, Groningen, The Netherlands)). Participants then had 2 minutes to drink water (ad libitum) and stand, before the final 3 minutes of recovery where they prepared and mounted their own bicycle on the treadmill ready for their next exercise bout. The five-minute data collection period began when the participant had reached the correct treadmill speed and gradient and riding normally. VO_2 and HR data was collected continuously throughout the 5-minute data collection period, and recorded for retrospective analysis. Perceptual ratings of RPE (BORG 6 -20 scale) (Borg, 1990), "Pain" (0 = no pain; 10 = worst pain) and "Comfort" (1 = comfortable; 10 = extremely uncomfortable) were recorded at the end of the final minute of exercise, and BLa (Lactate Pro 2 (Arkray, Amsterdam, Netherlands) was taken at rest, and at the end of the five-minute exercise bout. The total testing bouts involved 20 minutes of cycling, with 45 minutes of active recovery. The total time spent exercising was 75 minutes for each participant including warm-up.

Limb Loading (LL)

The LL trial utilised the same protocol and recorded the same measurements as the control condition. Participants wore Lila™ Exogen™ EXO-skeleton suit (Kuala Lumpur, Malaysia) on their lower limbs as a means of applying 4% added body load (thigh = 2/3 of the added load (evenly distributed); calf = 1/3 of the added load (evenly distributed)) (Macadam, et al., (2017)). The added load (4% added BW) was selected as the most optimal load from Study One and remained the same for each exercise bout. Each exercise bout used the same randomised gradient order (2%, 4%, 6% or 8%) as their first data collection session on the treadmill.

Bicycle Loading (B_{load})

The B_{load} trial utilised the same protocol and recorded the same measurements as the control, and LL conditions. However, participants rode with 4% added BW attached to their bicycle for each exercise bout using drink bottles with damp sand to reach the correct 4% added BW amount and attaching them to the bicycle through the use of the cyclists' own water bottle holder.

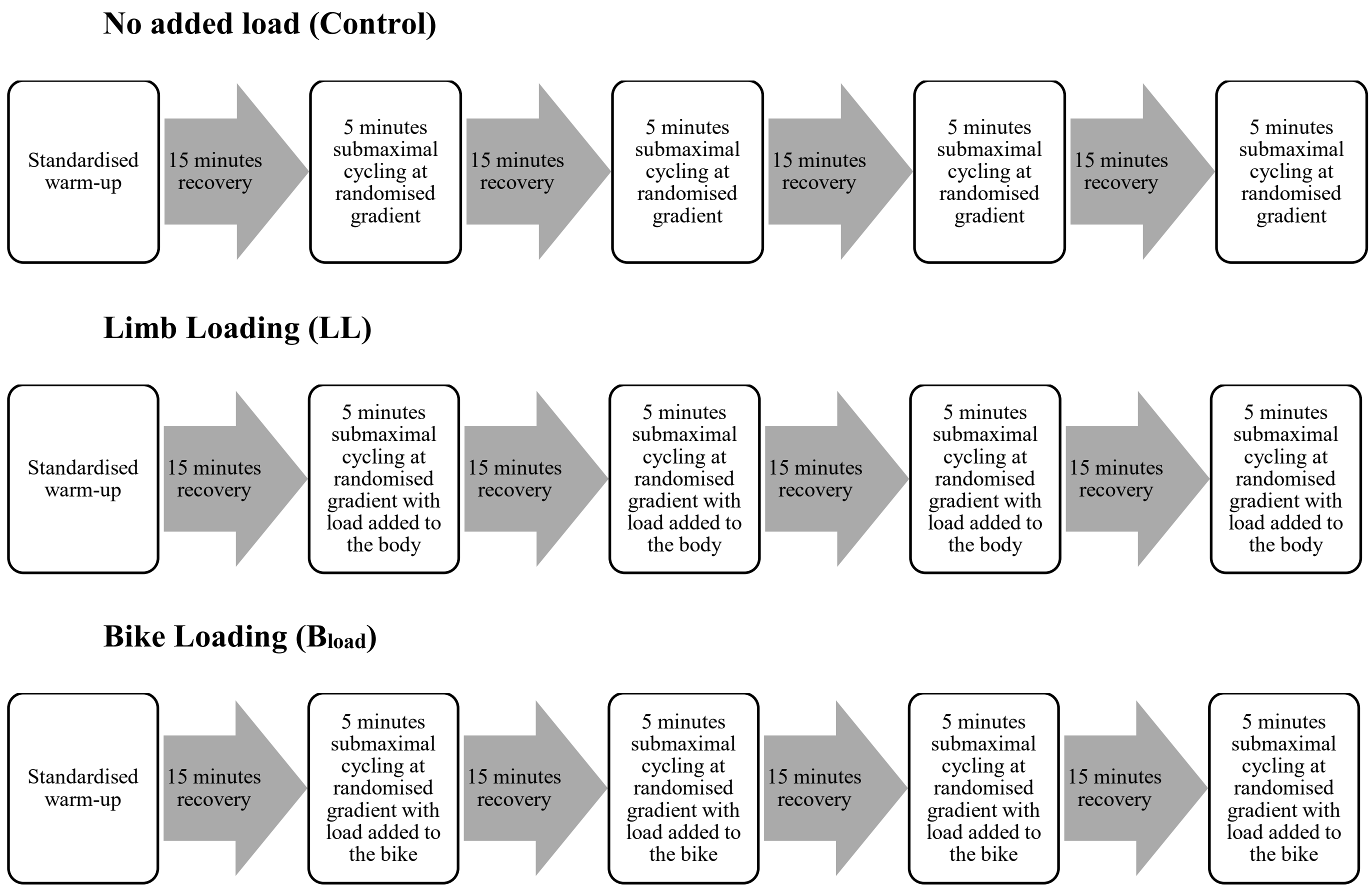


Figure 3.4 Schematic representation of the three experimental trials in Study Two.

3.12.1 Physiological measures

The data for all physiological measures was grouped for each loading condition at each gradient and averaged across the trial.

Oxygen Consumption (VO_2)

Oxygen uptake (ml/kg/min) was recorded for the first one minute of resting, and the consequent five minute exercise bout using a metabolic cart (TrueOne 2400, Parvo

Medics, Sandy, UT). Each exercise bout was recorded and saved separately. The VO_2 data was averaged over the final two minutes of the exercise bout for each participant.

Heart Rate (HR)

Heart rate (HR) (beats per minute (bpm)) data was recorded and saved for each exercise bout using Polar Heart Rate Monitor CS800RX (Polar Electro Oy, Kempele, Finland). The Polar HR monitors were set to average HR over a 15 s period. The HR data was then analysed retrospectively via Polar ProTrainer 5 software (Version 5.42.2, Polar Electro Oy, Kempele, Finland). HR was averaged over the last two minutes of each exercise bout.

Blood Lactate (BLa)

BLa (mmol/L) was taken in the final 30 seconds of the exercise bout using Lactate Pro 2 (Arkray, Amsterdam, Netherlands).

Perceptual Measures

Perceptual measures were taken at the end of exercise once the participants had safely stopped on the treadmill. Perceptual ratings were used to understand the sensations the participants were feeling in relation to the exercise they were performing. RPE has been validated to closely correlate with measures of physiological stress such as VO_2, HR, and PO (Borg, 1990; Faulkner & Eston, 2007). Participants were familiarised with RPE, “Pain” and “Comfort” scales prior to the commencement of the sub-maximal trials.

Rate of Perceived Exertion (RPE)

Rate of Perceived Exertion Scale (RPE): BORG 6 – 20 scale (Borg, 1990).

“Pain” Scale

“Pain” Scale: (0 = No pain; 10 = Worst pain possible).

“Comfort” Scale

“Comfort” Scale: (1 = comfortable; 10 = extremely uncomfortable).

Training Load

The training load of each loading condition and treadmill gradient was calculated for HR to understand the relationship between the different loading conditions and its effect on training load. Training load was calculated using the Training Peaks (2012) method to estimate $TSS®_{hr}$ (Figure 3.5).

$$TSS®_{hr} = (sec \times HR \times IF) / (\dot{V}T2\ (HR) \times 3600) \times 100$$

$$IF = HR / \dot{V}T2\ (HR)$$

Where: sec = time spent exercising; HR = HR during exercise bout; IF = HR / VT2 HR

Abbreviations: $TSS®_{hr}$; heart rate training stress score®; sec = seconds; HR = heart rate; IF = intensity factor; VT2 = second ventilatory threshold

Figure 3.5 Formula to calculate TSS® for HR, equation from Training Peaks (2012).

3.13 Statistical Analysis

Statistical analysis was performed using descriptive statistics with means ± standard deviations and 90% confidence limits (CL) for each measure in relation to each loading condition at each gradient to understand the inference and magnitude of the outcome. The statistical aim for this study was to understand the inference of different loading conditions at different gradients; therefore, a magnitude-based inference approach was applied.

Qualitative inferences evaluated the magnitude of each effect using a modified statistical spreadsheet (Hopkins, 2018) where standardised custom effects (Effect sizes) and 90% CL were calculated. The qualitative probabilities were established as <0.2, trivial; >0.2, small; >0.6, moderate; >1.2, large; >2.0, very large (Hopkins et al., 2009). Additionally, the percentage chances were evaluated qualitatively as follows: <1%, almost certainly not; >1%, very unlikely, > 5%, unlikely, > 25%, possible, > 75% likely, > 95% very likely, > 99%, almost certain (Hopkins et al., 2009).

Linear regression was used to establish the relationship between each measured variable at each gradient for each loading condition. The square root of each R^2 was then calculated and used in a modified Hopkins (2007) spreadsheet to establish a Pearson product-moment correlation analysis. Partial correlations were established using the thresholds: <0.1 (trivial), >0.1 (small), >0.3 (moderate), >0.5 (large), >0.7 (very large) and >0.9 (almost perfect) (Hopkins et al., 2009). The magnitude of correlation was deemed ‘unclear’ when the 90% confidence limit corresponded small negative and positive values (Hopkins et al., 2009).

Chapter Four: Results

Results: Study One

Table 4.1 contains the mean ± standard deviation, standardised custom effects, percentage chances and qualitative inference for acute physiological responses to added load on the lower limbs during submaximal stationary cycling. The mean HR response to added load at 2%, 4%, 6% and 8% added BW were 127bpm ± 14, 127bpm ± 12, 127bpm ± 13 and 128bpm ± 15 respectively. The between-trial effect sizes for 2%, 4% and 8% added BW were *trivial* when compared to baseline, whereas 6% added BW resulted in an *unclear* effect size. Figure 4.1 demonstrates that HR did not change as the load increased. There was an *unclear* relationship between added load and HR.

The mean VO_2 responses to added load at 2%, 4%, 6% and 8% added BW were 33.1ml/kg/min ± 5.5, 33.3ml/kg/min ± 5.2, 33.4ml/kg/min ± 5.5 and 33.6ml/kg/min ± 5.6 respectively, resulting in between-trial *trivial* effect sizes. Figure 4.2 demonstrates that VO_2 increased in a positive linear fashion with VO_2 increasing by 0.10ml/kg/min ($y = 0.0982x + 32.848$) with every 1% added BW ($r = 1.0$ (± 0.01)). There was a *most likely positive* relationship between added load and an increase in VO_2.

The mean BLa responses to added load at 2%, 4%, 6% and 8% added BW were 1.10mmol/L ± 0.44, 1.74mmol/L ± 1.02, 1.67mmol/L ± 0.73 and 1.96mmol/L ± 1.39 respectively with the between-trial response at 2% resulting in a *small* effect size (-0.51 ± 0.34), while the 4%, 6% and 8% added BW resulted in an *unclear* effect with more data needed to establish a true effect size. Figure 4.3 demonstrates that BLa increased positively in a linear fashion with BLa increasing by 0.10mmol/L ($y = 0.0844x + 1.3419$) with every 1% added BW ($r = 0.85$ (± 0.21)). There was a *most likely positive* relationship between added load and an increase in BLa.

Table 4.1 Acute physiological responses to added load on the lower limbs during submaximal cycling

	HR				VO_2				BLa			
Added % BW	**Mean HR (bpm) ± SD**	**Std Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**	**Mean VO_2 (ml/kg/min) ± SD**	**Std Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**	**Mean BLa (mmol/L) ± SD**	**Std Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**
0%	128 ± 13	n/a	n/a	n/a	32.8 ± 5.1	n/a	n/a	n/a	1.6 ± 0.8	n/a	n/a	n/a
2%	127 ± 14	-0.02 (-0.09; 0.06) -0.02 ± 0.08	0/100/0	Most likely trivial	33.1 ± 5.5	0.04 (-0.05; 0.13) 0.04 ± 0.09	1/99/0	Very likely trivial	1.1 ± 0.4	-0.51 (-0.85; -0.17) -0.51 ± 0.34	0/6/94	Likely small
4%	127 ± 12	-0.03 (-0.11; 0.05) -0.03 ± 0.08	0/100/0	Most likely trivial	33.3 ± 5.2	0.08 (0.02; 0.14) 0.08 ± 0.06	0/100/0	Most likely trivial	1.7 ± 1.0	0.28 (-0.52; 1.07) 0.28 ± 0.79	57/28/14	Unclear
6%	127 ± 13	-0.07 (-0.21; 0.07) -0.07 ± 0.14	0/94/6	Unclear	33.4 ± 5.5	0.10 (0.03; 0.18) 0.10 ± 0.07	2/98/0	Very likely trivial	1.7 ± 0.7	0.19 (-0.61; 0.99) 0.19 ± 0.80	49/32/19	Unclear
8%	128 ± 15	0.00 (-0.11; 0.11) 0.00 ± 0.11	0/99/0	Very likely trivial	33.6 ± 5.6	0.14 (0.05; 0.23) 0.14 ± 0.09	14/86/0	Likely trivial	2.0 ± 1.4	0.54 (-0.60; 1.68) 0.54 ± 1.14	71/17/13	Unclear

Abbreviations: BW = body weight; HR = heart rate; bpm = beats per minute; SD = standard deviation; VO_2 = oxygen consumption; BLa = blood lactate; Std Custom Effect = Standardised Custom Effect

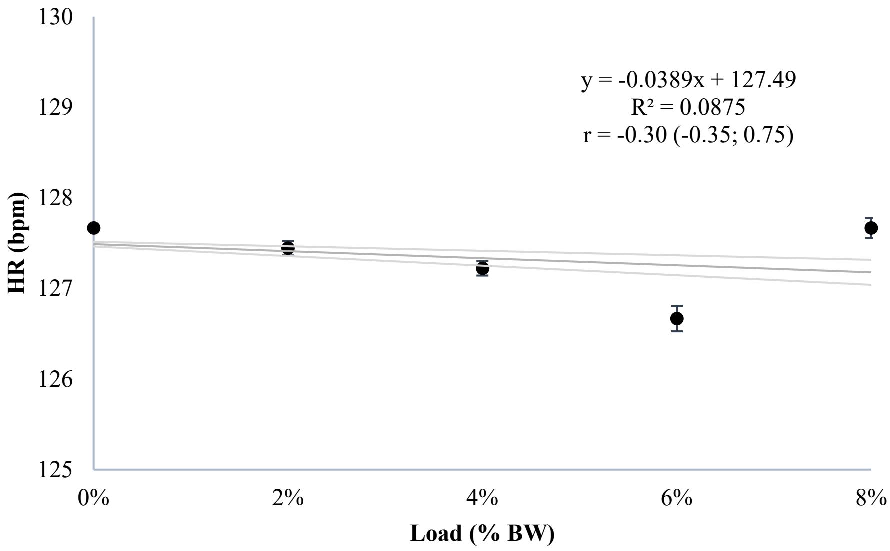


Figure 4.1 Heart rate response to submaximal cycling with lower limb loading (± 90% CL). HR = heart rate; bpm = beats per minute; BW = body weight.

