The acute demands and physical adaptations of repeated-sprint training

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THE ACUTE DEMANDS AND PHYSICAL ADAPTATIONS OF REPEATED-SPRINT TRAINING

by

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to fulfil the degree of Doctor of Philosophy
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THESIS ABSTRACT

Repeated-sprint training (RST) is a common training method used to prepare athletes for the intermittent, high-intensity demands of sports competition. However, there are many different RST programs applied in research and practice, leading to diverse acute and chronic effects. The overall aims of this thesis were to, 1) evaluate and summarise the acute demands and physical adaptations of RST, and 2) investigate the effects of manipulating programming variables on the acute demands and physical adaptations of RST. Studies 1 and 2 were systematic reviews and meta-analyses, which included data from 5470 athletes. Study 3 was a randomised, crossover study involving 14 trained athletes, and Study 4 was a parallel, two-group, training intervention that was performed by 24 rugby league players. Study 1 established that the acute physiological, neuromuscular, perceptual, and performance demands of RST are substantial, with these demands most influenced by sprint distance, rest time, and rest modality. Study 2 showed that RST improves a range of physical qualities and performing three sets of 6 × 30 m sprints, twice per week for six weeks is a highly effective training program. Study 3 demonstrated how larger session volumes increase the acute demands of RST, but by manipulating volume, sprint distance, and the number of repetitions, practitioners can alter the acute stimulus. Finally, in Study 4, after a six-week training intervention, both the RST and short high-intensity interval training (HIIT) groups increased hamstring fascicle length, but RST was more effective at improving hamstring strength and linear speed, while short-bout HIIT was more effective at improving aerobic fitness. These findings support the application of RST as a time-efficient conditioning method that elicits a considerable physiological stimulus and enhances an array of distinct physical qualities, which are important to sports performance. Furthermore, through the manipulation of programming

variables, coaches can use the findings from this thesis to design RST programs that achieve specific aims.

SIGNED DECLERATION

To the best of the authors knowledge, this thesis contains no material that has been extracted in whole or in part from a thesis that I have submitted towards the award of any other degree or diploma in any other tertiary institution.

No other person’s work has been used without due acknowledgment – all author contributions can be found in Appendix 42.

All research procedures reported in the thesis received the approval of the relevant Ethics/Safety Committees (where required).

Signature: **Date:** 10 / 1 / 2024

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DEFINITION OF TERMS AND ABBREVIATIONS

AMPK	Adenosine monophosphate-activated protein kinase
ATP	Adenosine triphosphate
BFlh	Biceps femoris long-head
B[La]	Blood lactate
CaMK	Calmodulin-dependent protein kinase
COD	Change of direction
CI	Confidence interval
CL	Confidence limit
CMJ	Countermovement jump
CR	Category ratio
dRPE	Differential rating of perceived exertion
ES	Effect size
F_0	Maximal theoretical force
FVP	Force-velocity-power
GPS	Global positioning system
HIIT	High-intensity interval training
HR_{avg}	Average heart rate
HR_{max}	Maximal heart rate
HR_{peak}	Peak heart rate
MAS	Maximal aerobic speed
MET	Minimum effects test
MSS	Maximal sprint speed
PI	Prediction interval
P_{max}	Maximal theoretical power
RF_{max}	Maximal ratio of horizontal force
RST	Repeated-sprint training
RSA	Repeated-sprint ability
RPE-B	Rating of perceived exertion for breathlessness
RPE-L	Rating of perceived exertion for the lower body muscles
S_{avg}	Average sprint time
S_{best}	Best sprint time
S_{dec}	Percentage sprint decrement
SD	Standard deviation
SMM	Spring-mass model
sRPE	Session rating of perceived exertion
SSC	Stretch-shortening cycle
V_0	Maximal theoretical velocity
VO_2	Oxygen consumption
VO_{2max}	Maximal oxygen consumption
YYIR1	Yo-Yo Intermittent Recovery Test level 1

CHAPTER 1

INTRODUCTION

Physical training is the systematic application of exercise to promote health and fitness (Stevenson, 2010). There are many different types of physical training (e.g., interval training, plyometric training), each with their own respective benefits. Often training methods need to be efficiently implemented to meet the time-constraints of sporting environments, where there is a need to balance technical, tactical, and physical training, as well as recovery (Laursen & Buchheit, 2019). Just as players are required to select the appropriate skill for a given match scenario, coaches must select the most appropriate training content to optimise performance. Therefore, knowledge of the most effective training methods and ways to manipulate individual programming variables (e.g., volume, rest time), which form the foundation of training design, is imperative for coaches.

Team and racket sports (i.e., intermittent sports) involve players that are organised into opposing teams to compete. Matches take place on fields or courts of ranging dimensions and surfaces and under a variety of different rules. Despite attempts to break down and control microscopic elements of match-play, the behavior of intermittent sports are chaotic by nature (Connolly & White, 2017). There are an infinite number of interactions and possible scenarios that connect to affect the outcome of the game. While notable differences in the physiological and movement demands of different intermittent sports exist, match play generally suggests that a well-developed level of aerobic fitness is important (Stone & Kilding, 2009). Additionally, peak periods of match play often require players to perform a series of repeated-high intensity efforts, interspersed with minimal recovery (Dawson, 2012b). Therefore, the ability to perform maximal sprints and recover quickly from such efforts may be important to performance (Carling et al., 2012; Johnston et al., 2018; Johnston et al., 2014; Spencer et al., 2004). Furthermore, due to the multidirectional demands of intermittent sports, the ability to rapidly change direction is also essential (Johnston et al., 2018; Johnston et al., 2014). Training methods that can be used to concurrently develop several physical qualities in an efficient manner may be valuable within the time-pressed environment of team and racket sports.

Repeated-sprint training (RST) is an effective and time-efficient training method that involves maximal effort, short duration sprints (≤ 10 s), interspersed with brief (≤ 60 s) recovery times (Girard, Mendez-Villanueva, et al., 2011). It can be administered with a variety of different exercise modalities (e.g., cycling, swimming), but when applied as a running-based intervention, RST provides intermittent sport athletes with exposure to maximal sprinting, acceleration, deceleration, and change of direction (COD), all of which are common during competition (Brughelli et al., 2008; Sheppard & Young, 2006; Taylor et al., 2017). Furthermore, RST causes physiological, neuromuscular, and morphological changes that enhance an athlete's physical performance. However, the outcomes of each RST program are specific to the type of stimulus (Coffey & Hawley, 2007), which can be altered through the manipulation of programming variables.

The prescription of RST consists of 11 primary programming variables. These include sprint modality (i.e., straight-line sprints, shuttle sprints, multi-directional sprints), number of sprint repetitions, number of sets, sprint repetition distance/duration, inter-repetition rest time, intra-set rest time, rest modality (i.e., passive or active), session volume, session duration, session frequency, and program duration. There is an infinite combination of how these programming variables can be applied in the design of RST, but there is a lack of consensus on how they influence the magnitude of acute internal and external demands, the time-course of recovery, and physical adaptation. Manipulation of these variables can be used to alter physiological, neuromuscular, perceptual, and performance demands, and more accurately target improvement in specific physical qualities.

One programming variable that is central to the design of RST is session volume (i.e., repetition distance × number of repetitions). Intermittent sport athletes require regular exposure to sprinting within the training environment to effectively prepare them for the high-speed demands of competition (Edouard et al., 2023; Malone et al., 2017; Oakley et al., 2018). In team sports such as Australian Rules Football and soccer, players can attain average sprint (> 23 $km \cdot h^{-1}$) distances of 571 m and 337 m per game, respectively (Coutts et al., 2010; Di Salvo et al., 2007). RST can provide controlled doses of maximal speed running (Edouard et al., 2019; Malone et al., 2017; Mendiguchia et al., 2020), but there lies a fine balance between achieving an optimal range of maximal velocity exposure and prescribing excessive or insufficient volumes of sprint training (Gabbett, 2016; Malone et al., 2017).

Due to the ‘all out’ nature of running-based RST, a high neuromuscular demand is imposed on the musculoskeletal system, which may be exacerbated by the prescription of larger session volumes (Buchheit & Laursen, 2013b). Compared to studies (J. Borges et al., 2016; García-Unanue et al., 2020) that have implemented low session volumes (i.e., 210 m), greater reductions in countermovement jump (CMJ) height were induced when a session volume of 600 m was prescribed (Clifford et al., 2016). Furthermore, significant declines in acute knee flexor strength have been demonstrated following sprint training with session volumes of between 360 to 450 m (Baumert et al., 2021; Timmins et al., 2014). Reductions in neuromuscular performance and elevated perceptions of muscle soreness have been observed up to 48 hours later (Baumert et al., 2021; Woolley et al., 2014), suggesting that fatigue from sprinting may persist for several days. Given this evidence, it is important to understand the effects of repetition distance and the number of repetitions, as well as the combination of these two programming factors (i.e., session volume), on the recovery time-course of neuromuscular performance following RST.

During the first few repetitions of a RST session, energy is primarily derived from the phosphagen and glycolytic energy systems (Girard, Mendez-Villanueva, et al., 2011; Spencer et al., 2005). These systems are heavily taxed across an entire session, which may enhance anaerobic capacity by stimulating increases in glycolytic enzymes (Bishop et al., 2011; Gharbi et al., 2014; Medbø & Burgers, 1990). As more sprints are repeated and greater session volumes are accumulated, the extended duration of the training sequence allows for an increase in cardiac output and up-regulation of oxidative pathways, resulting in large increases in oxygen consumption (VO_2) (Dawson et al., 1997; Gaitanos et al., 1993; McGawley & Bishop, 2015). Maximal oxygen consumption (VO_{2max}) is a key determinant of endurance performance (Billat et al., 2001; Foster, 1983; Noakes et al., 1990), thus training sessions that elicit greater cardiovascular demands, such as those prescribed with larger volumes, could be beneficial at inducing chronic improvements in aerobic capacity (Buchheit & Laursen, 2013a).

High-intensity interval training is defined as repeated bouts of short to moderate duration exercise (i.e., 10 seconds to 5 minutes) completed at an intensity that is greater than the anaerobic threshold (Laursen & Jenkins, 2002). It is well documented that HIIT improves the ability to perform high-intensity exercise (Clemente et al., 2021), with subsequent beneficial aerobic and anaerobic adaptations (Clemente et al., 2021; Hoffmann et al., 2014; Taylor et al., 2015). Although RST is effective in developing several fitness components (Taylor et al., 2016), there is a lack of evidence directly comparing RST to other modes of HIIT (Bravo et al., 2008; Buchheit et al., 2008; Fernandez-Fernandez et al., 2012) and RST has never been compared against short duration HIIT. Like RST, short-bout HIIT is an efficient training method, commonly implemented at similar stages of an athlete's season to enhance physical conditioning (Laursen & Buchheit, 2019). Short-bout HIIT consists of sub-maximal efforts (≥ 100% of maximal aerobic speed [MAS]) of less than 60 s with similar rest times (i.e., < 60 s), and has comparable set and repetition schemes to RST (e.g., 1–3 sets of 6–12 reps) (Buchheit & Laursen, 2013a). The physiological adaptations between these two high-intensity training methods may also be similar, with previous evidence demonstrating improvements in aerobic capacity and field-based tests of aerobic performance (Clemente et al., 2021; Taylor et al., 2015). However, due to the different intensities at which they are performed, the neuromuscular and morphological adaptations could be different. Despite this, several important outcomes are yet to be compared and quantified between RST and short-bout HIIT, including changes in muscle architecture and sprint force-velocity-power (FVP) profiles.

Repeated-sprint training is used to develop multiple fitness components that underpin athletic performance in short periods of time. However, the acute and chronic effects of RST on specific physiological, neuromuscular, morphological, perceptual, and performance outcomes, and the moderating effects of programming variables, requires investigation. Therefore, to enhance the understanding of RST and improve its prescription for intermittent sport athletes, this thesis aims to:

1. Investigate the acute physiological, neuromuscular, perceptual, and performance demands of running-based RST in intermittent sport athletes. This will be achieved by:

    a. Investigating the moderating effects of programming variables on acute physiological, neuromuscular, perceptual, and performance demands of running-based RST in intermittent sport athletes.
    b. Investigating the effects of manipulating session volume on acute physiological, perceptual, and performance demands, and the time-course of neuromuscular recovery.

2. Investigate the physical adaptations of running-based RST in intermittent sport athletes. This will be achieved by:
    a. Investigating the moderating effects of programming variables on physical adaptations in intermittent sport athletes.
    b. Comparing the physical adaptations between RST and short-bout HIIT.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Introduction

This literature review provides a broad overview of the bioenergetics of exercise and energy system development via common methods of training, including a summary of the acute demands and chronic adaptations to continuous and intermittent exercise. Later in this review, RST will be discussed in detail with specific attention given to fatigue and recovery, programming variables and the application of RST for intermittent sport athletes.

2.2 Energy Systems

Exercise helps to maintain and improve physical fitness, overall health and wellbeing, and consists of planned, structured and repetitive physical activity (Liguori, 2020). The frequency, intensity, time (duration), and type of exercise influence the specific physiological adaptations that are attained (Liguori, 2020). Within each exercise session, energy is primarily derived from the catabolism of carbohydrates and fats to produce adenosine triphosphate (ATP) for muscle contractions (Haff & Triplett, 2015). This occurs through the action of three biological energy systems: the phosphagen system, the glycolytic system, and the oxidative system. The oxidative system relies on aerobic metabolism and is the primary source of ATP at rest and during low-intensity activities. Conversely, the phosphagen system and glycolytic system do not require the presence of oxygen to produce energy, thus these anaerobic processes are primarily used during high-intensity, short-duration exercise (Haff & Triplett, 2015). For any activity, all three energy systems are active at any given time, but the relative contribution of each system to the overall work performance is dependent on the intensity and duration of the activity (Table 1 & Figure 1) (Haff & Triplett, 2015).

Table 1

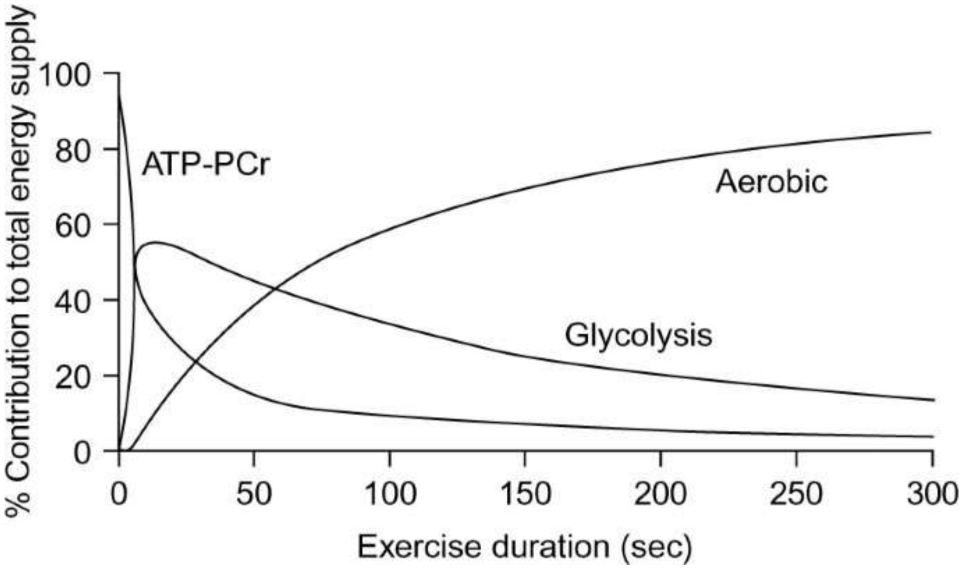
Primary Energy Systems During Exercise of Different Duration and Intensity

Duration of event	Intensity of event	Primary energy system
0–6 s	Extremely high	Phosphagen
6–30 s	Very high	Phosphagen & glycolytic
30 s to 2 min	High	Glycolytic
2–3 min	Moderate	Glycolytic & oxidative
> 3 min	Low	Oxidative

Note. Adapted from Haff and Triplett (2015)

Figure 1

The Relative Energy System Contribution to the Total Energy Supply for Exhaustive Exercise



Note. Extracted From Gastin (2001). ATP-PCr = Phosphagen System.

