The Effects of Repeated High Intensity Wattbike Sprints on Lower Body Horizontal Power and Power Endurance in Rugby Union Players

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Abstract

A Wattbike is a stationary cycle ergometer that was originally designed for cyclists to provide them with the most realistic cycling experience. However, Wattbikes are now frequently used by athletes of various sports such as rugby union as they provide an alternative off-feet training method that places less stress on the lower limbs. This reduction in the amount of load placed on the lower limbs during off-feet training becomes crucial in specific situations such as returning to play after a lower body injury. Currently, research surrounding the Wattbike is limited to its effects on different aspects of performance during cycling. As Wattbikes are used by athletes from a variety of field sports where over-ground sprinting is essential, it would be beneficial to understand what effects training on a Wattbike has on performance during over-ground sprinting. As such, the purpose of the current study was to determine the effects of repeated Wattbike sprints on lower body horizontal power and power endurance during over-ground sprinting in male rugby union players. Fourteen male rugby union players were assigned to one of three groups; control, Wattbike or treadmill. During baseline testing, the participants performed a 30-m sprint and a 2 x 20-m shuttle repeated-sprint ability test. Participants in the Wattbike group also performed a 6-s sprint test on a Wattbike. After the baseline testing, the participants in the Wattbike group completed two repeated-sprint training sessions a week on a Wattbike. The repeated-sprint training protocol involved three sets of five to eight, 5-s sprints at 80 to 95% of peak velocity. The treadmill group completed the same protocol as the Wattbike group but on a motorised treadmill. The participants in the control group did not take part in any repeated-sprint training over the four-week intervention period. All participants repeated the same testing procedure used during baseline testing following the four-week intervention. The Wattbike intervention resulted in meaningful improvements in lower body horizontal power and power endurance. This is evident through the increases in absolute peak horizontal power (P_{max}) (166.03 ± 147.00 W), and relative peak horizontal power (Rel P_{max}) (1.71 ± 1.57 W·kg^{-1}), and decreases in RSA fastest (RSA_f), slowest (RSA_s) and mean (RSA_m) sprint times (-0.17 ± 0.20, -0.25 ± 0.19, -0.21 ± 0.17, respectively). Furthermore, the increases seen in the Wattbike group for P_{max} and Rel P_{max} were greater than that of the treadmill group (ES = 0.77 ± 0.64 and 0.58 ± 0.50, respectively) and the changes in RSA_f, RSA_s and RSA_m were substantially better than that of the control group (ES = -1.35 ± 0.85, -1.34 ± 0.87 and -1.17 ± 1.00). The results of this study suggest that repeated Wattbike sprints are an effective method for increasing lower body horizontal power and power endurance during over-ground sprinting, though further research is still warranted.

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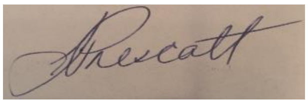
1RM	One repetition maximum
5BT	Five-bound test
Ag	Agility
ATS	Acceleration testing system
BDC	Bottom dead centre
BF	Biceps femoris
CL	Confidence limit
CMJ	Countermovement jump
DJ	Drop jump
EMG	Electromyography
ES	Effect size
F_0	Absolute theoretical maximal horizontal force
G	Gastrocnemius
GL	Gastrocnemius lateralis
GM	Gastrocnemius medialis
GMax	Gluteus maximus
GPS	Global positioning system
Hop	Hop test
HS	Hamstring
IC	Initial contact
IRB	International Rugby Board
ISOS	Isometric squat
$Km \cdot hr^{-1}$	Kilometres per hour
MS	Mid-stance
MST	Maximal sprint test on non-motorised treadmill
P	Propulsion
P_{max}	Absolute peak horizontal power
Rel F_0	Relative theoretical maximal horizontal force
Rel P_{max}	Relative peak horizontal power
RF	Rectus femoris
RF_{Opt}	Theoretical optimal ratio of force
RF_{peak}	Peak ratio of force
RSA	Repeated-sprint ability
$RSA_{\%DEC}$	Repeated-sprint ability percentage decrement
RSA_f	Repeated-sprint ability fastest sprint time
RSA_m	Repeated-sprint ability mean sprint time
RSA_s	Repeated-sprint ability slowest sprint time
RST	Repeated-sprint training
S	Soleus
SD	Standard deviation
SCG	Skill-based conditioning games
SEMG	Surface electromyography
SJ	Squat jump
SLJ	Standing long jump
SM	Semimembranosus
SSC	Stretch-shorten cycle
SSG	Small-sided games
SW	Swing
SWC	Smallest worthwhile change
TA	Tibialis anterior
TDC	Top dead centre
V_0	Theoretical maximal velocity
VJ	Vertical jump
VL	Vastus lateralis
VM	Vastus medialis
V_{max}	Peak velocity
VO_2peak	maximal oxygen uptake
W	Watts
$W \cdot kg^{-1}$	Watts per kilogram
Yo-yo	Yo-yo intermittent recovery test

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 degree or diploma of a university or other institution of higher learning.



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Date 01.02.18 ....

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Ethics approval

Ethical approval for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC; #16/431) on 8 December 2016 (see Appendix A).

Chapter 1

Introduction and rationale

Background and importance

The sport of rugby union first originated in the nineteenth century when a schoolboy named William Webb Ellis chose to disregard the rules of football by picking up the ball and running with it during a match (Biscombe & Drewett, 2010; Johnson, 2013). According to the International Rugby Board (IRB), rugby union is now played by men and women of all ages in over 100 countries, spanning six continents. The growth and popularity of rugby union is multiplying annually thanks to competitions such as the Rugby World Cup, which is held every four years and encompasses teams from all over the globe (Biscombe & Drewett, 2010; Johnson, 2013). The rules of rugby union have evolved dramatically since its early days; however, the main objective has remained the same. The primary goal for any rugby union team is to score more points than the opposition team before the end of the match. There are many ways to score points in rugby union, including tries (5 points), conversions (2 points), penalty kicks (3 points), and drop kicks (3 points). A try is awarded when a player carries the ball over the opposition’s goal line and touches the ball on the ground while still holding on to it. One player from the try scoring team then takes a conversion kick with the intention of kicking the ball over the crossbar of the opposition’s goal posts. Penalties are conceded when a player infringes one of the rules of rugby union. If the team that is awarded the penalty is close enough to the opposition’s goal posts, they can choose to take a kick at goal. Lastly, any player from either team can attempt to drop kick the ball over the crossbar of the opposition’s goal post at any time during a match (Biscombe & Drewett, 2010; Johnson, 2013; World Rugby, 2017).

At any level of competition rugby union is an extremely physically demanding sport, requiring players to perform an assortment of tasks and movements to score points. Rugby union has often been characterised as an intermittent, field-based team sport requiring frequent collisions and repeated bouts of high intensity activity interspersed by periods of low intensity activity (Austin, Gabbett, & Jenkins, 2011; Cross, Brughelli, Brown et al., 2015; De Villiers & Venter, 2015; Gannon, Stokes, & Trewartha, 2016; Hogarth, Burkett, & McKean, 2016). Due to the diverse array of activities performed by rugby union players researchers have analysed matches with the aim of providing a stronger understanding about the physical demands of rugby union. Multiple studies have adopted the use of global positioning systems (GPS) and time-motion analysis to evaluate the activities and physical demands of players throughout the duration of a rugby union match (Austin et al., 2011; Fuller, Brooks, Cancea, Hall, & Kemp, 2007; Hogarth et al., 2016; Quarrie & Hopkins, 2007). During an international rugby union match the ball is in play for an average of 36 minutes and 21 seconds ± 2 minutes and 40 seconds (Quarrie, Hopkins, Anthony, & Gill, 2013). The results of (Quarrie et al., 2013) suggest that the ball is out of play for more than half of the length of a rugby union match. While the ball is not in play, players will either be preparing for a scrum or lineout to take place, waiting for a penalty or conversion kick to be taken, waiting for a player to be assessed by medical staff, or awaiting a decision from match officials. These are periods of low intensity activity which provide players with an opportunity to rest and strategize before play resumes. Throughout the duration of a match players will be constantly switching between periods of high intensity and low intensity efforts.

During high intensity periods, players will be engaged in different running activities, including performing multiple sprints over various distances resulting in players working at approximately 80 to 85% of peak oxygen uptake (VO_2peak) with a mean heart rate of roughly 88% of their maximal heart rate through the course of a match (Cunniffe, Proctor, Baker, & Davies, 2009). Austin et al. (2011) and Duthie, Pyne, Marsh, and Hooper (2006) have shown that the average sprint distance of rugby union players is between 10- and 20-m for all positions. Furthermore, the mean frequency of sprints performed during a match was found to be 29 ± 10, 31 ± 6, 44 ± 22 and 27 ± 12 for front row forwards, back row forwards, inside backs and outside backs respectively. Moreover, Austin et al. (2011) stated that the average total distance covered while sprinting in a match was shown to be 501 ± 163, 547 ± 55, 918 ± 253, and 558 ± 282-m for front row forwards, back row forwards, inside backs and outside backs respectively. These results show that the inside backs perform more sprints and cover more distance while sprinting when compared with the other three positional groups. It is possible that the difference in sprinting distance is because of the varying distances between the players of the attacking team and the oppositions line of defence. Forwards are much closer to the oppositions line of defence which restricts the amount of space they have to move and their ability to reach high velocities. Conversely, inside backs and outside backs are further from the oppositions line of defence which gives them more room to move and reach greater velocities more frequently, resulting in a larger amount of distance covered while sprinting. In theory, the outside backs should cover the greatest distance while sprinting as they are the furthest away from the oppositions defensive line. However, outside backs receive the ball on a less frequent basis when compared to inside backs which results in fewer opportunities to sprint.

Sprinting is a key parameter of performance in rugby union and can have a significant impact on the outcome of a match. Research has shown that 10-m, 20-m and 30-m sprint times are moderately correlated to line breaks, metres advanced, tackle breaks and tries scored during rugby union matches which have been linked to positive phase and overall match outcomes (Smart, Hopkins, Quarrie, & Gill, 2014). Therefore, rugby union players must be proficient at sprinting to achieve success at competitive levels (Cross et al., 2015; Duthie et al., 2006). However, sprinting is a complex skill with multiple factors influencing an individual’s sprinting ability (Buchheit, Samozino, Glynn et al., 2014; Cross et al., 2015; Morin, Bourdin, Edouard et al., 2012; Morin, Edouard, & Samozino, 2011a).

One component of sprinting that has consistently shown high correlations with sprinting performance in athletes of many team sports such as rugby union and football is lower body power output (Buchheit et al., 2014; Cross et al., 2015; Lockie, Orjalo, Amran et al., 2016; López-Segovia, Dellal, Chamari, & González-Badillo, 2014; Morin et al., 2012; Taber, Bellon, Abbott, & Bingham, 2016). Cross et al. (2015) found that rugby union backs produced greater power outputs which resulted in faster sprint times than their rugby league counterparts over 30-m. Furthermore, the results of the study conducted by Morin et al. (2012) presented a positive correlation between mean sprint velocity and maximal power output during a 100-m sprint in both sprinters and non-sprinters. The results of Morin et al. (2012) are supported by Buchheit et al. (2014) who stated that football players that had faster sprint times also produced higher power outputs than players with slower sprint times. Additionally, López-Segovia et al. (2014) found that football players with high power outputs achieved better sprint times over 10-m than players with low power outputs. Lastly, the results of Lockie et al. (2016) elucidated a positive correlation between 20-m sprint performance and lower body power output in female rugby union players. The methods used in these studies to determine lower body power output varied from a simple standing long jump (SLJ) which assesses power based on maximal distance jumped, to more advanced radar devices. Radar devices such as the Stalker Acceleration Testing System (ATS) II (Applied Concepts, Dallas, TX, USA) are able to track the forward sprinting velocity of an individual. The raw data collected by the radar can then be analysed using specialised software to attain the following variables: theoretical maximal horizontal force (F_0), theoretical maximal velocity (V_0), and peak horizontal power (P_{max}) produced during a sprint (Cross et al., 2015). This method provides a more comprehensive analysis of lower body power than simple jumping tests such as the SLJ.

However, despite the difference in data collection methods, each study presented a positive relationship between sprint performance and lower body power output (Buchheit et al., 2014; Cross et al., 2015; Lockie et al., 2016; López-Segovia et al., 2014; Morin et al., 2012). Although these studies offer evidence suggesting single sprint performance can be improved through an increase in lower body power output, rugby union requires players to perform multiple sprints during a match, often with little rest between efforts which is shown by the position dependent work to rest ratios of 1:4 to 1:6 described by Austin et al. (2011). Repeated-sprint ability (RSA) is an important factor in performance of many team sports including rugby union (Smart, Hopkins, & Gill, 2013), football (Morcillo, Jiménez-Reyes, Cuadrado-Peñafiel et al., 2015) and cricket (Kumar, Kathayat, & Kadam, 2015).

Performing multiple sprints requires maximal power outputs to be produced continually through the lower limbs to reach high sprinting velocities when necessary. For the present study, the term power endurance will be used to describe an individual's ability to repeatedly produce maximal power. As speed is essential in rugby union, players that are unable to produce maximal power outputs required to reach high velocities throughout the duration of a match have a greater chance of being outrun by an attacking player or chased down by a defending player (Cross et al., 2015; Smart et al., 2014). There is little research regarding RSA or power endurance in rugby union players, however, Smart et al. (2013) found that professional rugby union players displayed greater RSA scores than their amateur counterparts, suggesting professional rugby union players possess superior power endurance than players at lower competition levels. Evidently a rugby union player's maximal lower body power output as well as their power endurance could have a significant impact on their performance during a match.

Thus, it would be beneficial for rugby union players to improve their maximal lower body power output and power endurance through training to potentially better their on-field performance.

Significance and purpose

Continual advances in technology means that there is a constant stream of new training equipment being developed. Moreover, this new equipment has the potential to enhance training programmes for athletes of all sports. However, an adequate understanding of the effects the equipment has on specific performance parameters is paramount before appropriate training prescription can be made by strength and conditioning professionals. The Wattbike (Wattbike Ltd, Nottingham, UK) is a combined magnetically and air braked cycle ergometer. Wattbikes are commonly used in both gym and laboratory settings as testing and training tools, and have been endorsed by national cycling teams (Herbert, Sculthorpe, Baker, & Grace, 2015; Hopker, Myers, Jobson, Bruce, & Passfield, 2010). Wattbikes offer users numerous benefits over other conventional gym bikes such as an authentic road riding sensation, the option to train at set power outputs and the Polar View function which provides a visual of how force is being applied to both pedals during each stroke. Current research has investigated the effects of various Wattbike training protocols on VO_2peak, maximal aerobic power, blood pressure, maximal metabolic capacity, RSA and body composition in populations such as triathletes (Etxebarria, Anson, Pyne, & Ferguson, 2014), untrained males (Muggeridge, Sculthorpe, James, & Easton, 2017) and sedentary aging males (Grace, Herbert, Elliot et al., 2017).

No studies have examined the effect of repeated Wattbike sprints on over-ground sprinting performance and RSA in male rugby union players. As Wattbikes are already being used in training programmes for team sports athletes such as rugby union players, it would be advantageous to gain a deeper knowledge of what the training effects caused by using a Wattbike are in this specific population. This would aid strength and conditioning professionals in designing effective training programmes for rugby union players. Thus, it is the purpose of this thesis to provide a greater scientific understanding about the effects of repeated Wattbike sprints on lower body horizontal power output and power endurance during over-ground sprinting in male rugby union players.

Thesis aims

The specific aims of this thesis were to:

1) Investigate the effects of a Wattbike repeated sprint protocol in comparison to a treadmill based sprinting protocol on lower body horizontal power output during over-ground sprinting.
2) Investigate the effects of Wattbike repeated sprint protocol in comparison to a treadmill based sprinting protocol on lower body power endurance.

Thesis hypotheses

1) Both the Wattbike repeated sprint protocol and the treadmill based sprinting protocol will cause significant improvements in both lower body horizontal power and power endurance.
2) The improvements in lower body horizontal power and power endurance following the Wattbike repeated sprint protocol will be similar to the improvements seen in the treadmill based sprinting group.

Thesis structure

This thesis is comprised of a series of chapters (to comply with the pathway one format) which are outlined below and illustrated in Figure 1;

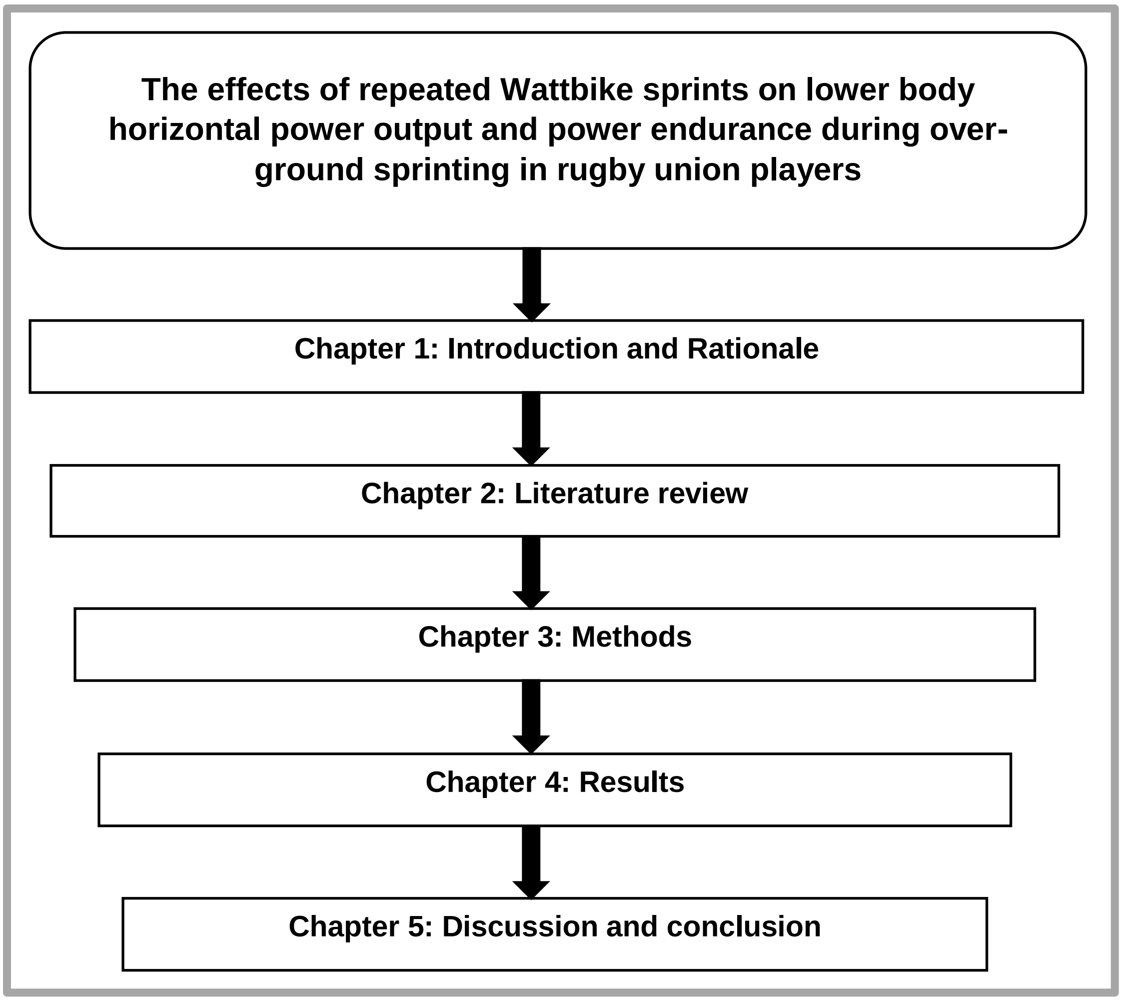

Figure 1. Thesis structure.

Chapter 1: This chapter provides the background to the thesis and rationale to the significance of the research.

Chapter 2: A narrative review of the existing literature surrounding rugby union, lower body power, power endurance, over-ground sprinting and cycling will be provided. The literature review will begin by exploring the demands of rugby union. The final sections of the literature review will focus on current training methods used in rugby union, characteristics of cycling and over-ground sprinting, the effects of current repeated-sprint training (RST) methods and a brief conclusion.

Chapter 3: This chapter gives a detailed description of the study including, subject characteristics, testing and training procedures, and statistical analysis methods of the collected data.

Chapter 4: This chapter will provide an overview and brief description of the results produced through data analysis.

Chapter 5: The final chapter of this thesis summaries the overall findings of the study which includes general conclusions, practical applications, thesis limitations and delimitations, and possibilities for future research.

Chapter 2

Literature review

Introduction

Over-ground sprinting is an integral attribute in rugby union and has been linked to positive phase (metres gained, line breaks and tackle busts) and overall match outcomes (Smart et al., 2014). Aerobic capacity is correlated to activity rates during a match, with higher activity rates linked to players with greater aerobic capacity (Smart et al., 2014). Furthermore, research has elucidated that professional rugby union players exhibit greater RSA than their amateur counterparts, making RSA important for success (Smart et al., 2013). Therefore, developing both sprint and RSA performance should be essential for all rugby union players to be successful in competition. Numerous training methods have been used with the intention of improving physical attributes that are specific to performance in rugby union including aerobic and anaerobic capacity, strength, and power (Brannigan, 2016). However, a constant flow of new training equipment and ideas from strength and conditioning professionals means alternative training methods are continually emerging.