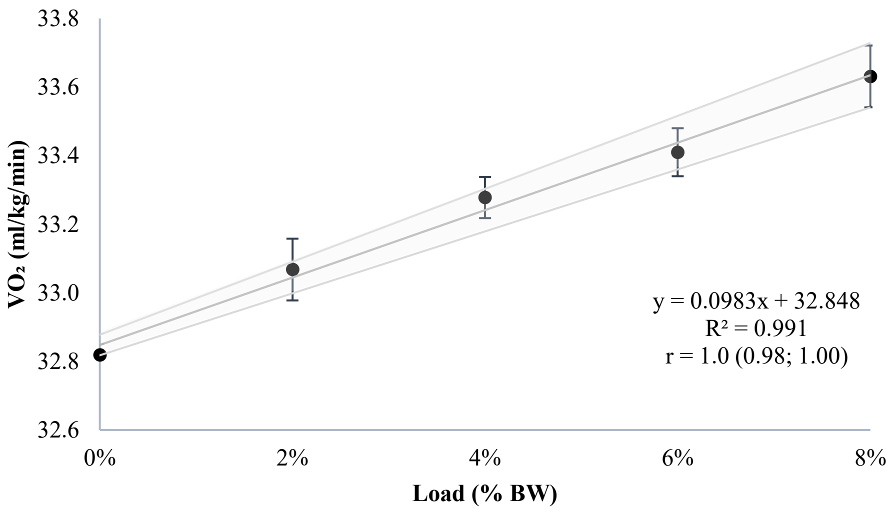


Figure 4.2 Oxygen consumption response to submaximal cycling with lower limb loading (± 90% CL). VO_2 = oxygen consumption; BW = body weight.

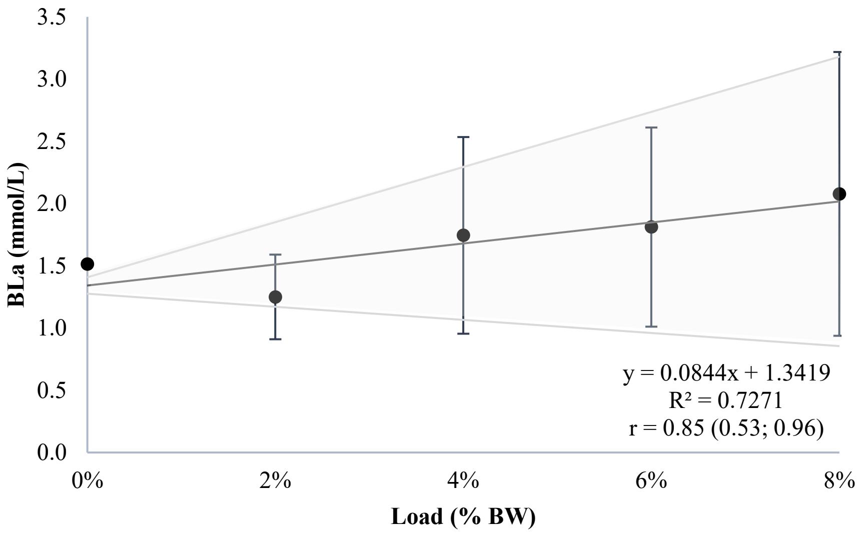


Figure 4.3 Blood lactate response to submaximal cycling with lower limb loading (± 90% CL). BLa = blood lactate; BW = body weight.

Table 4.2 contains the mean ± standard deviation, standardised custom effects, percentage chances and qualitative inference for acute perceptual responses to added load on the lower limbs during submaximal cycling.

Compared to baseline, the mean between-trial RPE response to added load at 2% added BW was 9.8 ± 1.6 resulting in a *small* effect size (0.24 ± 0.25). The mean between-trial RPE response at 4% added BW resulted in the mean RPE of 9.7 ± 1.9 and a *trivial* effect size (0.18 ± 0.17), whereas the between-trial RPE response at 6% and 8% added BW were 10.6 ± 1.2 and 10.9 ± 1.3 respectively resulting in a *moderate* effect size (0.67 ± 0.28 and 0.85 ± 0.38 respectively). Figure 4.4 demonstrates that when added load increases, RPE increases with a positive linear relationship with RPE increasing by 0.2 (y = 0.1944x + 9.2667) with every 1% added BW (r = 0.94 ± 0.09). There was a *most likely positive* relationship between added load and an increase in RPE.

Compared to baseline, the mean between-trial "Comfort" response to added load at 2% and 4% added BW was 2.1 ± 1.2 and 1.9 ± 0.7 respectively resulting in an *unclear* effect size (0.49 ± 1.08 and 0.16 ± 0.76). The mean between-trial "Comfort" response at 6% added BW was 2.4 ± 1.0 and a *moderate* effect size (0.82 ± 0.64). While the between-trial mean at 8% added BW resulted in the "Comfort" response of 2.9 ± 1.1 and a *large* effect size (1.31 ± 0.90). Figure 4.5 shows that when added load increases, "Comfort" decreases in a positive linear relationship with discomfort increasing by 0.1 ($y = 0.1286x + 1.6857$) with every 1% added BW ($r = 0.89 \pm 0.17$). There was a *most likely positive* relationship between added load and a decrease in "Comfort".

Compared to baseline, the mean between-trial "Pain" response to added load at 2% and 4% added BW was 0.7 ± 0.9 resulting in a *trivial* effect size (0.11 ± 0.21). The between-trial mean "Pain" response at 4% added BW was 0.6 ± 1.0 resulting in an *unclear* effect size (0.00 ± 0.32). The between-trial mean "Pain" response at 6% added BW was 1.1 ± 1.2 and a *small* effect size (0.57 ± 0.46). The between-trial mean "Pain" response at 8% added BW was 1.3 ± 1.4 resulting in a *moderate* effect size. Figure 4.6 demonstrates that when added load increases, "Pain" increases with a positive linear relationship by 0.1 ($y = 0.1x + 0.4444$) with every 1% added BW ($r = 0.89 \pm 0.17$). There was a *most likely positive* relationship between an increase in load and an increase in "Pain".

Table 4.2 Acute perceptual responses to added load on the lower limbs during submaximal cycling

	RPE				Comfort				Pain			
Added % BW	**Mean RPE ± SD**	**Std Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**	**Mean Comfort ± SD**	**Std Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**	**Mean Pain ± SD**	**Std Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**
0%	9.3 ± 1.7	n/a	n/a	n/a	1.7 ± 0.8	n/a	n/a	n/a	0.6 ± 0.9	n/a	n/a	n/a
2%	9.8 ± 1.6	0.24 (0.00; 0.49) 0.24 ± 0.25	62/37/1	Possibly small	2.1 ± 1.2	0.49 (-0.58; 1.57) 0.49 ± 1.08	69/18/13	Unclear	0.7 ± 0.9	0.11 (-0.10; 0.33) 0.11 ± 0.21	24/75/1	Likely trivial
4%	9.7 ± 1.9	0.18 (0.01; 0.35) 0.18 ± 0.17	42/58/0	Possibly trivial	1.9 ± 0.7	0.16 (-0.60; 0.92) 0.16 ± 0.76	47/34/19	Unclear	0.6 ± 1.0	0.00 (-0.32; 0.32) 0.00 ± 0.32	14/72/14	Unclear
6%	10.6 ± 1.3	0.67 (0.38; 0.95) 0.67 ± 0.28	99/1/0	Very likely moderate	2.4 ± 1.0	0.82 (0.18; 1.46) 0.82 ± 0.64	95/4/1	Very likely moderate	1.1 ± 1.2	0.57 (0.11; 1.03) 0.57 ± 0.46	91/8/1	Likely small
8%	10.9 ± 1.3	0.85 (0.47; 1.23) 0.85 ± 0.38	99/1/0	Very likely moderate	2.9 ± 1.1	1.31 (0.41; 2.22) 1.31 ± 0.90	97/2/1	Very likely large	1.3 ± 1.4	0.80 (0.18; 1.41) 0.80 ± 0.62	95/5/1	Very likely moderate

Abbreviations: BW = body weight; RPE = rate of perceived exertion; SD = standard deviation; Std Effect = standardised custom effect

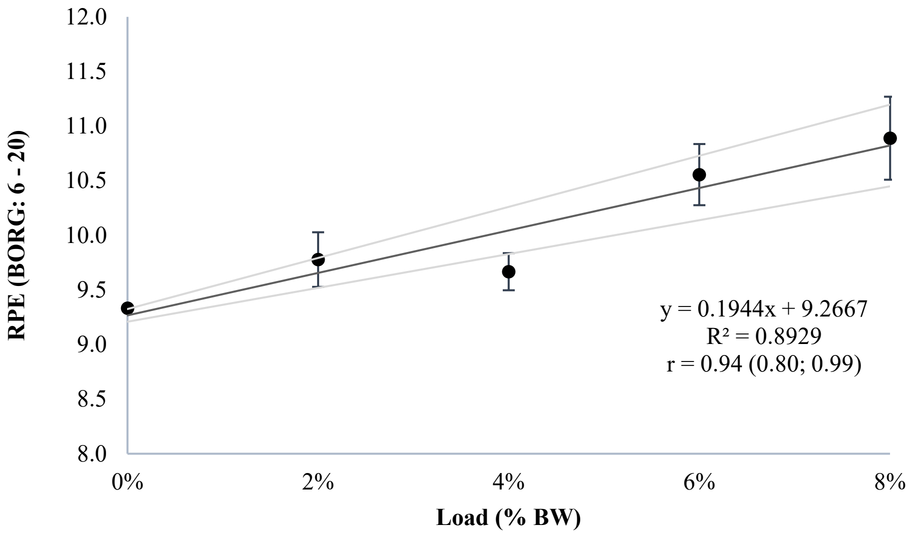


Figure 4.4 Rate of perceived exertion response to submaximal cycling with lower limb loading (± 90% CL). RPE = rate of perceived exertion; BW = body weight.

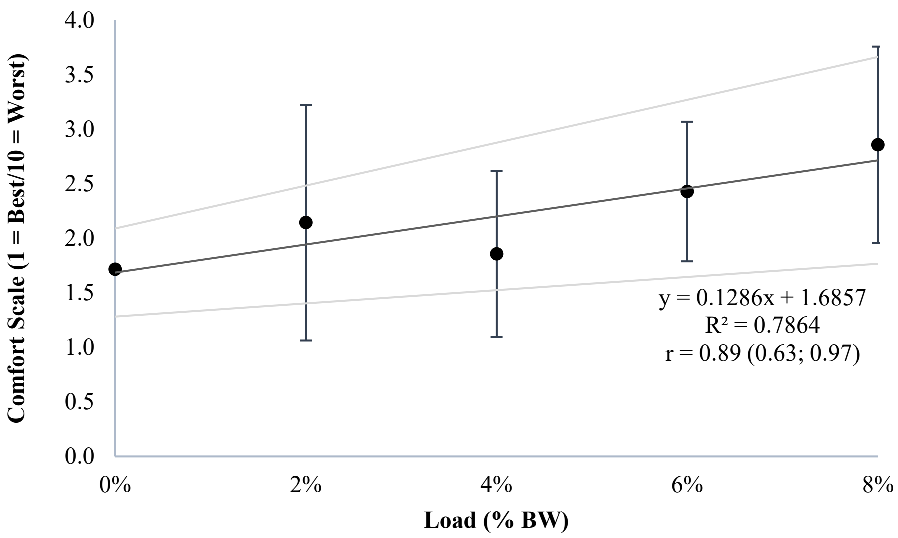


Figure 4.5 "Comfort" response to submaximal cycling with lower limb loading (± 90% CL). BW = body weight.

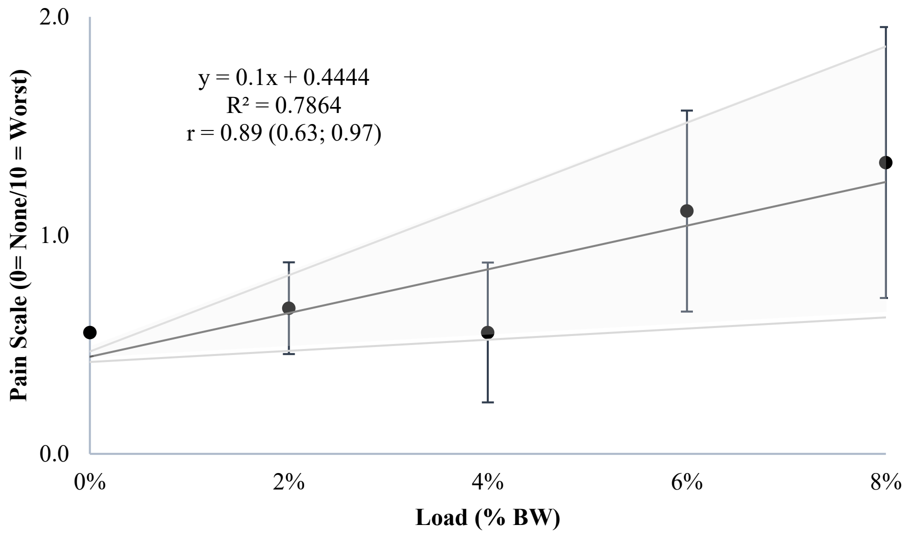


Figure 4.6 "Pain" response to submaximal cycling with lower limb loading (± 90% CL). BW = body weight.

Table 4.3 contains the mean ± standard deviation, standardised custom effects, percentage chances and qualitative inference for acute Pedal Force Measurement responses to added load on the lower limbs during submaximal cycling. The between-trial mean efficiency response to added load at 2%, 4% and 6% added BW was 66.7% ± 12.8, 65.7% ± 12.8% and 64.5% ± 12.3 respectively, each with a *trivial* effect size. The between-trial mean efficiency response to 8% added BW was 64.0% ± 12.6 resulting in a *small* effect size (-0.23 ± 0.07). There was a negative linear relationship between load and efficiency with efficiency decreasing by 0.4 (y = 0.4405x + 67.399) with every 1% added BW (r = 0.96 ± 0.02, Figure 4.7) with a *most likely positive* relationship between added load and a decrease in efficiency.