2.3 Acute Physiological Demands of Exercise

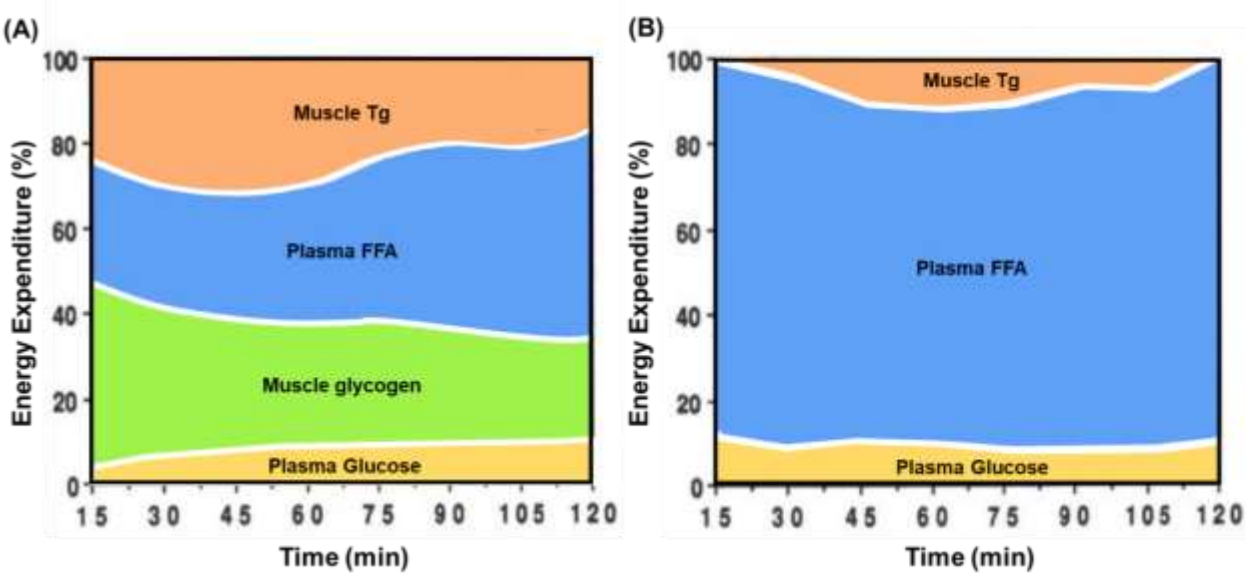
Physical training can be grouped under two main exercise categories:

- Continuous steady-state – exercise performed at a constant, low intensity (below maximal lactate steady state) for prolonged durations without rest. This intensity usually equates to < 70% of VO_{2max} or < 80% maximal heart rate (HR_{max}) (Haff & Triplett, 2015).
- Intermittent/interval – series of exercise, interspersed with series of rest, which allow more work to be accomplished at higher intensities (at or above maximal lactate steady state) (Billat, 2001a).

During continuous steady-state exercise, oxygen consumption (VO_2) increases exponentially for the first few minutes until a constant level of uptake is reached (Xu & Rhodes, 1999). While some of the energy needed to provide this effort is attained through anaerobic sources (i.e., oxygen deficit), the majority of ATP provision will be supplied by aerobic metabolism (Haff & Triplett, 2015). Therefore, the efficiency of oxygen delivery, extraction, and utilisation to generate ATP is fundamental to endurance performance (Bassett & Howley, 2000; Robergs & Roberts, 1997). Additionally, energy substrates are required to support ATP production for sustained muscle contractions. Fats and carbohydrates are the primary substrates used for metabolism during low-intensity exercise (Figure 2) (Hargreaves, 2000; Romijn et al., 1993). However, despite the presence of an adequate oxygen supply, muscle glycogen is gradually depleted as the duration and intensity of exercise increases, contributing to fatigue (Ørtenblad et al., 2013). This is commonly referred to as ‘hitting the wall’ and will eventually result in a decrease in exercise intensity (Ørtenblad et al., 2013; Stevinson & Biddle, 1998).

Figure 2

The Relative Contribution of Energy Substrates to Energy Production During Exercise at, a) 65% of VO_{2max}*, and B) 25% of* VO_{2max}



Note. Adapted From Romijn et al. (1993). FFA = Free Fatty Acids; Tg = Triglycerides.

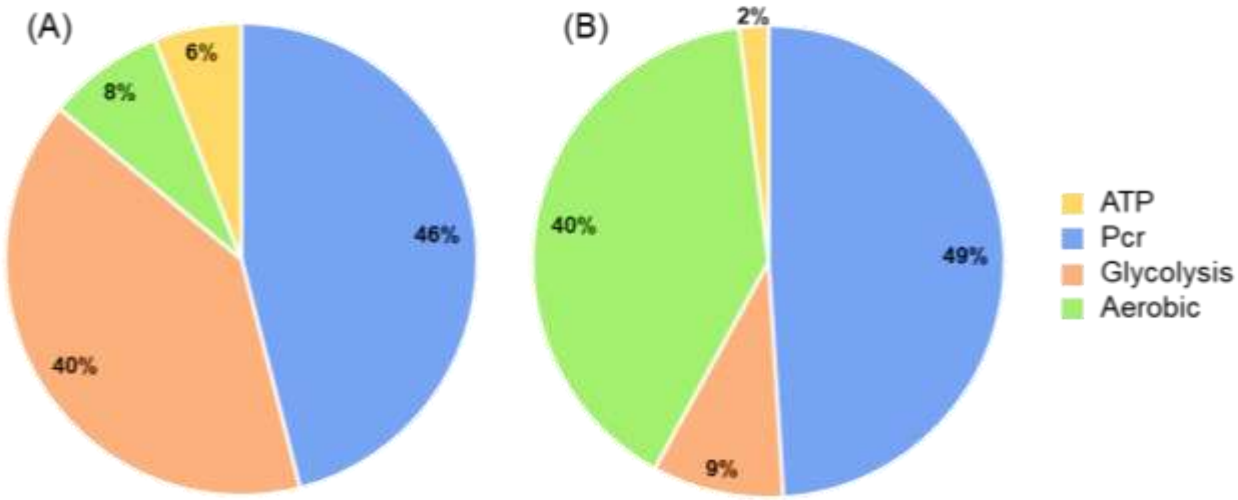
As exercise intensity increases, the anaerobic contribution also increases to meet energy demands. Lactate, produced from the lactate-dehydrogenase reaction during glycolysis and an indirect marker of the anaerobic glycolytic contribution to exercise (Beneke et al., 2011), is shuttled out of the cell and accumulates in the blood at higher work intensities. The first rise in blood lactate level above baseline is commonly known as the lactate threshold and typically occurs at 50–60% of VO_{2max} in untrained individuals and 70–80% in aerobically trained athletes (Cerretelli et al., 1975; Farrell et al., 1979). A second breakpoint in the lactate curve occurs beyond the maximal lactate steady state, which marks the highest intensity at which lactate production and clearance are in equilibrium (Faude et al., 2009). This corresponds with a non-linear, steep increase in ventilation and carbon dioxide production (Haff & Triplett, 2015) and can be an indication of increased reliance on glycolysis, a reflection of hypoxia in skeletal muscle, and/or greater recruitment of fast-twitch muscle fibres (Ghosh, 2004; Powers et al., 2007). If an individual continues to exercise at an intensity above their maximal lactate steady state, they will inevitably reach their aerobic capacity and will be unable to sustain the same output (Haff & Triplett, 2015; Powers et al., 2007). Therefore, the exercise intensity must reduce or the duration will be limited (i.e., the individual will reach exhaustion). It is important to note that while the anaerobic contribution increases with incremental exercise, the contribution of aerobic metabolism is predominant throughout when exercise is performed beyond ~2 min, irrespective of intensity (Gastin, 2001) (Figure 1).

Sprint training is performed at maximal intensity over short distances, interspersed with comparatively long rest periods compared to work durations. During a single maximal sprint of 6 s, the phosphagen system provides ~52% of the total energy demand, while glycolysis contributes around 40% (Figure 3a) (Gaitanos et al., 1993; Girard, Mendez-Villanueva, et al., 2011). Following a single sprint effort, phosphocreatine stores can be reduced to between 35−55% of resting levels and its complete recovery can require more than 5 min (Dawson et al., 1997; Gaitanos et al., 1993; Girard, Mendez-Villanueva, et al., 2011). As sprints are repeated with incomplete recovery times (e.g., < 60 s), the relative contribution of anaerobic energy production to energy yield decreases and an increased proportion of energy is derived from aerobic metabolism (Figure 3b) (Ross & Leveritt, 2001). This is accompanied by considerable increases in muscle and blood metabolites (Gaitanos et al., 1993; Girard, Mendez-Villanueva, et al., 2011), which contribute to a decline in speed as sprints are accumulated. The increase in aerobic metabolism is to such an extent that individuals can reach their VO_{2max} during a RST session

(Dupont et al., 2005). Therefore, the aerobic and anaerobic demands of RST indicate that a substantial physiological stimulus can be induced by this training method and when sessions are frequently implemented, may lead to beneficial adaptations (Taylor et al., 2015).

Figure 3

Changes in Metabolism during, a) the First, and b) the Last Repetition of 10 × 6 s Repeated Sprints



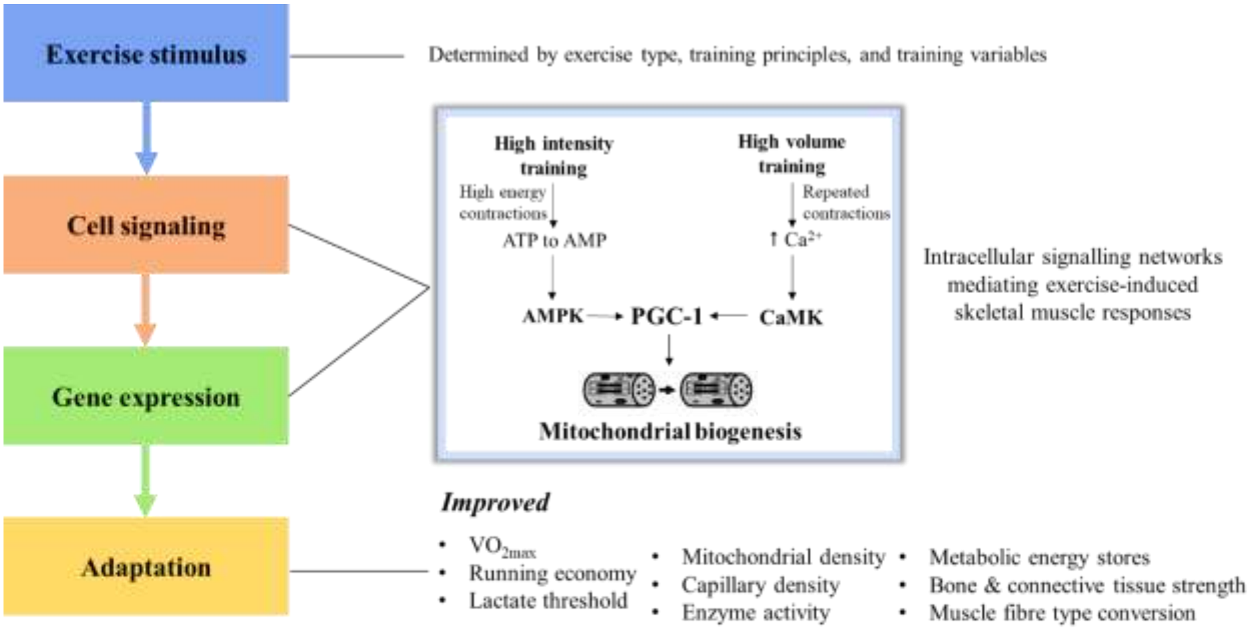
Note. Adapted from Girard, Mendez-Villanueva, et al. (2011). ATP = adenosine triphosphate; PCr = phosphocreatine.

2.4 Chronic Adaptations to Exercise

The acute stress of an exercise bout elicits a variety of physiological changes at the cellular and systemic levels that are specific to the type of stimulus (Coffey & Hawley, 2007; Haff & Triplett, 2015). A continuous or intermittent exercise session initiates intracellular signalling networks that mediate gene-specific transcriptional activation, with repeated exposure to such exercise ultimately resulting in a range of peripheral (Figure 4) and central adaptations (Hawley, 2002, 2009). Key peripheral adaptations are an increase in mitochondrial density, capillary density, and oxidative enzyme activity (Haff & Triplett, 2015; Hawley, 2002). Maximal cardiac output is the most important cardiovascular (central) adaptation to endurance training, which is the result of an enlargement in cardiac size, improved contractility, and an increase in blood volume (Blomqvist & Saltin, 1983; Hellsten & Nyberg, 2015). Other adaptations to endurance training include increases in metabolic energy stores (e.g., glycogen, creatine phosphate), greater bone and connective tissue strength, and muscle fibre type conversion from type 2x to type 2a (Haff & Triplett, 2015). Collectively, these adaptations result in a larger aerobic capacity, lower blood lactate concentrations at submaximal intensities, and improved exercise economy (Haff & Triplett, 2015).

Figure 4

A Summary of the Biological Process of Peripheral Adaptation to Endurance Training



Note. Adapted from Hawley (2009). ATP = adenosine triphosphate; AMP = adenosine monophosphate; AMPK = adenosine monophosphate-activated protein kinase; PGC-1 = Peroxisome proliferator-activated receptor-gamma coactivator 1-alpha; CaMK = calmodulin-dependent protein kinase; VO_{2max} = maximal oxygen consumption.

The physiological adaptations to endurance training can vary between individuals, depending on factors such as age, gender, genetic potential, muscle fibre type, training status, and fitness level (Jones & Carter, 2000; Sandford et al., 2021). Individuals with lower levels of initial fitness have greater increases in VO_{2max} after training compared to those with higher levels (Skinner et al., 2001). Because highly trained athletes are at the upper limit of their genetic potential, substantial changes in VO_{2max}, exercise economy, lactate/ventilatory threshold, and oxygen uptake kinetics are difficult to attain (Laursen & Jenkins, 2002). Rather, performance improvements are more likely to come from an improved ability of the skeletal muscle to buffer hydrogen ions, regulation of muscle pumps, and an increased capacity to utilise fatty acids (Laursen & Jenkins, 2002; Weston et al., 1996). Successful training programs are likely to benefit most from periods of high volumes and alternative periods of high intensities (Laursen, 2010). Additionally, the prescription of high-intensity training can allow athletes to achieve significant improvements in endurance performance without increasing total training volume (Laursen & Jenkins, 2002).

High-intensity interval training involves repeated short-long bouts of high-intensity exercise (i.e., from maximal lactate steady-state to all-out supramaximal intensities), interspersed with recovery periods of low-intensity exercise or complete rest (Laursen, 2010). Cellular changes to HIIT follow similar signaling pathways associated with traditional endurance training (Gibala, 2009), although HIIT predominantly signals via the adenosine monophosphate-activated protein kinase (AMPK) pathway, while high-volume training (e.g., continuous exercise) is more likely to operate through the calcium/calmodulin-dependent protein kinase CaMK pathway (Figure 4) (Laursen, 2010). The altered energy status (i.e., lower ATP concentrations) of muscle in response to high-intensity exercise elicits a concomitant rise in adenosine monophosphate (AMP), which activates the AMPK pathway (Laursen, 2010). Conversely, the prolonged rise in intramuscular calcium, which occurs with high volumes of training, signals the calcium-calmodulin kinases (Laursen, 2010). A small, but an intense dose of HIIT, equivalent to 2 min of all-out cycling, has been shown to increase the expression of peroxisome proliferator-activated receptor γ coactivator 1α (PGC-1a), which is the key regulator of mitochondrial biogenesis (Gibala, 2009; Gibala et al., 2009). Consequently, the physiological adaptations to HIIT closely resemble continuous steady-state training, but can be achieved with much shorter training durations, typically 10‒40 mins (Buchheit & Laursen, 2013b; Laursen & Buchheit, 2019). Studies on soccer players have shown that HIIT can substantially improve VO_{2max} (-2 to 11%), intermittent running performance (2 to 24%) (Clemente et al., 2021), and running economy (3‒7%) (Iaia et al., 2009), although the magnitude of physiological adaptation varies according to the HIIT format (Table 2). Furthermore, as HIIT can maximally stress the anaerobic system, improvement in anaerobic capacity may also be achieved alongside aerobic adaptations (Tabata et al., 1997; Tabata et al., 1996), which may not be possible with continuous steady-state exercise (Tabata et al., 1996). This is an important consideration for the training program design of athletes who compete in sports that require a considerable level of aerobic and anaerobic performance (e.g., football, tennis, rugby).

While the physiological benefits of HIIT are extensive (Laursen & Jenkins, 2002), the neuromuscular and morphological adaptations are also important. HIIT can improve an athlete's capability to produce maximal and rapid forces, likely through enhanced voluntary activation of their muscles and reduced antagonist coactivation (Creer et al., 2004; Kinnunen et al., 2019; Lucía et al., 2000; Martinez-Valdes et al., 2017). This has been demonstrated via laboratory (e.g., maximal voluntary contractions) and field-based (e.g., jumping tasks) methods (Creer et al., 2004; Kinnunen et al., 2019; Lucía et al., 2000; Martinez-Valdes et al., 2017). Furthermore, substantial improvements in speed and power can be achieved, particularly when HIIT is prescribed at supramaximal intensities (i.e., above 100% of maximal aerobic speed (short-bout HIIT, RST, and sprint interval training); Table 2) (Boullosa et al., 2022; Clemente et al., 2021; Taylor et al., 2015). This makes supramaximal HIIT methods particularly beneficial for team sport athletes, where there is a need to simultaneously develop both aerobic and anaerobic fitness qualities in limited training time. HIIT can alsodecrease fat mass, and induce favourable morphological adaptations, including a greater muscle cross-sectional area and increased sarcoplasmic reticulum volume to aid the release of calcium (Maillard et al., 2018; Moghaddam et al., 2020; Ross & Leveritt, 2001). However, evidence from (Clemente et al., 2021) has demonstrated that impairment in physical performance and physiological maladaptation can also occur following HIIT (Table 2), thus the design of HIIT programs requires close consideration.