These new training methods need to be tested to determine what effect they have on performance and if it is beneficial to the athlete. An extensive amount of research has delved into many facets of training for rugby union players as the popularity of the sport has grown over the years. However, there is limited literature on the effects of repeated cycle sprints on over-ground sprint performance and RSA in rugby union players. One study has investigated how repeated sprints on a stationary cycle ergometer affected over-ground sprinting and RSA in female soccer players (Gmada, Farhani, Bouhlel et al., 2014). Gmada et al. (2014) reported increases in absolute and relative peak power outputs during a cycle ergometer force-velocity test and five-bound test (5BT) following their RST programme. More importantly, the authors of this investigation also reported an improvement in sprint velocities over distances of 20- and 30-m (Gmada et al., 2014). These results suggest that there is a possible transference effect from training on a cycle ergometer to over-ground sprint performance. Therefore, RST on a cycle ergometer may be an effective training method for improving over-ground sprint performance in rugby union players.

Off-feet conditioning on a stationary cycle or in a pool provides a great alternative to traditional weight bearing exercises such as running and walking. These non-weight bearing exercises place less stress on the musculoskeletal system and reduce the risk of injury while still providing an effective training stimulus (Alkatan, Machin, Baker et al., 2016; Roe, Darrall-Jones, Till et al., 2017; Tanaka, 2009). It is beyond the scope of this study to investigate both aquatic based exercise and cycling, therefore, only the effects of repeated stationary cycle sprints will be explored. Furthermore, because stationary bikes such as Wattbikes are a common piece of equipment in many rugby union team gyms, it is vital to understand what training effects they produce. Currently no other studies have investigated the effects of repeated Wattbike sprints on lower body horizontal power and power endurance in any population.

The intention of this narrative literature review is to critically analyse the existing research surrounding the physical and physiological demands of rugby union, the development of lower body power and power endurance, and the efficacy of over-ground sprinting and cycling training methods for team sport conditioning. This will bring together a large amount of information from various peer reviewed sources to provide a clear understanding of these topics and establish the importance of this study.

Search parameters and criteria

A search of the literature surrounding rugby union, over-ground sprinting and cycling was conducted. The SPORTDiscus, Google Scholar, Science Direct and OVID databases, from January 2000 to May 2017, were searched for terms linked with the Boolean operators ('AND', 'OR', 'NOT'): 'repeated-sprint training', 'rugby union', 'cycling', 'running', 'treadmill', 'Wattbike', 'athletes', 'power', 'power endurance', 'sprint', 'interval', 'high intensity', 'speed training', 'conditioning', 'kinetics', 'kinematics', 'biomechanics', 'off-feet', 'small-sided games', 'skill-based games' and 'match demands'. Literature published prior to the year 2000 were excluded to ensure that only the most recent research was included in this review. Further literature was obtained from electronic 'related articles' searches and by manually screening the reference lists of included studies. The inclusion criteria for all articles were; 1) refereed articles published in English language journals and books from January 2000 until July, 2017, 2) athletes or active healthy individuals were used as the study population, and 3) the research specifically addressed either the physiological effects of cycling or running based repeated-sprint training, the physical and physiological demands of rugby union, kinetic and kinematic aspects of cycling or over-ground running, current training methods used for rugby union players, or current off-feet conditioning methods. The exclusion criteria for all articles were; 1) the article was not available in English, 2) the full-text of the article was not available, and 3) only the acute effects of repeated-sprint training methods were assessed.

Demands of rugby union

Rugby union has been described as an intermittent, field-based team sport involving repeated high-impact contacts with frequent periods of high intensity efforts interspersed by periods of low intensity efforts (Austin et al., 2011; Cross et al., 2015; De Villiers & Venter, 2015; Gannon et al., 2016; Hogarth et al., 2016). Throughout the duration of a rugby union match players will tackle, ruck, maul, scrum, perform lineouts, sprint, and contest for the ball in order to place their team in a favourable position to score points (Austin et al., 2011; Cross et al., 2015; De Villiers & Venter, 2015; Fuller et al., 2007; Gannon et al., 2016; Hogarth et al., 2016; Quarrie & Hopkins, 2007). A tackle is made when a defending player contacts an attacking player and brings them to the ground to briefly disrupt any forward momentum of the attacking team. Additionally, rucks occur after a player has been tackled and both teams contest for possession of the ball while the tackled player is on the ground. If an attacking player is held up by one or more defending players during a tackle and one or more attacking players bind with the ball carrier it is considered a maul. Furthermore, a scrum will take place to restart play after a minor infringement or stoppage. A scrum involves eight players from each team (all forwards) that face towards each other and form three rows. They will then crouch and bind tightly together after which the referee will then say ‘set’ which is an indication for the front row of each team to make contact. All scrumming players will then push forward against the opposition and the hooker will attempt to rake the ball (which has been rolled into the middle of the scrum) with their feet towards the back of their scrum for the ball to be removed and for play to continue. Lastly, a lineout happens when the ball goes out of play over one of the side-lines of the field. Players from each team will then form separate lines, one meter apart, on either side of the mark where the ball was called out. The team’s hooker will use an overhead throw to toss the ball down the middle of the lines created by the two teams. One or more players from each team will be lifted by their team mates in order to try and grab the ball from the air before the opposing team gets it (Biscombe & Drewett, 2010).

Strength and power are essential for players to overcome their own inertia and create forward movement for running and to also overpower opposition players during tackles, rucks, mauls and scrums to either retain or steal the ball (Brannigan, 2016). Stronger players have a greater chance of dominating contact aspects of rugby union. This results in the ball being retained for longer periods of time. Having possession of the ball for a greater amount of time potentially offers more opportunities to score points (Smart et al., 2014). Furthermore, lower body strength and power have been linked to sprinting performance and speed (Buchheit et al., 2014; Cross et al., 2015; Morin et al., 2012; Morin et al., 2011a). Faster players have been shown to reach the defensive line quicker which can force opposition players into a poor defensive position. This is essential to dominating contact and making tackle breaks. Research has shown that faster players break the line, break tackles, evade opposing players more frequently and ultimately score more tries (Smart et al., 2014).

Work to rest ratios are often used to describe the activity of players during sports matches. Austin et al. (2011) found that the work to rest ratios of Super 14 rugby union players were 1:4, 1:5 and 1:6 for front row and back row forwards, inside backs, and outside backs respectively. This means that for every second of work a player is doing, they are resting for four, five or six seconds (Austin et al., 2011). During these periods of high intensity and low intensity activity, players are covering a significant amount of distance and are involved in multiple high intensity running and non-running activities (Austin et al., 2011; Fuller et al., 2007; Hogarth et al., 2016; Quarrie & Hopkins, 2007). Hogarth et al. (2016) conducted a review on the demands of professional rugby union matches between the years 2008 and 2015. Their results showed that the distance covered by players during a match ranged from 4662 to 7227-m, depending on their playing position and the level of competition (Hogarth et al., 2016). During the 33-39 minute ball-in-play duration of a match, the total distance covered and the number of tasks performed per minute suggests that there is a significant demand on the player's aerobic system to provide the required energy to perform the necessary activities over this period of time (Brannigan, 2016). Moreover, there is also a significant amount of stress placed on the player's anaerobic system resulting from the short high intensity running and non-running activities that occur throughout a match (Brannigan, 2016). Austin et al. (2011) found that the mean frequency of maximal sprint efforts during a match was 29 ± 10, 31 ± 6, 44 ± 22 and 27 ± 12 for front row forwards, back row forwards, inside backs and outside backs respectively. Additionally, the mean frequency of non-running high intensity activities during a match for front row forwards, back row forwards, inside backs and outside backs is 20 ± 4, 19 ± 4, 25 ± 13 and 20 ± 7 respectively for tackles and 62 ± 13, 68 ± 15, 17 ± 7 and 14 ± 5 respectively for scrummages (rucks, mauls and scrums) (Austin et al., 2011).

The results of these studies illustrate that rugby union requires players to possess many different physical attributes to be successful. Aerobic and anaerobic capacity is necessary for players to be able to perform for the duration of the match and to recover effectively during periods of rest to allow them to execute the many high intensity activities such as sprinting and tackling (Brannigan, 2016). Therefore, players should be sufficiently prepared for the demands of rugby union through well designed training programmes.

Current training methods prescribed to rugby union players

The purpose a training programme for an athlete of any sport is to effectively prepare them for the demands of their sport. Strength and conditioning professionals should select training methods and exercises based on the requirements of competition so that training is focussed, and athletes do not waste time developing unnecessary physical attributes. Furthermore, in team sports such as rugby union it is crucial that the needs of each individual player are assessed as playing position, training status and injury status play a significant role in training prescription. Questionnaires and a variety of physical tests should be implemented to gather a detailed knowledge of each individual so that training programmes can be designed for the specific needs of each player (Baechle & Earle, 2008; Brannigan, 2016; Gamble, 2013; Joyce & Lewindon, 2014). Research has elucidated the complexity of rugby union and the various physical attributes that are required during a match such as aerobic and anaerobic capacity, strength and power (Austin et al., 2011; Brannigan, 2016; Hogarth et al., 2016; Quarrie & Hopkins, 2007).

Conditioning methods used for rugby union players

Traditional conditioning methods for many team sports, including rugby union, typically involve running laps of the field, performing shuttles of various distances (with and without resistance such as sleds), hill sprints, boxing and wrestling (Brannigan, 2016). However, these training methods exclude fundamental skills that are specific to match performance such as passing, kicking, defending and attacking (Gabbett, 2002; Gamble, 2004; Gamble, 2007; Vaz, Gonçalves, Figueira, & Garcia, 2016). In keeping with the principle of training specificity, training programmes are being designed to replicate the performance conditions of competition as closely as possible. This has resulted in the development of small-sided games (SSG) and skill-based conditioning games (SCG) (Gabbett, 2002; Gamble, 2004; Gamble, 2007; Vaz et al., 2016). SSG and SCG encompass sport specific games which feature modified rules and playing areas. As a result, SSG and SCG are less structured and performed in a more open setting than traditional team sports conditioning methods. This allows for the simulation of movement patterns and game situations that are not achieved during traditional conditioning methods (Gabbett, 2002; Gamble, 2004; Gamble, 2007; Vaz et al., 2016). Research suggests that the skill and competition specific elements of SSG and SCG encourage greater effort and compliance from the athletes, resulting in increased training intensities (Gabbett, 2002; Gamble, 2004). Gamble (2004) reported improvements in heart rate responses during and after an intermittent shuttle test in rugby union players after they had completed a nine-week period of SCG training. Significant decreases in percentage of maximal heart rate ($p < 0.01$) and significant increases in percentage of heart rate recovery ($p < 0.01$) were observed between pre-test and post-test scores after the nine-week SCG training period, suggesting an overall increase in cardiorespiratory fitness (Gamble, 2004). Although SSG and SCG provide a great training stimulus for team sports, they are typically land-based and involve a large amount of running. When an athlete has a lower limb injury or is returning to play after an injury, it is possible that they will not have the ability to perform on-feet conditioning such as SSG and SCG. Therefore, it is imperative that off-feet conditioning methods are available to ensure these athletes are sufficiently prepared to return to competition. Further research is required to determine how effective different off-feet conditioning methods are at preparing athletes for the demands of competition.

Methods used to develop lower body power of rugby union players

One of the most common methods used to develop lower body power in rugby union players is the prescription of high power resistance exercises such as the Olympic lifts (e.g. clean and jerk, snatch) and their derivatives (e.g. hang clean, push press) (Brannigan, 2016). Research has reported that weightlifters have displayed some of the largest absolute and relative peak power outputs during Olympic lifts such as the snatch and clean and jerk. Relative peak power outputs for male and female weightlifters range from 53 Watts per kilogram ($W \cdot kg^{-1}$) to 56 $W \cdot kg^{-1}$ and 38 $W \cdot kg^{-1}$ to 40 $W \cdot kg^{-1}$ respectively (Storey & Smith, 2012). Whereas relative peak power outputs ranging from ~4-12 $W \cdot kg^{-1}$ have been reported for male strength athletes during maximal bench press and deadlift exercises (Storey & Smith, 2012). Furthermore, Hori, Newton, Andrews et al. (2008) found that semi-professional Australian rules football players that produced higher scores for one repetition maximum (1RM) hang power clean relative to body mass also performed better in a 30-m sprint. These types of lifts not only require great strength but also high power outputs, making them a perfect training tool for sports where on-field performance necessitates both strength and power such as rugby union (Brannigan, 2016; Helland, Hole, Iversen et al., 2017; Hori et al., 2008).

Although previous studies have reported correlations between performance in weightlifting exercises and jumping (r = 0.59 to 0.93) and sprinting ability (r = -0.52 to -0.76) (Carlock, Smith, Hartman et al., 2004; Channell & Barfield, 2008; Hori et al., 2008; Tricoli, Lamas, Carnevale, & Ugrinowitsch, 2005), how well these vertically orientated type exercises transfer to match specific physical activities when used as a training tool for elite athletes is unclear (Zweifel, 2017). Furthermore, studies have shown that horizontal force and power have a larger impact on sprinting performance than vertical force and power, especially during the acceleration phase (Buchheit et al., 2014; Cross et al., 2015; Morin et al., 2012; Morin et al., 2011a). Therefore, implementing exercises that are horizontally orientated (e.g. heavy sled tows and prowler sleds) may have a greater transfer to horizontally orientated activities such as sprinting. However, further research is needed to fully understand the effects of exercises that require a horizontally orientated body position and if they transfer to sport specific activities.

Characterisation of cycling and over-ground sprinting

Previous research has analysed the biomechanics and muscle activation patterns of over-ground sprinting (Anderson, 2013; Bosch & Klomp, 2005; Hamner, Seth, & Delp, 2010; Moghaddam, 2015) and cycling (Bini & Diefenthaeler, 2010; Bini, Senger, Lanferdini, & Lopes, 2012; Carpes, Bini, & Quesada, 2014; Diefenthaeler, Coyle, Bini, Carpes, & Vaz, 2012) to gain a greater understanding of how each body segment moves and which muscles are recruited during these activities. Video analysis and surface electromyography (SEMG) has provided detailed information regarding human motion and muscle activity during over-ground sprinting and cycling. Understanding the phases, joint movements and muscle activities that occur during over-ground sprinting and cycling provides a greater knowledge of the importance of each phase and which joint movements and muscles should be targeted in a training programme.

Over-ground sprinting has been divided into four phases: initial contact, mid-stance, propulsion, and swing (Anderson, 2013; Bosch & Klomp, 2005; Hamner et al., 2010; Moghaddam, 2015). The initial contact phase begins when the foot first comes in to contact with the ground. The mid-stance phase comes next and at this point the whole body is balancing on one leg. While one foot is in contact with the ground during this phase the opposite leg will be swinging past the leg that is in contact with the ground preparing for the next step to be taken. The propulsion phase starts just before the support leg leaves the ground and prior to the opposite leg making initial contact. Lastly, during the swing phase the leg that is not in contact with the ground will swing past the support leg to prepare for the next step (Anderson, 2013; Bosch & Klomp, 2005; Hamner et al., 2010; Moghaddam, 2015). It is evident that the initial contact, mid stance and propulsion phases have a significant impact on sprinting performance as this is when the propulsive forces required to push the body forward are generated. Muscles about the hip, knee and ankle joints work as a cohesive unit to produce and transfer force which is consequently applied to the ground to create forward motion (Anderson, 2013; Bosch & Klomp, 2005; Hamner et al., 2010; Moghaddam, 2015). It would seem that training programmes should focus on the joint movements and muscle actions that occur during these phases to improve an individual's sprinting ability. However, an inefficient swing phase (e.g. inadequate flexion of the knee) will result in unnecessary energy being used to bring the leg back in front of the body in preparation for the next step (Anderson, 2013; Bosch & Klomp, 2005; Hamner et al., 2010; Moghaddam, 2015). Furthermore, during the swing phase the muscles used to generate force throughout the other three phases are stretched and elastic energy is stored within the musculotendinous unit. This stored energy is then transferred and utilised to provide additional force in the following phases (Anderson, 2013; Bosch & Klomp, 2005; Hamner et al., 2010; Moghaddam, 2015). Therefore, training programmes that aim to improve an individual's sprinting ability should also incorporate an eccentric-concentric stretch-shorten cycle (SSC) that replicates that of the sprinting gait.

Cycling has also been extensively analysed by video and SEMG (Bini & Diefenthaeler, 2010; Bini et al., 2012; Carpes et al., 2014; Diefenthaeler et al., 2012; Korff, Barrett, & Gardener, 2012). Similar to over-ground sprinting, the forces that drive forward movement during cycling are also caused by concentric extension of the hip and knee in conjunction with concentric plantar flexion of the ankle (Bini & Diefenthaeler, 2010; Bini et al., 2012; Carpes et al., 2014; Diefenthaeler et al., 2012; Korff et al., 2012). The muscles responsible for these contractions (gluteal, hamstrings, gastrocnemius and soleus) work together to form a kinematic chain which produces and transfers force from the body to the pedal of the cycle, almost identical to the initial contact, mid-stance and propulsion phases of the sprinting gait. Moreover, there is also an eccentric-concentric SSC component that occurs during cycling, though not to the extent of over-ground sprinting due to the predominantly concentric nature of cycling and the lack of impact forces during pedalling. As the hip and knee flex and ankle dorsiflexes to bring the pedal back to the top of the cycle revolution, the muscles responsible for generating force during the propulsive phase of cycling are stretched resulting in storage of elastic energy in the musculotendinous unit (Bini & Diefenthaeler, 2010; Bini et al., 2012; Carpes et al., 2014; Diefenthaeler et al., 2012; Korff et al., 2012).

Although there are lower body kinematic and kinetic similarities between over-ground sprinting and cycling, there are also some significant differences. Cycling involves primarily concentric muscle actions to produce movement which results in the amount of eccentric loading being significantly less than over-ground sprinting as there is no ground contact during cycling (Bijker, de Groot, & Hollander, 2002). Furthermore, the upper limbs have a greater role in performance during over-ground sprinting than they do in cycling. As the arms swing past the body during over-ground sprinting they can affect forward momentum (Anderson, 2013; Bosch & Klomp, 2005; Moghaddam, 2015). For example, if the arms swing too far back behind the body, that force is propelled backwards which counteracts against the forward momentum produced by the lower limbs (Anderson, 2013; Bosch & Klomp, 2005; Moghaddam, 2015). However, despite this difference in upper limb kinematics during over-ground sprinting and cycling, the similarities in joint movements and muscle activities of the lower limbs suggest that cycling has the potential to improve over-ground sprinting ability. A visual comparison of lower limb muscle activation patterns during cycling and over-ground sprinting are shown below in Figure 2.

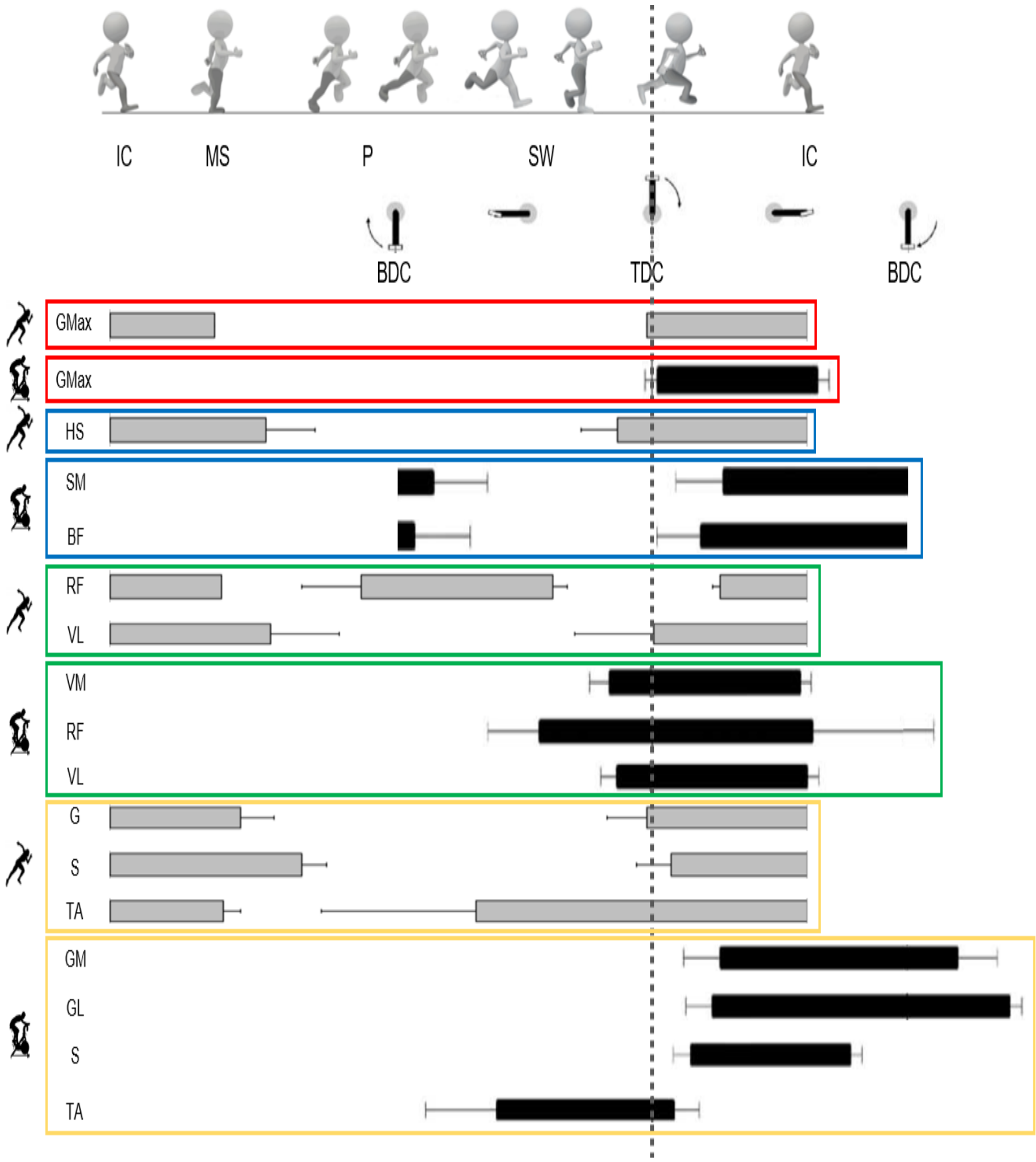

Figure 2. Lower limb electromyography (EMG) comparison between cycling and over-ground sprinting. Adapted from material published by Hug and Dorel (2009) and Howard, Conway, and Harrison (2018). The light grey (over-ground sprinting) and black (cycling) areas represent the mean onset, termination times and duration of muscle activity. The error bars represent the standard deviation (SD) of the mean onset and termination times. Abbreviations: IC, initial contact; MS, mid-stance; P, propulsion; SW, swing; TDC, top dead centre (0°); BDC, bottom dead centre (180°); GMax, gluteus maximus; HS, hamstring; SM, semimembranosus; BF, biceps femoris; RF, rectus femoris; VL, vastus lateralis; VM, vastus medialis; G, gastrocnemius; GM, gastrocnemius medialis; GL, gastrocnemius lateralis; S, soleus; and TA, tibialis anterior.