Table 4.3 Acute efficiency responses to added load on the lower limbs during submaximal cycling

Added % BW	Mean Efficiency (%) ± SD	Std Effect (± 90% CL)	% Chances (+/trivial/-)	Qualitative
0%	67.3 ± 13.1	n/a	n/a	n/a
2%	66.7 ± 12.8	-0.04 (-0.11; 0.02) -0.04 ± 0.07	0/100/0	Most likely trivial
4%	65.7 ± 12.8	-0.11 (-0.16; -0.06) -0.11 ± 0.05	0/100/0	Most likely trivial
6%	64.5 ± 12.3	-0.20 (-0.26; -0.13) -0.20 ± 0.06	0/53/47	Possibly trivial
8%	64.0 ± 12.6	-0.23 (-0.30; -0.15) -0.23 ± 0.07	0/25/75	Possibly small

Abbreviations: BW = body weight; SD = standard deviation; Std Effect = standardised custom effect

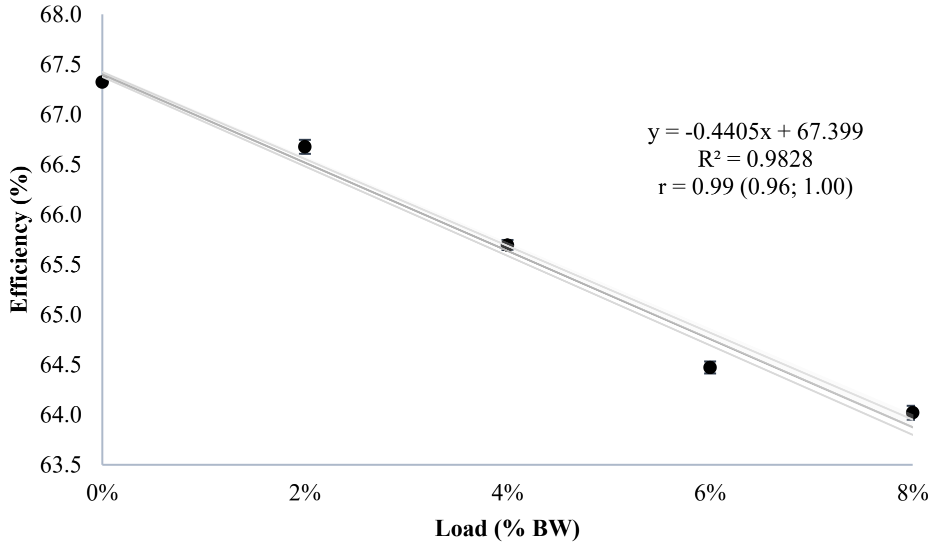


Figure 4.7 Efficiency response to submaximal cycling with lower limb loading (± 90% CL)

Figure 4.8 shows the correlation between cycling efficiency (%) and VO_2 as % added BW increases, where, as load increases, cycling efficiency decreases and VO_2 increases with a negative linear relationship (r = 0.97 ± 0.05), with a *most likely positive* relationship between added load and a decrease in efficiency and an increase in VO_2.

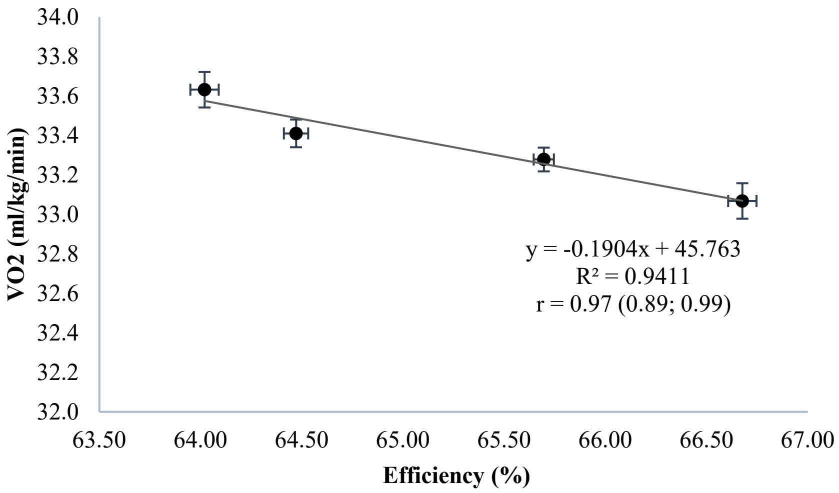


Figure 4.8 Relationship between VO_2 and efficiency during submaximal cycling with lower limb loading (± 90% CL)

Figure 4.9 shows the mean partial correlation coefficients (± 90 CL) of the measured variables during submaximal cycling under added load.

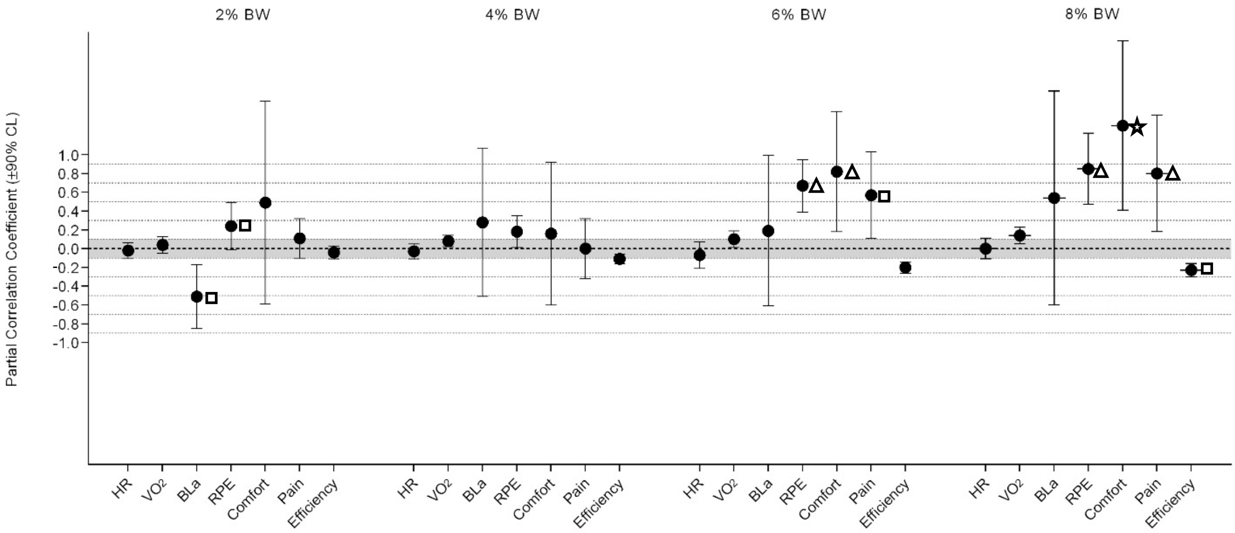


Figure 4.9 Mean partial correlation coefficient (± 90 CL) of measured variables during submaximal cycling with lower limb loading. ▫ = small; ▵ = moderate; ★ = large. HR = heart rate; VO_2 = oxygen consumption; BLa = blood lactate; RPE = rate of perceived exertion. The grey shaded area signifies trivial correlations.

Results: Study Two

4.1 Comparing loaded conditions to unloaded

Table 4.4 contains the mean ± standard deviation, standardised custom effects, percentage chances and qualitative inference for the acute physiological responses to added load using LL and B_{load} during treadmill cycling at different gradients in comparison to the control condition.

HR responses:

The mean HR response using B_{load} at 8% gradient was 169bpm ± 10 resulting in a *small* effect size (-0.33 ± 0.49) when compared to the control condition. Conversely, the mean HR response at 8% gradient using LL was 173bpm ± 10 resulting in an *unclear* effect size when compared to the control condition. The mean HR response to added load using LL and B_{load} at 2% gradient was 111bpm ± 12 and 108 bpm ± 12 resulting in *unclear* effects when compared to the control condition. At 4% gradient LL was 128.9bpm ± 13.6, resulting in an *unclear* effect when compared to the control condition. B_{load} at 4% gradient was 128bpm ± 13 resulting in a *trivial* effect size (0.19 ± 0.20) when compared to the control condition. The mean HR response to LL at 6% gradient was 158bpm ± 12 resulting in a *trivial* effect size (0.17 ± 0.24) when compared to the control condition. The mean HR responses to B_{load} at 6% gradient was 156bpm ± 15 resulting in an *unclear* effect size when compared to the control condition.

Figure 4.10 demonstrates the increase in HR at each gradient when using LL and B_{load} in a *positive* linear fashion with HR increasing by 11bpm (y = 10.572x + 90.813) using LL, and by 10bpm (y = 10.351x + 89.33) with B_{load} with every 1% gradient increase (LL: r = 1.00 (± 0.01); B_{load}: r = 0.99 (± 0.02)). There was a *most likely positive* relationship between added load at each gradient and an increase in HR.

VO_2 responses:

The mean VO_2 response to added load using LL at 2% gradient was 20.8ml/kg/min ± 3.6 resulting in a *small* effect size (0.28 ± 0.36). Whereas, the mean VO_2 response to added load using B_{load} at 2% gradient was 20.3ml/kg/min ± 3.3 resulting in an *unclear* effect when compared to the control condition. The mean VO_2 response to LL at 4% gradient was 31.0ml/kg/min ± 6.1 resulting in a *small* effect size (0.27 ± 0.38) when compared to the control condition. Whereas, the mean VO_2 response to added load using B_{load} at 4%

gradient was 32.1ml/kg/min ± 6.0 resulting in an *unclear* effect when compared to the control condition. The mean VO_2 response to LL and B_{load} at 6% gradient was 44.5ml/kg/min ± 8.6 and 44.7ml/kg/min ± 8.9 respectively, resulting in *small* effect sizes (LL = 0.24 ± 0.22; B_{load} = 0.26 ± 0.32) when compared to the control condition. The mean VO_2 response to added load using LL and B_{load} at 8% gradient were 49.9ml/kg/min ± 6.2 and 50.0ml/kg/min ± 6.2 respectively, both resulting in *trivial* effect sizes (LL = 0.02 ± 0.20; B_{load} = 0.00 ± 0.14) when compared to the control condition.

Figure 4.11 demonstrates the increase in VO_2 at each gradient when using LL and B_{load} is in a *positive* linear fashion with VO_2 increasing by 5.0ml/kg/min (y = 5.0423x + 11.296) with LL and by 5.1ml/kg/min (y = 5.0843x + 11.361) with B_{load} with every 1% gradient increase (LL: r = 0.99 (± 0.02); B_{load}: r = 0.99 (0.02)). There was a *most likely positive* relationship between added load at each gradient and an increase in VO_2.

BLa responses:

The mean BLa response to added load using LL at 6% gradient was 5.4mmol/L ± 2.1 resulting in a *moderate* effect size (0.68 ± 0.60). Whereas, the mean BLa response to added load using B_{load} at 6% gradient was 5.1mmol/L ± 2.4 resulting in a *small* effect size (0.47 ± 0.52). The mean BLa response to added load using B_{load} at 4% gradient was 2.3mmol/L ± 2.7 resulting in a *trivial* effect size (0.10 ± 0.27), whereas LL resulted in a mean BLa response of 2.5mmol/L ± 2.5 and an *unclear* effect. The mean Bla responses using LL and B_{load} at 2% and 8% gradients resulted in *unclear* effects (2%: LL= 2.0mmol/L ± 1.4; B_{load} = 1.9mmol/L ± 1.3) (8%: LL = 10.9mmol/L ± 4.2; B_{load} = 9.3mmol/L ± 2.7).

Figure 4.12 demonstrates that BLa increased positively in a linear fashion with LL and B_{load}. BLa increased by 1.5mmol/L (y = 1.4872x – 2.2554) with LL, and by 1.3mmol/L (y = 1.2544x - 1.6313) with every 1% change in gradient (LL: r = 0.94 (± 0.14); B_{load}: (r = 0.95 (± 0.10)). There was a *most likely positive* relationship between added load at each gradient and an increase in BLa.

Table 4.4 Acute physiological responses to added load on the lower limbs (LL) and bicycle loading (B_{load}) during treadmill cycling at different gradients.

	Control	**Limb Loaded (LL)**				**Bicycle Loaded (B_{load})**			
Acute HR responses									
Treadmill Gradient	**Mean HR (bpm) ± SD**	**Mean HR (bpm) ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**	**Mean HR (bpm) ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**
2%	109 ± 13	111 ± 12	0.16 (-0.22; 0.54) 0.16 ± 0.38	42/52/6	Unclear	108 ± 12	-0.08 (-0.29; 0.14) -0.08 ± 0.22	2/82/16	Unclear
4%	137 ± 12	129 ± 14	-0.11 (-0.42; 0.21) -0.11 ±0.32	6/65/29	Unclear	128± 13	-0.19 (-0.39; 0.01) -0.19 ± 0.20	0/54/46	Possibly trivial
6%	155 ± 13	158 ± 12	0.17 (-0.07; 0.41) 0.17 ± 0.24	41/58/1	Possibly trivial	156 ± 15	0.07 (-0.33; 0.47) 0.07 ± 0.40	28/60/12	Unclear
8%	172 ± 8	173 ± 10	0.14 (-0.42; 0.70) 0.14 ± 0.56	42/44/14	Unclear	169 ± 10	-0.33 (-0.82; 0.16) -0.33 ± 0.49	4/27/69	Possibly small
Acute VO_2 responses									
Treadmill Gradient	**Mean VO_2 (ml/kg/min) ± SD**	**Mean VO_2 (ml/kg/min) ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**	**Mean VO_2 (ml/kg/min) ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**
2%	20.0 ± 2.3	20.8 ± 3.6	0.28 (-0.08; 0.63) 0.28 ± 0.36	65/33/2	Possibly small	20.3 ± 3.3	0.11 (-0.75; 0.97) 0.11 ± 0.86	42/32/26	Unclear
4%	32.7 ± 5.8	31.0 ± 6.1	-0.27 (-0.65; 0.12) --0.27 ± 0.38	3/35/62	Possibly small	32.1 ± 6.0	-0.09 (-0.81; 0.64) -0.09 ± 0.73	24/37/39	Unclear

6%	42.1 ± 8.7	44.5 ± 8.6	0.24 (0.02; 0.47) 0.24 ± 0.22	64/36/0	Possibly small	44.7 ± 8.9	0.26 (-0.07; 0.58) 0.26 ± 0.32	63/36/2	Possibly small
8%	50.0 ± 6.7	49.9 ± 6.2	-0.02 (-0.14; 0.11) -0.02 ± 0.20	1/98/1	Very likely trivial	50.0 ± 6.2	0.00 (-0.13; 0.14) 0.00 ± 0.14	2/97/1	Very likely trivial
Acute BLa responses									
Treadmill Gradient	**Mean BLa (mmol/L) ± SD**	**Mean BLa (mmol/L) ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**	**Mean BLa (mmol/L) ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**
2%	2.1 ± 1.2	2.0 ± 1.4	-0.12 (-0.46; 0.22) -0.12 ± 0.34	6/61/33	Unclear	1.9 ± 1.3	-0.18 (-0.71; 0.34)- 0.18 ± 0.53	11/42/47	Unclear
4%	2.6 ± 2.2	2.5 ± 2.5	-0.04 (-0.33; 0.26) -0.04 ± 0.30	9/75/16	Unclear	2.3 ± 2.7	-0.10 (-0.37; 0.17) -0.10 ± 0.27	4/71/25	Possibly trivial
6%	4.2 ± 1.6	5.4 ± 2.1	0.68 (0.07; 1.28) 0.68 ± 0.60	91/7/1	Likely moderate	5.1 ± 2.4	0.47 (-0.04; 0.99) 0.47 ± 0.52	83/15/2	Likely small
8%	9.7 ± 3.2	10.9 ± 4.2	0.33 (-0.33; 1.00) 0.33 ± 0.67	64/27/9	Unclear	9.3 ± 2.7	0.14 (-0.74; 1.03) 0.14 ± 0.89	45/31/24	Unclear

Abbreviations: HR = heart rate; BPM = beats per minute; SD = standard deviation; Std Custom Effect: Standardised Custom Effect; CL = confidence limit; VO_2 = oxygen consumption; BLa = blood lactate

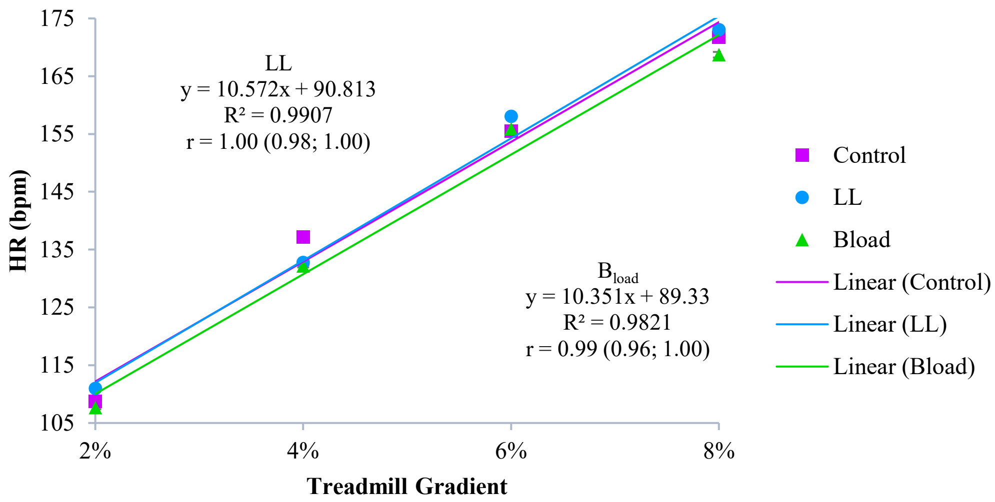


Figure 4.10 HR response to treadmill cycling under two different added load conditions at different gradients (± 90% CL). HR = heart rate; LL = limb loading; B_{load} = bicycle loading.