Table 2

The Effect of High-Intensity Interval Training on Changes in Physical Performance and Physiological Adaptation in Soccer Players

HIIT method	Range (# of training groups)				
	VO_{2max}	IRP	CMJ	Sprint time	RSA
Long HIIT	-2.0 to 10.7% (# 7)	11.1% (# 1)	-0.9 to 11.5% (# 3)	0.0 to 2.8% (# 4)	NA
Short HIIT	2.2% (# 1)	6.7 to 19.7% (# 3)	-4.5 to 8.5% (# 3)	0.7 to 6.8% (# 3)	8.6% (# 1)
RST	2.9 to 5.0% (# 2)	2.0 to 24.0% (# 10)	0 to 7.7% (# 4)	0.6 to 3.7% (# 11)	-3.0 to 3.5% (# 11)
SIT	3.0% (# 1)	1.6 to 18.1% (# 5)	0.7% (# 1)	0.9 to 1.4% (# 3)	-2.2 to 2.5% (# 3)
SSG	-0.7 to 8.6% (# 5)	-12.3 to 20.9% (# 7)	-1.6 to 9.8% (# 5)	-1.3 to 6.6% (# 7)	-1.4 to 5.8% (# 5)

Note. Adapted from Clemente et al. (2021). VO_{2max} includes data from direct measures (i.e., graded exercise test with gas analysis); intermittent running performance includes data from Yo-Yo tests and the $30:15_{IFT}$; CMJ with or without arm swing; RSA data based on mean or total time; sprint time data based on linear sprints over a distance of 10−40 m. HIIT = high-intensity interval training; SSG = small-sided games; VO2max = maximal oxygen consumption; IRP = intermittent running performance; CMJ = countermovement jump; RSA = repeated-sprint ability; NA = not applicable; # = number of training groups across all included studies.

2.5 Repeated-Sprint Training

The use of repeated bouts of short sprint exercise can be traced back to 1902, where British mile runner, Joe Binks, ran 60–110 yard intervals at top speed, interspersed with brief rest periods (Bourne, 2008). Since then, academic literature on this topic has increased exponentially. In 1976 it was suggested that the ability to perform repeated short-duration sprints is an integral fitness component of team sport match play (Reilly, 1976). Repeated sprinting is used in real-world practice and scientific research to train and assess athletes (Dawson, 2012a). The term ‘repeated-sprint ability’ (RSA) was coined to represent the mean or total time taken to complete repeated-sprint protocols. As a testing method, it has commonly been implemented to assess the effects of various ergogenic aids (AbuMoh’d & Abubaker, 2020; Izquierdo et al., 2002b; Russell et al., 2017a), different exercise regimes (Aguiar et al., 2008; Binnie et al., 2014; Iaia et al., 2015) or the RSA of specific cohorts (Cuadrado-Peñafiel et al., 2014; Fort-Vanmeerhaeghe et al., 2016b; Higham et al., 2013). In 1984, Dawson et al. (1984) developed a test to evaluate the phosphate energy system and its associated recovery, which involved 20 × 7 s running sprints, departing every 30 s. After seeing evidence of pacing and high blood lactate accumulation due to the substantial number and distance of sprints, the test was modified to 8 to 10 sprints of 5 s duration (approximately 30 to 35 m) (Dawson, 2012b). It was these early tests that showed the effects of manipulating repeated-sprint programming variables on subsequent physiological, perceptual, neuromuscular, and performance outcomes. Over time, the definition of what constitutes RST has changed and its practice has evolved. Because of its broad range of use, this thesis will refer to RST as, “maximal effort, short duration sprints (≤ 10 s), interspersed with brief (≤ 60 s) recovery times” (Girard, Mendez-Villanueva, et al., 2011).

While early literature on repeated-sprinting primarily focused on its implementation as a testing method, it can also be prescribed as an effective and efficient form of training which can be implemented with a variety of different exercise modalities (e.g., cycling, swimming). However, when applied as a running-based intervention, RST improves a range of physical qualities that are important to sports performance, including speed, RSA, endurance, and CMJ height (Taylor et al., 2015). Furthermore, physical adaptations and improvements in performance can be achieved in as little as two weeks with 6 × 10–20 min sessions (Taylor et al., 2016). RST is easily implemented, as it requires limited equipment and simply involves maximal effort sprints. While a range of training methods are required to optimally prepare athletes for competition, the ability of RST to enhance performance within real-world training environments makes its application highly beneficial for athletes and practical for coaches.

2.5.1 Repeated-Sprint Training Variables

Programming variables are fundamental to the design of RST. Appropriate manipulation of programming variables can target specific physiological, neuromuscular, perceptual and performance demands and the development of specific energy systems. Table 3 provides a definition of each of the RST training variables explored within this thesis.

Table 3

Repeated-sprint Training Variables

Programming variable	Definition	Common prescription
Sprint modality	The type of running-based RST (i.e., straight-line, shuttle or multi-directional sprints)	Straight-line sprints
Number of repetitions	The number of sprints performed per set	6 repetitions
Number of sets	The number of sprints performed per session	3 sets
Repetition distance	The distance of each sprint	30 m
Inter-repetition rest time	The rest time between each sprint	20 s
Inter-set rest time	The rest time between each set	4 min
Inter-repetition rest modality	The type of rest between repetitions (i.e., passive or active)	Passive
Inter-set rest modality	The type of rest between sets	Passive
Session volume	The total number of repetitions performed per session multiplied by the repetition distance	600 m
Session frequency	The number of RST sessions per week	2 per week
Program duration	The number of weeks a RST program is implemented	6 weeks

Note. RST = repeated-sprint training; m = metres; min = minutes; s = seconds

2.5.2 Mechanisms of Fatigue During Repeated-Sprint Training

A reduction in the ability to produce force during exercise can be attributed to metabolic disturbances within the active muscle (i.e., peripheral fatigue) and/or failure of the central nervous system to voluntarily activate the exercising muscle (i.e., central fatigue) (Hureau et al., 2016). Due to the maximal intensity of RST, which relies on the recruitment of high threshold motor units and heavily taxes anaerobic energy provision, there is a rapid appearance of neuromuscular fatigue

(Goodall et al., 2015b) and this can persist for several days (Baumert et al., 2021). Peripheral mechanisms are the main contributor to fatigue during RST (Girard et al., 2013; Hureau et al., 2016; Perrey et al., 2010), which manifests as a decline in sprint speed across repetitions. Marked increases in metabolic by-products within the intramuscular environment, particularly hydrogen ions, lead to inhibition of excitation-contraction coupling and impairment of sarcolemma excitability (Haff & Triplett, 2015; Perrey et al., 2010). Together with the rapid depletion of phosphocreatine, these mechanisms result in a reduction of force and power output (Haff & Triplett, 2015; Perrey et al., 2010). It should be noted that although muscular fatigue experienced during exercise often correlates with high concentrations of lactate, lactate is not the cause of fatigue (Brooks et al., 1996; Busa & Nuccitelli, 1984; Haff & Triplett, 2015). The hydrolysis of ATP outside the mitochondria is primarily responsible for the accumulation of hydrogen ions, which subsequently reduce intracellular pH and cause peripheral fatigue (Busa & Nuccitelli, 1984; Haff & Triplett, 2015). Central factors (e.g., reductions in neural output) can also contribute to fatigue during RST and may play a role in preventing excessive peripheral fatigue, thus acting as a potential safety mechanism to prevent damage (Collins et al., 2018; Girard et al., 2013; Hureau et al., 2016; Perrey et al., 2010). Evidence of central fatigue has been demonstrated by reduced muscle voluntary activation levels during the latter half (sprints 6−10) of a cycling repeated-sprint protocol (Hureau et al., 2016). Furthermore, in running-based RST, central alterations have contributed to significant supraspinal fatigue after just 2 × 30m sprints, indicating that the development of neuromuscular fatigue may depend on the specific task and design of the session (Collins et al., 2018; Tomazin et al., 2017).

The magnitude of fatigue accrued during RST is influenced by the prescription of programming variables. Shorter rest times, longer sprint distances, larger session volumes, a greater number of repetitions, and an active recovery period all have the potential to increase fatigue (Girard, Mendez-Villanueva, et al., 2011; J Padulo, M Tabben, LP Ardigò, et al., 2015; Ulupınar, Hazır, et al., 2021; Ulupınar, Özbay, et al., 2021). In a study by Gharbi et al. (2014) an increasing number of repetitions, ranging from 2 to 10, caused a larger within-set performance decrement. The sprint modality can also affect the extent of acute neuromuscular fatigue. Shuttle-based RST has been demonstrated to induce a greater post-session decline in CMJ height compared to straight-line sprints when all other programming variables are matched (Dal Pupo et al., 2013). Furthermore, the fatigue induced by RST can take several days to recover from (Baumert et al., 2021; Clifford et al., 2016; Howatson & Milak, 2009; Klatt et al., 2021; Woolley et al., 2014) although no study has compared the effects of manipulating exercise programming variables on the recovery time-course to RST.

2.5.3 Recovery from Repeated-Sprint Training

Muscle function during sprint running utilises the stretch-shortening cycle (SSC), whereby the preactivated muscle first lengthens (eccentric contraction) and then immediately shortens (concentric contraction) (Nicol et al., 2006). The fatigue responses of repeated SSC actions are complex, but the basic pattern follows an immediate reduction in performance with a quick recovery after 1–2 hours (Nicol et al., 2006). Indeed, 30 min following RST, it has been demonstrated that there is a restoration of central nervous system function, whereby maximal voluntary contraction torque of the plantar flexors, muscle activation (twitch interpolation) and muscle contractile properties have returned close to baseline (Perrey et al., 2010). Additionally, a

4–5% potentiation of peak twitch torque and its rate of development has been observed within 30 min (Perrey et al., 2010). However, peak reductions in performance and symptoms of muscle soreness/damage usually occur on the second day after exercise involving repeated SSC activity, and full recovery may require several days (Nicol et al., 2006). However, the extent of fatigue and the recovery time course will ultimately depend on the design of the RST session.

2.6 Summary

This review has presented a range of topics and literature relevant to this thesis. The following points help to provide a summary of the key findings:

- The phosphagen system, the glycolytic system, and the oxidative system are all active at any given time, but the relative contribution of each system to the overall work performance is dependent on the intensity and duration of exercise. The phosphagen system and glycolytic system provide the majority of energy for short-duration, high-intensity exercise, while the oxidative system is the primary source of ATP production at rest and during low-intensity activities.
- Continuous steady-state exercise is performed at a constant, low intensity (< 70% of VO_{2max}) for prolonged durations without rest.
- Interval training involves series of exercise, interspersed with series of rest, which allows more work to be accomplished at higher intensities and permits the attainment of specific physical qualities required for team sports.
- Enhanced performance following endurance training is attributed to peripheral adaptations (e.g., mitochondrial density, capillary density, and oxidative enzyme activity), and central adaptations (e.g., enlargement in cardiac size, improved contractility, and an increase in

blood volume). These adaptations ultimately result in a larger aerobic capacity, greater lactate threshold, and improved exercise economy.

- The physiological adaptations to endurance training can vary between individuals, depending on factors such as age, gender, genetic potential, muscle fibre type, training status, and fitness level.
- HIIT involves repeated bouts of high-intensity exercise (i.e., from maximal lactate steady-state to all-out supramaximal intensities), interspersed with recovery periods of low-intensity exercise or complete rest
- HIIT promotes aerobic, anaerobic, neuromuscular, and morphological adaptations, that can be achieved with lower training volumes and shorter training durations compared to continuous exercise.
- RST is defined as, “maximal effort short duration running sprints (≤ 10 s), interspersed with brief (≤ 60 s) recovery times.
- The aerobic and anaerobic demands of RST indicate that a substantial physiological stimulus can be induced by this training method.
- RST is associated with small to large improvements in power, speed, RSA and endurance.
- Appropriate manipulation of exercise programming variables can permit the selection of specific physiological, neuromuscular, perceptual, and performance demands during RST, while also allowing a more targeted development of certain energy systems.
- The magnitude of fatigue accrued during RST is influenced by the prescription of programming variables. Although, more evidence is needed to compare the recovery time-course to RST when key programming variables are manipulated.

CHAPTER 3

EXTENDED METHODS

In this chapter, common methodologies within this thesis are detailed. Additionally, a general research overview, information about the participants involved, experimental designs, and procedures are provided. Specific details pertaining to the methods within each study will be provided within the corresponding chapter.

3.1 Experimental Approach to the Problem

Four studies were conducted to, a) determine the acute demands and physical adaptations of running-based RST in intermittent sport athletes, and b) examine the influence of programming variables on these demands and adaptations. Findings obtained during prior studies within this thesis were used to inform the direction of further studies. The general progression of studies that were conducted within this thesis can be found in Figure 5 with the title, aims, participants, research design, and variables measured also reported. All data was collected between 1/8/2022 and 1/4/2023.

Figure 5

The Progression of Studies within this Thesis

Study 1 – The Acute Demands of Repeated-Sprint Training on Physiological, Neuromuscular, Perceptual and Performance Outcomes in Team Sport Athletes: A Systematic Review and Meta-Analysis

Aim	Participants	Design	Variables measured
(1) Identify the most common RST protocol; (2) evaluate and summarise the acute physiological, neuromuscular, perceptual and performance demands of RST; and (3) examine the meta-analytic effects of sprint modality, number of repetitions per set, sprint repetition distance, inter-repetition rest modality, and inter-repetition rest duration on the acute RST demands.	Healthy, able-bodied, team sport athletes > 16 years of age	Multi-level mixed-effects meta-analysis	HR, CK, B[La], VO_2, CMJ, sRPE, S_{dec}, sprint times, SMM parameters, Sprint FVP parameters

⬇

Study 2 – The Effects of Repeated-Sprint Training on Physical Adaptation: A Systematic Review and Meta-Analysis

Aim	Participants	Design	Variables measured
Quantify the pooled effects of running RST on changes in 10 and 20 m sprint time, VO_{2max}, YYIR1 distance, RSA, CMJ height, and COD ability in athletes, and, (2) examine the moderating effects of program duration, training frequency, weekly volume, sprint modality, repetition distance, number of repetitions per set, and number of sets per session on changes in these outcome measures.	Healthy, able-bodied, trained athletes ≤ 35 years of age	Multi-level mixed-effects meta-analysis	10 m sprint time, 20 m sprint time, CMJ height, COD ability, YYIR1, RSA, VO_{2max}

⬇

Study 3 – The Effects of Session Volume on Acute Demands During Repeated-Sprint Training and the Recovery Time-Course of Neuromuscular Performance

Aim	Participants	Design	Variables measured
(1) Examine the effects of manipulating session volume on acute physiological, perceptual, and performance demands during RST, and the recovery time-course of neuromuscular performance, and (2) determine whether repetition distance or the number of repetitions has a greater effect on the acute demands and the recovery time-course.	14 healthy, able-bodied, trained male and female athletes, between 20–30 years of age,	Randomised, crossover study	VO_2, HR, sRPE, dRPE, S_{dec}, GPS metrics, CMJ performance, leg stiffness, isometric hamstring strength

⬇

Study 4 – The Effects of Repeated-Sprint Training Vs Short-Bout High-Intensity Interval Training on Hamstring Architecture and Physical Fitness in Rugby League Players

Aim	Participants	Design	Variables measured
Quantify and compare the effects of RST vs short-bout HIIT on BFlh architecture, aerobic fitness, eccentric knee flexor strength, CMJ performance, and sprint FVP profiles in rugby league players	Healthy, able-bodied, male rugby league players, between 18–21 years of age.	Parallel, two group, pre-test – post-test	Aerobic fitness, sprint times and sprint FVP characteristics, CMJ performance, eccentric hamstring strength, BFlh muscle architecture

Note. ACU = Australian Catholic University; BFlh = biceps-femoris long-head; B[La] = blood lactate; CMJ = countermovement jump; COD = change of direction; CK = creatine kinase; FVP = force-velocity-power; GPS = global positioning system; HR = heart rate; RSA = repeated-sprint ability; S_{dec} = percentage sprint decrement; SMM = spring-mass model parameters; sRPE = session rating of perceived exertion; YYIR1 = Yo-Yo Intermittent Recovery Test Level 1; VO_{2max} = maximal oxygen consumption; VO_2 = oxygen consumption.