In terms of training specificity, the most effective way to improve an athletes over-ground sprinting performance would be to include over-ground sprinting exercises into their training programme. However, when an athlete sustains an injury to their lower limbs, weight bearing exercises such as running may be contraindicated to performance (Alkatan et al., 2016; Tanaka, 2009). Furthermore, Brooks, Fuller, Kemp, and Reddin (2005) found that the incidence for training injuries was 6.1/1000 training hours, with 60% of these injuries being to the lower limbs. Brooks and colleagues (2005) also demonstrated that during rugby union training sessions, on-feet conditioning (running) resulted in the highest number of injuries, more than contact and weight sessions, in international level rugby union players. Additionally, the results of Brooks et al. (2005) showed that no injuries were sustained during off-feet conditioning exercises such as rowing and cycling. Though off-feet conditioning results in fewer injuries than on-feet conditioning, it also reduces the relevance of training with respect to the specific match demands of rugby union (Brooks et al., 2005). Therefore, off-feet conditioning methods should not be used to replace traditional on-feet training, but rather as an alternative when a player has already sustained a lower limb injury, or it has been determined that there is a high risk that a player will sustain an injury due to an excessive training load. Because running is such an integral part of rugby union, it is necessary for exercises that aim to improve over-ground running performance to be included into training programmes.

Due to the injury risk associated with running and the amount of stress it places on the musculoskeletal system it is beneficial to develop off-feet training methods that reduce the risk of injury while simultaneously improving over-ground running performance. The kinematic and kinetic similarities between over-ground sprinting and cycling coupled with the reduced risk of injury promote cycling as a potential training method for enhancing over-ground sprint performance. However, the effects of training on a stationary cycle on over-ground sprinting performance in male rugby union players are unclear and further research into this area is warranted.

Repeated-sprint training

Over-ground sprinting is an important factor of performance in many team sports including rugby union. A player’s speed can have a considerable impact on many on-field situations such as avoiding defenders, breaking the line of defence and busting through tackles (Duthie et al., 2006; Smart et al., 2014). Furthermore, rugby union players perform between 19 and 66 maximal effort sprints with work to rest ratios of 1:4 to 1:6 depending on their playing position (Austin et al., 2011). As a result, it is essential that rugby union players are able to execute multiple maximal effort sprints with short rest periods throughout the duration of a match. Thus, it is beneficial for rugby union players to have training methods that develop over-ground sprint performance and RSA incorporated into their training programmes. RST encompasses performing multiple high intensity sprints interspersed by periods of active or passive rest (Boer & Van Aswegen, 2016; Fernandez-Fernandez, Zimek, Wiewelhove, & Ferrauti, 2012; Lockie, Murphy, Callaghan, & Jeffreiss, 2014; Srihirun, Boonrod, Mickleborough, & Suksom, 2014;

Suarez-Arrones, Tous-Fajardo, Núñez et al., 2014; Taylor, Macpherson, Spears, & Weston, 2015). The composition of RST protocols varies depending on the demands of the sport and the performance measures that are being assessed. Sets, repetitions, rest, repetition distance or duration and mode of exercise are all variables that can be manipulated to achieve the desired results from RST.

Many studies have investigated the effects of over-ground sprinting and stationary cycle based RST protocols on various performance measures such as aerobic capacity (Boer & Van Aswegen, 2016; Etxebarria et al., 2014; Fernandez-Fernandez et al., 2012; Montero & Lundby, 2017; Nedrehagen & Saeterbakken, 2015; Rønnestad, Hansen, Vegge, Tønnessen, & Slettaløkken, 2015; Shalfawi, Ingebrigsten, Dillern et al., 2012), sprint time and velocity (Boer & Van Aswegen, 2016; Buchheit, Mendez-Villanueva, Delhomel, Brughelli, & Ahmaidi, 2010; Fernandez-Fernandez et al., 2012; Gmada et al., 2014; Gunnar & Svein, 2015; Lockie et al., 2014; Markovic, Jukic, Milanovic, & Metikos, 2007; Ross, Ratamess, Hoffman et al., 2009; Shalfawi et al., 2012; Spinks, Murphy, Spinks, & Lockie, 2007), maximal lower body power (Boer & Van Aswegen, 2016; Buchheit et al., 2010; Etxebarria et al., 2014; Fernandez-Fernandez et al., 2012; Gmada et al., 2014; Markovic et al., 2007; Polczyk & Zatoń, 2015; Rønnestad et al., 2015; Ross et al., 2009; Shalfawi et al., 2012; Spinks et al., 2007; Suarez-Arrones et al., 2014) and RSA (Buchheit et al., 2010; Etxebarria et al., 2014; Fernandez-Fernandez et al., 2012; Montero & Lundby, 2017; Nedrehagen & Saeterbakken, 2015; Polczyk & Zatoń, 2015; Rønnestad et al., 2015; Shalfawi et al., 2012; Suarez-Arrones et al., 2014). RST has been shown to cause a high degree of neuromuscular and metabolic stress which results in improvements to both aerobic and anaerobic attributes (Taylor et al., 2015). Thus, the results from these studies suggest that repeated stationary cycle sprints may be a beneficial training method for rugby union players as RST has been shown to increase specific physical attributes that are crucial to on-field performance.

The effects of repeated-sprint training on aerobic function

Determining the effects of RST on aerobic capacity has been the aim of numerous studies in recent times. Research has shown that 3-10 weeks of over-ground sprinting or cycling RST can cause improvements in aerobic capacity which has been observed through increased VO_2peak outputs and yo-yo intermittent recovery test (yo-yo) scores of football players (Boer & Van Aswegen, 2016; Nedrehagen & Saeterbakken, 2015), tennis players (Fernandez-Fernandez et al., 2012), triathletes (Etxebarria et al., 2014) and cyclists (Rønnestad et al., 2015). However, increases in yo-yo performance and VO_2peak were not always observed after RST. Montero and Lundby (2017) found that four weeks of RST on a cycle in normoxia and hypoxia had no effect on VO_2peak in highly trained cyclists. Furthermore, Shalfawi et al. (2012) reported a decrease in yo-yo performance in elite male football players following eight weeks of RST. It is surprising that these studies resulted in such conflicting results as there were no significant differences in the training protocols implemented by these researchers. It is possible that the protocols used by Montero and Lundby (2017) and Shalfawi et al. (2012) did not provide their participants with a sufficient stimulus to improve their aerobic capacity as the participants of these studies were well trained and already had high levels of aerobic capacity prior to starting RST. Collectively, the results of these studies suggest that RST has the potential to improve aerobic capacity, although, contradicting results from recent studies indicates the need for further research to be conducted regarding the effects of RST on aerobic capacity.

The effects of repeated-sprint training on sprint ability and power output

Faster sprint times, increased sprint velocities over distances ranging from 5-40 m and greater RSA scores have been reported following RST programmes lasting 6-12 weeks in athletes of various sports including American football, football, rugby union and triathlon (Boer & Van Aswegen, 2016; Buchheit et al., 2010; Etxebarria et al., 2014; Gmada et al., 2014; Gunnar & Svein, 2015; Lockie et al., 2014; Markovic et al., 2007; Nedrehagen & Saeterbakken, 2015; Ross et al., 2009; Shalfawi et al., 2012; Spinks et al., 2007; Suarez-Arrones et al., 2014).

Performing repeated-sprints during RSA tests or RST programmes requires maximal power outputs to be maintained for a prolonged period. Thus, the effects of RST on lower body power output have been determined from various jump tests such as a countermovement jump (CMJ) (Buchheit et al., 2010; Fernandez-Fernandez et al., 2012; Markovic et al., 2007; Shalfawi et al., 2012; Spinks et al., 2007), squat jump (SJ), vertical jump (VJ) (Boer & Van Aswegen, 2016; Markovic et al., 2007; Shalfawi et al., 2012), standing long jump (SLJ) and five-bound test (5BT) (Boer & Van Aswegen, 2016; Gmada et al., 2014; Markovic et al., 2007). Spinks et al. (2007) reported that after their participants had completed a total of 16 resisted (weighted sled towing) or non-resisted RST sessions they observed increases in maximal CMJ height from 37.4 ± 4.4-cm to 39.6 ± 4.2-cm ($p < 0.001$) and maximal distance covered during a 5BT from 11.4 ± 0.7-m to 12.2 ± 0.9-m ($p < 0.001$). The results of Spinks et al. (2007) have been supported by numerous recent studies which have all reported increases in VJ or CMJ height following a RST programme (Boer & Van Aswegen, 2016; Buchheit et al., 2010; Markovic et al., 2007; Shalfawi et al., 2012). Furthermore, Gmada et al. (2014) reported that RST resulted in a greater distance covered during a 5BT, and both Boer and Van Aswegen (2016) and Markovic et al. (2007) saw an increase in distance jumped during a SLJ after RST. Furthermore, Suarez-Arrones et al. (2014) reported significantly increased power outputs from 907.8 ± 104.2 Watts (W) to 949.4 ± 82.1 W during an incremental loaded jump test following a RST programme. The results of these studies suggest that RST provides a sufficient training stimulus to cause significant improvements in lower body power outputs in both horizontal and vertical directions. This is important as lower body power is a significant contributor to performance in tasks such as sprinting which is a crucial component of rugby union (Smart et al., 2014).

In contrast to the positive outcomes of these studies, Fernandez-Fernandez et al. (2012) reported no improvement in CMJ height following their RST protocol. Fernandez-Fernandez et al. (2012) implemented a protocol involving three sets of ten, 5-s sprints with 15-s of rest between sprints and a two on one game of tennis between sets. It is likely that the participants of this study experienced a long continuous training session which would have targeted their aerobic capacity as opposed to lower body power. This is evident in the fact that Fernandez-Fernandez et al. (2012) reported significant improvements in VO_2peak and no change in CMJ height. Based on the results of previous literature it is likely that RST has a positive impact on both vertical and horizontal lower body power output in athletes from a variety of sports (Boer & Van Aswegen, 2016; Buchheit et al., 2010; Gmada et al., 2014; Markovic et al., 2007; Shalfawi et al., 2012; Spinks et al., 2007; Suarez-Arrones et al., 2014). However, the RST programme must be designed in a way that allows each sprint to be performed at a high intensity with sufficient rest between sprints and sets for succeeding sprints to be performed with maximal effort. The improvement in lower body power output elucidated by previous researchers suggests that RST has the potential to develop over-ground sprint performance as lower body power has been identified as a significant contributor to over-ground sprint performance (Buchheit et al., 2014; Morin et al., 2012).

Power output has been shown to have a strong positive correlation with sprinting speed (Buchheit et al., 2014; Morin et al., 2012). Furthermore, Buchheit et al. (2014) found that individuals that exhibited greater acceleration capabilities also produced larger maximal power outputs during a 40-m sprint recorded by a radar. Therefore, it is possible that RST could improve over-ground sprint performance as it has been shown to have a positive effect on lower body power output. Various sprint distances ranging from 5- to 40-m have been used to investigate the effects of RST on over-ground sprint performance. Moreover, sprint performance over these distances was determined by either the time it took to cover the distance or the maximal velocity reached at a certain distance (Boer & Van Aswegen, 2016; Buchheit et al., 2010; Fernandez-Fernandez et al., 2012; Gmada et al., 2014; Gunnar & Svein, 2015; Lockie et al., 2014; Markovic et al., 2007; Ross et al., 2009; Shalfawi et al., 2012). All but one study found that RST resulted in either faster sprint times or an increase in velocity. Markovic et al. (2007) showed that ten weeks of RST caused a significant decrease in 20-m sprint times. Similarly, faster sprint times over distances of 5-, 10-, 20-, 30- and 40-m have been reported after RST (Buchheit et al., 2010; Gmada et al., 2014; Gunnar & Svein, 2015; Lockie et al., 2014; Ross et al., 2009; Shalfawi et al., 2012). Additionally, Boer and Van Aswegen (2016) found that a six-week RST intervention was able to significantly increase sprint velocity over 30-m.

The aforementioned studies have either investigated the effects of over-ground RST on over-ground sprinting ability or off-feet RST on off-feet sprinting ability. The kinetic and kinematic similarities between over-ground sprinting and cycling suggest that off-feet RST on a stationary cycle may be an effective method for improving over-ground sprint performance and to date, only one study has looked at the effects of off-feet RST on over-ground sprinting performance. Gmada et al. (2014) investigated the effects of a 12-week RST programme on peak leg power in female football players. The effectiveness of the RST programme was determined by comparing the results of two groups; RST and control. The RST programme involved performing two sets of 15, 5-s sprints on a mechanically braked cycle ergometer (Monark 894E, Vansbro, Sweden) with 55-s between sprints and 15-minutes between sets. The RST group saw over-ground sprint times over 20- and 30-m decrease by -0.5 ± 0.3 s and -0.52 ± 0.4-s respectively. This was significantly greater than the improvements in sprint times seen in the control group, -0.01 ± 0.06-s and -0.03 ± 0.05-s for 20- and 30-m times respectively. Furthermore, the RST group saw greater increases than the control group in peak power output during a repeated maximal sprint test performed on a cycle ergometer, 96.4 ± 64 W and 43.9 ± 64.4 W for the RST and control groups respectively. The results of Gmada et al. (2014) provide evidence that cycle ergometers such as Wattbikes may be an effective training tool for improving over-ground sprinting ability and lower body peak power output. However, Gmada et al. (2014) did not investigate the effects of repeated cycle sprints on over-ground RSA which is a vital part of rugby union (Smart et al., 2013). Additionally, the participants of the study conducted by Gmada et al. (2014) were young female football players, therefore, these results may not be generalised in males of different sporting codes such as rugby union.

The only study that presented no change in sprint performance following RST was by Fernandez-Fernandez et al. (2012). As mentioned before, it is possible that the training programme implemented by Fernandez-Fernandez et al. (2012) was more suited for targeting aerobic performance. However, it is clear that there is a strong positive correlation between RST and sprint performance over distances ranging from 5- to 40-m (Boer & Van Aswegen, 2016; Buchheit et al., 2010; Gmada et al., 2014; Gunnar & Svein, 2015; Lockie et al., 2014; Markovic et al., 2007; Ross et al., 2009; Shalfawi et al., 2012). As the average distance rugby union players sprint during a match is 20-m, improvements in sprint performance over 5- to 40-m would have a significant impact on many in-game situations such as chasing down an attacking player that has broken the line of defence.

The current literature shows that there are many different adaptations that occur after RST including increases in VO_2peak, lower body power output, RSA and over-ground sprint performance which would all be beneficial to rugby union players. Though it seems that the changes in performance observed after RST are reliant on the protocol that is employed. Therefore, to gain the most benefit from RST the number of sets, repetitions, rest and exercises used should be carefully considered before a programme is designed. Currently no studies have looked at how repeated sprints on a Wattbike could affect lower body horizontal power and power endurance in rugby union players and further research is warranted in this area.

A summary of the aforementioned studies is provided in Table 1 below. This includes the study's cohort, the RST intervention implemented, the length of the intervention, frequency of training sessions, details of the training protocol, and the performance outcomes that were measured before and after each intervention.

Table 1.

Effects of RST

Author(s)	Subjects	Age	Duration (weeks)	Frequency (per week)	Mode of exercise	Training protocol						Testing
						Sets	Reps	Rep distance (m)	Rep duration (s)	Inter-rep rest (s)	Inter-set rest (s)	
(Boer & Van Aswegen, 2016)	17 Sub-elite male soccer players	22 ± 1.3	6	3	Running	3	6	40		10	240	YY, 30-m, Ag, VJ, SLJ, VO_2peak
(Buchheit et al., 2010)	7 Elite male youth soccer players	14.5 ± 0.5	10	1	Running	2-3	5-6	15-20		14-23		10-m, 30-m, RSA, CMJ, Hop
(Etxebarria et al., 2014)	7 Trained male triathletes	33 ± 8	3	2	Cycling	3	3-4		10-40	30-120		VO_2peak, RSA
(Fernandez-Fernandez et al., 2012)	12 Male tennis players	21.2 ± 5.1	6	3	Running	3	10	10-22		15	480	VO_2peak, 20-m, RSA, CMJ
(Lockie et al., 2014)	8 Male field sport athletes	21.8 ± 2.5	6	2	Running	1-3	3-5	5-20				5-m, 10-m
(Markovic et al., 2007)	30 Male PE students	20.1 ± 1.1	10	3	Running	3-4	3	10-50		60	180	ISOS, SJ, CMJ, DJ, SLJ, 20-m

Table 1. Continued.

Effects of RST

Author(s)	Subjects	Age	Duration (weeks)	Frequency (per week)	Mode of exercise	Training protocol						Testing
						Sets	Reps	Rep distance (m)	Rep duration (s)	Inter-rep rest (s)	Inter-set rest (s)	
(Gunnar & Svein, 2015)	10 Female youth soccer players	15.5 ± 0.7	8	1	Running	4	8	15-20	3-6	60-90		10-m, 20-m, Ag
(Montero & Lundby, 2017)	15 Trained males	24.9 ± 3.7	4	3	Cycling	4	5		10	20	300	RSA, VO_2peak
(Gmada et al., 2014)	14 Female soccer players	20.2 ± 1.5	12	3	Cycling	2	15		5	55	900	5BT, 10-m, 20-m, 30-m
(Nedrehagen & Saeterbakken, 2015)	22 Male and female soccer players	20.3 ± 3.0	8	1	Running	3-4	4-6	30		30	300	YY, RSA
(Polczyk & Zatoń, 2015)	13 Soccer players	16.6 ± 0.8	8	2	Running	2-4			15	45	900	Wingate
(Rønnestad et al., 2015)	9 Competitive male cyclists	33 ± 10	10	2	Cycling	3	13		30	15	180	VO_2peak, Wingate

Table 1. Continued.

Effects of RST

Author(s)	Subjects	Age	Duration (weeks)	Frequency (per week)	Mode of exercise	Training protocol						Testing
						Sets	Reps	Rep distance (m)	Rep duration (s)	Inter-rep rest (s)	Inter-set rest (s)	
(Ross et al., 2009)	6 Former athletes	19.8 ± 1.8	7	2	Running	1-3	8-12	40-60			120-180	30-m, MST, 1RM Sq
(Shalfawi et al., 2012)	15 Elite male youth soccer players	16.3 ± 0.5	8	2	Running	4	5	40		90	600	40-m, RSA, Ag, CMJ, SJ, YY
(Spinks et al., 2007)	20 Male soccer, rugby union and AF players	21.8 ± 4.2	8	2	Running	1-3	4-6	5-20		45-120	60-120	5-m, 10-m, 15-m, CMJ, 5BT, DJ
(Suarez-Arrones et al., 2014)	10 sub-elite rugby union players	27 ± 2.2	6	2	Running	3	6	40		20	240	RSA, CMJ

Note. Age is presented as mean ± SD. Abbreviations: 5-m, 10-m, 15-m, 20-m, 30-m, 40-m, over-ground sprint distances; 1RM Sq, one-repetition maximum squat; Ag, agility; 5BT, five-bound test; CMJ, countermovement jump; DJ, drop jump; Hop, hop test; SJ, squat jump; SLJ, standing long jump; VJ, vertical jump; ISOS, isometric squat; MST, maximal sprint test on non-motorised treadmill; RSA, repeated-sprint ability; YY, yo-yo intermittent recovery.

Conclusions and directions for future research

Rugby union is a complex and physically demanding sport, requiring players to possess a variety of physical characteristics including strength, power and aerobic capacity. Lower body horizontal power and power endurance are essential for tasks such as sprinting. Having the ability to repeatedly produce maximal power outputs through the lower limbs during a match is beneficial to rugby union players as it would enable them to execute multiple sprints successfully, giving them a greater chance of getting away from a defending player or chasing down an attacking player. There are many traditional methods used to develop lower body power in rugby union players, however, unique training equipment is constantly being produced, which could potentially provide new and improved methods for training athletes. Currently, only one study has investigated how RST on a stationary cycle affects over-ground sprint performance, and no studies have investigated how RST on a stationary cycle affects over-ground RSA. There are numerous kinetic and kinematic similarities between cycling and over-ground sprinting which suggest there may be a transference effect from training on a stationary cycle to over-ground sprinting performance. Furthermore, cycling places less stress on the musculoskeletal system than over-ground running which greatly decreases the risk of injury, making it an effective off-feet conditioning method for minimising excessive loading during training. Because stationary cycles such as Wattbikes are used as training tools by many field sport athletes including rugby union players, it would be beneficial to determine if RST on a stationary cycle results in improvements in horizontal power and power endurance during over-ground sprinting.