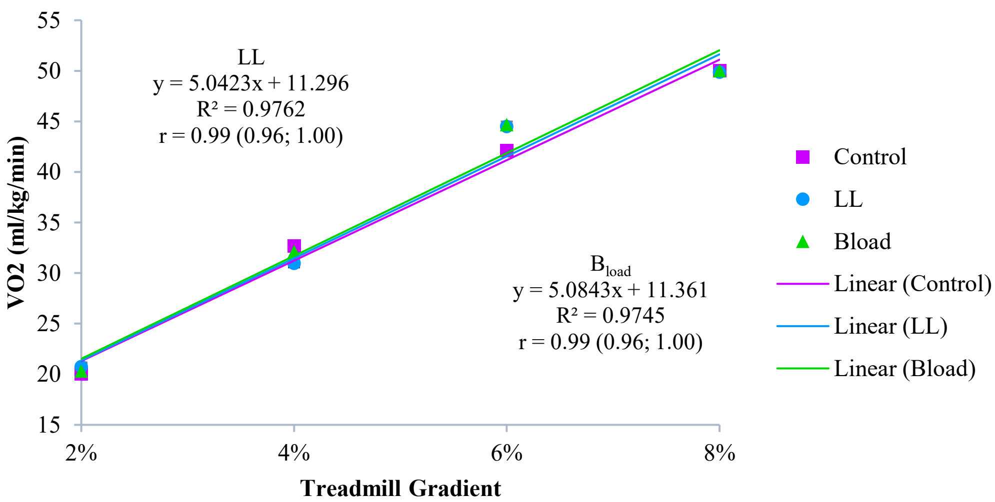


Figure 4.11 Oxygen consumption response to treadmill cycling under two different added load conditions at different gradients (± 90% CL). VO_2 = oxygen consumption; LL = limb loading; B_{load} = bicycle loading.

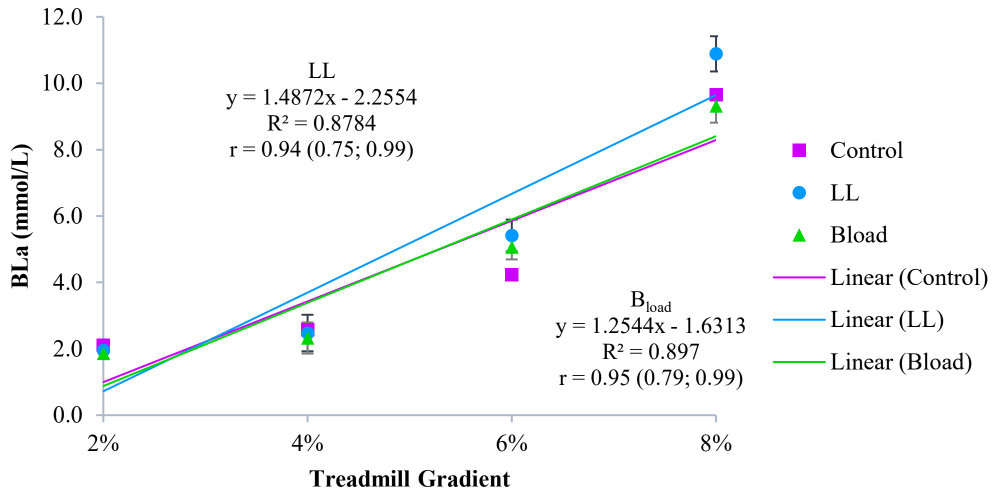


Figure 4.12 Blood lactate response to treadmill cycling under two different added load conditions at different gradients (± 90% CL). BLa = blood lactate; LL = limb loading; B_{load} = bicycle loading.

Table 4.5 contains the mean ± standard deviation, standardised custom effects, percentage chances and qualitative inference for the acute perceptual responses to added load using LL and B_{load} during treadmill cycling at different gradients in comparison to the control condition.

RPE

The mean between-trial RPE response at 4% gradient using LL resulted in the mean RPE of 10.9 ± 1.6 and a *moderate* effect size (0.60 ± 0.55). Whereas, the mean between-trial RPE response at 4% gradient using B_{load} was 10.6 ± 1.6 and a *small* effect size (0.53 ± 0.47). Compared to control, the mean between-trial RPE response to cycling at 2% gradient using B_{load} was 7.8 ± 1.2, resulting in *a trivial* effect size (0.08 ± 0.14). Whereas, the response at 2% gradient using LL was 8.0 ± 1.2 resulting in an *unclear* effect. The mean RPE responses using LL and B_{load} at 6% and 8% gradients resulted in *unclear* effects (6%: LL= 13.5 ± 2.0; B_{load} = 13.5 ± 2.0) (8%: LL = 17.8 ± 1.6; B_{load} = 17.8 ± 1.6).

Figure 4.13 demonstrates that when the gradient increased using LL and B_{load}, RPE increased with a positive linear relationship by 1.6 (y = 1.6031x + 4.5313) with LL and by 1.6 (y = 1.5906 + 4.4063) with B_{load} with every 1% change in gradient (LL: r = 0.99 ±

0.02; B_{load}: r = 1.00 ± 0.00). There was a *most likely positive* relationship between added load at each gradient and an increase in RPE.

"Comfort"

The mean between-trial "Comfort" response at 6% gradient using LL was 3.4 ± 1.3 and a *small* effect size (0.20 ± 0.37). Whereas, the mean between-trial "Comfort" at 6% gradient using B_{load} was 3.5 ± 1.4 and an *unclear* effect. The mean between-trial "Comfort" response at 8% gradient using B_{load} was 5.6 ± 2.2 and a *small* effect size (0.25 ± 0.38), whereas the mean between-trial "Comfort" response when using LL was 6.7 ± 2.5 resulting in an *unclear* effect. The mean between-trial responses at 4% gradient for both LL and B_{load} were 2.3 ± 1.8 and 1.8 ± 0.9 respectively, with both resulting in an *unclear* effect. Compared to control, the mean between-trial "Comfort" response to cycling at 2% gradient using LL and B_{load} was 1.1 ± 0.4 and 1.0 ± 0 respectively. However, the mean between trial responses at 2% gradient for the control condition had no change, meaning that no effect size could be calculated without a standard deviation at control.

Figure 4.14 demonstrates that when using LL and B_{load} and the gradient increased, "Comfort" decreased with a positive linear relationship by 0.8 (y = 0.8946x – 1.1071) with LL and by 0.6 (y = 0.7857 – 0.9732) with B_{load}, with every 1% change in gradient (LL: r = 0.96 ± 0.08; B_{load}: r = 0.98 ± 0.04). There was a *most likely positive* relationship between added load at each gradient, and an increase in discomfort.

"Pain"

The mean between-trial "Pain" response using LL at 8% gradient was 5.4 ± 3.5 resulting in a *small* effect size (-0.39 ± 0.39) with less "Pain" than the control condition (mean = 5.8 ± 2.7), whereas the mean between-trial response using B_{load} was 5.9 ± 2.1 resulting in an *unclear* effect. Compared to control, the mean between-trial "Pain" response to cycling at 2%, 4% and 6% gradients using LL was 0.0 ± 0, 1.0 ± 1.2 and 2.6 ± 2.4 respectively, with *unclear* effect sizes. Additionally, the mean between-trial "Pain" response to cycling at 2%, 4% and 6% gradients using B_{load} was 0.3 ± 0.5, 0.6 ± 0.9 and 2.3 ± 2.0 respectively, resulting in unclear effects.

Figure 4.15 demonstrates that when using LL and B_{load} and the gradient increased, "Pain" increased with a positive linear relationship by 0.9 (y = 0.8955x – 2.2143) with LL, and by 0.9 (y = 0.8219x – 2.0938) with B_{load}, with every 1% change in gradient (LL: r = 0.98 ± 0.04; B_{load}: r = 0.98 ± 0.04). There was a *most likely positive* relationship between added load at each gradient and an increase in "Pain".

Table 4.5 Acute perceptual responses to added load on the lower limbs (LL) and bicycle loading (B_{load}) during treadmill cycling at different gradients

	Control	**Limb Loaded (LL)**				**Bicycle Loaded (B_{load})**			
Acute RPE responses									
Treadmill Gradient	**Mean ± SD**	**Mean ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**	**Mean ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**
2%	7.9 ± 1.5	8.0 ± 1.2	0.08 (-0.19; 0.34) 0.08 ± 0.26	20/76/4	Unclear	7.8 ± 1.2	-0.08 (-0.22; 0.07) - -0.08 ± 0.14	0/92/7	Likely trivial
4%	9.8 ± 1.7	10.9 ± 1.6	0.60 (0.05; 1.15) 0.60 ± 0.55	89/9/1	Likely moderate	10.6 ± 1.6	0.53 (0.07; 1.00) 0.53 ± 0.47	89/10/1	Likely small
6%	13.3 ± 1.7	13.5 ± 2.0	0.07 (-0.41; 0.55) 0.07 ± 0.48	31/53/16	Unclear	13.9 ± 2.3	0.13 (-0.23; 0.50) 0.13 ± 0.37	37/57/6	Unclear
8%	17.5 ± 2.1	17.8 ± 1.6	0.16 (-0.37; 0.69) 0.16 ± 0.53	45/43/12	Unclear	17.3 ± 1.6	-0.05 (-0.55; 0.44) - -0.05 ± 0.50	18/52/30	Unclear
Acute "Comfort" responses									
Treadmill Gradient	**Mean ± SD**	**Mean ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**	**Mean ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**
	1.0 ± 0	1.1 ± 0.4	No difference	n/a	n/a	1.0 ± 0	No difference	n/a	n/a
4%	1.5 ± 0.8	2.3 ± 1.8	0.88 (-0.56; 2.33) 0.88 ± 1.44	80/10/10	Unclear	1.8 ± 0.9	0.29 (-0.26; 0.85) 0.29 ± 0.56	62/31/7	Unclear
6%	3.1 ± 1.7	3.4 ± 1.3	0.20 (-0.18; 0.57) 0.20 ± 0.37	49/46/4	Possibly small	3.5 ± 1.4	0.26 (-0.33; 0.86) 0.26 ± 0.60	58/33/9	Unclear

8%	6.3 ± 2.5	6.7 ± 2.5	0.15 (-0.26; 0.56) 0.15 ± 0.41	41/51/8	Unclear	5.6 ± 2.2	-0.25 (-0.63; 0.13) - -0.25 ± 0.38	3/38/59	Possibly small
Acute "Pain" responses									
Treadmill Gradient	**Mean ± SD**	**Mean ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**	**Mean ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**
2%	0.3 ± 0.7	0.0 ± 0	-0.31 (-0.91; 0.28) - -0.31 ± 0.90	7/29/64	Unclear	0.3 ± 0.5	0.00 (-0.78; 0.78) 0.00 ± 0.78	32/36/32	Unclear
4%	0.6 ± 0.7	1.0 ± 1.2	0.75 (-0.60; 2.10) 0.75 ± 1.35	77/12/11	Unclear	0.6 ± 0.9	0.00 (-0.35; 0.35) 0.00 ± 35	16/69/16	Unclear
6%	2.3 ± 1.1	2.6 ± 2.4	1.19 (-0.26; 2.64) 1.19 ± 1.45	88/6/6	Unclear	2.3 ± 2.0	0.00 (-0.72; 0.72) - 0.00 ± 0.72	31/39/31	Unclear
8%	6.6 ± 2.6	5.4 ± 3.5	-0.39 (0.78; 0.00) - 0.39 ± 0.39	1/18/81	Likely small	5.9 ± 2.1	-0.24 (0.71; 0.23) - 0.24 ± 0.47	6/38/57	Unclear

Abbreviations: RPE = rate of perceived exertion; SD = standard deviation; Std Custom Effect: Standardised Custom Effect; CL = confidence limit

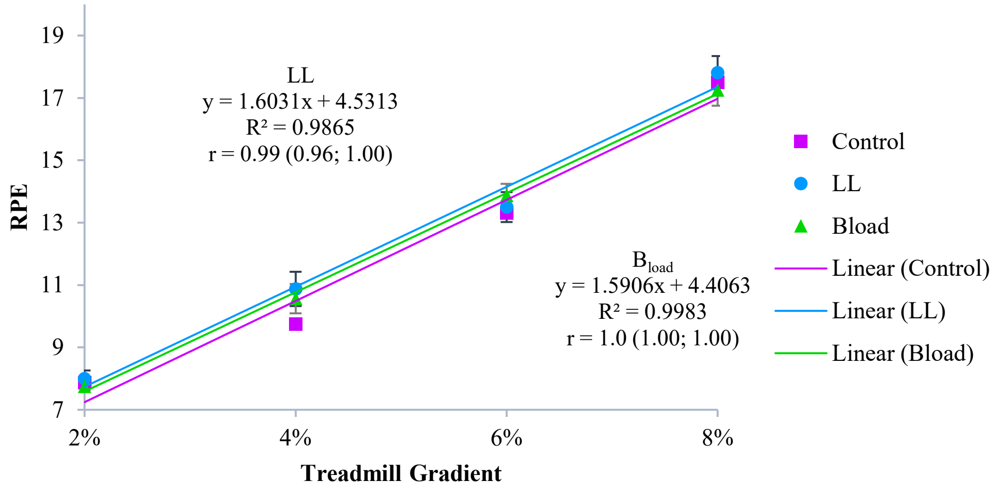


Figure 4.13 Rate of perceived exertion response to treadmill cycling under two different added load conditions at different gradients (± 90% CL). RPE = rate of perceived exertion; LL = limb loading; B_{load} = bicycle loading.