3.2 Participants

The participants within this thesis are all healthy, able-bodied, intermittent sport athletes, between the ages of 12‒35 y. The Participant Classification Framework (McKay et al., 2022) was used to define the training and performance calibre of the athletes included in our investigation, which ranged from recreational to elite/international level (McKay et al., 2022). There are 5572 athlete inclusions across the first two studies, which are systematic reviews and meta-analyses. Due to the sheer volume of literature on the acute demands of RST, Study 1 focuses on team sport athletes, while Studies 2 and 3 incorporate team and other intermittent sport athletes. Between studies 3‒4, there are 44 participants. All participants were informed of the risks and benefits of partaking in any study and signed a consent form prior to commencement of any data collection, which can be found in Appendix 43. Additionally, all experimental protocols were approved by the ACU ethics committee (application identification: 2021-244H and 2022-2773H). Prior to all testing, participants were instructed to refrain from strenuous activity and the consumption of alcohol for at least 24 h and to maintain normal dietary habits during the intervention, which included abstaining from caffeine for 12 h before all testing.

3.3 Procedures

To examine the effects of RST, a number of physiological, morphological, neuromuscular, perceptual, and performance measures were used, which will be detailed within this sub-section. Additionally, details regarding the methods of data collection (e.g., warm-ups) will be provided.

To assist in the standardisation of data collection, participants in the intervention studies (i.e., studies 3‒4) completed all testing at the same time of day using the same equipment, in the same footwear and in similar environmental conditions. Familiarisation was completed before study 3, which provided the participants with an opportunity to become familiar with the testing protocols and equipment. All intervention studies took place at institutes that had designated training facilities, with participants being tested at the same facility at all time points.

3.3.1 Warm-ups

Standarised warm-ups were delivered in study 3. At the beginning of each session (i.e., RST session, 24 and 48 h follow-ups) participants performed the following dynamic movements, which were completed over a distance of 10 m and administered in the same order:

1. Bodyweight squat and step forward
2. Heel sweeps
3. Walking lunges
4. Arabesque and step forward
5. High knee skip
6. Butt flicks
7. Ankle drives
8. Side skips
9. Forward leg swings × 10
10. lateral leg swings × 10

Following this initial warm-up, participants completed the indoor physical tests (i.e., isometric hamstring test, CMJ and hopping test). On days where the RST conditions were performed, the participants then transitioned to the sports oval where they completed 4 × 40 m run throughs at increasing intensity (i.e., 50, 70, 80 and 90% of self-perceived maximal speed), walking back to the starting point after each run.

3.3.2 Countermovement Jump Performance

The assessment of CMJ performance is a valid and reliable test for the estimation of lower-limb power (Gathercole, Sporer, et al., 2015a; Markovic et al., 2004). It is non-invasive, time-efficient and shares similarities with muscle actions involved in athletic tasks (i.e., the stretch-shortening cycle) (Gathercole, Sporer, & Stellingwerff, 2015; Gathercole, Sporer, et al., 2015a). This makes the CMJ a useful test to identify training induced changes in physical performance. Furthermore, the CMJ test is able to detect alterations in neuromuscular function following fatiguing exercise and compared to other jump protocols (e.g., squat jump, drop jump) it has demonstrated the greatest sensitivity and validity (Table 4) (Gathercole, Sporer, et al., 2015a; Gathercole, Sporer, et al., 2015b; Markovic et al., 2004). There are a wide range of kinematic and kinetic CMJ variables available to practitioners to assess physical ability and fatigue (Gathercole, Sporer, et al., 2015a). To provide a more detailed analysis that reflects changes in CMJ output and strategy, both ‘typical’ (i.e., jump height, relative peak power, relative mean power and flight time to contraction time ratio) and ‘alternative’ (i.e., eccentric duration) variables have been selected (Table 4) (Gathercole, Sporer, et al., 2015a). However, it should be noted that ‘alternative’ variables reflect the neuromuscular strategy of the jump, they have higher coefficient of variation (CV > 5%) (Gathercole, Sporer, et al., 2015a).

Table 4

Countermovement Jump Variables Measured within this Thesis and their Associated Reliability

CMJ variable	Study	Reliability	
		Intraday CV (%)	Interday CV (%)
Jump height	1–4	5.3 ± 3.6	4.9 ± 2.4
Relative peak power	4	2.3 ± 1.6	2.7 ± 1.7
Relative concentric power	3	3.0 ± 1.9	2.8 ± 1.0
Flight time to contraction time ratio	3	4.0 ± 1.5	5.2 ± 3.2
Eccentric duration	3	6.2 ± 3.2	8.0 ± 3.7

Note. Data extracted from Gathercole, Sporer, et al. (2015a). Data given as mean ± standard deviation.

CMJ = countermovement jump; CV = coefficient of variation.

The analysis of CMJ performance for Studies 3 and 4 was completed using a set of portable force plates (ForceDecks, VALD Performance, Brisbane, Australia), which sampled at a rate of 1000 Hz. The force plates were connected to a laptop via Bluetooth and data was expressed through ForceDecks Software (VALD Performance, Brisbane, Australia). The primary CMJ variable was jump height with the best of three trials selected for analysis (Al Haddad et al., 2015). The impulse-momentum method of calculating CMJ height was used as it gives the most accurate result (Linthorne, 2001). Jump initiation was detected as a change of 20 N from the start of the movement. Participants were asked to jump as high as possible while keeping their hands on their hips (Weakley, Till, et al., 2019; Weakley et al., 2017). They began each trial with their knees extended and feet in a position of their choice before performing the jump with a self-selected countermovement depth (Weakley, Till, et al., 2019; Weakley et al., 2017). One minute rest was provided between each trial (Weakley, Till, et al., 2019; Weakley et al., 2017).

3.3.3 Hopping test

A double-leg hopping test was employed in Study 3 to assess acute changes in leg stiffness (Dalleau et al., 2004). During running and jumping activities, the muscles, tendons and ligaments of the lower leg operate together in a spring like manner by compressing and then lengthening during the ground contact phase (Farley & Morgenroth, 1999). The stiffness of the leg represents the average stiffness of the overall musculoskeletal system (Farley & Morgenroth, 1999), which can be impaired by fatiguing exercise (Leduc et al., 2020; Oliver et al., 2014). The double-leg hopping test has previously been used with athletic populations to provide a measure of leg stiffness and consists of sub-maximal rebounding at 2.5 Hz (150 bpm) (Dalleau et al., 2004; Leduc et al., 2020; Oliver et al., 2015). This frequency possesses the highest reliability (coefficient of variation = 9.48–10.17%) and allows participants to maintain a consistent hopping pace (Lloyd et al., 2009). Participants completed one trial of 20 consecutive hops on the same set of force plates as the CMJ, with hopping frequency controlled by a digital metronome (TempoPerfect, version 4.07, HCH Software). The first and last five hops were discarded, with an average of the hops 6–15 used for analysis. Leg stiffness was calculated through Dalleau's equation (Dalleau et al., 2004), where M is the mass (kg), Ft is the flight time (s) and Ct is the contact time (s).

$$Leg\ stiffness = \frac{M * \pi\ (Ft + Ct)}{Ct^2\ ((\frac{FT + Ct}{\pi}) - (\frac{Ct}{4}))}$$

3.3.4 Isometric Hamstring Strength

An isometric hamstring strength test was used in Study 3 to assess acute changes in hamstring strength (McCall et al., 2015). Maximal sprinting induces a high degree of stress and strain on the musculoskeletal system, particularly the hamstring muscles, which rapidly lengthen during the terminal swing phase (Schache et al., 2012; Thelen et al., 2005; Timmins et al., 2014). Furthermore, previous evidence has shown that declines in hamstring strength may persist for several days following repeated-sprints, which could affect the quality of subsequent training and increase injury susceptibility (Baumert et al., 2021; Timmins et al., 2014). Tests to assess acute changes in hamstring strength can therefore provide important information relating to fatigue and recovery. Such tests commonly include maximal eccentric contractions (e.g., isokinetic dynamometry, Nordic hamstring lower) (Opar et al., 2013; Sconce et al., 2015; Timmins et al., 2014). While valuable, the usage of such tests immediately after and in the days following training could impede the natural recovery process (McCall et al., 2015; Nosaka et al., 2002). Alternatively, isometric contractions have been shown to result in little or no structural muscle damage (Faulkner et al., 1993; Lieber et al., 1991; McCall et al., 2015; Nosaka et al., 2002), thus can be useful to assess muscle function between recovery time-points. Additionally, the ease and efficiency of an isometric strength test makes it highly practical for coaches in the field (McCall et al., 2015; O'Keefe, 2020).

Assessment of isometric hamstring strength was performed on the same set of force plates as the jumping tests. The test was performed on the athletes’ dominant limb at knee angles of 90° and 30°, which has previously demonstrated good τo high reliability (Table 5) (McCall et al., 2015). Participants laid on their back on a mat, with the heel of the working leg positioned on the force plate, which was placed on a firm box and the heel of the non-working leg positioned on the edge of the box (Figure 6). The athletes' knee was flexed to 90° using a goniometer (EZ Read Jamar, Patterson Medical, Warrenville, USA), and then to 30°. The athlete was instructed to push their heel into the force platform as hard as possible as though they were trying to perform a hamstring curl, without lifting their hips, hands or head off the mat. The contraction was performed for 3 s and repeated three times at each angle with 30 s rest between trials. The highest peak force (N) was recorded for analysis. Investigators ensured strict adherence to technique by pressing the athletes' hips to the floor during each repetition and giving loud verbal encouragement throughout to ensure maximal effort.

Table 5

Reliability of the Posterior Lower-Limb Isometric Strength Test on the Dominant Limb

Variable	CV (%)	Change in the mean (90% CL)	Typical error (90% CL)	ICC (90% CL)
Force at 90°	4.34	2.1 N (-3.8 to -7.9)	9.4 N (7.3–13.6)	0.95 (0.88–0.98)
Force at 30°	6.31	1.0 N (-6.9 to -9.0)	13.3 N (10.4–18.9)	0.86 (0.69–0.94)

Note. Extracted from McCall et al. (2015). Abbreviations: CV = coefficient of variation; CL = confidence limit; ICC = intraclass correlation coefficient

Figure 6

The Set-up for the Isometric Hamstring Strength Test at 90° (Left) and 30° (Right) Knee Angles

3.3.5 Oxygen Consumption and Heart Rate

A graded exercise test to exhaustion with respiratory gas exchange is widely considered to be the ‘gold standard’ for the assessment of aerobic capacity (Poole & Jones, 2017). It was performed on a motorised treadmill (T22.1, Vertex Fitness, Abu Dhabi, United Arab Emirates) in Study 3 to help determine the cardiorespiratory demands of the RST sessions. Respiratory gas exchange data was collected via a portable metabolic system (K5, COSMED, Rome, Italy) and heart rate was measured using a chest strap monitor (HRM-Dual, Garmin Australasia Pty Ltd, New South Wales, Australia), which was integrated with the metabolic system. To become familiarised with the portable metabolic system and associated Hans Rudolph face mask, participants wore these apparatuses during the warm-up, which consisted of 3–5 min of running at a self-selected pace and any other preparatory exercise of their choosing. Depending on the participants approximate fitness level, the test then began at a speed between 6–10 km·h^{-1}. Each stage lasted for 2 min and increased by 2 km·h^{-1} for the first three stages, followed by a 2% increase in gradient, until the participant reached volitional exhaustion, which was achieved within 10−14 min for all participants. The graded exercise test was considered a true VO_{2max} when a plateau in VO_2 (≤ 150 ml) was achieved despite an increase in workload (Beltz et al., 2016). Analysis of the graded exercise test was performed by removing erroneous fluctuations in raw data and then averaging VO_2 into 15 s time bins, with the highest 15 s time bin used to determine the participants VO_{2max}. Raw VO_2 data was removed from the analysis if considered to be higher or lower than physiologically possible according to the following criteria: data was considered too high if it was more than 10% above the highest 15 s average obtained during the graded exercise test, and too low if it was below the average VO_2 attained during the first stage of the graded exercise test. Furthermore, any values that were considered physiologically impossible were also removed. All trials were analysed by the same investigator to avoid inter-observer differences.

To determine the cardiorespiratory demands of the RST sessions in Study 3, the same portable metabolic system and heart rate monitor was used. Heart rate and respiratory gas exchange data was continuously recorded from the time of the initiation of the first sprint, to exactly 30 s following the final sprint, which marked the end of the last repetitions recovery period. Before each session, the gas analysis systems were calibrated as recommended by the manufacturer and the participant was fitted with the same sized Hans Rudolph face mask. Raw data was exported to Microsoft Excel (Microsoft Office 2019, Version 2209), where erroneous fluctuations were removed by following the same methodological approach as described in the previous paragraph. Velocity data from a 10 Hz global positioning system (GPS) imbedded within the metabolic system allowed for the start of each repetition to be determined. Subsequently, heart rate and VO_2

data were then averaged for each repetition, each set and for the overall RST session (excluding the inter-set recovery period).

3.3.6 Repeated-Sprint Training Sessions

Specific details pertaining to the RST protocols within each study will be provided within the corresponding chapter. In Study 3, to standardise sprint testing methods, participants started each sprint in a standing start position with their front foot 0.3 m behind the first timing gate (Weakley, McCosker, et al., 2023). During the RST sessions of Study 4, participants started each sprint with their foot on a line marked out by cones. A 10 s warning and 3 s countdown was provided for each repetition. Participants were instructed to give maximal effort and sprint through the finish line. Loud verbal encouragement was given to all participants during each repetition. During the inter-repetition recovery period, athletes decelerated and walked back to the starting point. Standardised inter-repetition rest times were used instead of work to rest ratio's because they are more common in literature and more practical within real world training environments. In Study 3, two sets of single-beam timing gates (TCi, Brower Timing Systems, Draper, USA) were used that worked in both directions, which allowed the athletes to start each sprint from each end. The timing gates were set at a height of 1 m and were used to determine the mean velocity of each repetition. Additionally, participants were fitted with the same GPS (Apex, STATSports, Newry, Northern Ireland), which was used to determine the peak velocity of each repetition (Beato et al., 2018; Beato & de Keijzer, 2019). The same GPS was also used to determine the locomotor profiles of each RST session in Study 3 (i.e., acceleration demands and volume of running >90% of maximal sprint speed (MSS)). To attain the volume of running >90% of MSS, a single 40 m maximal sprint, performed 5 min prior to the RST session, for each participant, on each training day, was used as the reference peak speed, which was derived from the GPS. This approach allowed for daily individual fluctuations in sprint performance to be accounted for (Ravindrakumar et al., 2022). The assessment of within-session performance fatigue is a common outcome from a repeated-sprint test (Glaister et al., 2008). To calculate this (i.e., the decline in sprint speed across each set), the percentage sprint decrement (S_{dec}) score was used (Glaister et al., 2008). While S_{dec} has been shown to be less reliable than best and average RSA times for detecting changes in performance (Impellizzeri et al., 2008) it is the most ecologically valid index to quantify fatigue during RST (Glaister et al., 2008). It was calculated as:

$$S_{dec} = (100 \times (\text{total sprint time} \div \text{ideal sprint time})) - 100$$

where total sprint time represents sum of sprint times from all sprints, and ideal sprint time represents the number of sprints multiplied by the fastest sprint time.

3.3.7 Sprint Force-Velocity-Power Profiling

Sprint FVP profiling was conducted in Study 4 to measure changes in mechanical sprint performance. The ability to accelerate quickly during sprint running has been related to the capacity to produce and effectively apply high amounts of horizontal external force onto the ground at increasing velocities (Jaskolska et al., 1998; Rabita et al., 2015; Samozino et al., 2016). This mechanical capability has been described by the inverse linear force-velocity and the parabolic power-velocity relationships (Jaskolska et al., 1998; Rabita et al., 2015; Samozino et al., 2016). Determining individual FVP relationships during sprint propulsion can provide coaches with a reliable understanding (Table 6) of an athlete's mechanical sprint effectiveness (Jiménez-

Reyes et al., 2022; Mendiguchia et al., 2016; Morin & Samozino, 2016; Nagahara et al., 2016; Samozino et al., 2016).

Table 6

Reliability of the Measured Force-velocity-power Variables

Variable	CV (%)	Change in the mean	SE (%)
F_0	2.93 ± 2.00	-1.5 ± 32.2 N	3.57
V_0	1.11 ± 0.86	-0.17 ± 0.78 $m \cdot s^{-1}$	1.40
P_{max}	1.90 ± 1.40	-0.16 ± 0.67 W	2.37
D_{RF}	3.99 ± 2.80	-0.11 ± 0.45%	4.86

Note. Extracted from Samozino et al. (2016). Data given as mean ± standard deviation. CV = coefficient of variation; SE = standard error; F_0 = maximal theoretical force; V_0 = maximal theoretical velocity; P_{max} = maximal theoretical power; D_{RF} = decrease in the ratio of horizontal force with increasing velocity.

To determine sprint FVP profiles in Study 4, two maximal 40 m sprints were performed from a standing start position with 3–5 mins rest in between. Upon instruction, athletes began the sprint at their own convenience with their front foot on the start line. Athletes were instructed to give maximal effort and sprint through the finish line. Loud verbal encouragement was given to all athletes during each trial. Instantaneous velocity-time data was collected by a laser testing system (LaserSpeed, MuscleLab, Stathelle, Norway) sampling at 1000 Hz positioned on a tripod 10-m behind the subject and at a height of 1 m, corresponding approximately to the subject's centre of mass (Cross et al., 2018). Raw data were analysed using a custom-made R script (RStudio: Integrated Development for R. Version 4.2.3, Boston, USA). The sprint FVP variables of interest are interpretated in Table 7.