Chapter 3

Methods

Study design

This study aimed to investigate the effects of repeated Wattbike sprints on lower body horizontal power and power endurance in rugby union players. Participants performed a 30-m sprint and RSA test prior to a four-week RST programme. After the initial testing, participants were assigned to either a control, Wattbike, or treadmill group. It was not possible to randomly assign participants to each group as coaches requested that certain players remained grouped. The Wattbike group participated in a four-week RST intervention on a Wattbike Pro cycle ergometer (Wattbike Ltd, Nottingham, UK). Furthermore, the treadmill group completed the same four-week RST intervention on a Star Trac motorised treadmill (Core Health and Fitness, Vancouver, WA, USA). Participants in the control group did not perform any RST during the four-week intervention. All groups continued with their regular training programmes throughout the duration of the intervention. After the RST intervention, all participants repeated the 30-m sprint and RSA test. Ethical approval for this study was granted by the Auckland University of Technology Ethics Committee.

Subjects

Twenty male rugby union athletes volunteered to participate in this study. However, due to dropouts and injuries, fourteen participants completed the study. All participants recruited for this study were competing in either a secondary school level first fifteen rugby union team, or a development team for a Mitre 10 Cup franchise. Thirteen of the participants were backs (either halfback, first five, second five, centre or wing) while the fourteenth participant was a forward (prop). A description of the participant's characteristics is provided below in Table 2. A description of each training group including the number of forwards and backs, which team they belong to, and the number of hours spent on external training each week is given in Table 3. All participants were devoid of injury and provided written informed consent prior to participating in this study.

Table 2.

Participant characteristics

	Age	Height	Weight	Training age
Control (n = 4)	19.5 ± 2.1	185.7 ± 9.6	99.1 ± 13.0	1.7 ± 0.5
Wattbike (n = 6)	19.2 ± 2.4	185.3 ± 5.7	100.5 ± 8.4	1.7 ± 0.8
Treadmill (n = 4)	16.8 ± 0.5	180.8 ± 10.0	99.3 ± 18.6	1.8 ± 0.5

Note. Participant age, height, weight and training age are presented as mean ± SD

Table 3.

Playing position, team, and external training hours of each group

	Playing position		Team		External training	
	Forward	Back	Mitre 10	Secondary school 1st 15	Strength (hr/week)	On-field/skills (hr/week)
Control	n = 0	n = 4	n = 4	n = 0	4	4
Wattbike	n = 0	n = 6	n = 6	n = 0	4	4
Treadmill	n = 1	n = 3	n = 0	n = 4	4	4

Testing

All testing was conducted at the same time of day on an indoor artificial grass surface. Pre-testing was conducted within seven days of the first training session and post-testing was conducted within seven days of the final training session. Both testing sessions were conducted prior to any other testing or training that was occurring that day. The participants performed both tests wearing their regular running shoes and athletic clothing. All participants were familiar with the 30-m sprint and RSA test; therefore, no familiarisation session was required. However, a detailed description of the testing procedures and a demonstration of each test was provided prior to the participants performing each test. On both testing occasions, the participants were taken through a 15-minute warm-up which consisted of 5-minutes of jogging followed by multiple dynamic stretches of the whole body and three submaximal 30-m sprints at ~70-90% of their maximal sprinting velocity. There was a 3-minute passive rest period after the warm-up was completed. The participants performed the 30-m sprint first which was followed by 5-minute active rest period, which was restricted to walking around the testing facility before they completed the RSA test. On a separate day to the 30-m sprint and RSA test, the participants of the Wattbike group also performed a 6-s sprint test on the Wattbike ergometer. The 6-s sprint test was conducted 48 hours after the 30-m sprint and RSA test. All aspects of testing were identical including time of day, meals, warm-ups, order of testing and rests. Participants were asked to record their food intake prior to the pre-testing session to ensure they would be able to repeat it before the post-testing session.

30-m sprint

After completing the warm-up, all participants performed three maximal effort 30-m sprints which were followed by 3-minutes of passive rest. For each sprint, the participant would position themselves at the starting line in a standing split-stance with their preferred lead foot forward directly behind a line of tape that was secured to the ground 50 cm behind the starting line. Each sprint was performed at maximal velocity through a straight path marked by parallel cones at 10 m increments. The participants were instructed to sprint “through” each set of cones to ensure each sprint was devoid of any deceleration. Each participant received strong verbal encouragement from the researcher throughout all sprints. All sprints were tracked using a Stalker Acceleration Testing System (ATS) II radar device (Applied Concepts Inc, Dallas, TX, USA). The radar device was secured to a heavy-duty tripod via a bracket adapter positioned 3 m behind the starting line and at a height of 1 m above the ground which approximately corresponds to the participant’s centre of mass. The radar device was remotely operated via a laptop connection and was set to measure the participant’s forward sprinting velocity at a rate of 46.9 samples/s. Previous studies that have examined sprinting performance have compared this device against photoelectric cells which has proven its validity (Chelly & Denis, 2001; di Prampero, Fusi, Sepulcri, & Antonutto, 2005; Morin, Jeannin, Chevallier, & Belli, 2006). All radar data were collected using STATS software (Stalker ATS II Version 5.0.2.1, Applied Concepts, Dallas, TX, USA) provided by the radar device’s manufacturer. The raw data sets were then analysed with a custom-designed LabVIEW program (Version: 14.0, National Instruments Corp, Austin, TX, USA). The reliability of this testing method has been investigated with the results presenting coefficient of variation values of 2.93 ± 2.00%, 1.11 ± 0.86%, and 1.87 ± 1.36% for F_0, V_0 and P_{max}, respectively (Samozino, Rabita, Dorel et al., 2016). Key variables of interest to this study were; theoretical maximal velocity (V_0), peak velocity (V_{max}), absolute theoretical maximal horizontal force (F_0), relative theoretical maximal horizontal force (Rel F_0), absolute peak horizontal power (P_{max}), relative peak horizontal power (Rel P_{max}), peak ratio of force (RF_{peak}), theoretical optimal ratio of force (RF_{Opt}), and sprint times (5-, 10-, 20- and 30-m). The LabVIEW program used in this study calculates a force-velocity profile for each participant from the raw radar data. In each of the force-velocity profiles F_0 represents the *x*-intercept while V_0 represents the *y*-intercept (Figure 3). Additionally, a force application profile is also calculated which illustrates how each participant applies force horizontally against the ground as velocity increases during over-ground sprinting. RF_{Opt} represents the *x*-intercept of the force application profile (Figure 4).

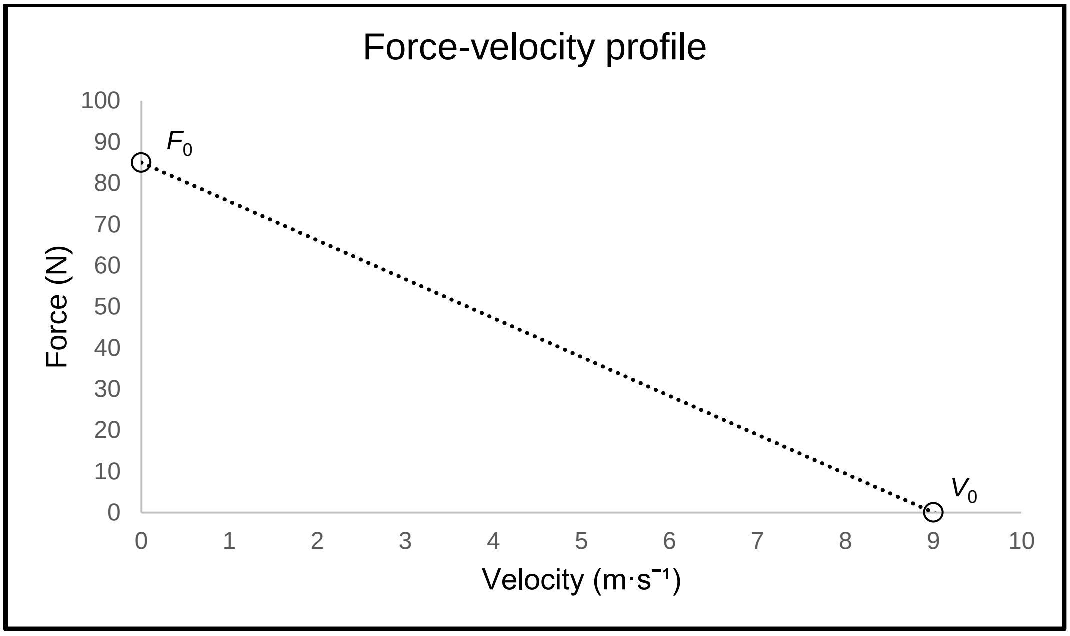

Figure 3. Over-ground sprint force-velocity profile. Abbreviations: F_0, absolute theoretical maximal horizontal force; V_0, theoretical maximal velocity.

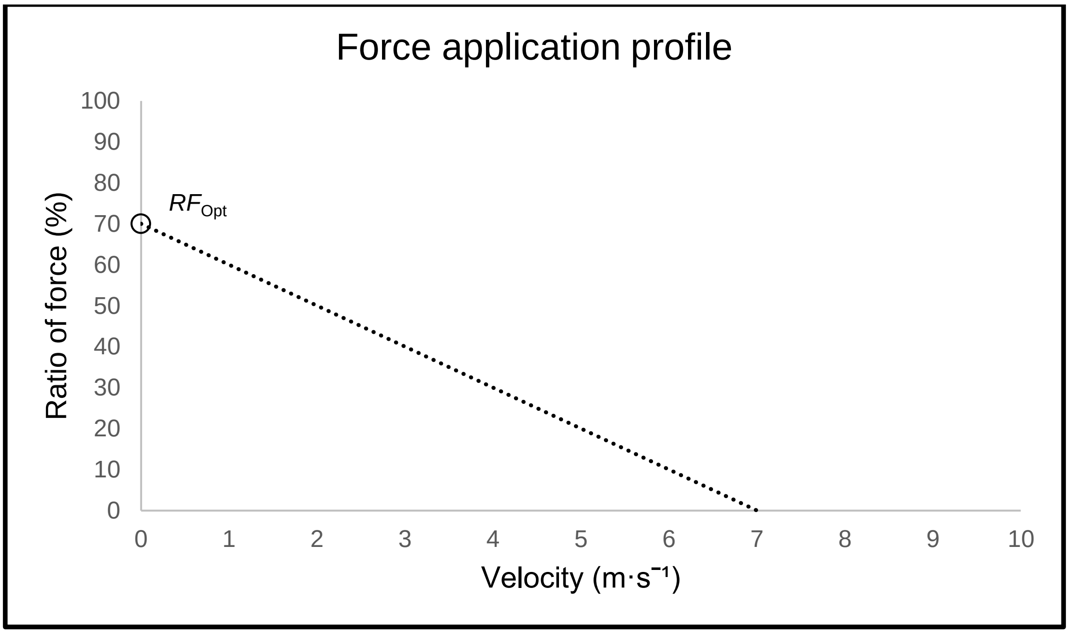

Figure 4. Over-ground sprint force application profile. Abbreviations: RF_{Opt}, theoretical optimal ratio of force.

RSA test

Following the 30-m sprint testing, the participants had 5-minutes of active rest prior to starting the RSA test. The RSA test involved six repetitions of 2 x 20-m maximal shuttle sprints interspersed by 20-s of passive rest between repetitions (Gatterer, Philippe, Menz et al., 2014; Gonzalo-Skok, Tous-Fajardo, Arjol-Serrano et al., 2016; Nedrehagen & Saeterbakken, 2015). The participants started each shuttle sprint in a standing split-stance with their preferred lead foot forward. Their lead foot was placed on a line that was set 50 cm behind the starting line of the 20-m shuttle. Another line was positioned across the 20-m mark. Participants were instructed to run at maximal velocity towards the 20-m mark, place one foot over the line marking the 20-m distance then turn and sprint back through the starting line. Each participant received strong verbal encouragement from the researcher during all shuttle sprints. During the 20-s rest period between sprints the participants were to remain standing. The participants were informed when there was 10-s of rest remaining, at which point they would get into their starting position, ready for the next sprint. A 5-s countdown was given to all participants followed by the command “go” which signalled the start of the next sprint. Each sprint time was recorded by a single timing gate which was positioned on the starting line, SMARTSPEED LITE (Fusion Sport, Chicago, IL, USA). SMARTSPEED LITE is a processed single beam gate that can be used to measure sprint times over various distances. Single beam timing gates are subject to frequent errors caused by the hands, feet or other body parts passing through the gate before the torso. This can seriously affect the accuracy of testing. However, all timing gates developed by Fusion Sport are equipped with error correction processing systems which have been shown to eliminate these errors (Earp & Newton, 2012). Each participant’s fastest sprint time (RSA_f), slowest sprint time (RSA_s), mean sprint time (RSA_m), and percentage decrement ($RSA_{\%DEC}$) were recorded for the RSA test. The percentage decrement was calculated using the formula listed below:

Percentage decrement ($RSA_{\%DEC}$) = (100 x (total sprint time/ideal sprint time)) – 100

Ideal sprint time was calculated by multiplying the fastest sprint time by six as this would represent a zero percent decrement in performance during the RSA test. Previous research has shown that this method is a valid way to quantify fatigue during repeated sprint performance (Glaister, Howatson, Pattison, & McInnes, 2008). The reliability of this test has been shown by intraclass correlation coefficient values with 90% confidence intervals (CI) of 0.87 (CI = 0.75 to 0.94), 0.81 (CI = 0.63 to 0.90), 0.94 (CI = 0.87 to 0.97), and 0.53 (CI = 0.22 to 0.74) for RSA_f, RSA_s, RSA_m, and $RSA_{\%DEC}$, respectively (Gonzalo-Skok et al., 2016).

Wattbike 6-s sprint test

In addition to the RSA test and 30-m sprint, the participants in the Wattbike group also performed a 6-s sprint test on a Wattbike ergometer to determine their peak velocity during cycling. The results of this test were used to determine the power output of each participant in the Wattbike during the training sessions. As the participants of the control and treadmill groups were not performing any training sessions on a Wattbike they were not required to complete Wattbike 6-s sprint test. Before the testing took place, the participants completed 5-minutes of cycling on the Wattbike at a slow, steady pace followed by the same dynamic stretches performed in the standardised warm-up used during the previous testing sessions and three submaximal 6-s sprints on the Wattbike at ~70-90% of their peak velocity. Prior to starting the test each

Wattbike had to be set up for the participant. The seat height was adjusted so that the participants knee was close to full extension when the foot was at the bottom of the crack cycle. Furthermore, the handlebars were set at half the height of the seat to force the participants to lean forward when on the Wattbike. Moreover, both the seat and handlebars were positioned as far forward as possible to create greater forward lean which better represents the position of the body during the acceleration phase of sprinting (Kugler & Janshen, 2010; Majumder & Robergs, 2011). The difference in bike set up and forward lean between a traditional Wattbike set up and the set up used in this study can be seen in Figure 3. A greater forward lean during the acceleration phase of sprinting has been strongly correlated (r = 0.93, p < 0.001) with larger horizontal and propulsive forces which are significant contributors to sprinting performance (Kugler & Janshen, 2010).

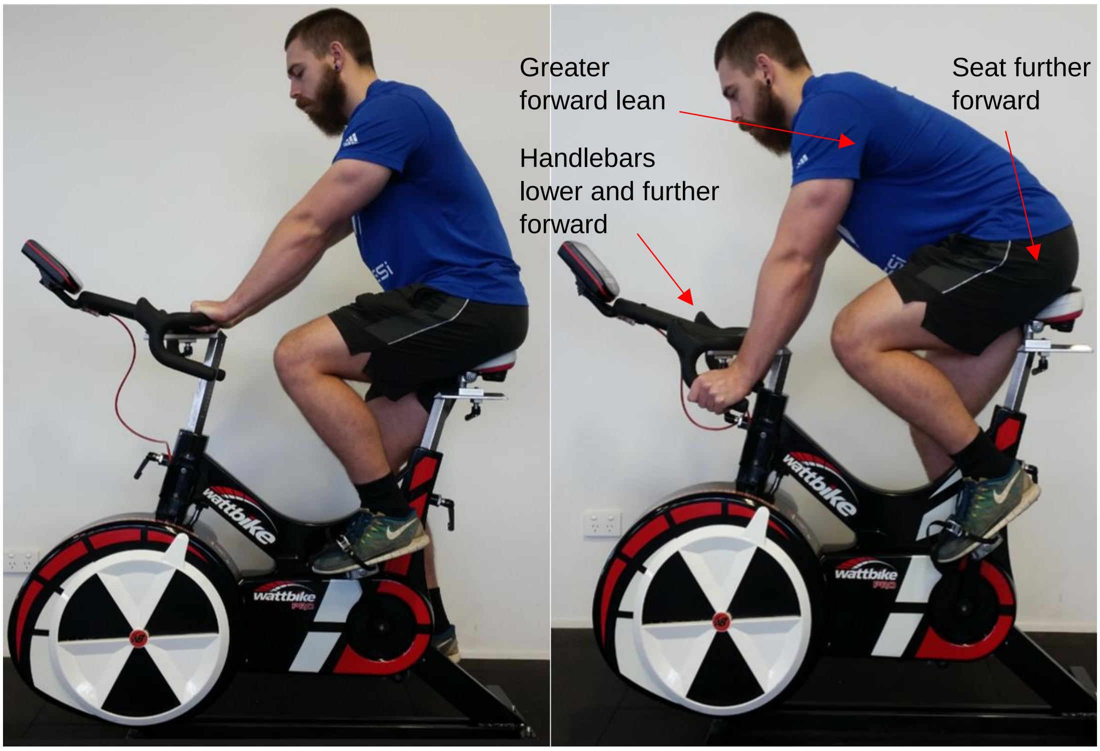

Figure 5. Difference in Wattbike set up and forward lean. Traditional set up (left). Set up used in this study (right).

The participants were instructed to keep their hands on the drop-down part of the handlebars and to remain seated during the 6-s sprint test. At the start of each sprint the participants would get into their starting position with their dominant foot initiating the first down-stroke of the pedal. All participants performed a familiarisation session of the 6-s sprint test 48 hours prior to the official testing session. The air braking resistance of the Wattbike was set to level ten and the magnetic resistance was set to level one in accordance with the protocol used by Herbert et al. (2015). The 6-s sprint test was repeated three times with a passive rest period of 3-minutes between each sprint. The Wattbike was connected to a laptop via a

Bluetooth ANT2 USB device (Wattbike Ltd, Nottingham, UK). Peak velocity in kilometres per hour (KPH) was recorded for each sprint.

Training intervention

Following the initial testing session, the participants that were assigned to the Wattbike and treadmill groups performed four weeks of RST. The participants in both groups performed two RST sessions each week with 48 hours between the two sessions. At the start of each session the participants completed a standardised warm-up. The warm-up for the Wattbike group consisted of 5-minutes of cycling on the Wattbike at 30-40% of their peak velocity followed by the same dynamic stretches used during the testing sessions. Furthermore, the warm-up for the treadmill group consisted of 5-minutes of jogging on the treadmill at 30-40% of the peak velocity reached during the 30-m sprint followed by the same dynamic stretches used during the testing sessions. After completing the warm-up, the participants started the RST session. The RST programme was designed according to work to rest ratios of rugby union backs (i.e. 1:6) as the majority or the participants were backs, and current strength and conditioning guidelines (Austin et al., 2011; Baechle & Earle, 2008; Gamble, 2013; Joyce & Lewindon, 2014). The training stimulus for both intervention groups was equated using percentages of the peak velocity reached during the 30-m sprint for the treadmill group and the peak velocity reached during the 6-s sprint test for the Wattbike group. Research has suggested that velocity-based training programmes are an appropriate training method when the aim of the training programme is to improve performance in activities that involve high movement velocities such as sprinting (González-Badillo & Sánchez-Medina, 2010; Murray & Brown, 2006; Pareja-Blanco, Rodríguez-Rosell, Sánchez-Medina, Gorostiaga, & González-Badillo, 2014; Pereira & Gomes, 2003; Ramírez, Núñez, Lancho, Poblador, & Lancho, 2015). The RST programme was the same for both groups and is presented in Table 3.

Table 4.

RST programme for Wattbike and treadmill groups

Week	Velocity (% of maximal)	Sets	Reps	Duration of reps (s)	Rest between reps (s)	Rest between sets (s)
1	80	3	5	5	30	180
2	90	3	6	5	30	180
3	85	3	8	5	30	180
4	95	3	5	5	30	180

Wattbike

All participants in the Wattbike group performed a familiarisation session of the Wattbike training protocol 48 hours prior to the first RST training session. The familiarisation session consisted of 5-s sprints at varying speeds between 80 and 95% of the participant's peak velocity reached during the 6-s sprint test. After the familiarisation session all participants were capable of maintaining a given speed for multiple sprints. The Wattbikes were set up in the same configuration that was used during the 6-s sprint test for every RST session. After completing the same standardised warm-up protocol described previously the participants in the Wattbike group had 3-minutes of passive rest prior to beginning the first set of sprints. During each set the participants could monitor their speeds on a screen that is attached to the Wattbike to ensure they were reaching and maintaining the correct speed for the session. Furthermore, each Wattbike was connected to a laptop via a Bluetooth ANT2 USB device (Wattbike Ltd, Nottingham, UK) which was placed in front of the researcher so that they could also monitor the speeds of the participants in real-time. Prior to the start of each sprint the participants were instructed to assume the same starting position that was used during the 6-s sprint test with their hands on the drop-down part of the handlebars and their dominant foot initiating the first down-stroke. Moreover, the participants were instructed to remain seated during each sprint. During each rest period between sprints the participants remained on the Wattbike in their starting position and a 10-s countdown was given prior to the start of the next sprint. Additionally, the participants were informed when there was 1-minute of rest remaining between sets and once again assumed their starting position when there was 30-s before the first sprint of the next set. A 10-s countdown was given before the commencement of the following set.