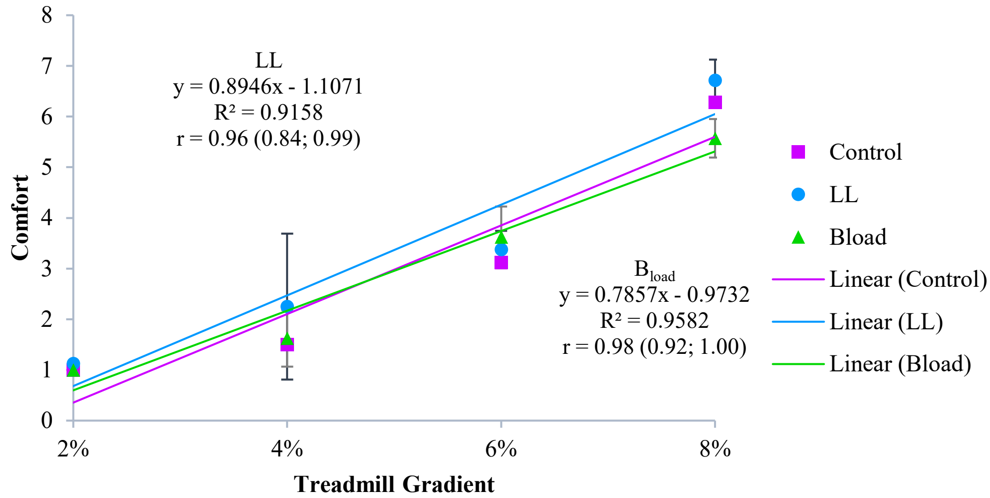


Figure 4.14 "Comfort" response to treadmill cycling under two different added load conditions at different gradients (± 90% CL). LL = limb loading; B_{load} = bicycle loading.

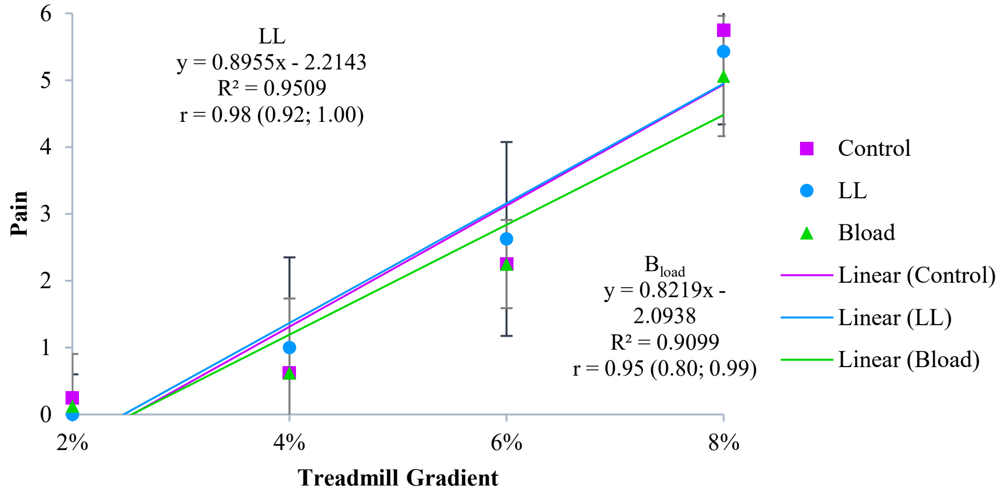


Figure 4.15 "Pain" response to treadmill cycling under two different added load conditions at different gradients (± 90% CL). BLa = blood lactate; LL = limb loading; B_{load} = bicycle loading.

Training load response

Table 4.6 contains the mean ± standard deviation, standardised custom effects, percentage chances and qualitative inference for the acute training load responses to added load using LL and B_{load} during treadmill cycling at different gradients in comparison to the control condition.

Compared to control, the mean between-trial $TSS®_{hr}$ response to cycling at 2%, 4%, 6% and 8% gradients using LL was 4.2 ± 0.7, 6.0 ± 1.4, 8.4 ± 0.9 and 10.0 ± 0.7 respectively, with *unclear* effect sizes. Additionally, compared to control, the mean between-trial $TSS®_{hr}$ response to cycling at 2%, 4%, 6% and 8% gradients using B_{load} was 4.0 ± 0.8, 5.9 ± 1.3, 8.2 ± 0.9 and 9.5 ± 0.7 respectively, with *unclear* effect sizes.

Figure 4.16 demonstrates that when using LL and B_{load} and the gradient increased, $TSS®_{hr}$ increased with a positive linear relationship by 0.8 (y = 0.8142x + 2.7481) with LL and by 0.8 (y = 0.7769x + 2.705) with B_{load} with every 1% change in gradient (LL: r = 0.97 ± 0.06; B_{load}: r = 0.96 ± 0.08). There was a *most likely positive* relationship between added load at each gradient and an increase in $TSS®_{hr}$.

Table 4.6 Acute heart rate training load responses to added load on the lower limbs (LL) and bicycle loading (B_{load}) during treadmill cycling at different gradients

	Control	**Limb Loaded (LL)**				**Bicycle Loaded (B_{load})**			
Treadmill Gradient	**Mean ± SD**	**Mean ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**	**Mean ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**
2%	1.0 ± 0	4.2 ± 0.7	0.21 (-0.29; 0.70) 0.21 ± 0.50	51/41/8	Unclear	4.0 ± 0.8	-0.09 (-0.49;0.30) -0.09 ± 0.39	10/59/31	Unclear
4%	1.5 ± 0.8	6.0 ± 1.4	0.04 (-0.34; 0.41) 0.04 ± 0.37	22/65/13	Unclear	5.9 ± 1.3	0.06 (-0.27; 0.38) 0.06 ± 0.32	22/69/9	Unclear
6%	3.1 ± 1.7	8.4 ± 0.9	0.18 (-0.27; 0.63) 0.18 ± 0.45	47/46/8	Unclear	8.2 ± 0.9	0.03 (-0.60; 0.66) 0.03 ± 0.63	31/43/26	Unclear
8%	6.3 ± 2.5	10.0 ± 0.7	0.37 (-0.80; 1.53) 0.37 ± 1.16	60/20/19	Unclear	9.5 ± 0.7	-0.73 (-1.78; 0.32) -0.73 ± 1.05	7/11/82	Unclear

Abbreviations: $TSS®_{hr}$ = heart rate training stress score®; SD = standard deviation; Std Custom Effect: Standardised Custom Effect; CL = confidence limit

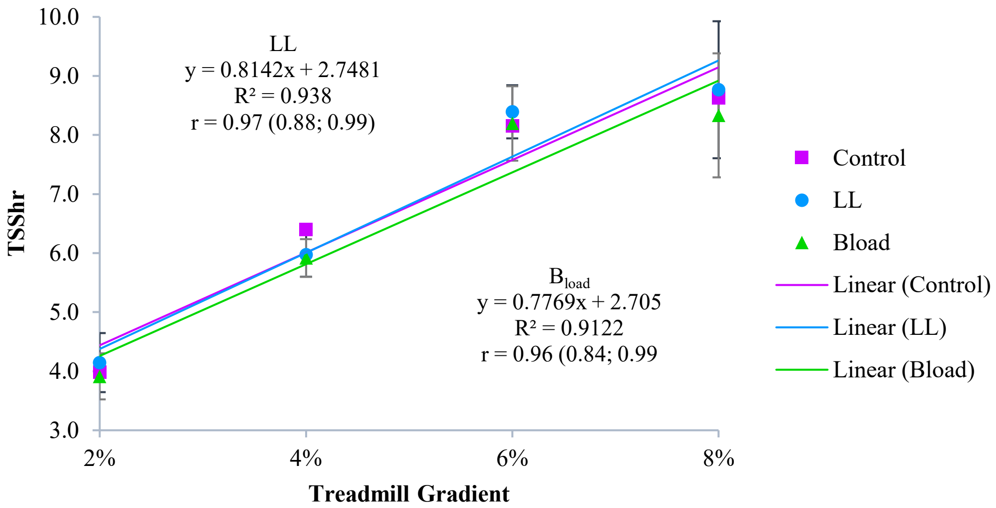


Figure 4.16 Training load response to treadmill cycling under two different added load conditions at different gradients (± 90% CL). TSS_{hr} = heart rate training stress score; blood lactate; LL = limb loading; B_{load} = bicycle loading.

Figure 4.17 shows the mean partial correlation coefficients (± 90 CL) of the measured variables during cycling at different gradients under added load.

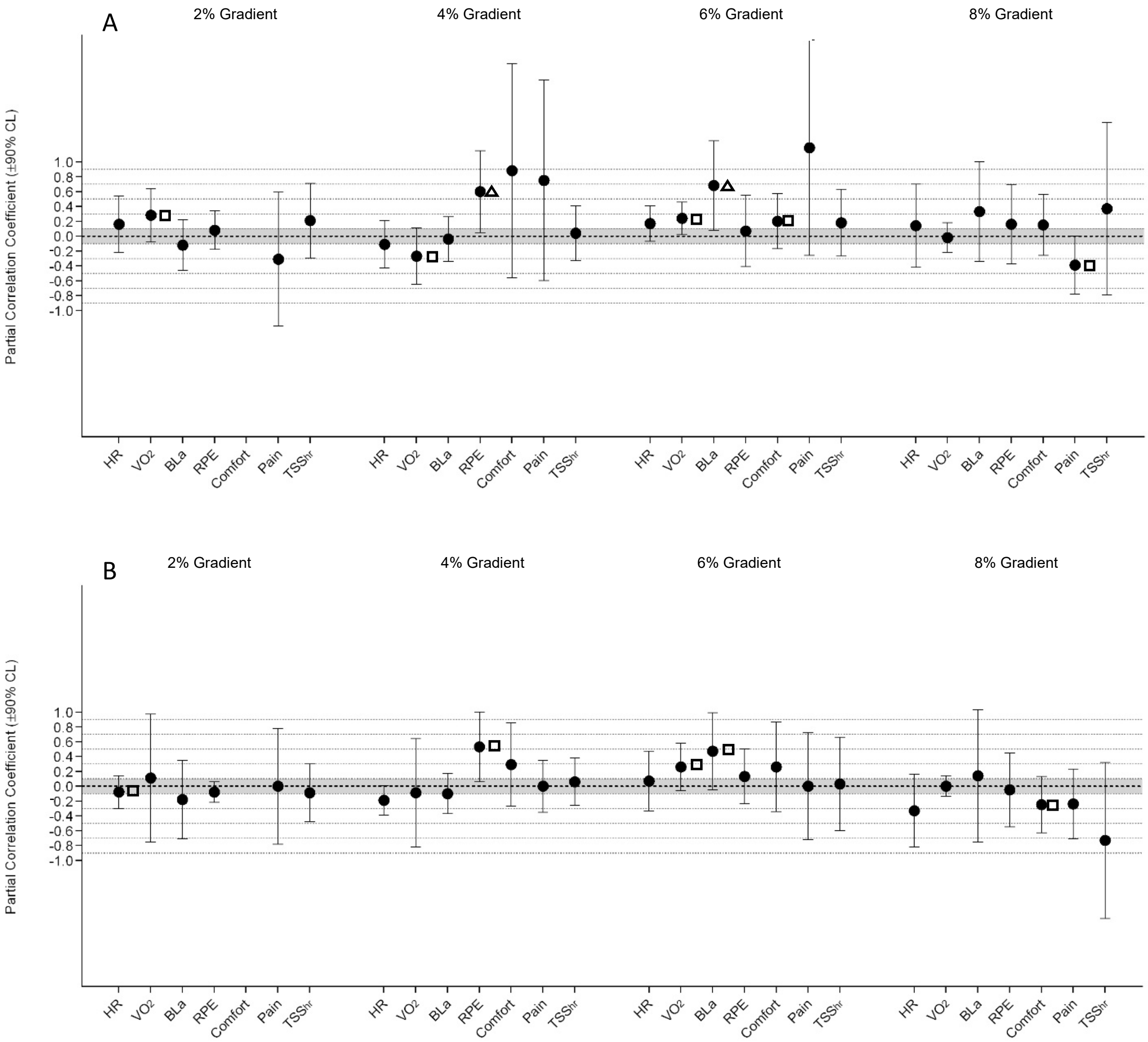


Figure 4.17 Mean partial correlation coefficient (± 90 CL) of measured varibales during cycling at different gradients under added load. A = Limb loading (LL); B = bicycle loading (B_{load}); □ = small; △ = moderate; ★ = large. HR = heart rate; VO_2 = oxygen consumption; BLa = blood lactate; RPE = rate of perceived exertion; TSS®$_{hr}$ = heart rate training stress score®. The grey shaded area signifies trivial correlations.

4.2 Between-loading comparisons (LL vs B_{load} for a given % gradient)

Table 4.7 contains the mean ± standard deviation, standardised custom effects, percentage chances and qualitative inference for the acute physiological responses comparing LL to B_{load} during treadmill cycling at different gradients.

When comparing HR between the two loaded conditions (LL and B_{load}), LL elicited higher mean HR than B_{load} by at least 1.2bpm across all gradients. The difference at 2% and 8% gradients was *small* (0.25 ± 0.37 and 0.36 ± 0.53 respectively). At 4% and 6% gradients, the differences were *trivial* (4% = 0.07 ± 0.21; 6% = 0.13 ± 0.29).

When comparing VO_2 between LL and B_{load} the effect at 2%, 4% and 6% gradients was *unclear*. At 8% gradient there was a *trivial* effect (-0.02 ± 0.10).

When comparing BLa between LL and B_{load} the effect at 2%, 6% and 8% gradient was *unclear*. At 4% gradient there was a trivial effect (0.05 ± 0.12) even though LL elicited a higher BLa than B_{load} (2.5 ± 2.5 vs. 2.3 ± 2.7mmol/L).

Table 4.7 Standardised custom effects of physiological variables (LL vs. B_{load})

	LL	**B_{load}**	**LL vs. B_{load}**		
HR					
Treadmill Gradient	**Mean HR (bpm) ± SD**	**Mean HR (bpm) ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**
2%	111 ± 12.0	108 ± 12.1	0.25 (-0.12; 0.62) 0.25 ± 0.37	60/38/3	Possibly small
4%	129 ± 13.6	128 ± 13.4	0.07 (-0.13; 0.28) 0.07 ± 0.21	14/83/2	Likely trivial
6%	158 ± 11.7	156 ± 15.0	0.13 (-0.16; 0.41) 0.13 ± 0.29	32/65/3	Possibly trivial
8%	173 ± 9.8	169 ± 10.3	0.36 (-0.17; 0.89) 0.36 ± 0.53	71/25/4	Possibly small
VO_2					
Treadmill Gradient	**Mean VO_2 (ml/kg/min) ± SD**	**Mean VO_2 (ml/kg/min) ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**
2%	20.8 ± 3.6	20.0 ± 2.3	0.12 (-0.63; 0.86) 0.12 ± 0.75	42/36/22	Unclear
4%	31.0 ± 6.1	32.7 ± 5.8	-0.17 (-0.89; 0.55) -0.17 ± 0.72	18/35/47	Unclear
6%	44.5 ± 8.6	42.1 ± 8.7	0.11 (-0.33;0.56) 0.11 ± 0.44	36/53/11	Unclear
8%	49.9 ± 6.2	50.0 ± 6.7	-0.02 (-0.12; 0.07) -0.02 ± 0.10	0/99/1	Very likely trivial
BLa					
Treadmill Gradient	**Mean BLa (mmol/L) ± SD**	**Mean BLa (mmol/L) ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**
2%	2.0 ± 1.4	1.9 ± 1.3	0.06 (-0.21; 0.33) 0.06 ± 0.27	18/76/6	Unclear
4%	2.5 ± 2.5	2.3 ± 2.7	0.05 (-0.07; 0.17) 0.05 ± 0.12	2/98/0	Very likely trivial
6%	5.4 ± 2.1	5.1 ± 2.4	0.13 (-0.20; 0.46) 0.13 ± 0.33	35/60/5	Unclear
8%	10.9 ± 4.2	9.3 ± 2.7	0.23 (-0.61; 1.07) 0.23 ± 0.84	53/29/18	Unclear

Abbreviations: HR = heart rate; bpm = beats per minute; VO_2 = oxygen consumption; Bla = blood lactate; LL = limb loading; B_{load} = bicycle loading; SD = standard deviation; Std custom effect = standardised custom effect; CL = confidence limits

Table 4.8 contains the mean ± standard deviation, standardised custom effects, percentage chances and qualitative inference for the acute perceptual responses comparing LL to B_{load} during treadmill cycling at different gradients.