Table 7

Practical Interpretation of the Sprint Force-velocity-power Variables of Interest.

Variable	Practical interpretation
F_0	Maximal force output (per unit body mass) in the horizontal direction. Corresponds to the initial push of the athlete onto the ground during sprint acceleration. The higher the value, the higher the sprint-specific horizontal force production.
V_0	Sprint-running maximal velocity capability of the athlete. Slightly higher than the actual maximal velocity. The theoretical maximal running velocity the athlete would be able to reach should mechanical resistances (ie, internal and external) against movement be null. It also represents the capability to produce horizontal force at very high running velocities.
P_{max}	Maximal power-output capability of the athlete in the horizontal direction (per unit body mass) during sprint acceleration.
RF_{max}	Theoretically maximal effectiveness of force application. Direct measurement of the proportion of the total force production that is directed in the forward direction of motion at sprint start.
D_{RF}	Describes the athlete's capability to limit the inevitable decrease in mechanical effectiveness with increasing speed, ie, an index of the ability to maintain a net horizontal force production despite increasing running velocity. The more negative the slope, the faster the loss of effectiveness of force application during acceleration, and vice versa.

Note. Extracted from Morin & Samozino, 2016.

3.3.8 Ratings of Perceived Exertion

Ratings of perceived exertion were meta-analysed in Study 1 and collected in Studies 3 and 4. An athlete's perception of effort is one of the most common means of assessing the intensity of exercise (Halson, 2014). The session rating of perceived exertion (sRPE) method allows a subjective intensity rating of the entire training session (Foster, 1998; McLaren et al., 2017). It involves multiplying an athletes rating of perceived exertion on a 0–10 scale by the duration of the training session (in min) (Halson, 2014). The test-re-test reliability of rating of perceived exertion is reported to be high (intraclass correlation coefficient = 0.99; typical error = 4.0%) (Gabbett & Domrow, 2007). Furthermore, differential ratings of perceived exertion (dRPE) can enhance the accuracy of internal load measurement by better discriminating between central (e.g., uptake and transport of oxygen, central nervous system) and peripheral exertion (e.g., neuromuscular, musculoskeletal and metabolite characteristics) (McLaren, Graham, et al., 2016). The use of dRPE has also been validated across a number of different forms of exercise, including RST (McLaren et al., 2020; Weakley, McLaren, et al., 2019).

During the familiarisation session of Study 3, and at the beginning of the first training session for Study 4, participants were informed about the definition of perceived exertion and its scaling, including the importance of separating rating of perceived exertion from other exercise related sensations such as pain, discomfort, and fatigue (McLaren et al., 2020). Instruction was also given to participants in Study 3 on how to appraise dRPE, such that dRPE for breathlessness (RPE-B) depends mainly on breathing rate and/or heart effort, and dRPE for leg muscle exertion (RPE-L) depends mainly on the strain and exertion in the leg muscles (McLaren et al., 2020).

Approximately 5 min after the RST sessions in Study 3, and 15 min after the field-based training sessions in Study 4, participants indicated their sRPE to the investigator by considering the verbal anchors on a modified version (Foster et al., 2001) of the Borg CR10 (category ratio)

Scale® (Table 8) (Borg, 2010). Perceived exertion was recorded at these times because it was most practical, considering that participants had follow-up testing (Study 3) and other training (Study 4, e.g., resistance training) to perform afterwards. The assessment of RPE-B and RPE-L were recorded 2 min after set one and set two in Study 3. Participants were instructed that their ratings should reflect the perceptions of effort experienced for the preceding set only (McLaren et al., 2020). They then indicated their dRPE to the investigator by considering the verbal anchors on a Borg CR100 Scale® (Figure 7) (Borg, 2010).

Table 8

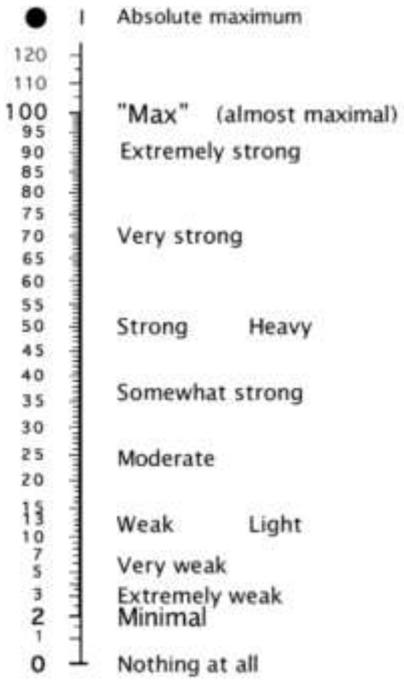
Modified Borg CR10 Scale®

Rating	Descriptor
0	Rest
1	Very, very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	.
7	Very hard
8	.
9	.
10	Maximal

Note. Extracted from Foster et al. (2001).

Figure 7.

Borg CR100 Scale®



Note. Extracted from (Borg, 2010)

3.3.9 General Overview of Data and Statistical Analysis

Various statistical methods are used throughout this thesis. Details of each statistical test used are explained within each corresponding study/chapter. However, below is a brief overview of the statistical tests used within the five studies:

- Study 1: multi-level mixed-effects meta-analyses with meta-regression. Effects were evaluated based on coverage of their confidence limits (CL) against elected thresholds of practical importance.

- Study 2: multi-level mixed-effects meta-analyses with meta-regression. Effects were evaluated based on coverage of their CL's against standardised effects, using a strength and conditioning specific reference value of ±0.25 to declare an improvement or impairment in outcome measures (Swinton et al., 2022).
- Study 3: univariate analysis of variance (ANOVA) was used to compare between and within protocol differences in outcomes. All effects were expressed as an effect size (ES) and to provide a probabilistic interpretation of difference, a minimum effects test (MET) was used.
- Study 4: paired sample T-tests were used to determine the within group changes for each outcome, and analysis of covariance (ANCOVA) were performed to determine the between-group differences of the within group changes for each outcome. Between-group differences in training load were analysed using linear mixed models. All effects were expressed as an effect size (ES) and to provide a probabilistic interpretation of difference, a MET was used.

CHAPTER 4

STUDY 1

The Acute Demands of Repeated-Sprint Training on Physiological, Neuromuscular, Perceptual and Performance Outcomes in Team Sport Athletes: A Systematic Review and Meta-Analysis

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This chapter is presented in the pre-publication format, adapted from:

Thurlow, F., Weakley, J., Townshend, A. D., Timmins, R. G., Morrison, M., & McLaren, S. J. (2023). The Acute Demands of Repeated-Sprint Training on Physiological, Neuromuscular, Perceptual and Performance Outcomes in Team Sport Athletes: A Systematic Review and Meta-analysis. Sports Medicine, 1-32.

4.1 PRELUDE

The following chapter presents the first study within this thesis. It extensively reviews the acute physiological, neuromuscular, perceptual, and performance demands of running-based RST in team sport athletes, while also synthesising the moderating effects of programming variables on these outcomes. In doing so, this chapter provides practitioners with the most effective programming strategies to elicit specific responses to a RST session.

4.2 ABSTRACT

Background: Knowledge about the acute demands of running-based RST and the influence of programming variables has implications for the training prescription of team sport athletes.

Purpose: To investigate the physiological, neuromuscular, perceptual and performance demands of running-based RST in team sport athletes, while also examining the moderating effects of programming variables (sprint modality, number of repetitions per set, sprint repetition distance, inter-repetition rest modality, and inter-repetition rest duration) on these outcomes.

Methods: The databases Pubmed, SPORTDiscus, MEDLINE and Scopus were searched for original research articles investigating overground running RST in team sport athletes ≥ 16 y. Eligible data were analysed using multi-level mixed effects meta-analysis, with meta-regression performed on outcomes with ~50 samples (10 per moderator) to examine the influence of programming factors. Effects were evaluated based on coverage of their confidence (compatibility) limits (CL) against elected thresholds of practical importance.

Results: From 908 data samples nested within 176 studies eligible for meta-analysis, the pooled demands (± 90% CL) of RST were as follows: average heart rate (HR_{avg}), 163; ±9 b·min^{-1}; peak heart rate (HR_{peak}), 182; ± 3 b·min^{-1}; average VO_2, 42.4; ±10.1 ml·kg^{-1}·min^{-1}; end-set blood lactate concentration (B[La]), 10.7; ±0.6 mmol·L^{-1}; sRPE, 6.5; ±0.5 au; average sprint time (S_{avg}), 5.57; ±0.26 s; best sprint time (S_{best}), 5.52; ±0.27 s, and; S_{dec}, 5.0; ±0.3%. When compared to a reference protocol of 6 × 30 m straight-line sprints with 20 s passive inter-repetition rest, shuttle-based sprints were associated with a meaningful increase in repetition time (S_{avg}: 1.42; ±0.11 s, S_{best}: 1.55; ±0.13 s), whereas the effect on sRPE was trivial (0.6; ±0.9 au). Performing two more repetitions per set had a trivial effect on HR_{peak} (0.8; ±1.0 b·min^{-1}), B[La] (0.3; ±0.2 mmol·L^{-1}), sRPE (0.2; ±0.2 au), S_{avg} (0.01; ±0.03) and S_{dec} (0.4; ±0.2%). Sprinting 10 m further per repetition was associated with a substantial increase in B[La] (2.7; ±0.7 mmol·L^{-1}) and S_{dec} (1.7; ±0.4%), whereas the effect on sRPE was trivial (0.7; ±0.6). Resting for 10 s longer between repetitions was associated with a substantial reduction in B[La] (-1.1; ±0.5 mmol·L^{-1}), S_{avg} (-0.09; ±0.06 s), and S_{dec} (-1.4; ±0.4%), while the effects on HR_{peak} (-0.7; ±1.8 b·min^{-1}) and sRPE (-0.5; ±0.5 au) were trivial. All other moderating effects were compatible with both trivial and substantial effects (i.e., equal coverage of the CI across a trivial and a substantial region in only one direction), or inconclusive (i.e., the CI spanned across substantial and trivial regions in both positive and negative directions).

Conclusions: The physiological, neuromuscular, perceptual, and performance demands of RST are substantial, with some of these outcomes moderated by the manipulation of programming variables. To amplify physiological demands and performance decrement, longer sprint distances (> 30 m) and shorter, inter-repetition rest (≤ 20 s) are recommended. Alternatively, to mitigate

fatigue and enhance acute sprint performance, shorter sprint distances (e.g., 15–25 m) with longer, passive inter-repetition rest (≥ 30 s) are recommended.

4.2.1 Key Points

- The most common RST set configuration is 6 × 30 m straight-line sprints with 20 s passive inter-repetition rest.
- The reference estimates for HR_{avg} (90% of HR_{max}), VO_{2avg} (~70–80% of VO_{2max}) and B[La] (10.8 $mmol \cdot L^{-1}$) demonstrate the substantial physiological demands of RST in team sport athletes. Associated prediction intervals for these estimates suggest that most of these demands are consistently substantial across many RST protocols, sports, and athlete characteristics.
- Shorter inter-repetition rest periods (≤ 20 s) and longer repetition distances (> 30 m) amplify physiological demands and cause greater inter-set reductions in sprint performance (i.e., performance fatigue). Inversely, longer inter-repetition rest periods (≥ 30 s) and shorter repetition distances (≤ 20 m) enhance acute sprint performance and reduce the physiological demands.
- Shuttle-based protocols are associated with slower repetition times, likely due to the added change-of-direction component but may reduce sprint decrement. The effect of shuttle vs straight-line RST protocols on physiological and perceptual outcomes remains inconclusive.
- Performing two less repetitions per set (e.g., 4 as opposed to 6 repetitions) maintains the perceptual, performance, and physiological demands of RST.

- The findings from our investigation provide practitioners with the expected demands of RST and can be used to help optimise training prescription through the manipulation of programming variables.

4.3 INTRODUCTION

Repeated-sprint training appears to be an effective and time-efficient training modality for physical adaptations in team-sport athletes, with as few as six sessions over two weeks shown to enhance high-speed running abilities (Taylor et al., 2016). The implementation of RST can also provide athletes with exposure to maximal sprinting, acceleration and deceleration, which are important components of team sport (Malone et al., 2017; Mendiguchia et al., 2020; Taylor et al., 2017). Throughout an athlete's training program, there is a range of opportunities for RST to be used, such as during a pre-season where a progressive reduction in running volume and an increase in intensity is often implemented (Bompa & Buzzichelli, 2019). Alternatively, it could be employed during the playing season to promote the maintenance of specific physical qualities (e.g., speed, aerobic fitness), used as part of late-stage rehabilitation or implemented at a time when a training 'shock-cycle' is required. However, each training program requires different outcomes, with these attained through the manipulation of programming variables.

The type of stimulus is an important driver of the chronic adaptive response to training (Coffey & Hawley, 2007). RST is low-volume and short in duration, with typical sessions less than 1000 m in volume and 10–20 min in duration. Due to the maximal intensity at which it is performed, it can generate adaptive events that ultimately result in the capacity for enhanced performance (Clemente et al., 2021; Taylor et al., 2015). This includes an improved aerobic capacity and faster sprint performance (Boer & Van Aswegen, 2016; Bravo et al., 2008; Fernandez-Fernandez et al., 2012; Gantois et al., 2019; Kaynak et al., 2017b; Maggioni et al., 2019; Ross & Leveritt, 2001; Serpiello et al., 2012). However, there is considerable variation in RST prescription, with acute programming variables (e.g., sprint distance, rest duration) regularly manipulated in research and practice (Buchheit & Laursen, 2013b; Taylor et al., 2015). These changes can influence the internal and external load experienced by athletes during RST (i.e., the acute demands), and subsequently have the potential to cause diverse training adaptations (Ross & Leveritt, 2001). For instance, in a study by Iaia et al. (2017), higher within-set B[La] (~3 $\text{mmol}\cdot\text{L}^{-1}$) was recorded during RST with shorter rest times (15 s vs 30 s), which can indicate a greater anaerobic contribution to exercise (Beneke et al., 2011). Accordingly, after six weeks of training, the 15 s rest group achieved greater improvement in 200 m sprint time and the Yo-Yo intermittent recovery test level 2 compared to the 30 s group (Iaia et al., 2017), with anaerobic energy production central to performance in these events (Hautier et al., 1994; Krustrup, Mohr, Nybo, et al., 2006). Thus, it is important to understand how the manipulation of programming variables affects the acute demands of RST, as this evidence can be useful to help explain how and why training adaptations may manifest.

There is conflicting evidence within and across studies regarding the effects of programming variables on the acute demands of RST. In a study by Alemdaroğlu et al. (2018), B[La] and S_{dec} were greater with 6 × 40 m shuttle repeated-sprints compared to the same straight-line protocol. Conversely, compared to shuttle-based sprints, straight-line sprints induced greater demands when more repetitions were performed over a shorter distance (8 × 30 m repeated-sprints) (Alemdaroğlu et al., 2018). The prescription of active inter-repetition rest has been shown to promote higher heart rate and VO_2 compared to passive rest (Madueno et al., 2018). However, Keir et al. (2013) found that demands were greater when passive rest, fewer repetitions, shorter rest time, and a longer sprint distance were prescribed. Ultimately, there is an infinite combination of programming variables that can alter the training outcome, but the acute effects of these factors are not well understood. Therefore, to guide training prescription and enhance the effectiveness of RST, it is important to gain a quantitative understanding of the acute effects of each programming factor.

While excessive training loads can contribute to fatigue, an appropriate training dose may allow for greater improvements in fitness and performance (Laursen & Buchheit, 2019). Knowledge of the acute demands of RST can help practitioners manage fatigue and target specific training outcomes. Therefore, our systematic review and meta-analysis aims to (1) identify the most common RST set configuration; (2) evaluate and summarise the acute physiological, neuromuscular, perceptual and performance demands of RST; and (3) examine the meta-analytic effects of sprint modality, number of repetitions per set, sprint repetition distance, inter-repetition rest modality, and inter-repetition rest duration on the acute RST demands.

4.4 METHODS

4.4.1 Search Strategy

This study was conducted in accordance with the ‘Preferred Reporting Items for Systematic Reviews and Meta-analyses’ (PRISMA) guidelines (Moher et al., 2009) and registered on Open Science Framework (Registration DOI: 10.17605/OSF.IO/2XQ3A). A systematic search of the literature was conducted to find original research articles investigating the acute demands of RST in team sport athletes. The latest search was performed on January 10, 2022, using the electronic databases Pubmed, SPORTDiscus, MEDLINE and Scopus. No restrictions were imposed on the publication date. Relevant keywords for each search term were identified through pilot searching of titles/abstracts/full-texts of previously known articles. Key search terms were grouped and searched within the article title, abstract and keywords using the search phrase ("repeat* sprint*" OR "intermittent sprint*" OR “multiple sprint*”) AND ("exercise" OR "ability" OR "training") AND ("team sport" OR “players” OR "athletes") AND (“physiological” OR “perceptual” OR “neuromuscular” OR “metabolic” OR “fatigue”) NOT (“cycling” OR “swimming”). No medical subject headings were applied to the search phrase.