Motorised treadmill

All participants in the treadmill group performed a familiarisation session of the treadmill training protocol 48 hours prior to the first RST training session. The familiarisation session consisted of 5-s sprints at varying speeds between 80 and 95% of the participant's peak velocity reached during the 30-m sprint. After the familiarisation session it was evident that the participants were confident with the protocol and would be able to complete all sessions. At the beginning of each session the participants would complete the warm-up that was previously described. After completing the warm-up, the participants would set their treadmills to the speed that corresponded to 80, 85, 90, or 95% of their peak velocity. The treadmills were kept at a constant speed for each sprint and were only slowed to a stop after a set was completed. Before a sprint was started, the participants would stand with their feet on the frame of the treadmill on either side of the treadmill belt with their hands holding on to the supports (Figure 4). The participants were given a 10-s countdown prior to the start of each sprint. During the last 5-s of the countdown the participants would keep one foot on the frame of the treadmill while repeatedly running their opposite foot over the belt of the treadmill to get comfortable with the speed (Figure 5). At the end of the countdown the participants would start running on the treadmill, removing both hands from the support as soon as possible. A 3-s countdown was given during the last 3-s of each sprint, after which the participants would place their hands back on the supports to lift themselves off the moving belt and place their feet back on the frame of the treadmill (Figure 4). Between subsequent sets, the researcher would inform the participants when there was 1-minute of rest remaining, so the participants could prepare themselves accordingly.

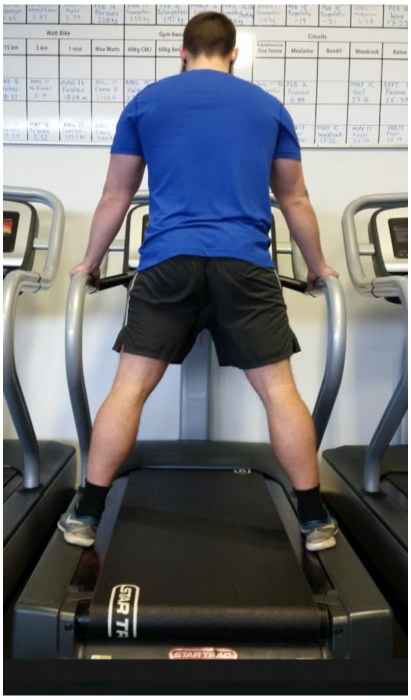

Figure 6. Participant's position on the treadmill before and after each sprint.

Figure 7. Movement of the participant's swing leg during the last 5-s before each sprint.

Statistical analysis

All data are presented as mean ± standard deviations (SD) and effect size (ES) ± 90% confidence limits (CL). Magnitude-based inferences were used to analyse within- (Post-only crossover.xls) and between-group (Pre-post parallel groups trial.xls) changes using Excel spreadsheets from sportsci.org. The smallest worthwhile change (SWC) was set to an equivalent value to Cohen's *d* of 0.2. For all variables, Cohen's *d* statistic was calculated as the estimated marginal means divided by the square root of N multiplied by the Standard Error (i.e. the standard deviation) to provide additional information on the magnitude of the associations, with 0.2, 0.5, and 0.8 representing small, moderate, and large effects, respectively (Cohen, 1992). Threshold values of <0.2, 0.2 to <0.6, 0.6 to <1.2, and >1.2 were then used to analyse the calculated standardised effects. These threshold values represented differences of trivial, small, moderate and large respectively. Qualitative probabilities that changes were higher than, lower than, or similar to the smallest worthwhile change were evaluated as possibly, 25% to 74.9%; and likely 75% to 94.9%. Positive and neutral descriptors qualitatively describe the differences in the descriptive statistics within and between each group. Positive descriptors refer to any increases from pre- to post-testing. Neutral descriptors refer to any decreases from pre-to post-testing. Neutral is used as the descriptors are not an indication of whether the change is negative or not. When probabilities of the effect were >5%, both positive and negative, the effect was deemed to be unclear (Hopkins, Marshall, Batterham, & Hanin, 2009). Changes in pre-post means with 90% CL were calculated to provide an estimate of where the true value lies.

Chapter 4

Results

Differences in participant characteristics

Chronological age showed that the participants in the treadmill group were younger than those in the control group (ES = -1.38 ± 1.26), and the participants in the Wattbike group were also older than those in the treadmill group (ES = 1.20 ± 1.01). Between-group differences for all other participant characteristics were unclear.

Sprint times

The Wattbike group had moderate to large improvements in sprint times for each distance; 5-m (ES = -1.18 ± 0.94), 10-m (ES = -1.27 ± 1.02), 20-m (ES = -1.38 ± 1.13), and 30-m (ES = -3.12 ± 1.61) (Figure 8). The treadmill group had a decrease in 5- and 10-m sprint times (ES = -0.04 ± 0.19 and -0.01 ± 0.16, respectively) and a trivial increase in 20- and 30-m sprint times (ES = 0.02 ± 0.12 and 0.04 ± 0.10, respectively) showing that after the intervention they were faster over the 5 to 10-m distances but slower as they reached the 20 and 30-m marks (Figure 8). The control group had moderate decreases in sprint times over the 5- and 10-m distances and a small decrease over the 20-m distance (ES = -0.76 ± 0.55, -0.76 ± 0.61 and -0.60 ± 0.78, respectively) meaning they were faster over these distances after four weeks. The change in sprint time over 30-m was unclear for the control group, although a slight decrease can be seen in Figure 8. The differences between the Wattbike and control groups for the 5-, 10- and 20-m sprint times were all unclear. There was a moderate, neutral (ES = -0.82 ± 0.87) difference in 30-m sprint time between the Wattbike and control groups suggesting a greater improvement in the Wattbike group. When compared to the control group, there were trivial, positive differences in 5-, 10-, 20- and 30- m sprint times for the treadmill group (ES = 0.13 ± 0.25, 0.16 ± 0.21, 0.17 ± 0.21 and 0.18 ± 0.23, respectively) which shows that the improvements seen in the control group were larger than those of the treadmill group. Moreover, there were small, neutral differences in 5- (ES = -0.45 ± 0.47), 10- (ES = -0.41 ± 0.40), 20- (ES = -0.33 ± 0.29) and 30-m (ES = -0.57 ± 0.29) sprint times between the Wattbike and treadmill groups (Figure 8 and refer to Appendix D for a full list of results).

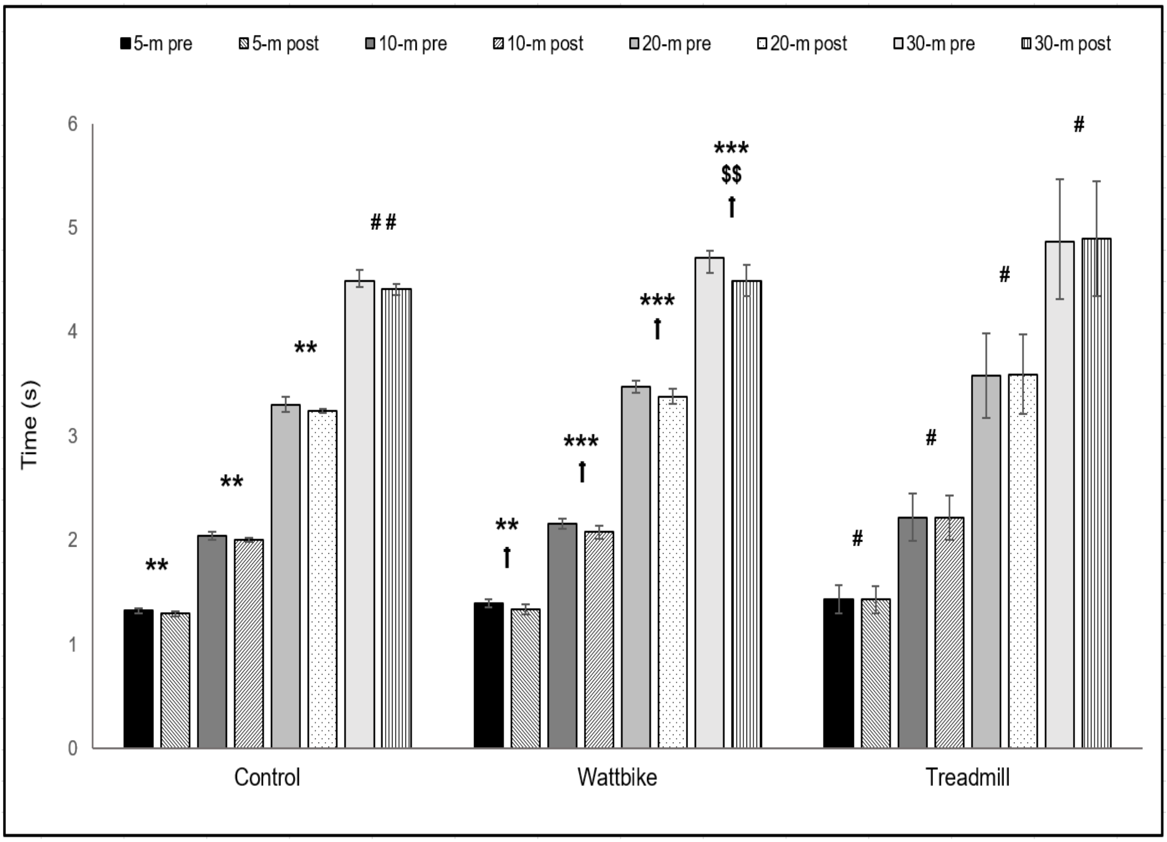

Figure 8. Pre-post changes in over-ground sprint times. 5-m, 10-m, 20-m and 30-m sprint times are presented as mean ± SD. Mechanistic inferences of the within-group pre-post changes are represented by: *small, (0.2 to <0.6); **moderate, (0.6 to <1.2); and ***large (>1.2). Mechanistic inferences of the differences in pre-post changes between each group are represented by: $$, moderate difference from control; # small difference from Wattbike; # #, moderate difference from Wattbike; □, small difference from treadmill. Abbreviations: 5-m, 10-m, 20-m and 30-m, over-ground sprint distances.

Velocity

Changes in V_0 and V_{max} were unclear for the control group and Wattbike groups. However, there was a decrease in V_0 (ES = -0.13 ± 0.16) and V_{max} (ES = -0.11 ± 0.15) in the treadmill group showing that they ran slower during the 30-m sprint after the intervention, which is reflected by their 20 and 30-m sprint times (Figure 9, 10, 11 and Appendix D). The differences in the changes in V_0 and V_{max} during the 30-m over-ground sprint were unclear between the Wattbike and control groups and were also unclear between the treadmill and control groups (Table 5). There was a small, positive (ES = 0.20 ± 0.32) difference in the change in V_0 between the Wattbike and treadmill groups and a small, positive (ES = 0.24 ± 0.30) difference in the change in V_{max} between the two groups which shows that the improvement in overall velocity of the Wattbike group following the intervention was greater than that of the treadmill group (Table 5).

Maximal force

The changes in F_0 were unclear in the treadmill group. Moreover, the control group saw a small increase in F_0 (ES = 0.22 ± 0.27), while a moderate increase in F_0 was seen in the Wattbike group (ES = 0.82 ± 0.60) (Figure 9, 10, 11 and Appendix D). There was a small, positive (ES = 0.37 ± 0.56) difference in the change in F_0 between the Wattbike and control groups (Table 5). Furthermore, a moderate, positive (ES = 0.71 ± 0.82) difference in the change in F_0 was observed between the Wattbike and treadmill groups. The difference in the change in F_0 between the treadmill and control groups was unclear (Table 5).

Maximal power

The control group and Wattbike group had a small (ES = 0.22 ± 0.22) and moderate increase (ES = 0.98 ± 0.71) in P_{max} respectively while the change was unclear for the treadmill group (Figure 9, 10, 11 and Appendix D). The difference in the change in P_{max} between the Wattbike and control groups was unclear. When compared to the control group, there was a small, neutral (ES = -0.22 ± 0.27) difference in the change in P_{max} for the treadmill group suggesting that the increase in P_{max} of the control group was greater than the change seen in the treadmill group (Table 5). The difference in P_{max} between the Wattbike and treadmill groups was moderately, positive (ES = 0.77 ± 0.64) which shows that the increase in P_{max} of the Wattbike group was also greater than the change in P_{max} of the treadmill group (Table 5).

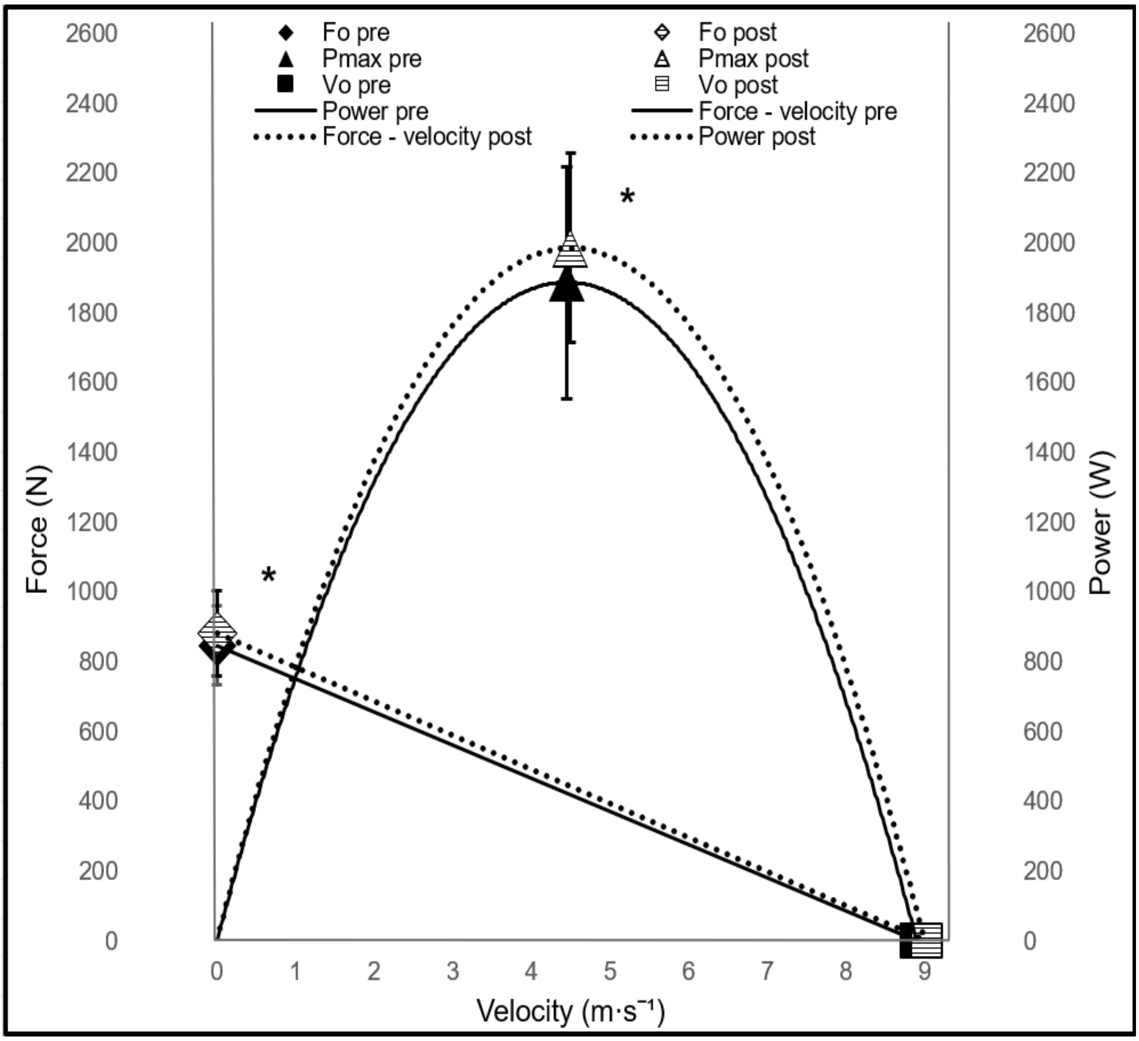

Figure 9. Control within-group pre-post changes in over-ground sprint F_0, V_0, and P_{max}. F_0, V_0, and P_{max} are presented as mean ± SD. Mechanistic inferences of the pre-post changes are represented by: *small, (0.2 - <0.6). Abbreviations: F_0, absolute theoretical maximal horizontal force; P_{max}, absolute peak horizontal power; V_0, theoretical maximal velocity.

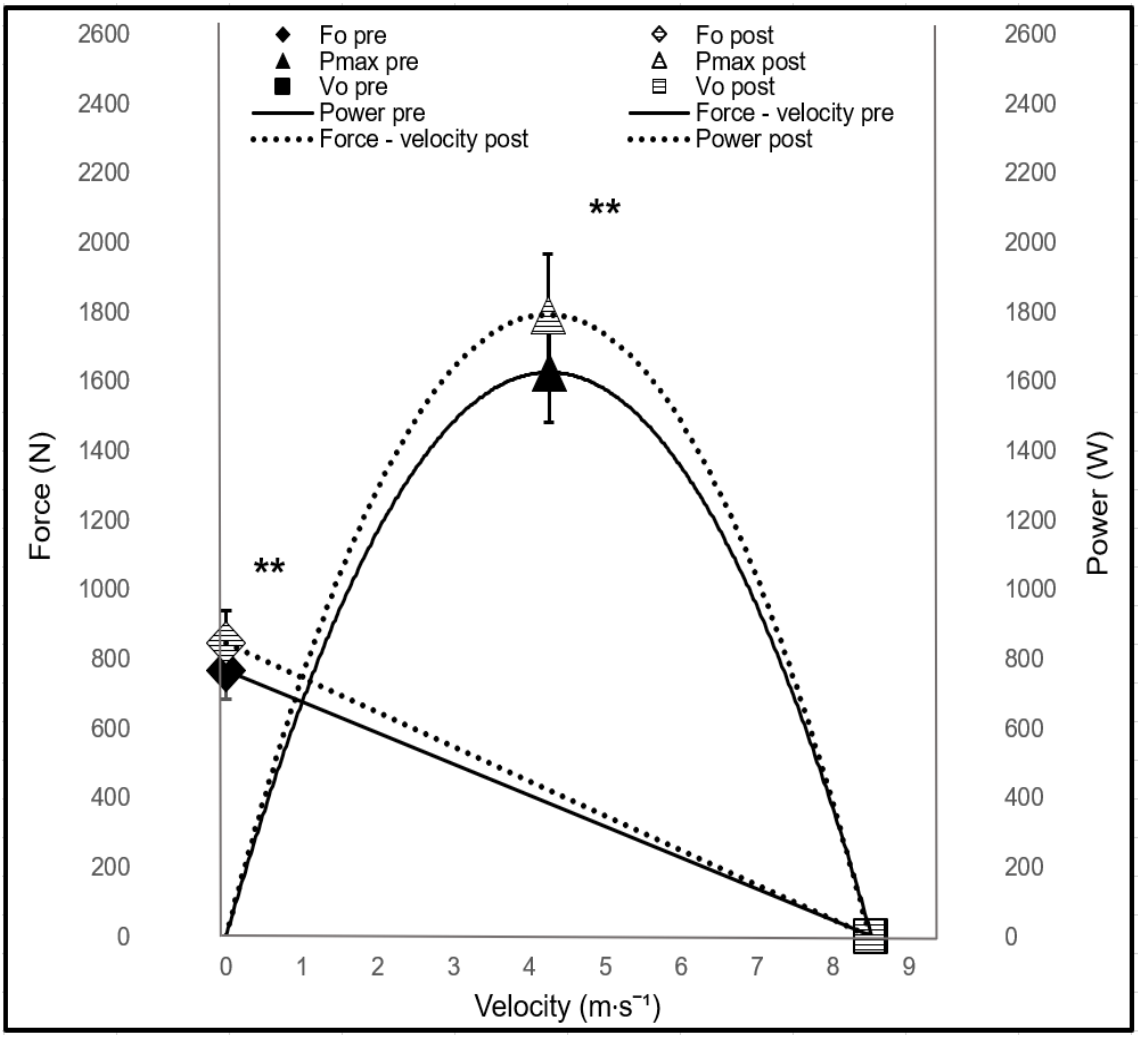

Figure 10. Wattbike within-group pre-post changes in over-ground sprint F_0, V_0, and P_{max}. F_0, V_0, and P_{max} are presented as mean ± SD. Mechanistic inferences of the pre-post changes are represented by: **moderate, (0.6 to <1.2). Abbreviations: F_0, absolute theoretical maximal horizontal force; P_{max}, absolute peak horizontal power; V_0, theoretical maximal velocity.