When comparing RPE between the two (LL and B_{load}) loaded conditions the difference at 2% gradient was *trivial* (0.19 ± 0.24). The responses at 4% and 6% gradients were *unclear*. The response at 8% gradient was *small* (0.28 ± 0.40).

It was not possible to compare "Comfort" between the two (LL and B_{load}) loaded conditions at 2% gradient with an effect size as there was no SD for B_{load}. The responses at 4% and 6% gradients were *unclear*. The response at 8% gradient was *small* (0.45 ± 0.54).

When comparing "Pain" between the two (LL and B_{load}) loaded conditions the difference at 2% *small* (-0.48 ± 0.60). The responses at 4%, 6% and 8% gradients were *unclear*.

Table 4.8 Standardised custom effects of perceptual variables (LL vs. B_{load})

	LL	**B_{load}**	**LL vs. B_{load}**		
RPE					
Treadmill Gradient	**Mean ± SD**	**Mean ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**
2%	8.0 ± 1.2	7.8 ± 1.2	0.19 (-0.05; 0.43) 0.19 ± 0.24	47/52/1	Possibly trivial
4%	10.9 ± 1.6	10.6 ± 1.6	0.07 (-0.30; 0.44) 0.07 ± 0.37	27/63/11	Unclear
6%	13.5 ± 2.0	13.9 ± 2.3	-0.05 (-0.34; 0.24) -0.05 ± 0.29	7/75/18	Unclear
8%	17.8 ± 1.6	17.3 ± 1.6	0.28 (-0.12; 0.68) 0.28 ± 0.40	64/33/3	Possibly small
"Comfort"					
Treadmill Gradient	**Mean ± SD**	**Mean ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**
2%	1.1 ± 0.4	1.0 ± 0	n/a	n/a	n/a
4%	2.3 ± 1.8	1.8 ± 0.9	0.50 (-0.63; 1.64) 0.5 ± 1.14	68/18/14	Unclear
6%	3.4 ± 1.3	3.5 ± 1.4	-0.08 (-0.81; 0.65) -0.08 ± 0.73	25/37/38	Unclear
8%	6.7 ± 2.5	5.6 ± 2.2	0.45 (-0.09; 0.98) 0.45 ± 0.54	80/17/3	Likely small
"Pain"					
Treadmill Gradient	**Mean ± SD**	**Mean ± SD**	**Std Custom Effect (± 90% CL)**	**% Chances (+/trivial/-)**	**Qualitative**
2%	0.0 ± 0	0.3 ± 0.5	-0.48 (-1.08; 0.12) -0.48 ± 0.60	3/17/80	Likely small
4%	1.0 ± 1.2	0.4 ± 0.8	0.36 (-0.23; 0.96) 0.36 ± 0.60	69/25/6	Unclear
6%	2.6 ± 2.4	2.3 ± 2.0	0.17 (-0.63; 0.97) 0.17 ± 0.80	47/32/21	Unclear
8%	5.4 ± 3.5	5.9 ± 2.1	-0.18 (-0.97; 0.62) -0.18 ± 0.80	20/33/48	Unclear

Abbreviations: RPE = rate of perceived exertion; LL = limb loading; B_{load} = bicycle loading; SD = standard deviation; Std custom effect = standardised custom effect; CL = confidence limits

Chapter Five: Discussion and Conclusion

Sport-specific targeted training is crucial to enhance performance as margins between winning and losing in professional and high-performance sport are becoming increasingly narrower. Training programmes are required to target the physiology that is essential to perform in a specific manner to achieve the appropriate physiological adaptations (Reilly et al., 2009). In physiology this is known as 'specific adaptations to imposed demands' or SAID (Mathews & Fox, 1976). For resistance training in endurance cycling, this means targeting and overloading the working muscles and the physiology used during a competition. The use of FRT has been found to induce specific kinematic and kinetic adaptations that are required in the sports of sprinting, running and jumping (Table 2.2). However, the application and understanding of the physiological effects of FRT in cycling have not been well understood. The objective of the present thesis was to extend the current body of knowledge on the use of FRT and to investigate the acute physiological and perceptual responses of LL in cycling, and how LL alters physiological and perceptual responses during cycling at various gradients in comparison to adding load to the bicycle.

The literature review in Chapter Two identified that FRT has proved to be beneficial in improving indicators of performance in running, sprinting and jumping. In running FRT was found to improve running time (Cureton & Sparling, 1980) and VO_{2max} (Rusko & Bosco, 1987). Benefits were found in sprinting through improvements in sprint time (Cronin et al., 2008), flight time and contact time time (Cross et al., 2014; Macadam et al., 2018; Simperingham & Cronin, 2014) through various loading techniques of FRT (sled towing, weighted vests and LL). Additionally, in jumping, performance improved following a dynamic warm-up involving FRT (Thompsen, et al., 2007). However, the literature review highlighted that research was limited on the use of FRT in cycling, despite the technology advancing in recent years that have allowed it to be more applicable in its modality. The limited current literature in cycling has not investigated the acute physiological effects of LL on the working muscles, or any studies that had attempted to investigate LL in a 'real-world' cycling manner. As a result, further research was required in order apply LL meaningfully into a cyclist's training.

5.1 Study One: Discussion

The aim of this study was to determine the acute physiological and perceptual effects of LL in cycling. Quantifying such responses would allow practitioners to understand if LL could provide desirable physiological benefits as a training stimulus to aid cycling performance. To answer this question, participants performed 5 submaximal exercise bouts for 5 minutes at VT_1 under different LL (calf 1/3; thigh 2/3) conditions (0, 2%, 4%, 6% and 8% BW) on a stationary cycling ergometer. The key finding of this study was that LL has *trivial* or *unclear* physiological effects on cycling indoors at a constant submaximal power output, despite having *small*, *moderate* and *large* effects on perceptual ratings.

Study One measured a range of cardiovascular and metabolic responses to the various limb loading conditions. For BLa, with the exception of a *small* effect size (-0.51 ± 0.34) at 2% added BW where BLa decreased compared to baseline, the responses at 4%, 6% and 8% added BW were *unclear*. Despite randomising the order of loading conditions, it seems that there may have been a randomisation issue, as it appears contradictory that BLa would be lower when a cyclist was riding with extra weight compared to baseline. Regardless of the amount of load added, there was no change in HR and VO_2 from control (no added load, 0%) with *trivial* responses to added % BW on the lower limbs during submaximal cycling at VT_1 power outputs (Table 3.2). The HR and VO_2 response in the Study One are similar to the findings of Carriker, Mclean and Mccormick (2013), who found no significant response in either variable when compared to an unloaded condition. Despite Study One being different in its methodology (all seated cycling under different loads for five minutes) compared to Carriker et al., (2013) (where larger added loads were all added to standing cycling over four minutes (refer to Table 2.3)), the physiological response to LL remained the same.

Perceptual responses in the current study demonstrated that as the percentage of added BW increased during steady-state VT_1 cycling, RPE and "Pain" both increased, while the exercise felt increasingly uncomfortable (Table 3.3). With every 2% added BW RPE increased by 0.2 ($r = 0.94 \pm 0.09$), "Comfort" decreased by 0.1 ($r = 0.89 \pm 0.17$) and "Pain" increased by 0.1 ($r = 0.89 \pm 0.17$) with every 1% added BW. While the participants were blinded as to how much weight was being utilised for each exercise bout, they likely could feel and see the weights added to them, therefore there may have been a placebo effect when it came to their perceptual responses. In practical terms, when using LL as a form of sport-specific overload, the exercise will feel harder, more painful and less comfortable. However, caution needs to be taken not to mistake the level of difficulty and discomfort experienced by an athlete as beneficial training overload. It was established that as the LL increased, cycling efficiency decreased and VO_2 increased ($r = 0.97 \pm 0.05$) (Figure 3.9). This provides particularly useful information as it has been established that cycling efficiency is a key performance indicator for PRC even in the absence of high VO_{2max} levels (Lucía et al., 2002). When training with FRT it would be important to monitor the effects of LL on the riders' efficiency levels through monitoring power and heart rate data. A training study would be beneficial to understand the long-term effects on efficiency (beneficial or detrimental) and cycling performance.

To fully understand the effect of LL on cycling mechanics EMG would be required to investigate the impact of added load on the working muscles. Study One indicated that "perceptually" LL using 2% and 4% of added BW were the most comfortable and least painful. However, it is still important when incorporating FRT into training programmes to understand that the amount of weight added needs to be relevant to the type of training session (i.e. smaller loading amounts 2% and 4% added BW would be more comfortable and practical for longer endurance training sessions than 6% and 8% added BW, which may be more tolerable on shorter high-intensity workouts).

With the limited current body of literature on LL in cycling it is difficult to draw comparisons between the literature and the current study. While the majority of the current literature has investigated the kinetic and kinematic effects of FRT on exercise (Couture et al., 2018; Macadam et al., 2016; Simperingham & Cronin, 2014), FRT has been found to have beneficial effects as a training stimulus (Cronin et al., 2008; Cross et al., 2014; Cureton & Sparling, 1980; Macadam et al., 2016; Rusko & Bosco, 1987; Simperingham & Cronin, 2014; Thompsen et al., 2007). Conversely, Study One found little physiological change from the use of LL in submaximal ergometer cycling. We can therefore postulate that it would also have no additive effect in terms of a training stimulus. One of the key differences that could be used to answer the differences experienced between cycling and the investigated sports (running, sprinting and jumping) is the low-impact and essentially non-weight bearing nature of cycling. While running, sprinting and jumping are high-impact sports with large loading forces vertically exerted through ground contact, cycling is the opposite and considered a low-impact sport

(Callaghan, 2005; Mero, Komi, & Gregor, 1992). Additionally, cycling has three different phases of the pedal stroke (propulsive/downstroke phase, pulling/upstroke phase, and the pushing phase from top dead centre) requiring different working muscles, the cyclic low-impact nature of the pedal stroke is different to the many and varied phases of movement seen in sprinting and jumping (So, Ng, & Ng, 2005). The counter balance design of a bicycle means that throughout the full pedal stroke, the downstroke on one leg is aiding the upstroke of the opposite leg. With both legs equally weighted, the counter balance design of the full pedal stoke may have nullified any effect for each individual. Different responses may have been observed if only one leg was weighted, however this is difficult to ascertain without EMG data.

Another, potential rationale for the different responses experienced in cycling is that Study One investigated the use of LL in a controlled indoor environment on a stationary ergometer. Whereas many of the studies investigating FRT in sprinting and jumping were performed in the field. There is potential that if FRT was investigated in a more sport-specific manner where cyclists are required to ride their own bicycles and deal with differing gradients (up hills and down hills), the true physiological effects of LL in cycling may be better understood. Furthermore, despite a stationary ergometer being set at the rider's saddle, handle bar and crank requirements, participants are not required to stabilise the bicycle. A logical method to understand the physiological effects of FRT in cycling would be to use LL in a more 'real-world' environment, with cyclists riding their own bicycles on various gradients. Additionally, a longitudinal training study, where cyclists are riding in the environment, may provide further insight into the effects and practicalities and training effect of using FRT in cycling.

In conclusion, the findings of the current study suggest that adding load during submaximal cycling has *trivial* or *unclear* effects on submaximal physiological responses in cycling. However, *moderate* and *large* responses perceptually indicate that the use of LL results in the exercise feeling harder, more "uncomfortable" and more "painful" than riding without added load. The results suggest that while the exercise is perceived to induce physiological overload, it is in fact not. The findings from this study did not support the hypothesis that theorised when added load increases in percentage BW, the physiological effect of carrying the load will increase. Despite no physiological benefit found from LL in submaximal cycling, if FRT were to be used in practice, 2% and 4% BW would be the most appropriate due to their limited impact on "Comfort", "Pain", RPE and efficiency. Future research is required to understand the physiological effect of LL in cycling when a cyclist is riding in a more sport-specific environment on their own bicycle. Examining the effects of LL in a more 'real-world' setting would allow researchers, coaches and athletes to understand the effects of LL as a sport-specific training tool and how LL could be applied in training.

5.2 Study Two: Discussion

The aim of this study was to determine how FRT, using LL, alters acute physiological responses during 'real-world' cycling at various cycling gradients, compared to simply loading the bicycle (B_{load}). It was hoped that such information would help to understand the most effective mode of sport-specific overload to use for training purposes in cycling. To answer this question, participants completed three separate testing sessions, each consisting of 4 x 5 minute exercise bouts at different treadmill gradients (2%, 4% 6% and 8%). The exercise bouts were all performed at the same treadmill speed which was calculated to match the power output of VT_1 cycling at 4% gradient (Coleman et al., 2007). Consequently, the intensity of each bout was different due to the differing treadmill gradients. Participants performed the experimental trials on their own bicycles under different loading conditions (no added load, LL and B_{load}) in laboratory conditions.

The key finding from this study was that LL was found to be a slightly more effective method of sport-specific overload through an increased training stimulus in select gradients, although this was inconsistent. LL induced an increase in VO_2 at the same set power output, at 2% and 6% gradients with *small* effects (2% = 0.28 ± 0.36; 6% = 0.24 ± 0.22). Whereas, B_{load} only induced a *small* effect (0.26 ± 0.32) through an increase in VO_2 at 6% gradient. Conversely, LL at 4% gradient resulted in a *small* (-0.27 ± 0.38) decrease in VO_2 when compared to control (31.0 ± 6.1 vs. 32.7 ± 5.8) with an *unclear* effect for B_{load}. However, when compared to control, LL resulted in a *moderate* (0.68 ± 0.60) increase in BLa at 6% gradient, whereas B_{load} only increased BLa with a small effect (0.47 ± 0.52). Considering this, LL encourages a slightly greater training stimulus over a variety of gradients through metabolic overload, compared to B_{load}. However, neither loading condition induced beneficial physiological changes at 4% or 8% gradients. The results partially supported the hypothesis where LL was assumed to be the more optimal method of sport-specific overload at different gradients than B_{load}, through increased physiological overload as a result of wearing the load on the working muscles. Rather, LL was found to be the optimal method of sport-specific overload over B_{load}, but only at 2% and 6% gradients.