Following the initial search of the literature, results were exported to EndNote library (Endnote X9, Clarivate Analytics, USA) and duplicates were removed. The remaining articles were then uploaded to Covidence (www.covidence.org, Melbourne, Australia), with the titles and abstracts independently screened by two authors (FT, MM). Full-texts of the remaining articles were then accessed to determine their final inclusion-exclusion status. Articles selected for inclusion were agreed upon by both authors, with any disagreements resolved by discussion or a third author (JW). Furthermore, Google Scholar, as well as reference lists of all eligible articles and reviews (Bishop et al., 2011; Clemente et al., 2021; Girard, Mendez-Villanueva, et al., 2011; Taylor et al., 2015) were searched to retrieve any additional studies. Figure 8 displays the strategy for the study selection process used in this review.

4.4.2 Inclusion-Exclusion Criteria

The inclusion and exclusion criteria can be found in Table 9. We chose to omit any studies in which the mean athlete age was ≤ 16 y, as children may respond differently to RST (Groslambert & Mahon, 2006; Ratel et al., 2006). Studies were excluded if RST was performed in ≥ 30°C because larger performance decrements may occur in hot compared to cool conditions (Girard et al., 2015). We acknowledge that the residual effects of intense exercise may last up to 72 h (Doeven et al., 2018), but acute demands measured up to 24 h following RST was selected because: (a) it is common for RST and other team sport activity to be interspersed with minimal recovery time (i.e., < 72 h), (b) pilot scoping of the literature only identified five studies (Clifford et al., 2016; Eryılmaz et al., 2019; Howatson & Milak, 2009; Klatt et al., 2021; Woolley et al., 2014) that recorded measurements on athletes > 24 h. Several studies/protocols were excluded from this investigation that implemented repeated-sprint sequences with sport skill elements (Austin et al., 2013; Iacono et al., 2016; Johnston & Gabbett, 2011; Lemmink et al., 2004; López-Segovia et al., 2015) or involved a reactive component in response to an external stimulus (e.g., light sensor) (Brini, Boullosa, et al., 2021; Di Mascio et al., 2015; Di Mascio et al., 2020; Wragg et al., 2000). Evidence from studies involving both single-set and multi-set repeated sprints was recorded, including the acute demands from RSA tests. For studies that involved pre-post testing of RST, separated by an intervention period (e.g., training, supplementation), only the RST baseline results were reported to ensure that the intervention period did not bias the results. Where observational time-series studies measured RST across a season, results were included for each phase (e.g., pre-season, mid-season, post-season), providing that no intervention was implemented outside of usual practice.

Table 9

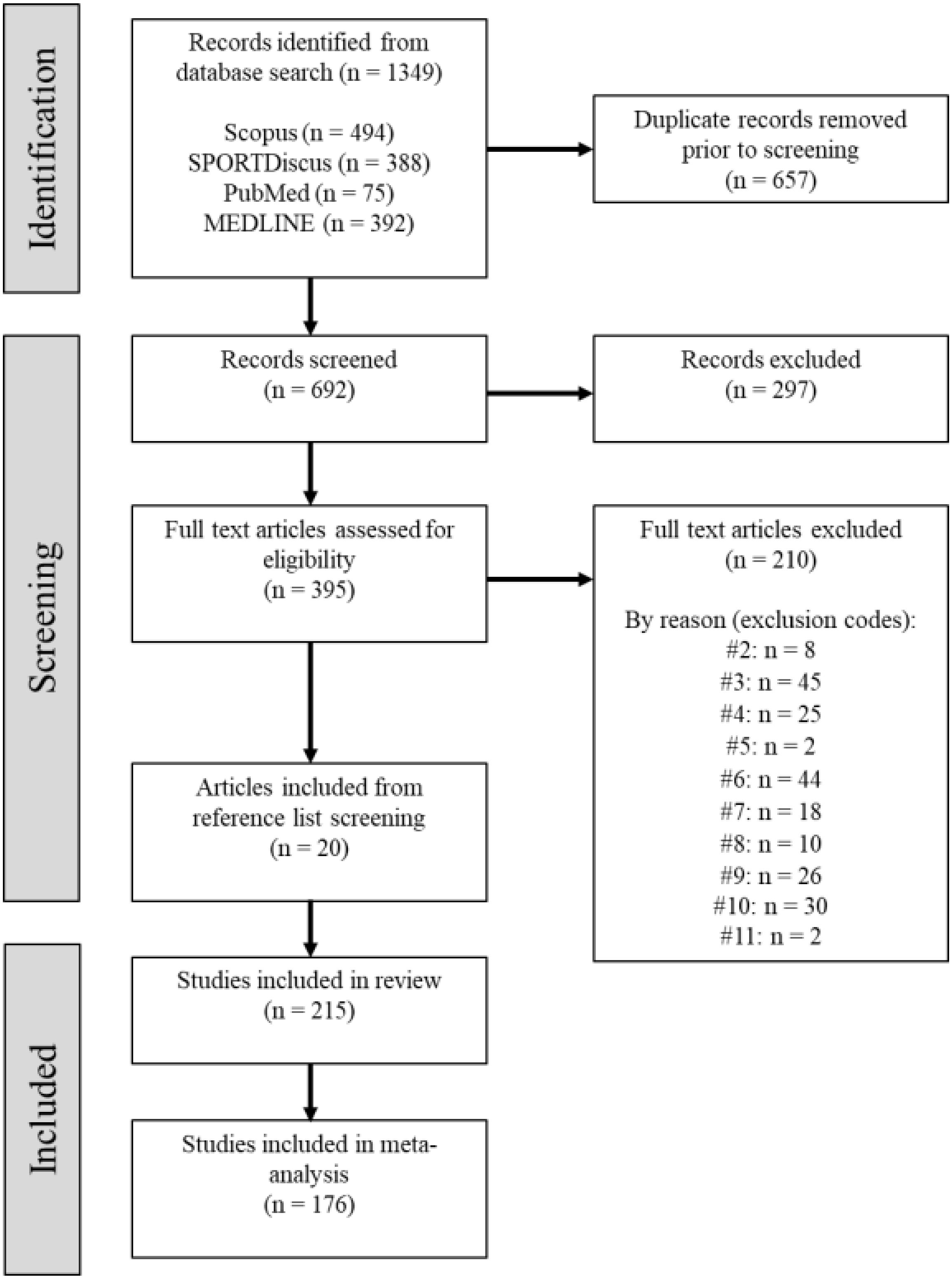
Study 1 inclusion-exclusion Criteria

Criteria	Inclusion	Exclusion
1	Original research article	Reviews, surveys, opinion pieces, books, periodicals, editorials, case studies, non-academic/non-peer-reviewed text.
2	Full-text available in English	Cannot access the full text in English.
3	Team sport athletes (field- or court-based invasion sports) of any gender.	Non-team sports (e.g., solo, racquet, or combat sports), ice-, sand-, or water-based team sports, match officials, non-athletic populations. Studies that described participants as playing intermittent sports or used a combination of team sport and non-team sport athletes, unless group results were separated.
4	Participants mean age ≥ 16 y. Where mean age was not provided, and if an age group was listed as U17 or above, this was accepted	Mean athlete age was < 16 y, or participants were described as U16 or below. Additionally, studies that used a combination of athletes below and above the age cut-off, unless group results were separated.
5	Healthy, able-bodied, non-injured athletes	Special populations (e.g., clinical, patients), athletes with a physical or mental disability, or athletes considered to be injured or returning from injury.
6	RST was over-ground running on a flat surface.	RST was performed on a treadmill, cycle or another implement. RST was performed on a slope or sand.
7	RST was performed at maximal intensity, with a mean work duration of ≤ 10 s or ≤ 80 m in distance, a recovery duration of ≤ 60 s and ≥ 2 repetitions performed in total. Single set and multi-set repeated-sprints.	RST was performed at submaximal intensity, with a work duration of > 10 s or > 80 m, a recovery duration of > 60 s, and only a single sprint repetition.
8	RST was a fixed protocol, without any sport skill elements.	RST involved a reactive COD in response to an external stimulus (e.g., light sensor) or sport skill elements (e.g., passing, kicking, shooting).
9	Studies must have reported ≥ 1 acute outcome measure (outcome measures are presented in Table 10). Acute demands must have occurred during (within) or immediately following RST up to 24 h.	No relevant outcome measures were reported. RST demands occurred > 24 h.
10	≥ 1 condition or group must have performed the intervention under normal conditions (e.g., usual nutritional intake, hydrated state, normoxia, absence of ergogenic aids, ≤ 30° C, regular warm-up protocol).	RST was performed in a possibly fatigued or potentiated state (e.g., sports training, maximal fitness assessment, pre-conditioning strategies) occurring within or 24 h before RST. Placebo treatments were used before or during RST.
11	Sprint times were recorded using electronic timing gates.	Sprint times were recorded with a hand-held stopwatch or a video-camera.

Note. RST = repeated-sprint training; COD = change of direction; y = years; h = hours; s = seconds; m = metres

Figure 8

Flow Diagram of the Study Selection Process



4.4.3 Classification of Study Design

To provide information on study design, studies were categorised under four designs as follows: (1) Observational – non-experimental; (2) single group pre-test post-test – experimental treatment applied to a single group of participants, with the dependent variable/s measured before and after treatment; (3) crossover – two or more experimental conditions applied to the same participants, with or without a control condition; (4) parallel groups – two or more experimental conditions applied to two groups of different participants, with or without a control condition. Additionally, single-group time-series designs were categorised under observational and denoted.

4.3.4 Selection of Outcome Measures and Programming variables

The outcome measures (Table 10) were selected based on pilot scoping of the literature that identified commonly used indicators of internal responses to exercise and performance capacity in team sport settings (Bishop et al., 2011; Halson, 2014; Morcillo et al., 2015). Percentage sprint decrement, as defined by Fitzsimons et al. (1993), was chosen as it is the most ecologically valid index to quantify performance fatigue during RST (Glaister et al., 2008). However, caution should be taken when interpreting S_{dec} as weak relative and absolute reliability exists between RSA tests (Lopes-Silva et al., 2019). Blood lactate is sensitive to changes in exercise intensity and duration and is one of the preferred methods used to assess the anaerobic glycolytic contribution to exercise (Beneke et al., 2011). Sprint FVP parameters, as defined by Samozino et al. (2016), and spring-mass model (SMM) parameters, as defined by Morin et al. (2005), were chosen as they represent field-based methods used to assess the mechanical effectiveness of sprinting and the neuromuscular manifestation of fatigue during over-ground running (Franck Brocherie et al., 2015a).

Table 10

Summary of the Outcome Measures of Interest

Category	Measure	Metric
Physiological	HR	HR_{avg}, $HR_{peak,}$ HR_{post}, and/or % HR_{max}
	CK	CK 24 h
	B[La]	Post (0-10 min)
	VO_2	VO_{2avg}, VO_{2peak} and/or % VO_{2max}
Neuromuscular	CMJ	JH
	Sprint FVP parameters	V_0, F_0, P_0, RF_{peak}, D_{RF}
	SMM parameters	K_{vert}, K_{leg}, ΔL, Δz, $F_z max$
Perceptual	sRPE	CR10® and 6-20 sRPE scales
Performance	Sprint times	S_{best}, S_{avg}, S_{total}
	Performance fatigue	S_{dec}

Note. sRPE = session ratings of perceived exertion; CR10 = Category-Ratio 10; CMJ = counter movement jump; JH = jump height; FVP = force-velocity-power; V_0 = theoretical maximal velocity F_0 = theoretical maximal force; P_0 = theoretical maximal power; RF_{peak} = maximal ratio of force; D_{RF} = slope/rate of decrease in ratio of force with increasing velocity; SMM = spring-mass model; K_{vert} = vertical stiffness;; K_{leg} = leg stiffness; ΔL = leg compression; Δz = centre of mass vertical displacement; $F_z max$ = maximal vertical force; HR = heart rate; HR_{avg} = average heart rate; HR_{peak} = peak heart rate; HRpost = heart rate recorded immediately post exercise;% HRmax = percentage of maximal heart rate; CK = serum creatine kinase; CK 24 h = serum creatine kinase measured 24 hours post exercise; B[La] = blood lactate; VO_{2avg} = average oxygen consumption;% VO_{2peak} = percentage of peak oxygen consumption;% VO_{2max} = percentage of max oxygen consumption; S_{best} = best sprint time; S_{avg} = average sprint time; S_{total} = total sprint time; S_{dec} = percentage sprint decrement.

The programming variables recorded were: sprint modality (i.e., straight-line, 180° shuttle or multi-directional), number of repetitions per set, number of sets per session, sprint distance or duration per repetition, inter-repetition rest duration, inter-repetition rest modality, inter-set rest duration and inter-set rest modality.

4.4.5 Extraction of Study Information

Mean and standard deviation (SD) data were extracted directly from tables and within the text of the included studies. To obtain data from studies where information was provided in figures, graph digitising software (WebPlotDigitizer, version 4.3, USA) was used. For studies where rest duration was given as an exercise to rest ratio or on a time cycle that included sprint time, an estimated 'actual' rest time was also established. This was determined by extracting average sprint time (S_{avg}) data from studies, where provided. For example, if S_{avg} was 3.2 s and the recovery duration was given as 1:5 exercise to rest ratio, then the estimated recovery duration was 16 s; or if the recovery duration was given on a 30 s cycle, then the estimated recovery duration was 27 s, with recovery durations rounded to the nearest whole number.

With regards to sprint modality, shuttle repeated-sprints were defined as RST where one or more 180° changes of direction were performed. Multi-directional repeated-sprints involved RST where changes of direction were performed with angles other than 180°, but due to the large variety of designs (e.g., different angles and courses), this format was excluded from the meta-analysis. For rest modality, 'passive' included protocols where participants were required to walk back to a two-way start line (sprints alternating from both ends) in preparation for the next sprint. Where information relating to exercise protocols (e.g., sprint distance) could not be found within the study or clarification was required, authors were contacted. If authors did not respond, samples were removed from the meta-analysis. The Participant Classification Framework (McKay et al., 2022) was used to define training and performance calibre of the athletes included in our investigation.

Twenty-four estimates nested within 13 studies collected session ratings of perceived exertion (sRPE) via Borg's 6–20 scale. For consistency with other included studies and to comply with more standard practice, 6–20 values were converted to Category–Ratio 10 (CR10®) units (deciMax) using the appropriate table conversion (Borg, 2010). Standard deviations were converted by a factor that was proportionate to the mean value of each estimate, which ranged between 13–19 (conversion factors = 0.27–0.53). Where VO_2 was expressed in absolute terms ($L{\cdot}min^{-1}$) (Keir et al., 2013), it was converted to relative terms ($ml{\cdot}min^{-1}{\cdot}kg^{-1}$) by extracting the mean body mass of the participants from the study. Where S_{dec} of 5% was set as the termination criteria (Akenhead et al., 2017), the mean number of repetitions was used for meta-analysis. Heart rates were inclusive of both the sprint component and inter-repetition rest periods, but samples were excluded (Selmi et al., 2016) which continuously recorded heart rate during the inter-set rest periods. Due to a lack of studies reporting the effect of RST on HR_{peak} as a percentage of maximal heart rate (HR_{max}), this data was unable to be meta-analysed. However, these results (Buchheit, 2010; M. Buchheit, D. Bishop, et al., 2010; Dellal et al., 2015; T. Haugen et al., 2014; Taylor et al., 2016) are summarised in section 3.4.3. Post-exercise B[La] samples were meta-analysed together, irrespective of the exact time point that they were measured (i.e., 0–10 min). Although, for context, specific time-points of each sample are given in Appendix 3. Where studies provided multiple time-points of B[La] collection, the highest value was used for meta-analysis. The considerable variation in measurement error between different jump systems makes it difficult to compare CMJ height between different studies (Till et al., 2017) and as such, CMJ height results were recorded, but not meta-analysed. For context, the type of jump measurement systems used in each study are noted alongside the results in Appendix 3.

4.4.6 Assessment of Reporting Quality and Risk of Bias

To assess the reporting quality and risk of bias within the studies included in this review, two authors (FT and MM) independently evaluated the literature using a modified version of the Downs and Black index. This scale includes 14 original items and ranks each item as 0 or 1, with higher total scores (out of 14) indicating higher quality studies. The original Downs and Black scale was reported to have acceptable test-retest (r = 0.88) and inter-rater reliability (r = 0.75) (Downs & Black, 1998). If there was an absence of clear information to assess an item on either scale, it was scored as 0. Any disagreements between the two authors were resolved by discussion or a third author (JW).