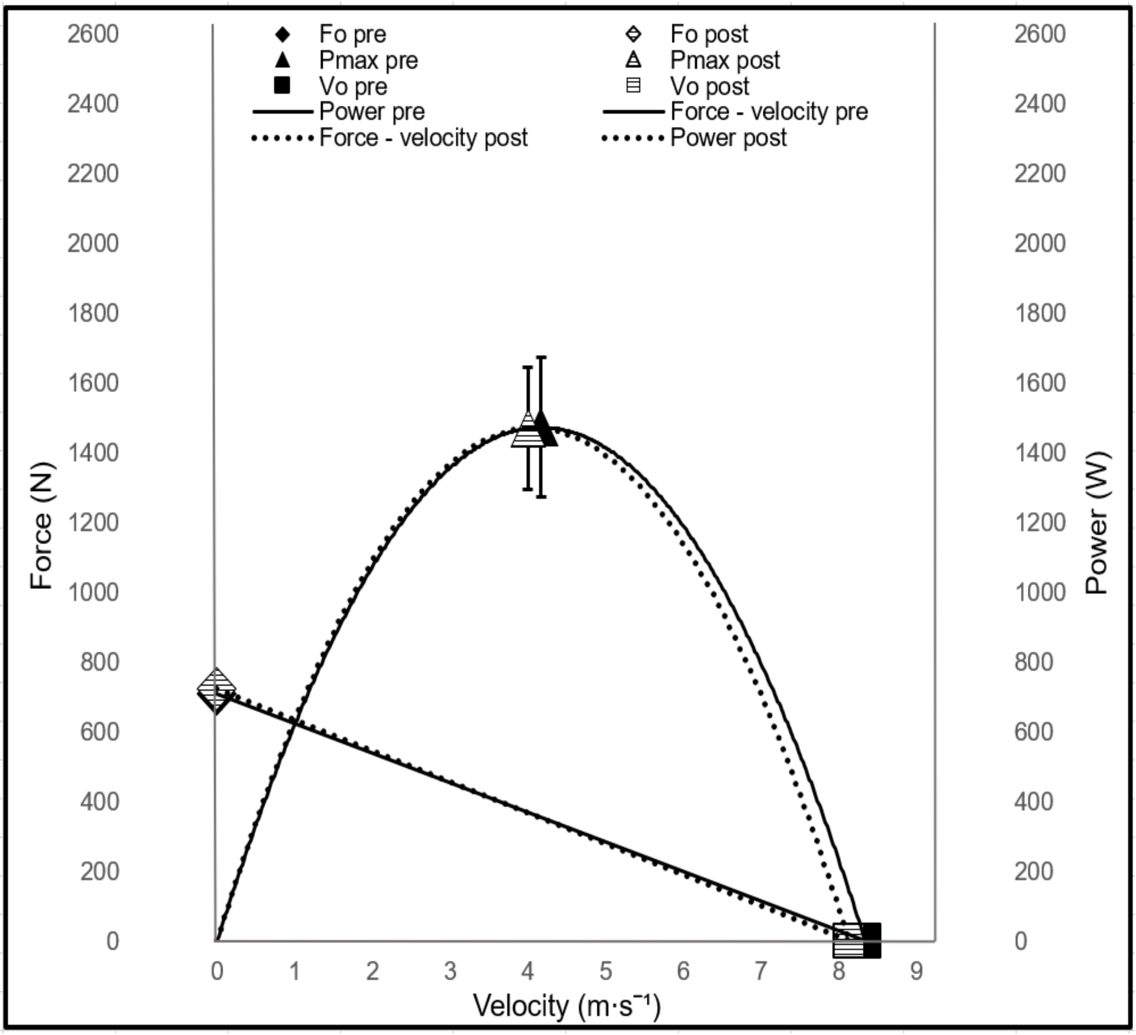

Figure 11. Treadmill within-group pre-post changes in over-ground sprint F_0, V_0, and P_{max}. F_0, V_0, and P_{max} are presented as mean ± SD. Abbreviations: F_0, absolute theoretical maximal horizontal force; P_{max}, absolute peak horizontal power; and V_0, theoretical maximal velocity.

Table 5.

Between-group differences for F_0, V_0, and P_{max}

	Wattbike group – control group		Treadmill group – control group		Wattbike group – treadmill group	
Variable	ES ± 90% CL	Mechanistic inference	ES ± 90% CL	Mechanistic inference	ES ± 90% CL	Mechanistic inference
V_0 ($m \cdot s^{-1}$)	-0.37 ± 1.49	**Unclear**	-0.28 ± 0.50	**Unclear**	0.20 ± 0.32	**Small***(positive)
F_0 (N)	0.37 ± 0.56	**Small***(positive)	-0.13 ± 0.40	**Unclear**	0.71 ± 0.82	**Moderate****(positive)
P_{max} (W)	0.21 ± 0.43	**Unclear**	-0.22 ± 0.27	**Small***(neutral)	0.77 ± 0.64	**Moderate****(positive)

Relative force and power

The control group had a moderate increase in Rel F_0, while the Wattbike group had a large increase (ES = 0.64 ± 0.80 and 1.26 ± 1.03, respectively). The change in Rel F_0 of the treadmill group was unclear. The difference in the change in Rel F_0 was unclear between the Wattbike and control groups and between the treadmill and control groups. There was a moderate, positive (ES = 0.70 ± 0.85) difference in the change in Rel F_0 between the Wattbike and treadmill groups which represents a larger increase in relative force output in the Wattbike group compared to the treadmill group (Figure 12 and refer to Appendix D). There was a moderate increase in Rel P_{max} for the control group, a large increase in the Wattbike group and a decrease in the treadmill group (ES = 0.69 ± 0.65, 1.54 ± 1.16 and -0.01 ± 0.21, respectively) (Figure 12). The difference in the change in Rel P_{max} was unclear between the Wattbike and control groups. There was a small, neutral (ES = -0.24 ± 0.28) difference in the change in Rel P_{max} between the treadmill and control groups reflecting a larger increase in relative power output in the control group compared to the treadmill group. Furthermore, there was a small, positive (ES = 0.58 ± 0.50) difference in the change in Rel P_{max} between the Wattbike and treadmill groups which shows that after the four-week intervention the Wattbike group had a greater increase in relative power output when compared to the treadmill group (Figure 12 and refer to Appendix D).

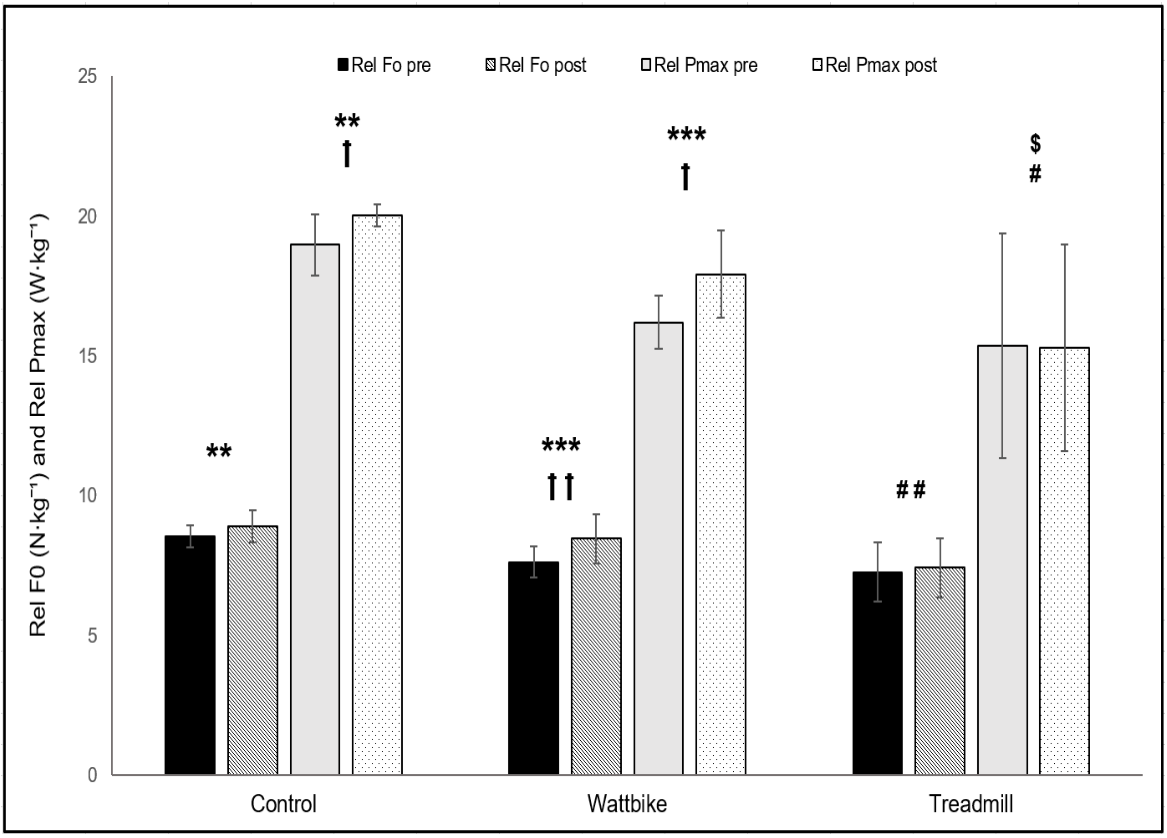

Figure 12. Pre-post changes in over-ground sprint Rel F_0 and Rel P_{max}. Rel F_0 and Rel P_{max} are presented as mean ± SD. Mechanistic inferences of the within-group pre-post changes are represented by: **moderate, (0.6 to <1.2); and ***large (>1.2). Mechanistic inferences of the differences in pre-post changes between each group are represented by: $, small difference from control; #, small difference from Wattbike; # #, moderate difference from Wattbike; , small difference from treadmill; and , moderate difference from treadmill. Abbreviations: Rel F_0, relative theoretical maximal horizontal force; and Rel P_{max}, relative maximal horizontal power.

Ratio of force

RF_{peak} and RF_{Opt} increased moderately in the control group (ES = 0.73 ± 0.61 and 0.61 ± 0.81, respectively). Furthermore, a moderate increase in RF_{peak} and large increase in RF_{Opt} were seen in the Wattbike group (ES = 1.17 ± 0.97 and 1.21 ± 1.01, respectively) (Figure 13 and 14). These results show that the force application technique of the participants in both the Wattbike group and control group improved from pre-testing to post-testing. The changes in RF_{peak} and RF_{Opt} of the treadmill group were both unclear (Figure 13 and 14). The difference in the changes in RF_{peak} and RF_{Opt} were both unclear between the Wattbike and control groups. There was a trivial, neutral (ES = -0.14 ± 0.31) difference in the change in RF_{peak} between the treadmill and control groups, while the difference in RF_{Opt} was unclear. There was a small, positive (ES = 0.52 ± 0.58) difference in the change in RF_{peak} and a moderately, positive (ES = 0.69 ± 0.87) difference in the change in

RF_{Opt} between the Wattbike and treadmill groups. The between-group differences suggest that the improvements in force application of the Wattbike and control groups were greater than that seen in the treadmill group (Figure 13, 14 and refer to Appendix D).

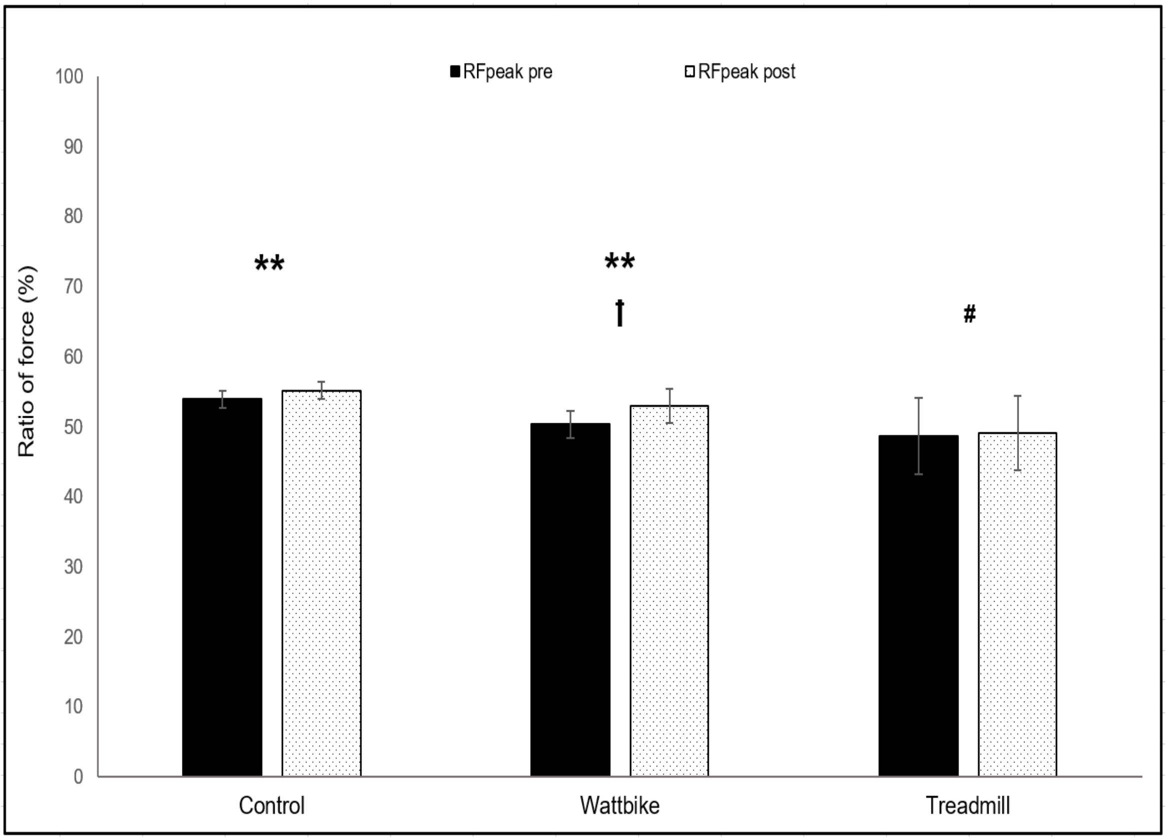

Figure 13. Pre-post changes in over-ground sprint RF_{peak}. RF_{peak} is presented as mean ± SD. Mechanistic inferences of the within-group pre-post changes are represented by: **moderate, (0.6 to <1.2); and ***large (>1.2). Mechanistic inferences of the differences in pre-post changes between each group are represented by: #, small difference from Wattbike; □, small difference from treadmill. Abbreviations: RF_{peak}, peak ratio of force.

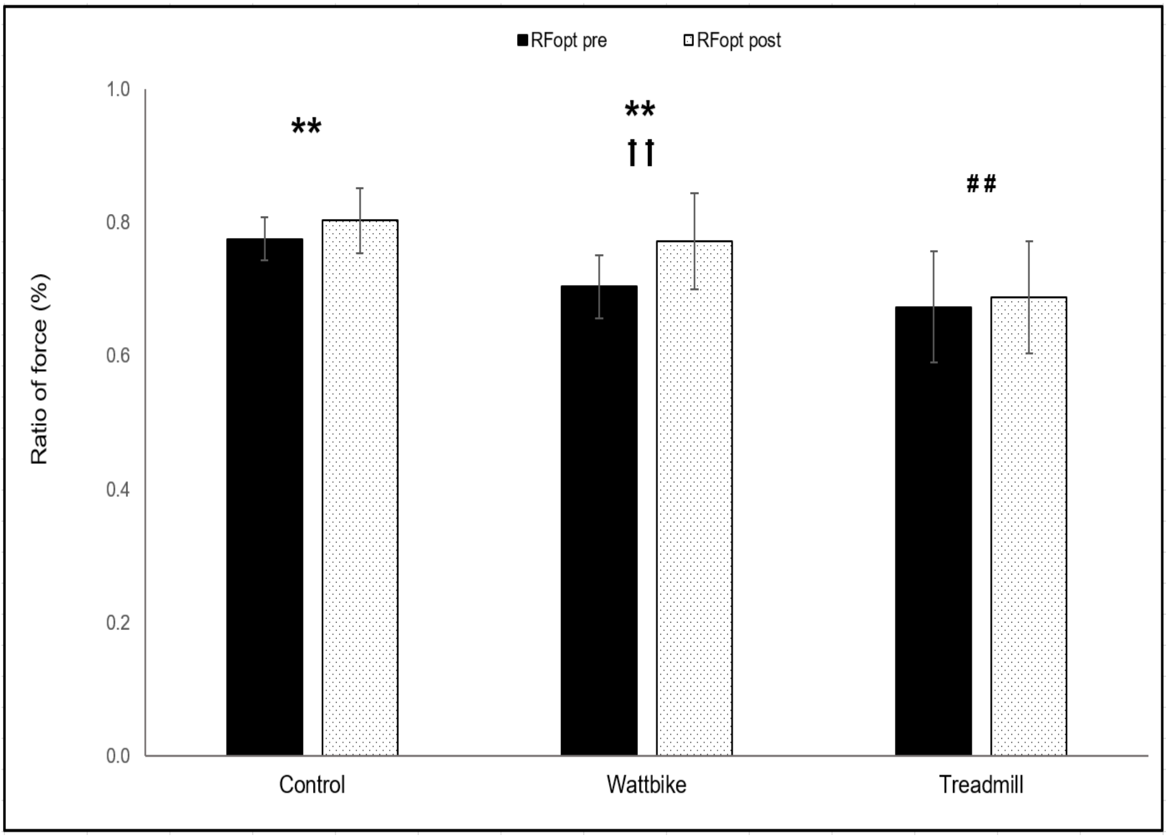

Figure 14. Pre-post changes in over-ground sprint RF_{Opt}. RF_{Opt} is presented as mean ± SD. Mechanistic inferences of the within-group pre-post changes are represented by: **moderate, (>0.6). Mechanistic inferences of the differences in pre-post changes between each group are represented by: # #, moderate difference from Wattbike; and , moderate difference from treadmill. Abbreviations: RF_{Opt}, theoretical optimal ratio of force.

Repeated sprint ability

There was a large increase in RSA_f sprint time in the control group (ES = 1.98 ± 2.06). The Wattbike group had a moderate decrease in RSA_f sprint time (ES = -0.70 ± 0.69), while there was also a decrease in the treadmill group (ES = -0.11 ± 0.19) (Figure 15). There was a large, neutral (ES = -1.35 ± 0.85) difference seen in the change in RSA_f between the Wattbike and control groups. A small, neutral (ES = -0.35 ± 0.28) difference in the change in RSA_f was observed between the treadmill and control groups. Moreover, the difference in the change in RSA_f between the Wattbike and treadmill groups was unclear (Figure 15). Though the changes in RSA_s and RSA_m sprint times were unclear for the control group, a slight increase in these variables can be seen in Figure 15. The Wattbike group had a moderate decrease in both RSA_s (ES = -0.75 ± 0.48) and RSA_m (ES = -0.89 ± 0.59) sprint times. Furthermore, there was a decrease in RSA_s and RSA_m in the treadmill group (ES = -0.12 ± 0.25 and -0.13 ± 0.13, respectively) (Figure 15). There was a large, neutral difference in the change in RSA_s (ES = -1.34 ± 087) and a moderate, neutral difference in the change in RSA_m (ES = -1.17 ± 1.00) between the Wattbike and control groups. Small, neutral differences were observed for the changes in RSA_s (ES = -0.45 ± 0.44) and RSA_m (ES = -0.27 ± 0.32) between the treadmill and control groups. There was a small, neutral (ES = -0.23 ± 0.42) difference in the change in RSA_s and a trivial, neutral (ES = -0.12 ± 0.28) difference was observed for the change in RSA_m between the Wattbike and treadmill groups (Figure 15). The $RSA_{\%Dec}$ changes and between-group differences were unclear for all groups (Figure 16 and refer to Appendix D). Overall the Wattbike and treadmill groups improved their RSA which is evident in the decreased $RSA_{f,}$ $RSA_{s,}$ and RSA_m sprint times, with the largest improvements seen in the Wattbike group. In contrast, $RSA_{f,}$ $RSA_{s,}$ RSA_m sprint times and $RSA_{\%Dec}$ of the control group all worsened from pre-test to post-test suggesting their RSA declined.

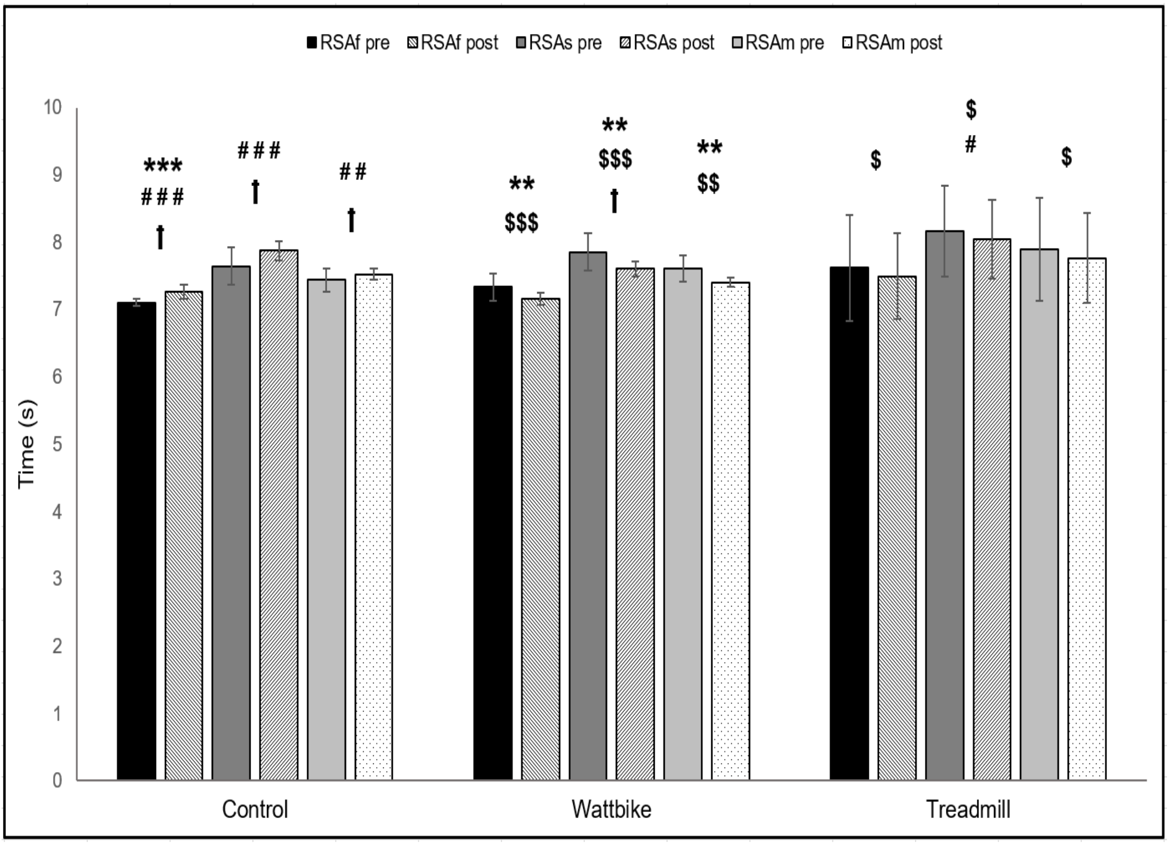

Figure 15. Pre-post changes in RSA sprint times. RSA_f, RSA_s and RSA_m are presented as mean ± SD. Mechanistic inferences of the within-group pre-post changes are represented by: **moderate, (0.6 to <1.2); and ***large (>1.2). Mechanistic inferences of the differences in pre-post changes between each group are represented by: $, small difference from control; $$, moderate difference from control; $$$, large difference from control; #, small difference from Wattbike; # #, moderate difference from Wattbike; # # #, large difference from Wattbike; and □, small difference from treadmill. Abbreviations: RSA_f, repeated-sprint ability fastest sprint time; RSA_s, repeated-sprint ability slowest sprint time; and RSA_m, repeated-sprint ability mean sprint time.