While no research has been performed investigating the effects of different gradients on VO_2 and HR in loaded uphill cycling or running, in unweighted uphill running studies similar results have been found with an increase in VO_2 when gradient increases (Minetti, Moia, Roi, Susta, & Ferretti, 2002; Padulo, Powell, Milia, & Ardigò, 2013; Vernillo et al., 2017), therefore inducing a greater physiological strain anaerobically, and increasing the metabolic demands of the uphill exercise bout. In Study Two, all loading conditions increased VO_2 as the gradient increased. However, LL and B_{load} resulted in an overall higher VO_2 than control (Figure 4.11) despite only seeing effect sizes at 2% (LL) and 6% (LL and B_{load}) gradients.

From a perceptual perspective, while LL provided greater physiological benefits as a training stimulus, exercising at 4% gradient felt harder with LL than B_{load}. At 4% gradient LL resulted in a *moderate* effect (0.60 ± 0.55) with an increase in RPE, whereas B_{load} only induced a *small* effect (0.53 ± 0.47) with an increase in RPE, while the effects of LL and B_{load} at all other gradients were *trivial* or *unclear*. The increase in RPE using LL may be explained by the extra load applied to the working muscles, resulting in the cyclists having to work harder to overcome the inertia of their lower limbs. Whereas, when using B_{load}, the weight was added externally to the body, where the cyclists may not have noticed the impact of the extra load. There may have been a placebo effect with the perceptual response through the positioning of the added load. With B_{load}, the added weight was attached using the water bottle carriers in the centre of the bicycle frame. Cyclists are used to carrying extra weight in that particular part of the bicycle with their drink bottles. Despite a water bottle being lighter than the B_{load}, carrying extra weight in the frame is not abnormal to a cyclist's usual practice. However, wearing a weighted suit certainly is. Perceptually, there may have been a variance in responses if a different part of the bicycle was loaded. If the moment of inertia was moved forward with the added load over the front wheel on the fork of the bicycle, the amount of torque required to overcome the added resistance and the moment of inertia may be affected. However, to understand what is happening at a muscular level with the effect of added load, and how it may affect cycling mechanics, EMG data would be required.

In Study Two, the loading conditions saw some results that were converse to what would be assumed where lower physiological and perceptual results were found when compared to the unloaded condition. When added load is applied, it would be expected for the exercise bouts to feel harder with greater physiological overload, however in the present study there were some surprising results. The *unclear* and *trivial* effects established at 4% gradient may have resulted from the methodology used to calculate the treadmill speed for VT_1 intensity, which was based off matching 4% gradient to VT_1. As a result, the added load at 4% gradient may have not been enough to induce overload at a lower gradient that was aimed to be an aerobic exercise bout. Additionally, at 8% gradient there were some confounding results. Figure 4.10 demonstrates that HR was lower using B_{load} than control and LL. At 2%, 4% and 8% gradients there was a decrease in HR from control, resulting in a *small* effect (0.33 ± 0.49) at 8% gradient (B_{load} = 169 ± 10 vs. control = 172 ± 8). While all conditions saw a rise in HR as the gradient increased, B_{load} saw the lowest positive linear increase, whereas, LL resulted in the highest overall *positive* linear increase (Figure 4.5). Additionally, perceptual data also demonstrated improvements at the same set-power output at certain gradients when loaded. At 8% gradient, "Comfort" improved when using B_{load} compared to control (B_{load} = 5.6 ± 2.2 vs. control = 6.3 ± 2.5) with a *small* effect (-0.25 ± 0.38) and "Pain" decreased with a *small* effect (-0.39 ± 0.39) when using LL. The effects seen at 8% gradient are interesting given the overload benefits induced by LL and B_{load} at 6% gradient. There is potential that while randomisation was applied to both the loading conditions and gradients, it appears that there may have been a potential study design issue. Despite having a familiarisation session, participants appeared to become more comfortable riding their bicycles on the treadmill in the latter experimental trials, which despite randomisation, may have influenced the results. Additionally, not all participants were able to complete the 8% gradient trial. If a participant did not complete more than two minutes of the trial, their data was excluded from analysis for that gradient, resulting in one participant excluded from analysis at 8% gradient. While the majority of participants were able to complete 3 – 5 minutes of the 5-minute exercise bout, in comparison to the 2%, 4% and 6% gradients where all participants completed every exercise bout, the data at 8% gradient may not have provided a true representation of the results without complete trials.

The application of sport-specific overload in cycling:

From the present study, it appears that LL is the slighlty more optimal method of sport-specific overload when riding at 2% or 6% gradients, through its ability to increase VO_2 and Bla, indicating greater metabolic overload than B_{load} at the same power output. However, in doing so, the exercise bout was less comfortable at 6% gradient with a *small* effect (0.20 ± 0.37) when compared to the control condition. In practical terms, cyclists may be able to induce metabolic overload but only at certain gradients (2% and 6%), however the exercise will be more uncomfortable than riding with no added load.

The limited current body of literature on FRT in cycling makes it difficult to draw comparisons to the present study. The current literature investigating the effects of FRT in cycling has been performed on a stationary cycling ergometer, making the present study novel in its design. While Carriker et al., (2013) found no improvement in VO_2 during standing cycling, the present study found that VO_2 did increase at 2% (LL) and 6% (LL and B_{load}) gradient. While Carriker et al., (2013) were using heavier loading quantities than the present study (5, 10 and 15% BW vs. 4%BW), data collection was performed on a stationary ergometer on a flat gradient. Study One identified that there was no increase in VO_2 during stationary ergometer cycling, aligning with Carriker et al., (2013) who found that performing standing stationary cycling on a stationary ergometer did not increase VO_2 or HR. However, the present study found that when hill climbing is performed while weighted, VO_2 increased in a similar fashion to what has been examined in unweighted uphill running (Minetti et al., 2002; Vernillo et al., 2017). This may be explained by the cyclists in the present study having to work to stabilise their bicycle going uphill, therefore eliciting changes in VO_2 through the body requiring more oxygen to meet the respiratory demands of the working muscles and necessitating an increase in torque required to overcome inertia.

Hill climbing is an integral part of the performance for professional road cycling. Cyclists need to generate high power outputs in hill climbs and have been found to spend ~123 minutes above 70% VO_{2max} in mountain stages (Faria et al., 2005; Fernandez-Garcia et al., 2000; Lucia et al., 2000). The use of sport-specific overload at specific gradients may be useful to target the requirements of professional road cycling. While the present study examined the physiological effects of added load at certain gradients, cyclists in most locations would struggle to find a cycling route where 2% or 6% gradients, could be targeted in isolation. Rather, LL may be applicable to use over a variety of gradients, when compared to unweighted and B_{load}, depending on the requirements of the targeted cycling stages. Additionally, while the present study aimed to simulate 'real-world' uphill cycling in a controlled environment, it was unable to examine the effects of loading on cornering or environmental conditions such as wind. A training study would be required to understand how the effects of cycling over various gradients using LL or B_{load} might benefit professional road cyclists.

One of the three mechanisms of specificity to stress the physiological systems connected with performance, is the muscle group (Reilly et al., 2009). While, the other two (the energy system and the skill required for the sport (Reilly et al., 2009)) were targeted, it could be assumed, but not for certain, how the working muscles were affected when added load was applied, and whether it was in the correct manner. To be able to understand the true mechanistic difference of the two overload conditions from control, EMG data would need to be collected. Despite studies demonstrating that there is no change in muscular activation between 0-8% gradients when cycling seated (Duc, Bertucci, Pernin, & Grappe, 2008; Li & Caldwell, 1998), collecting EMG data from the working muscles would allow a greater understanding of the effects of additional load on the muscles, and whether it alters the mechanics of cycling. Furthermore, it may provide valuable information regarding whether body or bicycle is the optimal form of loading when targeting a muscular resistance overload. Understanding such information at certain gradients may help to understand that while some physiological measures (such as VO_2 at 2% and 6% gradients when using LL) can be targeted, there may be beneficial adaptations for strength and power in cycling as observed with other methods of sport-specific overload. For example, Paton, et al., (2009) found higher pedal forces and testosterone levels after performing sport-specific over-gearing training. Additionally, assessing hormone data such as cortisol and testosterone may provide greater insight to sport-specific overload and the optimal modalities.

The present study assessed physiological measures over an acute five-minute period. If loaded trials were performed over longer durations, there may be a greater variance in the results. In particular, training load increments between the loaded conditions were similar in the present study. LL resulted in $TSS®_{hr}$ increasing by 0.8 ($y = 0.8142x + 2.7481$) and B_{load} by 0.8 ($y = 0.7769x + 2.705$) with every 1% change in gradient (LL: $r = 0.97 \pm 0.06$; B_{load}: $r = 0.96 \pm 0.08$). However, if the duration of assessed exercise increased, the difference in training load between the two overload modalities may become more substantial. Additionally, further research would be warranted to understand the practical implications and physiological effects of using LL for longer durations. On longer rides, smaller quantities of added load may be more appropriate (2% and 4% added BW), whereas heavier loads (6% and 8% added BW) may be tolerable on shorter high-intensity rides.

In conclusion, LL was found to be the slightly more optimal method of sport-specific overload when compared to B_{load}, but only at 2% and 6% gradients. LL was found to have a potential effect on VO_2 and BLa, however this was inconsistent across all gradients. B_{load} also resulted in an increase in VO_2 at 6% gradient, however there was no increase in BLa as evident with LL. To be able to fully understand the effect of added load on cycling, future studies would benefit from researching the chronic effects of using LL or B_{load} as a training tool on variable terrain and over longer durations. Additionally, the collection of EMG and hormonal data would prove beneficial to understand how sport-specific overload is affecting cycling mechanics and the working muscles.

5.3 Limitations of the research

The current thesis attempted to ensure scientific rigour was maintained throughout the research process, however there are aspects of it that need to be kept in mind when interpreting the findings. These are as follows:

1. This project studied the acute physiological effects of added load in cycling. To fully understand the effects of added load in cycling a longitudinal training study would need to be performed.
2. This study, despite having a sample size that met the requirements for appropriate statistical sample size, was small. The sample population reflected the varied endurance cycling population as discussed in the Literature Review where cyclists come from a range of backgrounds, ages, abilities and genders. The population in this thesis included endurance cyclists from a range of backgrounds including professional Ironman, former elite triathletes, track cyclists, road racers, and weekend warriors across a diverse age range including males and a female.
3. The present thesis researched one loading pattern and placement technique for applying the weights using Lila™ Exogen™ EXO-skeleton suit (Kuala Lumpur,

Malaysia) (2/3 on the thigh and 1/3 on the calf – evenly distributed). The aim of this project was to understand the acute physiological effects of wearing the garment during cycling and not the pattern or placement of the added load. Further research would be required to understand the effects of different patterns and load placements.

4. Study One researched the effects of load at VT_1 and did not notice significant changes between the effects of added load at 2% and 4% added BW. 4% added BW was chosen to take into Study Two as it was the larger load of the two that didn't have negative pain or comfort scores, despite only trivial physiological effects found across all added loads.
5. Both Study One and Study Two examined the effects of added body load on cycling in a controlled laboratory environment. While every effort was taken to mimic riding in the 'real-world' uphill in Study Two, the effects of a cyclist riding with added load in the environment may be slightly different because of the uncontrolled variables experienced such as weather, corners, traffic and pack riding.
6. The treadmill speed in Study Two, remained the same no matter the gradient. As a result, not all participants were able to complete full stages of the highest gradient, therefore their data was excluded from the analysis.
7. In hindsight, the 2% jumps in treadmill gradient in Study Two may have been too great and 0.5% or 1% change between gradients may have been more appropriate.
8. In Study Two, the power outputs for treadmill speed was calculated off the participant's preliminary VO_2 test. However, power output could have been standardised across all participants using a predicated power output at all gradients. For example, calculate based off a 'typical' male cyclist who weighs on average 69kgs with a 10kg bicycle.

5.4 Practical applications

The findings of this thesis provide evidence that during stationary submaximal ergometer cycling there is no effect on the metabolic cost of exercise with added load in cycling with only a *small* (-0.51 ± 0.34) response seen at 2% added BW for BLa. Smaller loads (2% and 4% added BW) were found to be more appropriate in cycling as a result of their limited impact on “comfort”, “pain” and efficiency levels when compared to the heavier weights (6% and 8% added BW) despite limited physiological benefits being found.

In simulated ‘real-world’ uphill cycling, LL with 4% added BW was found to be the optimal method of sport-specific overload compared to B_{load} with 4% added BW, but only at 2% and 6% gradients with no physiological benefits found at 4% and 8% gradients. Metabolic overload can be targeted at 6% gradient with 4% added BW, through an increase in demand on the respiratory system which saw small effects in VO_2 (0.24 ± 0.22) and a *moderate* effect on BLa (0.68 ± 0.60). Cycling with LL over a variety of gradients that include 2% and 6% gradients may provide a novel way of introducing overload in a sport-specific manner. However, the exercise will be more uncomfortable than riding with no added load.

5.5 Future research

The current thesis helps to understand the acute physiological effects of added body load on stationary ergometer and simulated ‘real-world’ cycling at different gradients, where, to the best of the author’s knowledge, no other research has been undertaken. To fully understand the effects of LL and its application in the endurance sport of cycling, further research would be required. It is suggested that the following areas should be used to help to guide future research:

- A longitudinal training study would be beneficial to understand the physiological effects of using LL as a form of FRT overtime.
- The physiological effects of LL should be examined when applied to different modes of training such as comparing the differences in endurance training, threshold training, and HIIT etc. The physiological responses of LL may be more pronounced over longer durations or more intense exercise bouts when compared to the results from Study One and Study Two.
- Researching the physiological effects of LL on specific disciplines in cycling may help to understand how LL can be applied to specific types of cyclists (e.g. mountain bikers may see very different results to road riders).
- 4% added BW was found to be the ‘optimal load’ for this thesis despite only trivial physiological responses being found. Further research should investigate if there

are ways of training with added BW that induce greater physiological responses which may include different loading patterns and placement of added load.

- The effects of LL in cycling should be examined for its application of sport-specific overload in terms of kinetic and kinematic effects. LL may offer areas for adaptations to strength, endurance and power in cycling.
- The collection of EMG and hormonal data would prove beneficial to understand how sport-specific overload is affecting cycling mechanics and the working muscles.
- Added body load was examined in the present study as a training tool and a way of applying sport-specific overload in cycling. Further research should examine the potential for added body load in warm-ups as a method of pre-activation potentiation.

5.6 Conclusion

The objective of this thesis was to extend the current body of knowledge on the use of functional resistance training and to investigate the acute physiological effects of LL in cycling. Accordingly, this thesis had two aims answered over two studies. First, to understand the acute physiological and perceptual responses of LL in cycling. And second, to understand how LL alters physiological and perceptual responses to cycling at various cycling gradients, and do responses differ when compared to adding weight to the bicycle (B_{load}). The experimental trials were the first to investigate the acute physiological effects of LL in cycling. Additionally, no other research has investigated the physiological effects of LL in cycling when compared to external loading of a bicycle.