4.4.7 Data Analysis

All analyses were performed in the statistical computing software *R* (Version 4.0.0; R Core Team, 2020). Studies eligible for meta-analysis often reported RST outcomes from several subgroups (elite vs non-elite, males vs females, etc.), from repeated measures taken on the same group of athletes (e.g., set 1 & set 2, warm-up A vs warm-up B, etc.), or a combination of both. To appropriately account for this hierarchical structure, in particular, the within-study correlation arising from repeated measures (Cheung, 2019) and on the assumption that the true acute demand of RST varies between studies (Borenstein et al., 2010), data were analysed using multi-level mixed-effects meta-analysis via the *metafor* package (Viechtbauer, 2010). Initial (baseline) models were run for each outcome measure with 10 or more estimates and fit using restricted maximum-likelihood. These models included only random effects, which were specified in a nested structure as studies (i.e., individual research papers; outer factor) and groups within studies (inner factor; (Cheung, 2019)). Units of analysis were therefore individual estimates from groups within studies, given as the mean value of the outcome measure following RST. Both the associated SD and sample size were used to calculate the variance of each estimate. When a study involved repeated measures (i.e., multiple rows of data for the same group of athletes), dependency was accounted for by replacing variance with the entire 'V' matrix; that is, the variance–covariance matrix of the estimates (Cheung, 2019). Block-diagonal covariance matrices were estimated with an assumed correlation of $r = 0.5$ using the *clubSandwich* package (Pustejovsky, 2021). Since it is uncommon for studies to report the correlation coefficient between repeated measures (Riley, 2009), our assumption was informed by re-analysis of our previous (unpublished) work in team-sport RST.

Uncertainty in meta-analysed estimates was expressed using 90% compatibility (confidence) intervals (CI), calculated based on a *t*-distribution with denominator degrees of freedom given from the unique number of ‘Group’ levels (i.e., the inner level of the random effects structure). Pooled estimates were also presented with 90% prediction intervals, which convey the likely range of the true demand of RST in similar future studies (IntHout et al., 2016). Between-study and between-group heterogeneity in each meta-analysed estimate was quantified as a SD (Sigma [σ]; (Higgins, 2008)), with 90% CI calculated using the Q-profile method (Viechtbauer, 2007).

To examine the effect of programming variables on acute RST outcomes, candidate factors were added to the aforementioned baseline models as fixed effects for outcomes with sufficient estimates available (approximately 10 per moderator (Higgins et al., 2019)). The five moderator variables were: sprint modality (categorical: straight-line or 180° shuttle), number of repetitions per set (continuous, linear), total distance covered in each repetition (continuous, linear), inter-repetition rest modality (categorical: active or passive), and inter-repetition rest duration (continuous, linear). Factors were re-scaled so that the reference (intercept) effect represented the performance or response to 6 × 30 m straight-line sprints with 20 s passive rest between repetitions. The effects of each moderator were then estimated (along with 90% CI and 90% prediction intervals where appropriate), with all other factors being held constant. Categorical moderators were given as the difference between levels (shuttle compared to straight-line sprints and active compared to passive inter-repetition rest). Continuous moderators were evaluated at a magnitude deemed to be practically relevant for training prescription: performing two more repetitions, sprinting 10m further per repetition, and resting for 10 s longer between repetitions. The effects of repetition distance on repetition time (average and fastest sprint) were not shown (but were still offset to a distance of 30 m), because the time taken to complete a sprint repetition is almost entirely dependent on the distance to be covered. The total amount of variance explained by the combination of moderators was given as a pseudo-R^2 value, calculated by subtracting the total (pooled) variance from final models (σ^2_{mods}) as a fraction of baseline models (σ^2_{base}) from 1 ($1 - [\sigma^2_{\text{mods}} / \sigma^2_{\text{base}}]$).

To provide an interpretation of programming moderators, we (subjectively) considered the entire range of the CI representative of values compatible with our models and assumptions

(Greenland, 2019), relying mostly on the point estimate. To further contextualise the practical relevance of moderators, we visually scaled effects against regions of practical significance. That is, reference values for each outcome measure that have been empirically or theoretically anchored to some real-world importance in the context of team-sport athletes and/or RST. These thresholds were: 2 $b \cdot min^{-1}$ (~1%) in HR_{peak} (Buchheit, 2014), 1-au in CR10-scaled sRPE (McLaren, 2018), a 1% faster or slower sprint time (Haugen & Buchheit, 2016) based on the reference performance given as the intercept: 0.05 s for S_{avg} , 0.04 s for best sprint time (S_{best}), and 1% for S_{dec} across a set (Haugen & Buchheit, 2016). In absence of a recognised practical reference value for a change in B[La] above the anaerobic threshold, we used the value of a small, standardized effect. Between-athlete SD's from included estimates (n = 120) were meta-analysed on the log scale, as previously described (SD = 1.9 $mmol \cdot L^{-1}$; 90% CI: 1.7 to 2.22), before being multiplied by 0.2. The threshold for a moderate standardized effect (0.6×1.9 $mmol \cdot L^{-1}$) was also calculated and shown for visual purposes. When a CI fell entirely inside the region of practical significance or predominantly inside one region, we declared an effect as trivial. When a CI fell entirely outside the region of practical significance or predominantly outside the region, we declared an effect substantial. If there was equal coverage of the CI across the trivial region and the substantial region in only one direction (i.e., positive or negative), the effect was deemed compatible with both trivial and substantial effects. Finally, when the CI spanned across substantial regions in both positive and negative directions, including the trivial region, an effect was deemed inconclusive.

4.5 RESULTS

Following the screening process (Figure 8), 215 publications were included in our investigation, with data from 908 samples nested within 176 studies eligible for meta-analysis. Across all studies, there were 4818 athlete inclusions from 282 repeated-sprint protocols reported.

4.5.1 Study characteristics

The most common study design for investigations of acute demands of RST was single group, cross sectional observational (n = 87 studies, 40%). Soccer was the most investigated sport (n = 104, 48%), followed by basketball (n = 33, 15%), rugby (league, union and sevens) (n = 15, 7%), futsal (n = 14, 7%), handball (n = 12, 6%), field hockey (n = 10, 5%), Australian rules football (n = 5, 2%), volleyball (n = 3, 1%), netball (n = 2, 1%) and a mixture of team sports (n = 17, 8%). Of these sports, 21 (10%) studies involved elite/international level athletes, 125 (58%) studies involved highly trained/national level athletes and 58 (27%) studies involved trained/development level athletes, with 11 (5%) studies not reporting the training and performance calibre of the athletes. Female athletes were represented in 31 (14%) studies. A summary of the participants and study characteristics of included publications are provided in Appendix 2.

4.5.2 Outcomes for the assessment of Reporting Quality and Risk of Bias

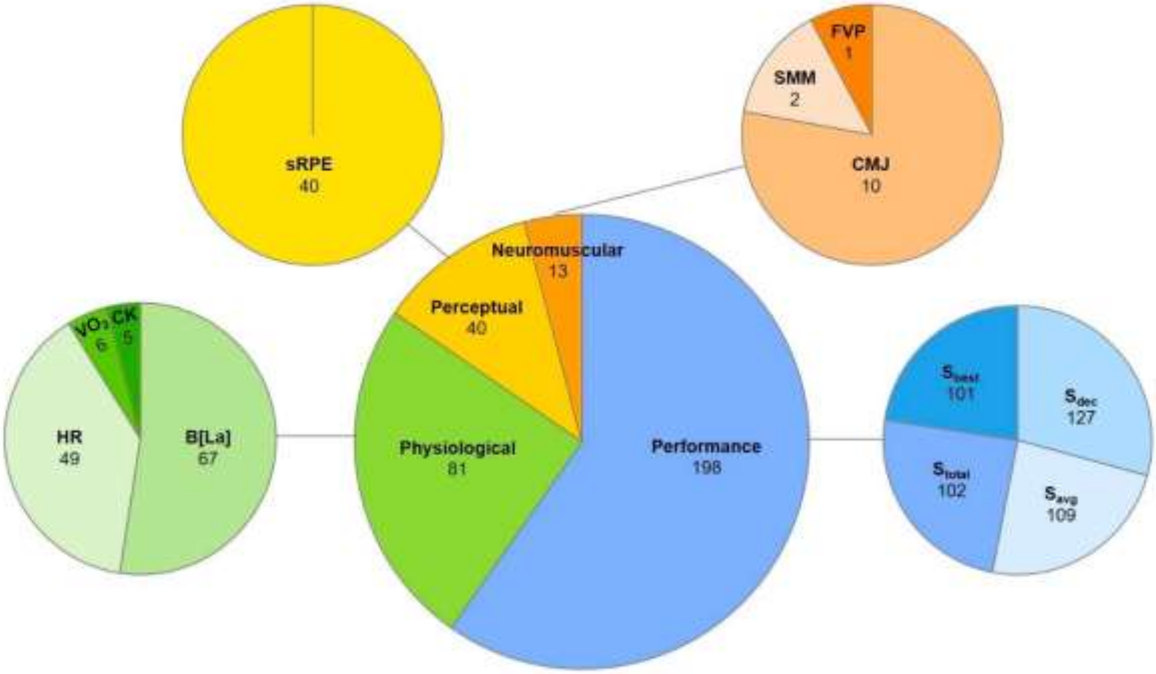
Appendix 1 summarises the outcomes of the modified Downs and Black scale for the assessment of reporting quality and risk of bias. Results ranged from 7–12, with a mean score of 9.6 ± 0.9.

4.5.3 Study outcomes

A summary of the training protocols and study outcomes of included publications are provided in Appendix 3. Performance outcomes were represented in 198 (92%) of studies and the most common outcome measure was S_{dec} (n = 127 studies, 59%) (Figure 9).

Figure 9

The Distribution of Outcome Measures Within all Studies Included in Chapter 4

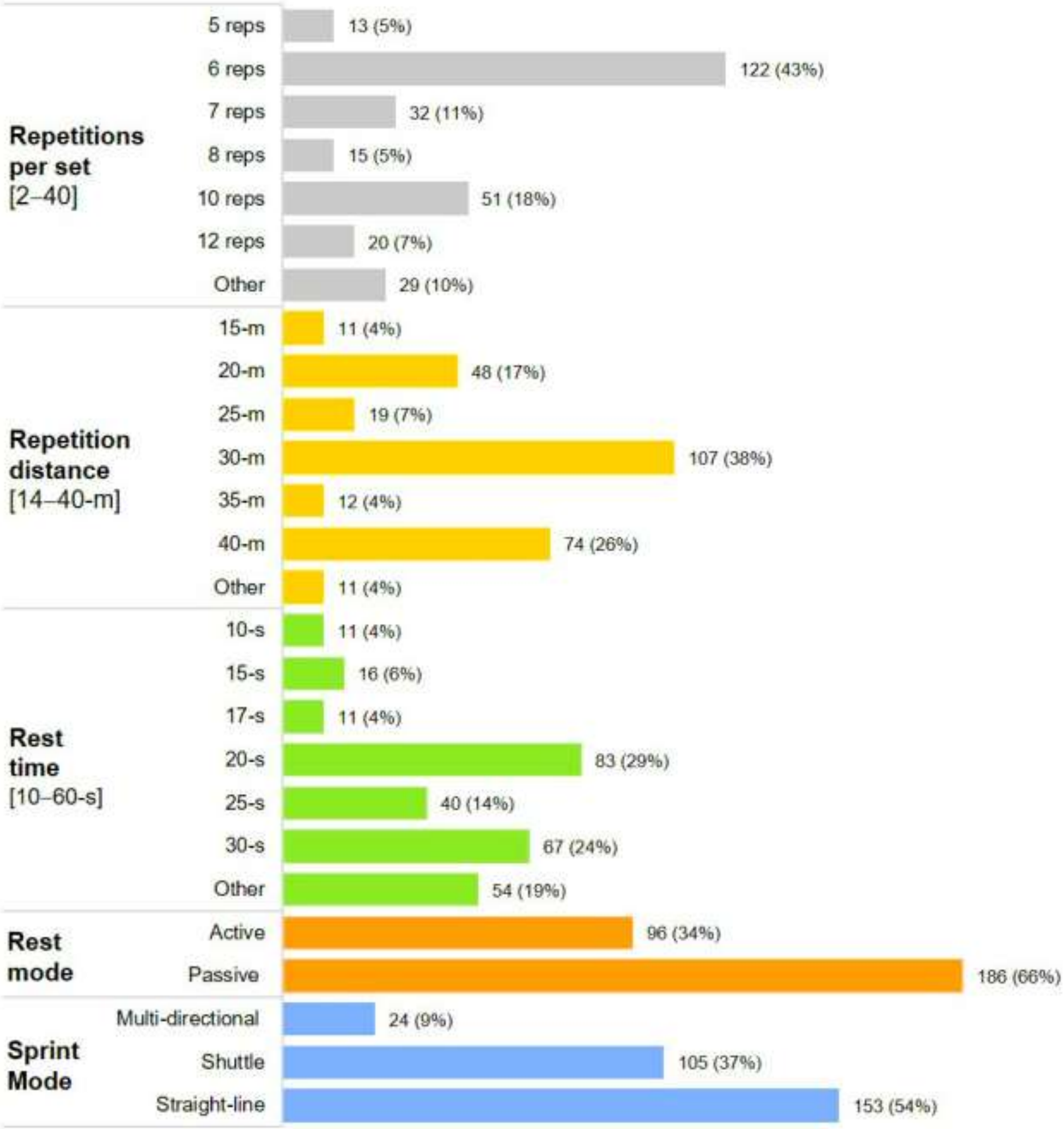


Note. Data given as the total number of studies represented (out of 215). S_{best} = best sprint time; S_{avg} = average sprint time; S_{total} = total sprint time; S_{dec} = percentage sprint decrement; CMJ = countermovement jump; SMM = spring-mass model characteristics; FVP = sprint force-velocity-power profiling; sRPE = ratings of perceived exertion; HR = heart rate; B[La] = blood lactate; CK = serum creatine kinase; VO_2 = oxygen consumption.

The most common prescription of each programming variable were straight-line sprints (n = 153 protocols, 54%), performed over 30 m (n = 107, 38%), with a passive recovery (n = 186, 66%) lasting 20 s (n = 83, 29%), prescribed as one set of six repetitions (n = 122, 43%; Figure 10). The majority of protocols (n = 263, 93%) employed one set of repeated-sprints, with two sets, three sets and four sets used in five (2%), 10 (4%) and four (1%) protocols, respectively. The most common inter-set rest times for all multi-set protocols were 4 min (six protocols) and 5 min (five protocols). The number of 180° changes of direction prescribed for shuttle repeated-sprints ranged from one to two. The most common mode of active recovery was a slow jog back to a one-way start line (n = 32 protocols, 33%; i.e., sprints start from one end only). There was one study (Woolley et al., 2014) that strictly enforced a 5 m deceleration zone and one other study (Lakomy & Haydon, 2004) that enforced a 6 m deceleration zone.

Figure 10

The distribution of RST prescription across all 282 protocols



Note. Data are given as the total number of protocols represented (percentage) [range].

4.5.4 Meta-Analysed Acute Demands of Repeated-Sprint Training

The acute physiological, perceptual and performance demands of RST in team sport athletes are presented in Table 11. Also presented are the 90% CI and PI for each estimate, as well as the between sample and between study variability (σ).

Table 11

Meta-Analysed Acute Physiological, Perceptual, and Performance Demands of Repeated-sprint Training in Team Sport Athletes

Outcome Measure		**Number of…**		**Pooled Effect**			**Variation (σ; 90% CI) between…**	
		Studies	**Samples**	**Estimate**	**90% CI**	**90% PI**	**Studies (σ_1)**	**Samples (σ_2)**
HR$_{\text{avg}}$	b·min^{-1}	12	24	163	154 to 171	131 to 194	16 (11 to 24)	6 (4 to 9)
	% HR$_{\text{max}}$	10	21	90	87 to 92	82 to 97	3 (2 to 6)	2 (1 to 3)
HR$_{\text{peak}}$	b·min^{-1}	29	54	182	179 to 184	168 to 195	7 (6 to 10)	2 (1 to 3)
VO$_{\text{2avg}}$	ml·kg^{-1}·min^{-1}	6	6	42.4	32.3 to 52.4	16.0 to 68.7	9.2 (0.0 to 20.6)	2.4 (0.8 to 9.4)
B[La]	mmol·L^{-1}	64	120	10.7	10.1 to 11.3	5.6 to 15.8	2.6 (2.1 to 3.1)	1.7 (1.4 to 2.0)
sRPE	au (deciMax)	40	68	6.5	6.0 to 6.9	3.5 to 9.5	1.2 (0.7 to 1.6)	1.3 (1.1 to 1.6)
S$_{\text{best}}$	s	103	191	5.52	5.26 to 5.79	2.79 to 8.25	1.57 (1.40 to 1.79)	0.45 (0.40 to 0.51)
S$_{\text{avg}}$	s	112	200	5.57	5.31 to 5.82	2.83 to 8.3	1.54 (1.37 to 1.74)	0.57 (0.51 to 0.65)
S$_{\text{dec}}$	%	125	224	5.0	4.7 to 5.3	1.4 to 8.7	2.0 (1.8 to 2.3)	0.9 (0.8 to 1.1)

Note. Multi-directional protocols are excluded. Heart rate results are independent of each other ($\text{HR}_{\text{peak}} \neq \text{HR}_{\text{max}}$). HR$_{\text{peak}}$ as % HR$_{\text{max}}$ was not evaluated due to an insufficient number of samples. CI = confidence interval; PI = prediction interval; HR$_{\text{avg}}$ = average heart rate; % HR$_{\text{max}}$ = percentage of maximal heart rate; HR$_{\text{peak}}$ = peak heart rate; VO$_{\text{2avg}}$ = average oxygen consumption; B[La] = blood lactate; sRPE = session ratings of perceived exertion; S$_{\text{best}}$ = best sprint time; S$_{\text{avg}}$ = average sprint time; S$_{\text{dec}}$ = percentage sprint decrement.