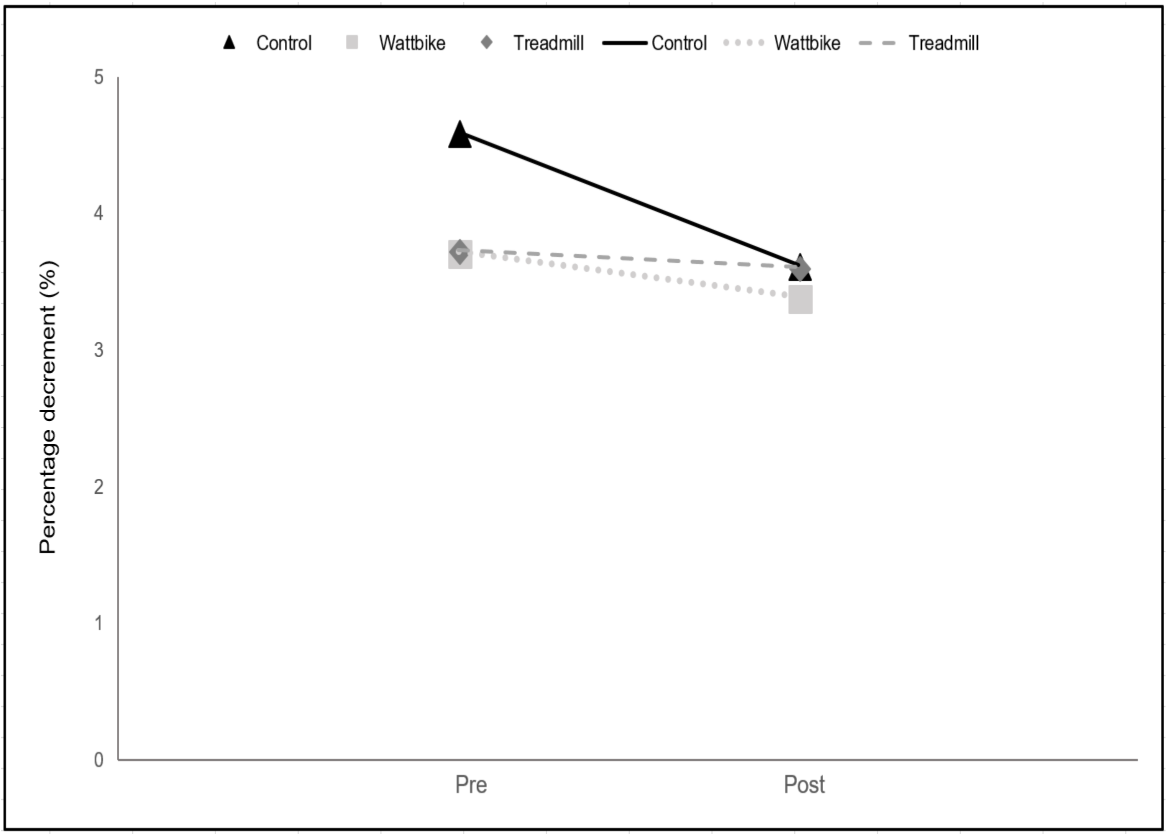

Figure 16. Pre-post changes in $RSA_{\%DEC}$. $RSA_{\%DEC}$ is presented as mean ± SD. Abbreviations: $RSA_{\%DEC}$, repeated-sprint ability percentage decrement.

Chapter 5

Discussion and conclusion

Discussion

Repeated Wattbike sprints are frequently performed by rugby union teams during training sessions. However, it is unclear what effect, if any, this training modality has on lower body horizontal power and power endurance. Thus, the purpose of this research was to determine the effects of a four-week repeated Wattbike sprint protocol, in comparison to a treadmill based sprinting protocol, on lower body horizontal power and power endurance in rugby union players. It was hypothesised that both the Wattbike and treadmill sprint protocols would result in significant improvements in lower body horizontal power and power endurance, with the improvements caused by the Wattbike protocol being similar to those of the treadmill protocol.

To the best of our knowledge, this is the first study that has investigated the effects of repeated Wattbike sprints on over-ground sprinting performance. The main findings of this investigation were: 1) the Wattbike protocol caused substantially greater increases in both absolute and relative force outputs during the 30-m sprint compared to the treadmill group, 2) absolute and relative power outputs increased only in the Wattbike and control groups, with the largest increases observed in the Wattbike group, 3) the Wattbike protocol resulted in the most meaningful decreases in sprint times over all distances, 4) all groups had improvements in horizontal force application technique, with the largest improvement seen in the Wattbike group and, 5) the over-ground RSA of the Wattbike and treadmill groups improved substantially, while the RSA of the control group worsened. It should be noted that the sample size of the present study was small due to unforeseen circumstances such as participant dropouts, which significantly reduced the statistical power of the results. Furthermore, the majority of the participants were male rugby union backs and as such the results of this study may not be generalised for females or rugby union forwards. Although these findings are promising and provide grounds for future research, the noticeable improvements seen in the control group and the amount of variation within the treadmill group suggests that a larger sample size and more stringent control of external factors is required to make any definitive conclusions about the effect of repeated Wattbike sprints on lower body horizontal power and power endurance in male rugby union players. Future research should look to recruit a larger number of participants from a variety of playing positions, skill levels and both genders to provide statistically strong evidence about the effects of repeated Wattbike sprints.

The results of the current study showed that each group increased F_0 and Rel F_0 during the 30-m over-ground sprint after four weeks, with the largest increase seen in the Wattbike group. The small, positive difference in F_0 between the Wattbike and control groups along with the moderate, positive differences in F_0 and Rel F_0 between the Wattbike and treadmill groups suggests that the training stimulus provided by the Wattbike protocol was slightly more effective in terms of improving absolute and relative force outputs during over-ground sprinting. The large increase in force production seen in the Wattbike group could be due to the high resistance level that the Wattbikes were set to during training sessions. The participants of the Wattbike group needed to activate the muscles in their lower limbs to generate enough force to overcome the inertia created by the air resistance placed on the flywheel of the Wattbike to accelerate and reach a specific cadence during each sprint. Overloading muscles with resistance is a very effective method for improving an individual’s strength (Gamble, 2013; Joyce & Lewindon, 2014; Kenney, Wilmore, & Costill, 2012). Therefore, it is possible that the resistance of the Wattbike was sufficient enough to overload the participant’s lower limb muscles during each training session, providing a training stimulus that enabled an increase in lower body strength and in turn their force outputs during over-ground sprinting.

In contrast to the large increases in absolute and relative force outputs of the Wattbike group, the treadmill protocol resulted in only minimal increases in both F_0 and Rel F_0. Contrary to the Wattbike group, the participants of the treadmill group did not have to overcome an initial inertial force to create movement, as the belt of the treadmill was already moving. As such, the participants of the treadmill group would not have experienced the same overload of the lower limb muscles as the Wattbike group, which may explain the difference in the changes in F_0 and Rel F_0 seen between the two groups. Additionally, prior studies have reported differences in kinetic and kinematic variables between motorised treadmill and over-ground running, showing that a different running style is adopted when running on a motorised treadmill (Baur, Hirschmüller, Müller, Gollhofer, & Mayer, 2007; McKenna & Riches, 2007; Nigg, De Boer, & Fisher, 1995; Riley, Dicharry, Franz et al., 2008; Schache, Blanch, Rath et al., 2001; Van Caekenberghe, Segers, Willems et al., 2013; Wank, Frick, & Schmidtbleicher, 1998). Wank et al. (1998) found that ground contact times during motorised treadmill running were shorter than over-ground running contact times resulting in less time for an individual to apply force against the ground to create forward momentum. Moreover, Schache and colleagues (2001) reported a reduction in maximal hip extension at toe-off during motorised treadmill running when compared to over-ground running and these findings were confirmed by McKenna and Riches (2007). Knee extension and ankle plantar flexion during motorised treadmill running have also been reported to be significantly less than over-ground running (Baur et al., 2007; Riley et al., 2008) which highlights the different running gait that is adopted by individuals on a treadmill. The propulsive forces that create forward movement during sprinting are generated through extension of the hip and knee coupled with plantar flexion of the ankle. Baur and colleagues (2007) showed motorised treadmill running resulted in lower EMG magnitudes from the soleus muscle during the propulsive phase. Furthermore, the motion of the belt of a motorised treadmill moves the foot backwards during the support phase which could potentially change the timing and magnitude of muscle activation. It was beyond the scope of the current study to measure muscle activation and kinematic variables. However, based on findings of previous studies, the four weeks of treadmill sprints may have caused some unwanted adaptations to the participants’ running style such as reduced ground contact times, as well as less hip and knee extension, and ankle plantar flexion combined with a possible reduction in muscle activity around the hip, knee and ankle joints. These undesirable adaptations could have led to a diminished ability to generate and apply force effectively during the 30-m over-ground sprint, which would explain the smaller absolute and relative force outputs seen in the treadmill group compared to the Wattbike group.

Changes were also observed in P_{max} and Rel P_{max} across all groups. There were increases in absolute and relative power outputs of the control and Wattbike groups, with a larger increase seen in the Wattbike group. The changes in P_{max} and Rel P_{max} seen after the Wattbike protocol support the improvements in lower limb peak power output observed in previous studies that investigated the effects of cycle ergometer RST on performance during cycle ergometer tests (Etxebarria et al., 2014; Gmada et al., 2014; Montero & Lundby, 2017; Rønnestad et al., 2015). The increase in power output observed in the Wattbike group may have been the result of the enhanced force generation capabilities of this group. Because power is the product of force multiplied by velocity, an increase in force would theoretically increase power. However, it is difficult to compare the effectiveness of the Wattbike protocol to the protocols implemented in previous studies as the methods used to measure power were different. The only results that can be confidently compared against the Wattbike protocol are those of the treadmill group in the current study as the testing methods were identical for both groups and all training sessions were matched based on the number of sets, repetitions, repetition duration, and rest between sets and repetitions. In contrast to the Wattbike and control groups, the treadmill group experienced a decrease in P_{max} and Rel P_{max} from pre- to post-testing. This suggests that four weeks of repeated sprints on a motorised treadmill has a negative effect on both absolute and relative lower limb power. Furthermore, it is evident that repeated Wattbike sprints are more effective for improving power output during over-ground sprinting than repeated sprints performed on a motorised treadmill in amateur male rugby union players.

Force output may not be the only variable that contributed to the decrease in power outputs seen in the treadmill group as a reduction in overall velocity throughout the 30-m sprint would also result in smaller power outputs. The treadmill group saw a reduction in both V_0 and V_{max} which is likely to have contributed to the decreases seen in absolute and relative power outputs in this group. Surprisingly, the control group was the only group to show an increase in both V_0 and V_{max} after four weeks, while the Wattbike group increased V_{max} but saw a decrease in V_0. It is feasible that the control group experienced a taper effect as their training load would have been substantially lower than the Wattbike and treadmill groups over the four-week period.

Research has elucidated that it is possible for sprinting velocity to increase while training load is decreased. Sprinting velocity over distances of 10- and 30-m was seen to improve after reduced training loads in both trained and untrained males (Coutts, Reaburn, Piva, & Murphy, 2007; Randers, Nielsen, Krustrup et al., 2010). These findings are interesting as V_0 has been reported as a significant determinant factor of an individual's sprinting ability during both the acceleration and maximal velocity phases of sprinting (Buchheit et al., 2014; Morin et al., 2012). Buchheit and colleagues (2014) found that elite youth football players who exhibited a higher V_0 had faster 40-m sprint times than those with a lower V_0. Furthermore, Morin et al. (2012) showed that performance in a 100-m sprint was highly correlated to V_0 ($r^2 = 0.819$, $P < 0.01$).

Based on the changes in V_0 scores, it would be expected that the sprint times of the treadmill and Wattbike groups would increase and the only improvements in sprint times would have been observed in the control group as they were the only group to increase V_0. However, contrary to this assumption, the treadmill group decreased their 5-m sprint time but either maintained or increased their times over the 10-, 20- and 30-m distances, while both the Wattbike and control groups decreased their sprint times over each distance. Furthermore, our results show that the Wattbike intervention produced the largest improvements in sprint times over all distances. This outcome is similar to the results of Gmada and colleagues (2014) who reported greater improvements in over-ground sprint times in female youth football players following RST on a cycle ergometer when compared to a control group. The improvements in sprint times observed by Gmada et al. (2014) after the RST protocol they implemented were larger than the improvements seen in the Wattbike group of the current study. The greater improvement seen in Gmada et al. (2014) cohort is likely due to the fact that they completed 36 training sessions compared to the eight training sessions completed by the Wattbike group in the present study. However, other recent studies have reported significant improvements in single and repeated sprint performance, and lower body power output after only six to eight RST sessions (Etxebarria et al., 2014; Gunnar & Svein, 2015; Nedrehagen & Saeterbakken, 2015). The fact that the participants of the Wattbike group improved their sprint times while their V_0 decreased emphasises the complexity of sprinting and implies that there are other variables that have a strong influence on sprinting ability.

How force is applied against the ground during each ground contact can have a significant impact on sprinting performance, particularly throughout the acceleration phase. The direction that force is applied during ground contact is said to be of more importance to over-ground sprinting performance than the overall magnitude of the force itself (Buchheit et al., 2014; Cross et al., 2015; Kawamori, Nosaka, & Newton, 2013; Kugler & Janshen, 2010; Morin et al., 2012; Morin et al., 2011a; Morin, Samozino, Edouard, & Tomazin, 2011b). Therefore, it is not the amount of force that is generated by the lower limbs but the technical ability to effectively apply force that determines performance during over-ground sprinting. Maximising horizontal force production while maintaining enough vertical force to reposition the opposite leg should be the goal when attempting to improve force application technique during over-ground sprinting (Buchheit et al., 2014; Kawamori et al., 2013; Morin et al., 2011a). To the best of our knowledge, no other studies have investigated changes in force application technique during over-ground sprinting after RST on a cycle ergometer. However, previous research has illustrated improvements in force application technique after resisted over-ground RST (Morin, Petrakos, Jiménez-Reyes et al., 2017; Rumpf, Cronin, Mohamad et al., 2015). Increases in horizontal force output were seen in both studies following a sled towing intervention. Furthermore, Morin and colleagues (2017) reported an increase of 5.13 ± 6.09% in RF_{max} after eight weeks of heavy sled towing (80% body mass sled load). The results of the current study show that all groups improved their force application technique, which is evident from the increases in both RF_{peak} and RF_{Opt} from pre- to post-testing, suggesting all participants were applying more force horizontally after the four-week training period. The improvements in RF_{peak} and RF_{Opt} seen in the Wattbike group were substantially larger than both the control and treadmill groups. This could explain why the Wattbike group had the greatest decrease in sprint times, as force application technique has been linked to over-ground sprint performance (Kawamori et al., 2013; Kugler & Janshen, 2010; Morin et al., 2012; Morin et al., 2011a). Moreover, the increase in RF_{peak} of the

Wattbike group was similar to that of the heavy sled towing group in the study by Morin et al. (2017). As a result, repeated Wattbike sprints could be used as an alternative training method for improving force application technique when resisted over-ground sprinting is not possible due to injury or loading constraints.

The results of the RSA test varied between the three groups, with both the Wattbike and treadmill groups showing improvements in RSA and the control group showing a decrease in RSA. The decrease in RSA of the control group is interesting as this group had meaningful improvements in the 30-m sprint test. This emphasises the different training stimulus required to elicit changes in these variables. As the 30-m sprint took the participants less than 10-s to complete the main energy system involved would have been the ATP-PCr system. Contrary to this, the RSA test involves multiple sprints performed consecutively with little recovery time meaning both the glycolytic and oxidative systems would have been recruited to provide further energy to complete each sprint (Kenney et al., 2012). It is possible that the external training sessions of the control group only recruited the ATP-PCr system for energy production which would not have provided a sufficient metabolic training stimulus to increase the capabilities of the glycolytic and oxidative systems, hence their marked improvement during the 30-m sprint and the decrease in performance in the RSA test. The Wattbike and treadmill groups both decreased their RSA_f, RSA_s and RSA_m sprint times, displaying their ability to continually cover the 2 x 20-m shuttle distance faster throughout the RSA test after the four-week intervention. In contrast, the control group increased their RSA_f, RSA_s and RSA_m sprint times. The increase in RSA seen in the treadmill group is intriguing as this group showed little improvement during the 30-m sprint test. This suggests that although the treadmill intervention had only a minimal effect on single sprint performance, it did require a significant metabolic demand which resulted in an increase in multiple sprint performance. The improvement in RSA of the Wattbike group was greater than that seen in the treadmill group, implying that the repeated-sprints performed on a Wattbike may provide a superior metabolic training stimulus than RST on a motorised treadmill. Furthermore, the results of the current study corroborate the findings of previously published studies showing increases in over-ground RSA following RST (Buchheit et al., 2010; Fernandez-Fernandez et al., 2012; Shalfawi et al., 2012; Suarez-Arrones et al., 2014). These previous studies have demonstrated the effectiveness of over-ground RST on over-ground RSA. However, the results of the current study show that over-ground RSA can also be improved through RST on a Wattbike. This validates the implementation of repeated Wattbike sprints into training programmes for athletes participating in sports which require multiple over-ground sprints to be performed throughout the duration of a match such as rugby union.

Conclusion

The aim of this research was to investigate the effects of a short-term Wattbike RST protocol on lower body horizontal power and power endurance in rugby union players. Our results have demonstrated that eight RST sessions on a Wattbike over four weeks causes increases in absolute and relative lower body horizontal power output and power endurance during over-ground sprinting. Moreover, when compared to RST performed on a motorised treadmill, the increases observed after repeated Wattbike sprints were larger for several performance variables. The improvements seen after four weeks of repeated Wattbike sprints were similar to traditional training methods used to improve over-ground sprint performance such as weighted sled-towing. Though the results of this study show the RST on a Wattbike has the potential to cause improvements in over-ground sprint performance and RSA, the between-group data suggests further research is needed to determine the effectiveness of RST on a Wattbike compared to other training methods used to develop lower body horizontal power and power endurance. However, the within-group results show that RST on a Wattbike can cause meaningful improvements to over-ground sprint performance in male rugby union players. As such, practitioners should look to implement repeated Wattbike sprints into their athlete's training programmes particularly when reducing the amount of stress placed on the lower limbs is an important factor.

Practical applications

Repeated sprints performed on a Wattbike caused meaningful physical and physiological adaptations within the cohort used in this study. Therefore, RST on a Wattbike can be considered by practitioners when designing training programmes for rugby union players. Furthermore, many field sports such as rugby union require players to cover a significant distance while running during training sessions. However, there are certain factors such as lower limb injuries that make it impractical for a player to perform over-ground running. Therefore, it is necessary to have an alternative training method that reduces the amount of stress placed on the lower limbs and provides a training stimulus that will maintain or improve specific physical attributes. Cycle ergometers such as the Wattbike reduce the amount of stress placed on the lower limbs when compared to over-ground running while providing an effective training stimulus. This makes repeated Wattbike sprints a suitable training modality for players that have sustained an injury and are preparing to return to play or situations where training load needs to be decreased. Practitioners can consider implementing three sets of five to eight, 5-s Wattbike sprints at velocities between 80 and 95% of peak velocity into the training programmes of rugby union players when the objective of the programme is to improve lower body horizontal power and power endurance during over-ground sprinting.

Thesis limitations

There are some methodological constraints that may have limited the research featured in this thesis. Therefore, it is imperative that these limitations are considered when interpreting the results of this thesis. Rationale and justification is included where necessary.

1. The statistical power of this study was weakened as the optimal number of participants was not reached. Thus, the only definitive conclusion that can be made from this study is that a treatment effect was observed. The findings of this study would have been strengthened by a greater number

of participants, providing more conclusive evidence about the effectiveness of the training intervention.