The key findings of this thesis were that there is no physiological effect of added load during submaximal cycling on a stationary ergometer. However, when 'real-world' cycling was simulated using a treadmill at different gradients, LL was found to be the slightly more optimal method of sport-specific overload over B_{load}, but only at certain gradients. At 2% and 6% gradients LL increased VO_2 at the same set power output with *small* effects (2% = 0.28 ± 0.36; 6% = 0.24 ± 0.22), while at 6% gradient BLa also increased with a *moderate* effect (0.68 ± 0.60). Whereas B_{load} only increased VO_2 at 6% gradient with a *small* effect (0.26 ± 0.32) but found no change in BLa. As a result, LL was found to induce slightly greater metablic overload than B_{load} at 2% and 6% gradients.

Together the two studies in this thesis demonstrate that LL results in varying responses on physiological overload during cycling. However, at targeted gradients some form of physiological overload was observed, which is worthy of further exploration. These findings contribute to the body of knowledge on FRT, and even more so, to the application of LL through understanding the acute physiological and perceptual responses in the endurance sport of cycling.

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Appendices

Appendix 1: Ethical approval letter

13 September 2017

Daniel Plews
Faculty of Health and Environmental Sciences

Dear Daniel

Re Ethics Application: **17/279 The physiological response of functional limb weighting in cycling**

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 13 September 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: anna.skipper@gmail.com; Andrew Kilding

Appendix 2: Participant Information Sheet

Participant Information Sheet

Date Information Sheet Produced:

13/08/2017

Project Title

The physiological responses of functional limb weighting in cycling.

An Invitation

Hi, my name is Anna Skipper, I am a Masters student at AUT University, as well as Performance Physiologist at High Performance Sport New Zealand (HPSNZ). Along with Dr Daniel Plews and Assoc. Prof Andrew Kilding, I invite you to help with a project that examines how the physiological response of functional limb weight in cycling. The information obtained from this study could help to inform training programme design and the practical applications of using functional resistance training in cycling.

What is the purpose of this research?

Sport-specific training is crucial to enhance performance as margins between winning and losing in professional and high performance sport is becoming seemingly smaller. Specificity is a fundamental principle of training, where an athlete's prescribed exercise in training is purposeful to match the requirements of their sport. Functional resistance training (FRT) provides a means for doing this. Functional resistance training involves applying load to specific body parts, allowing an athlete to perform sport-specific movements at an additional load to increase PO and performance in those movements. This can be done without negatively affecting the mechanics of the movement and unlike traditional resistance training, can be performed within the context of sport (sprinting, running etc.). Functional resistance training provides added resistance to typical training, and may optimise training adaptations through a greater stimulus/stress applied to the working muscles. Functional resistance training has previously been researched in daily activities, walking/stair climbing programmes, and sprint and power based sports as a practical means for incorporating specificity and progressive overload into training programmes. Some studies have recorded improvements to strength, power, endurance, balance and bone mineral density, others have reported no benefits to these factors that influence performance. Research in FRT is still in its infancy with very little research carried out in endurance sport and cycling. Therefore, this study aims to answer the following questions:

1. What are the acute physiological and biomechanical effects of functional resistance training, using limb weighting, in cycling?
2. How does functional resistance training, using limb weighting, alter physiological responses to cycling at various cycling gradients, and do responses differ compared to adding weight to the bicycle?

Furthermore, the findings of this research will contribute to a Masters qualification, and findings may be used for academic publications and presentations.

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

Advertisements were circulated in-person and online through social media (Facebook) to cycling, triathlon, and ironman training groups. You have responded to the advertisement and have identified that you are interested in taking part in this research as you are a trained cyclist and a member of regular training group. You are invited to voluntarily take part in this study if you are eligible and meet the following criteria:

- Have more than 2 years cycling training
- Ride more than 150 km a week
- Have prior experience riding on rollers?
- Are not suffering from any illness or injuries which may impair your ability to perform exercise?
- Are between the ages of 18-45 years of age?

How do I agree to participate in this research?

Participation in this study is voluntary and whether you choose to participate or not will neither advantage nor disadvantage you. At any point throughout the study you are able to withdraw, if you choose to withdraw from the study you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

Involvement in this research will require you to perform: 1) Preliminary testing; 2) acute physiological and biomechanical assessment and 3) simulated 'real world' loaded trials.

1) Preliminary testing:

Familiarisation sessions will take place at the AUT Millennium, 2-weeks prior to the experimental trials beginning. During this familiarisation you will perform a 15 – 25-minute maximum oxygen consumption (VO_2max) testing to assess VO_2max and aerobic and anaerobic thresholds. This is the gold standard for VO_2max assessment. You will also practice riding your bicycle on the treadmill and you will have the option to perform multiple familiarisations cycling on the treadmill to feel comfortable and confident doing so before the assessments starts.

2) Acute Physiological and Biomechanical Assessment:

Following a standardised warm up, you will be required to complete five submaximal cycling efforts wearing added load on the thigh and calf on a stationary bicycle ergometer. Each exercise bout will be performed at the same submaximal power output and cadence at ventilator threshold (VT_1), and be 5 minutes in duration. Following each exercise bout, you will have 15 mins of passive recovery. The total exercise bout will take 30 minutes for each subject including warm-up.

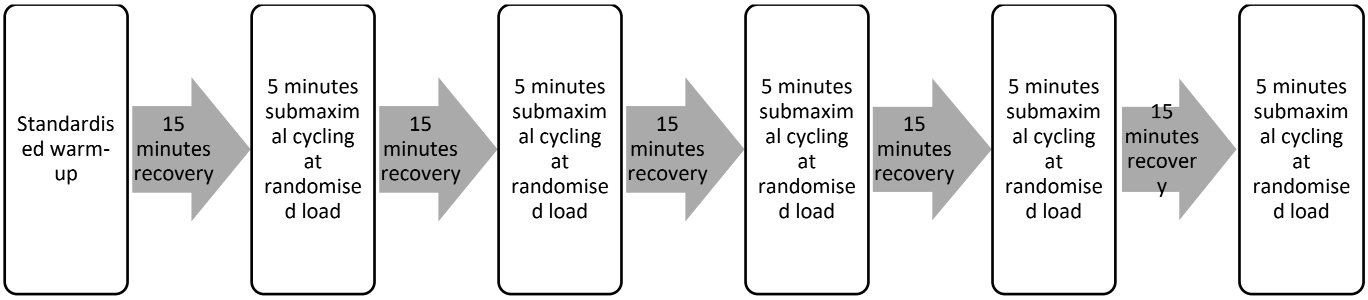
Measures collected pre – assessment:

Prior to cycling one maximal voluntary isometric contraction (MVIC) will be performed on the Humac Norm Isokinetic Dynamometer MVIC and one will be performed by performed by hanging over the edge of a bench and performing a maximal flexor effort. These measures are taken to normalize the surface electromyogram (EMG) data.

Measures collected during exercise:

During each exercise bout VO_2max, heart rate (HR) and pedal force measurement (PFM) data will be collected. Rate of perceived exertion (RPE) will be recorded at the end of every minute, and blood lactate analysis (BLa) will be taken at rest and after 5 minutes of cycling using a finger prick blood sample. At the end of the exercise bout surface electromyography (EMG) will record muscle activation of the right side of the body. The total exercise bout will take 30 minutes for each subject including warm-up.

An overview of the protocol is outlined below:



3) Simulated 'real world' loaded trials:

The simulated 'real world' loaded trials will take place over 3 separate visits to the laboratory spaced over 72 hours apart. Following a standardised warm up, you will be required to complete five submaximal cycling efforts wearing added load on the thigh and calf on your own bicycles on a purpose-built treadmill (whilst wearing safety equipment) at different gradients under laboratory conditions.

The simulated 'real world' loaded trials will take place over 3 separate visits to the laboratory spaced over 72 hours apart. Each visit to the laboratory will be under a different condition: - No added load, bike loading (where a set load will be added to your bike), and functional loading (FRT) to assess the training/physiological stress such additional loading may represent.

Measures collected pre – assessment:

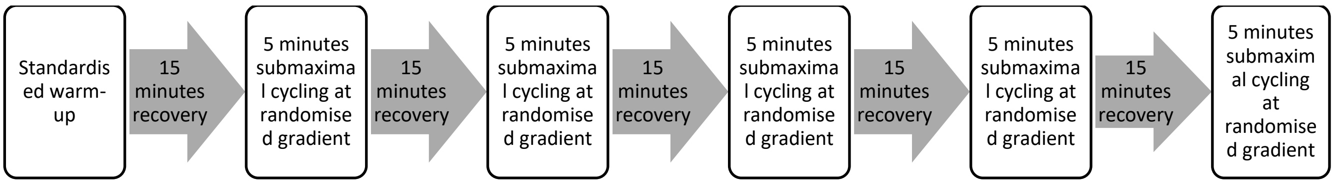
Prior to cycling one maximal voluntary isometric contraction (MVIC) will be performed on the Humac Norm Isokinetic Dynamometer MVIC and one will be performed by performed by hanging over the edge of a bench and performing a maximal flexor effort. These measures are taken to normalize the EMG data.

Measures collected during exercise:

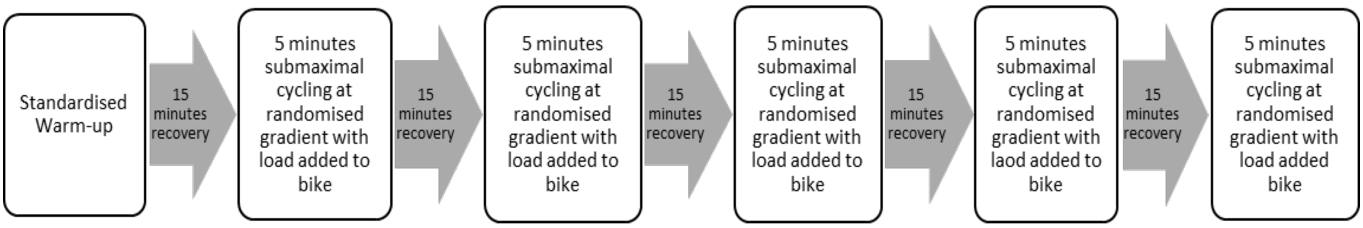
During each exercise bout VO_2max and HR and RPE data will be collected. BLa will be taken at rest and after 5 minutes of cycling using a finger prick blood sample. At the end of the exercise bout EMG will record muscle activation of the right side of the body. The total exercise bout will take 30 minutes for each subject including warm-up.

An overview of the protocol is outlined below:

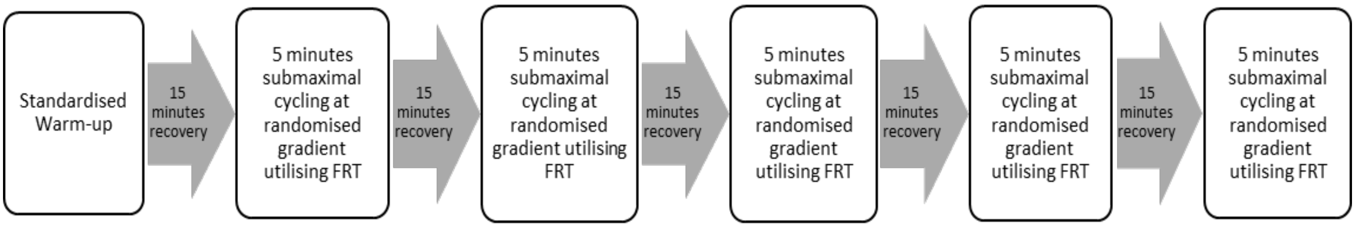
<u>No Added Load:</u>



<u>Bike Loading:</u>



Functional Loading:



Water will be available for consumption. You are advised to bring your own water bottle and snacks according to standard exercise practice for post-exercise.

If you have any personal or cultural issues regarding the above procedures please let the primary researcher now of these prior to the study so that these can be accommodated for.

What are the discomforts and risks?

Any discomforts you may experience during this research would be the same you could experience during training or competition. You may experience minor discomfort during the blood collection in the form of a small sting from the needle prick. When placing the EMG electrodes on the skin small alcohol wipes will be used to clean the skin and the stickers will be placed in locations on the legs and abdomen through palpating the muscles. This will involve light pressure being palpated on each muscle location. Proper technique, and all laboratory safety requirements will be taken to minimise any risks including the use of gloves. Therefore, the risks associated are minimal. Riding on a treadmill may feel unnatural in the beginning but you will have the opportunity to perform familiarisations prior to starting data collection. During all treadmill riding sessions the utmost care will be taken to minimise risks by wearing safety equipment and wearing a safety harness. If you feel uncomfortable or wish to stop at any point you will be able to do so. If any complications arise, a certified researcher will always be present to perform first aid.

What are the benefits?

You can benefit from this research through:

- Finding out your training zones and VO_2max
- Gain an understanding of functional resistance training and different ways of executing it.

The researchers will also benefit from completing this research as the findings will contribute to a Master's thesis, and may be used for submission to peer reviewed journals and conferences. Lila Movement Technology, are funding the course fee costs of the Master's thesis for the Masters student.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result 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?

All data collected during this study will only be available to the researchers involved, If the data is published in a public domain, you name as a subject will not be revealed as all reported data will remain de-identifiable.

What are the costs of participating in this research?

There will be no financial costs associated with this study, however if you choose to participate you will be required to give up approximately 6 – 7 hours spread over a 4 week period; 1-2 hour for preliminary familiarisation sessions, 1 hour for acute physiological and biomechanical assessment and 3 hours for simulated 'real world' loaded trials.

What opportunity do I have to consider this invitation?

You have two weeks to decide whether you wish to participate in the study, if you decide to participate you can withdraw from the study at any time.

Will I receive feedback on the results of this research?

At the end of the study, verbal feedback will be given to you and a 1-2 page summary of the research findings will be provided.

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 Project Supervisor, Daniel Plews, plews@plewsandprof.com or 09 921 9999

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?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Anna Skipper – anna.skipper@gmail.com

Project Supervisor Contact Details:

Dr Daniel Plews – plews@plewsandprof.com

Approved by the Auckland University of Technology Ethics Committee on *13th September 2017*, AUTEC Reference number *type 17/279*.

Appendix 3: Participant Consent Form

Consent Form

Project title: ***The physiological responses of functional limb weighting in cycling.***

Project Supervisor: ***Dr Daniel Plews***

Researcher: ***Anna Skipper***

○ I have read and understood the information provided about this research project in the Information Sheet dated 13/08/2017.

○ 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 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

○ 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 have 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 signature: ……………………………………………………………………………………

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

Participant's Contact Details (if appropriate):

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

Date:

Approved by the Auckland University of Technology Ethics Committee on 13th September 2017 AUTEC Reference number 17/279

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

Appendix 4: Study Advertisement Flyer

WANTED

Research Participants

Get the cutting edge in your training!

"The physiological responses of functional limb weighting in cycling"

You will gain valuable information about how your body responds to functional limb weight and your training zones to optimise your training programme
You may be eligible to take part in this study if you meet the following criteria:

- Have more than 2 years cycling training
- Ride more than 150 km a week
- Have prior experience riding on rollers?
- Are not suffering from any illness or injuries which may impair your ability to perform exercise?
- Are between the ages of 18-45 years of age?

If you are interested, please see the contact details bellow to get further information:

Primary Researcher:

Anna Skipper

anna.skipper@gmail.com

Primary Supervisor:

Dr Daniel Plews, 09 921 9999

plews@plewsandprof.com

AUT UNIVERSITY