2. The participants of this study were from two separate rugby union teams. As a result, the training sessions, external to the ones completed as part of this study, were not identical. As such, it is possible that adaptations from these external training sessions could have impacted the results of each group during post-testing.
3. Ideally the control group in this study would have been restricted from engaging in any exercise during the four-week intervention period. However, as both teams were nearing the start of their competitive season the participants of the control group were unable to completely refrain from exercising. It is likely that this would have had an impact on the post-testing results of the control group.
4. Although each participant met the inclusion criteria of this study, there was not an even spread of forwards and backs (thirteen backs and one forward). It is possible that this uneven spread positively or negatively influenced the baseline testing results. As such, this limitation should be considered for future research.
5. Multiple kinematic variables of over-ground sprinting have been mentioned throughout this study. However, it was beyond the scope of this research to investigate how these variables are affected by cycling. Studying these variables would have provided a more definitive understanding of how repeated Wattbike sprints affect over-ground sprinting.

Thesis delimitations

Though there were some methodological constraints that may have restricted this thesis, various delimitations have strengthened the findings of this research.

1. The tests and testing environment used in this study were selected so that testing attempted to replicate the demands and setting of a rugby union match. This ensured ecological validity of the study, meaning the results can be applied to real-world situations and not strictly a laboratory environment.
2. The participants of this research were required to take part in familiarisation sessions of both testing and training procedures. This ensured that all participants were comfortable with the testing and training procedures which would have reduced the possibility of any learning effect influencing the testing and training sessions.
3. The data gathered from the radar device used in this research allowed for a highly detailed understanding of an individual’s over-ground sprinting ability. Furthermore, the sampling rate of the radar makes it a very precise measuring tool for high speed movements such as sprinting.
4. The timing gates used in the RSA test provided a more accurate measure of the participants sprint times as they remove any human error that occurs when using more rudimentary timing equipment such as stop watches.

5. The Wattbikes helped to ensure that the training load that was set out in the programme was adhered to as they provide real-time feedback on the power output of the participant as they pedal. This allowed for the researcher to monitor their power outputs throughout the entire session to confirm that all participants were reaching their required output during each sprint and they were receiving the desired training load.

Future research

The current study has provided a greater understanding of how over-ground sprinting performance is affected by repeated Wattbike sprints. However, it is evident from the findings of this study that there are areas that future research should explore. Future research should consider employing the methods used in this study over longer durations (e.g. 8-12 weeks) and examining the effects across more time points (e.g. pre-mid-post testing). Such studies would provide greater detail of how over-ground sprint performance is affected by repeated Wattbike sprints over a specific period, which could then be used as a guide when developing training programmes for rugby union players. As it was beyond the scope of this study to investigate the kinematics and muscle activation patterns of the two training modalities, it would be beneficial for future studies to explore this so that any similarities and differences between Wattbike cycling and motorised treadmill sprinting can be brought to light. The current study featured an uneven number of rugby union forwards and backs within the sample population. Therefore, it would be beneficial for future studies to include an even number of players from each position to investigate whether repeated Wattbike sprints have a larger effect on over-ground sprint performance in one positional group over another. Moreover, only male rugby union players were selected to participate in the current study. As rugby union is also played by females at all levels of competition, understanding how repeated Wattbike sprints affect over-ground sprint performance in a female population would provide valuable information for practitioners. Another area that future research should focus on is athletes of higher skill levels. As the participants of the current study were deemed to be at an amateur level, future studies might consider recruiting more experienced athletes (e.g. semi-professional or professional) who have a greater level of skill and training experience. Lastly, due to the importance of short repeated sprints in many other team sports such as football and field hockey, future research should investigate the effects of repeated Wattbike sprints on athletes of various sports.

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Appendix A: Ethics approval

AUTEC Secretariat

Auckland University of Technology
D-88, WU406 Level 4 WU Building City Campus
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

8 December 2016

Adam Storey
Faculty of Health and Environmental Sciences

Dear Adam

Ethics Application: 16/431 **The effects of repeated high intensity Wattbike sprints on lower body horizontal power and power endurance in rugby union players**

Thank you for submitting your application for ethical review. I am pleased to confirm that the Auckland University of Technology Ethics Committee (AUTEC) has approved your ethics application for three years until 5 December 2019.

AUTEC would like to commend the researchers for the consideration given to the issue and management of the potential for a conflict of interest.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 5 December 2019;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 5 December 2019 or on completion of the project;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply there.

To enable us to provide you with efficient service, we ask that you use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

K O'Connor

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

Cc: s_prescott@windowslive.com

Appendix B: Participant consent form

Consent Form

Project title: The effects of repeated high intensity Wattbike sprints on lower body horizontal power and power endurance in rugby union players.

Project Supervisor: Dr. Adam Storey

Researcher: Stephen Prescott

O I have read and understood the information provided about this research project in the Information Sheet dated 15th November 2016.

O I have had an opportunity to ask questions and to have them answered.

O 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.

O I understand that if I withdraw from the study then I will be offered the choice between having any data 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.

O I am not suffering from any current injury or illness that may impair my ability to perform the required tasks.

O I am drug free and comply with the international drug testing standards.

O I agree to take part in this research.

O I wish to receive a summary of the research findings (please tick one): YesO NoO

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

....

....

....

....

Date:

Approved by the Auckland University of Technology Ethics Committee on 8 December 2016 AUTEC Reference number 16/431.

Note: The Participant should retain a copy of this form

Appendix C: Participant information sheet

Participant Information Sheet

AUT
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Date Information Sheet Produced:

15th November 2016

Project Title

The effects of repeated high intensity Wattbike sprints on lower body horizontal power and power endurance in rugby union players.

An Invitation

Hello, my name is Stephen Prescott and I am a Masters student at the Auckland University of Technology (AUT). I would like to personally invite you to assist me with my research project that aims to determine the effects of repeated high intensity sprints on a Wattbike on the development of lower body horizontal power and power endurance. Upon the completion and grading of this research project I will be awarded a Master of Sport and Exercise degree.

It is entirely your choice as to whether you participate in the project or not. If you decide you no longer want to participate you are free to withdraw yourself or any information that you have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way. If you do choose to participate in this research, your position in the team you play for will not be affected. Your consent to participate in this research will be indicated by your signing and dating the consent form. Signing the consent form indicates that you have read and understood this information sheet, freely given your consent to participate, and that there has been no coercion or inducement to participate by the researchers from AUT.

What is the purpose of this research?

Lower body horizontal power is a crucial aspect of many tasks in rugby union including, sprinting, tackling, and contesting for the ball after a tackle. Furthermore, these tasks are performed frequently throughout a match and often with the presence of fatigue. Therefore, implementing training methods that significantly increase a player's ability to produce horizontal power through their lower body is of notable importance to both the player and their coaching staff. A novel way of improving a player's lower body horizontal power output and power endurance is by performing off-feet conditioning. Off-feet conditioning involves repeated high intensity sprints on a Wattbike. A Wattbike is an air-braked cycle that displays an individual's power output as they are exercising. The reasons that this method has the potential to improve lower body horizontal power and power endurance are: 1) the muscle groups recruited during cycling are similar to those used during the previously mentioned rugby specific tasks; 2) the energy systems used during repeated high intensity sprints are the same as the systems used throughout a rugby match; and 3) the position of the body during cycling is very close to the orientation of the body during many rugby specific tasks. Therefore, the purpose of this research is to investigate the effects off off-feet conditioning on lower body horizontal power and power endurance in rugby union players. The information gained from this research will be presented in a thesis which will be submitted by the primary researcher in order to obtain a Master of Sport and Exercise degree. This information will also be submitted for publication in academic journals related to sport science.

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

You have either seen an advertisement about this research project around your training facility or have been presented the research details during a face-to-face meeting with the primary researcher. Your contact details should be provided by you to the primary researcher if you are interested in participating in this research in order for communication to take place regarding this research. You are eligible to participate in this research if you are: 1) a male; 2) of an age >16 years old; 3) currently have a position in a Super Rugby team, Mitre 10 Cup team, a development team for one of these competitions, or a secondary school 1st XV team; 4) are free of any acute or chronic injury that may affect your ability to participate in this research; 5) not currently using and have never used anabolic steroids.

How do I agree to participate in this research?

If you are interested in participating in this research project please feel free to contact the primary researcher. You will be emailed an AUT consent to participate form which will you will need to fill out and sign then return to the primary researcher either by email or in person. You will then be given a copy of your signed consent form which you will need to keep for future reference.

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then 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?

Once you have agreed to participate in this research you will firstly be required to take part in a familiarisation session which will accustom you to the testing and training procedures that will be used for this research. The duration of the familiarisation session will be approximately two hours, depending on the number of participants. The tests that will be used in this research are a 6-s sprint test on a Wattbike, a repeated sprint ability (RSA) test and a 30-meter sprint test. The 6-s sprint test will involve a number of sprints performed on a Wattbike. The RSA test will involve six 2 x 20-meter shuttle runs at maximal effort with your times registered by timing gates. Lastly, during the 30-meter sprint test you will be required to perform three maximal effort sprints over a distance of 30 meters with your time recorded using a radar system. After the familiarisation session you will need to participate in a baseline testing session that will consist of the same tests as the familiarisation session, this will also take approximately two hours. You will then be assigned to either a control group, Wattbike group, or treadmill group. If you are assigned to the control group you will not be required to participate in any repeated sprint training sessions, however, regular contact will be maintained to ensure you are aware of the next testing sessions. If you are assigned to the Wattbike or treadmill group, you will be required to take part in two repeated sprint training sessions each week for four weeks (8 sessions in total). The number of sprints performed in each training session will progressively increase from 15 to 24 through the duration of the four week intervention. The training sessions will last approximately one hour, including a warm up and cool down. Following the four week intervention, both groups will once again be required to perform the same tests that were used in the baseline testing session. Again this session will last approximately two hours.

What are the discomforts and risks?

The testing and training sessions will require you to perform maximal physical efforts which may cause you to experience some temporary discomfort. This level of discomfort should not be any different to what you feel during your regular training and competition.

How will these discomforts and risks be alleviated?

Being an experienced athlete that regularly competes and trains at high intensities, the testing and training sessions will be similar to what you are familiar with during your week to week competition and training programs. Although you may be familiar with this type of training intensity, you are encouraged to inform the researcher if you are experiencing any discomfort at any time so that the problem can be addressed in the best possible way. If you have any questions regarding the risks or discomfort involved in this research, please feel free to bring these concerns to the attention of the researcher so that you feel comfortable throughout each stage of this process.

What are the benefits?

In addition to having a personalised assessment of lower body power capabilities, each participant will gain practical experience in using repeated sprint training on a Wattbike. The researcher will gain valuable practical experience working within a research setting with high level athletes. The primary researcher may also be awarded a Master of Sport and Exercise degree upon submission and grading of this research. Practitioners and researchers will be provided with new knowledge on the effects of repeated high intensity sprints using a Wattbike on lower body power capabilities. This could lead to the development of new exercise prescription techniques for rugby union athletes.

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?

Your privacy will be protected by data being de-identified (coded numbers i.e. ID 123 instead of your name to be used throughout), and the researcher will not disclose anyone's participation in this study. No names or pictures will be used in reporting (unless the participant gives explicit additional written consent for media purposes following AUT protocols and organised via the AUT university relations team). During the project, only the applicant and named investigators will have access to the data collected. The results of the study may be used for further analysis and submission to peer-reviewed journals or submitted at conferences. However, your name will remain coded and anonymous. Your privacy and anonymity will be of primary concern when handling the data.

What are the costs of participating in this research?

The only financial cost to the participant will be money spent on petrol to get to the testing and training facilities. Each testing session will take approximately two hours and each training session will last approximately one hour, including a warm up and cool down.

What opportunity do I have to consider this invitation?

We would appreciate it if you could let us know within four weeks whether or not you are able to participate in this research. After consideration you may withdraw your participation at any time.

Will I receive feedback on the results of this research?

Yes, each participant will receive a personalised athletic assessment of their performance in each lower body power test following the completion of the data collection. It is your choice whether you share this information with your coach or other people.

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, Dr. Adam Storey, adam.storey@aut.ac.nz.

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:

Stephen Prescott, s_prescott@windowslive.com

Project Supervisor Contact Details:

Dr. Adam Storey, adam.storey@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on 8 December 2016, AUTEC Reference number 16/431.

Appendix D: Within- and between-group results tables

Table 6.

Control and Wattbike within-group changes

	Control group (n = 4)			Wattbike group (n = 6)		
Variable	$\bar{x}$ ± SD	ES ± 90% CL	Mechanistic inference	$\bar{x}$ ± SD	ES ± 90% CL	Mechanistic inference
V_0 (m·s⁻¹)	0.13 ± 0.50	0.25 ± 1.16	**Unclear**	-0.03 ± 0.24	-0.11 ± 0.59	**Unclear**
F_0 (N)	34.75 ± 36.26	0.22 ± 0.27	**Small***(positive)	80.64 ± 78.33	0.82 ± 0.6	**Moderate****(positive)
Rel F_0 (N·kg⁻¹)	0.35 ± 0.37	0.64 ± 0.80	**Moderate****(positive)	0.83 ± 0.83	1.26 ± 1.03	**Large****(positive)
P_{max} (W)	98.72 ± 83.70	0.22 ± 0.22	**Small***(positive)	166.03 ± 147.00	0.98 ± 0.71	**Moderate****(positive)
Rel P_{max} (W·kg⁻¹)	1.04 ± 0.83	0.69 ± 0.65	**Moderate****(positive)	1.71 ± 1.57	1.54 ± 1.16	**Large****(positive)
RF_{peak}	1.25 ± 0.89	0.73 ± 0.61	**Moderate****(positive)	2.65 ± 2.66	1.17 ± 0.97	**Moderate****(positive)
RF_{Opt}	0.03 ± 0.03	0.61 ± 0.81	**Moderate****(positive)	0.07 ± 0.07	1.21 ± 1.01	**Large****(neutral)
V_{max} (m·s⁻¹)	0.13 ± 0.43	0.29 ± 1.11	**Unclear**	0.02 ± 0.21	0.12 ± 0.96	**Moderate****(neutral)
5 m (s)	-0.03 ± 0.02	-0.76 ± 0.55	**Moderate****(neutral)	-0.06 ± 0.05	-1.18 ± 0.94	**Moderate****(neutral)
10 m (s)	-0.04 ± 0.03	-0.76 ± 0.61	**Moderate****(neutral)	-0.08 ± 0.07	-1.27 ± 1.02	**Large****(neutral)
20 m (s)	-0.06 ± 0.07	-0.60 ± 0.78	**Small****(neutral)	-0.09 ± 0.09	-1.38 ± 1.13	**Large****(neutral)
30 m (s)	-0.08 ± 0.11	-0.53 ± 0.88	**Unclear**	-0.22 ± 0.14	-3.12 ± 1.61	**Large****(neutral)
RSA_f (s)	0.16 ± 0.14	1.98 ± 2.06	**Large****(positive)	-0.17 ± 0.20	-0.70 ± 0.69	**Moderate****(neutral)
RSA_s (s)	0.23 ± 0.27	0.60 ± 0.82	**Unclear**	-0.25 ± 0.19	-0.75 ± 0.48	**Moderate****(neutral)
RSA_m (s)	0.08 ± 0.21	0.35 ± 1.02	**Unclear**	-0.21 ± 0.17	-0.89 ± 0.59	**Moderate****(neutral)
$RSA_{\%Dec}$	-0.97 ± 2.58	-0.39 ± 1.24	**Unclear**	-0.33 ± 1.10	-0.19 ± 0.51	**Unclear**

Note. Values are presented as mean ± SD or effect size (ES) ± 90% CL (confidence limit). Qualitative inferences are: small (0.2 - <0.6); moderate (0.6 to <1.2), and large (>1.2); *possibly, 25 to 74.9%, and **likely, 75 to 94.9%. Positive and neutral descriptors qualitatively describe the differences in the descriptive statistics between each group and its importance relative to the specific variable. Positive descriptors refer to any increases from pre- to post-testing. Neutral descriptors refer to any decreases from pre-to post-testing. Neutral is used as the descriptors are not an indication of whether the change is negative or not.

Table 7.

Treadmill within-group changes

	Treadmill group (n = 4)		
Variable	$\bar{x}$ ± SD	ES ± 90% CL	Mechanistic inference
V_0 ($m \cdot s^{-1}$)	-0.21 ± 0.22	-0.13 ± 0.16	**Trivial****(neutral)
F_0 (N)	15.77 ± 46.59	0.28 ± 0.97	**Unclear**
Rel F_0 ($N \cdot kg^{-1}$)	0.16 ± 0.52	0.11 ± 0.42	**Unclear**
P_{max} (W)	-2.54 ± 89.34	-0.01 ± 0.38	**Unclear**
Rel P_{max} ($W \cdot kg^{-1}$)	-0.07 ± 0.99	-0.01 ± 0.21	**Trivial****(neutral)
RF_{peak}	0.36 ± 1.63	0.05 ± 0.26	**Unclear**
RF_{Opt}	0.01 ± 0.04	0.13 ± 0.44	**Unclear**
V_{max} ($m \cdot s^{-1}$)	-0.16 ± 0.18	-0.11 ± 0.15	**Trivial****(neutral)
5 m (s)	-0.01 ± 0.03	-0.04 ± 0.19	**Trivial****(neutral)
10 m (s)	0.00 ± 0.04	-0.01 ± 0.16	**Trivial****(neutral)
20 m (s)	0.01 ± 0.06	0.02 ± 0.12	**Trivial****(positive)
30 m (s)	0.03 ± 0.07	0.04 ± 0.10	**Trivial****(positive)
RSA_f (s)	-0.12 ± 0.17	-0.11 ± 0.19	**Trivial****(neutral)
RSA_s (s)	-0.11 ± 0.20	-0.12 ± 0.25	**Trivial***(neutral)
RSA_m (s)	-0.13 ± 0.12	-0.13 ± 0.13	**Trivial****(neutral)
$RSA_{\%Dec}$	-0.12 ± 2.19	-0.06 ± 1.18	**Unclear**

Note. Values are presented as mean ± SD or effect size (ES) ± 90% CL (confidence limit). Qualitative inferences are: trivial (<0.2); *possibly, 25 to 74.9%, and **likely, 75 to 94.9%. Positive and neutral descriptors qualitatively describe the differences in the descriptive statistics between each group and its importance relative to the specific variable. Positive descriptors refer to any increases from pre- to post-testing. Neutral descriptors refer to any decreases from pre-to post-testing. Neutral is used as the descriptors are not an indication of whether the change is negative or not.

Table 8.

Between-group changes

	Wattbike group – control group		Treadmill group – control group		Wattbike group – treadmill group	
Variable	ES ± 90% CL	Mechanistic inference	ES ± 90% CL	Mechanistic inference	ES ± 90% CL	Mechanistic inference
Rel F_0 (N·kg⁻¹)	0.58 ± 0.87	**Unclear**	-0.13 ± 0.46	**Unclear**	0.70 ± 0.85	**Moderate****(positive)
Rel P_{max} (W·kg⁻¹)	0.32 ± 0.68	**Unclear**	-0.24 ± 0.28	**Small***(neutral)	0.58 ± 0.50	**Small****(positive)
RF_{peak}	0.46 ± 0.75	**Unclear**	-0.14 ± 0.31	**Trivial***(neutral)	0.52 ± 0.58	**Small****(positive)
RF_{Opt}	0.59 ± 0.90	**Unclear**	-0.11 ± 0.48	**Unclear**	0.69 ± 0.87	**Moderate****(positive)
V_{max} (m·s⁻¹)	-0.30 ± 1.46	**Unclear**	-0.28 ± 0.51	**Unclear**	0.24 ± 0.30	**Small***(positive)
5 m (s)	-0.46 ± 0.73	**Unclear**	0.13 ± 0.25	**Trivial***(positive)	-0.45 ± 0.47	**Small****(neutral)
10 m (s)	-0.37 ± 0.71	**Unclear**	0.16 ± 0.21	**Trivial***(positive)	-0.41 ± 0.40	**Small****(neutral)
20 m (s)	-0.24 ± 0.71	**Unclear**	0.17 ± 0.21	**Trivial***(positive)	-0.33 ± 0.29	**Small****(neutral)
30 m (s)	-0.82 ± 0.87	**Moderate****(neutral)	0.18 ± 0.23	**Trivial***(positive)	-0.57 ± 0.29	**Small****(neutral)
RSA_f (s)	-1.35 ± 0.85	**Large****(neutral)	-0.35 ± 0.28	**Small****(neutral)	-0.08 ± 0.36	**Unclear**
RSA_s (s)	-1.34 ± 0.87	**Large****(neutral)	-0.45 ± 0.44	**Small****(neutral)	-0.23 ± 0.42	**Small****(neutral)
RSA_m (s)	-1.17 ± 1.00	**Moderate****(neutral)	-0.27 ± 0.32	**Small****(neutral)	-0.12 ± 0.28	**Trivial***(neutral)
$RSA_{\%Dec}$	0.32 ± 1.62	**Unclear**	0.38 ± 1.52	**Unclear**	-0.12 ± 1.39	**Unclear**

Note. Values are presented as mean ± SD or effect size (ES) ± 90% CL (confidence limit). Qualitative inferences are trivial (<0.2), small (0.2 to <0.6) moderate (0.6 to <1.2), and large (>1.2); *possibly, 25 to 74.9%, and **likely, 75 to 94.9%. Positive and neutral descriptors qualitatively describe the differences in the descriptive statistics between each group and its importance relative to the specific variable. Positive descriptors refer to any increases from pre- to post-testing. Neutral descriptors refer to any decreases from pre-to post-testing. Neutral is used as the descriptors are not an indication of whether the change is negative or not.