4.5.5 Moderating Effects of Programming Variables on the Acute Demands of Repeated-Sprint Training

The moderating effects of programming variables on the acute physiological, perceptual and performance demands of RST are presented in Figures 11–22. All effects were evaluated as the change in each outcome measure when compared to a reference protocol of 6 × 30 m straight-line sprints with 20 s passive inter-repetition rest. Unless noted in the subsequent sections, moderating effects were deemed inconclusive (i.e., a CL spanning across substantial regions in both positive and negative directions, including the trivial region).

4.5.5.1 Shuttle-based sprints

Shuttle-based sprints were associated with a substantial increase in S_{avg} and S_{best} (i.e., slower times; Figures 17–20), whereas the effect on sRPE was trivial (Figure 13 & 14). Performing shuttle-based sprints was compatible with a trivial and substantial reduction in S_{dec} (i.e., a less pronounced decline in sprint times [faster] throughout the set; Figure 21 & 22).

4.5.5.2 Performing two more repetitions per set

Performing two more repetitions per set had a trivial effect on HR_{peak} (Figure 11 & 12), sRPE (Figure 13 & 14), S_{avg} (Figure 19 & 20), S_{dec} (Figure 21 & 22), and B[La] (Figure 15 & 16). Additionally, performing two more repetitions per set was compatible with a trivial and substantial increase in S_{best} (i.e., slower time; Figure 19 & 20).

4.5.5.3 Sprinting 10 m further per repetition

Sprinting 10 m further per repetition was associated with a substantial increase in B[La] (Figure 15 & 16) and S_{dec} (i.e., a more pronounced decline in sprint times [slower] throughout the set; Figure 21 & 22) whereas the effect on sRPE was trivial (Figure 13 & 14). Additionally, sprinting 10 m further per repetition was compatible with a trivial and substantial increase in HR_{peak} (Figure 11 & 12). The effects on S_{best} and S_{avg} were not evaluated.

4.5.5.4 Resting for 10 s longer

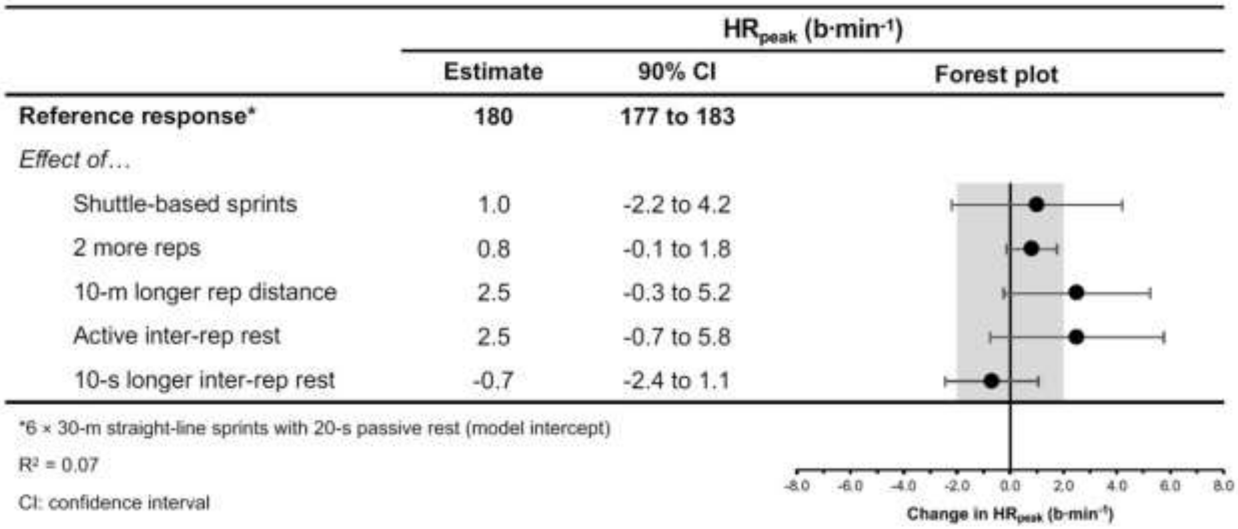
Resting for 10 s longer between repetitions was associated with a substantial reduction in B[La] (Figure 15 & 16), S_{avg} (Figure 19 & 20), and S_{dec} (Figure 21 & 22), while the effects on HR_{peak} (Figure 11 & 12) and sRPE (Figure 13 & 14) were trivial. Resting for 10 s longer between repetitions was compatible with trivial and substantial reduction in S_{best} (i.e., faster time; Figure 17 & 18).

4.5.5.5 Performing active inter-repetition rest

Using an active inter-repetition rest modality was compatible with a trivial and substantial increase in HR_{peak} (Figure 11 & 12), sRPE (Figure 13 & 14) and S_{dec} (Figure 21 & 22).

Figure 11

The Moderating Effects of Programming Variables on Peak Heart Rate During Repeated-Sprint Training with Team Sport Athletes



	HR_{peak} ($b{\cdot}min^{-1}$)		
	Estimate	**90% CI**	**Forest plot**
Reference response*	**180**	**177 to 183**	
Effect of…			
Shuttle-based sprints	1.0	-2.2 to 4.2	
2 more reps	0.8	-0.1 to 1.8	
10-m longer rep distance	2.5	-0.3 to 5.2	
Active inter-rep rest	2.5	-0.7 to 5.8	
10-s longer inter-rep rest	-0.7	-2.4 to 1.1	

*6 × 30-m straight-line sprints with 20-s passive rest (model intercept)

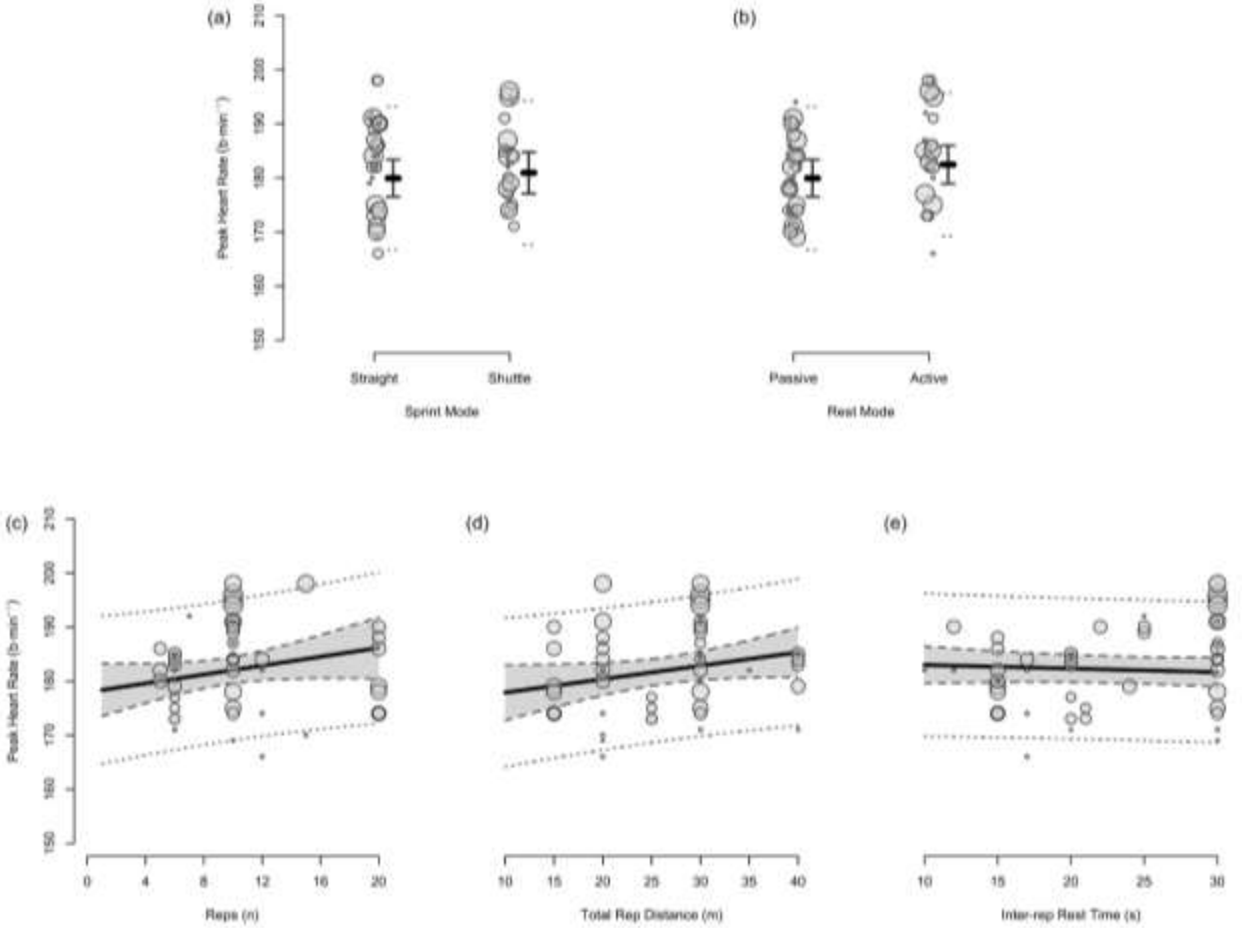
$R^2 = 0.07$

CI: confidence interval

Note. Area outside the shaded zone represents the region of practical significance; HR_{peak} = peak heart rate.

Figure 12

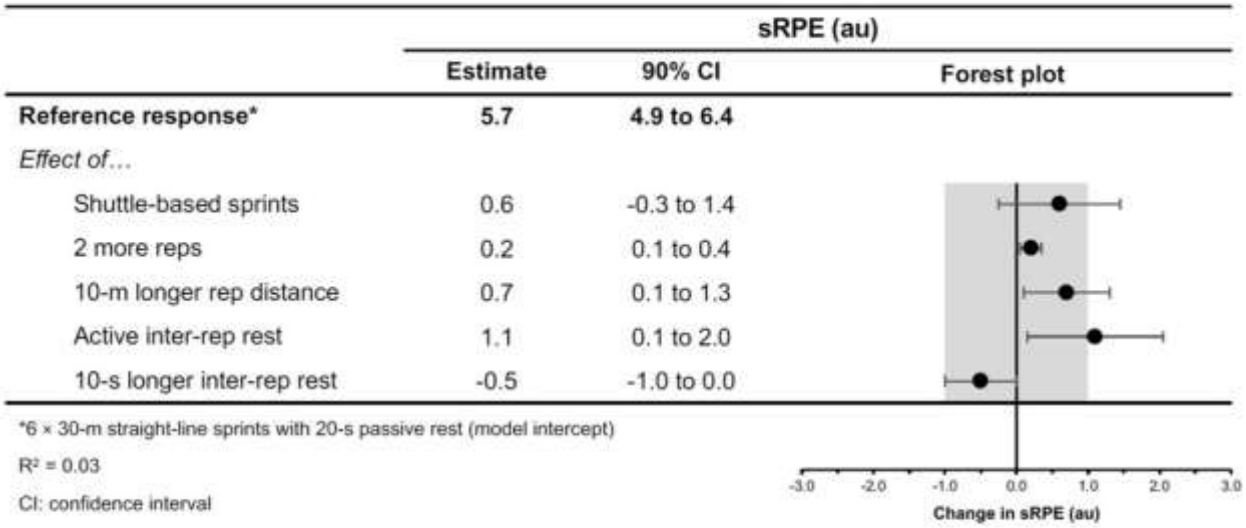
The Moderating Effects of (a) Sprint Modality; (b) Inter-Repetition Rest Mode; (c) Repetitions Per Set; d) Total Repetition Distance; and (e) Inter-repetition Rest Time on Peak Heart Rate During Repeated-Sprint Training with Team Sport Athletes



Note. Larger circles = greater study size.

Figure 13

The Moderating Effects of Programming Variables on Session Ratings of Perceived Exertion Following Repeated-Sprint Training with Team Sport Athletes



	sRPE (au)		
	Estimate	**90% CI**	**Forest plot**
Reference response*	**5.7**	**4.9 to 6.4**	
Effect of…			
Shuttle-based sprints	0.6	-0.3 to 1.4	
2 more reps	0.2	0.1 to 0.4	
10-m longer rep distance	0.7	0.1 to 1.3	
Active inter-rep rest	1.1	0.1 to 2.0	
10-s longer inter-rep rest	-0.5	-1.0 to 0.0	

*6 × 30-m straight-line sprints with 20-s passive rest (model intercept)

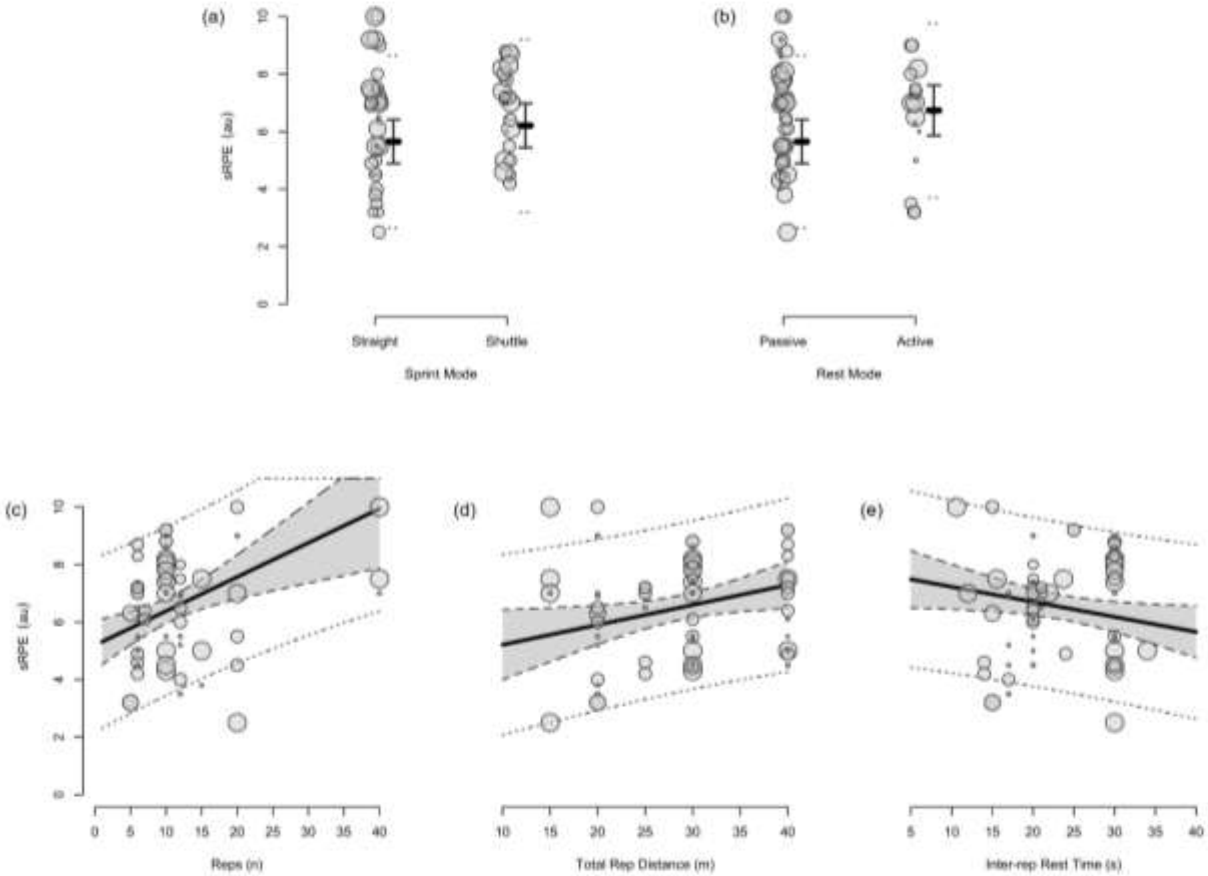
$R^2 = 0.03$

CI: confidence interval

Note. Area outside the shaded zone represents the region of practical significance; sRPE = session ratings of perceived exertion.

Figure 14

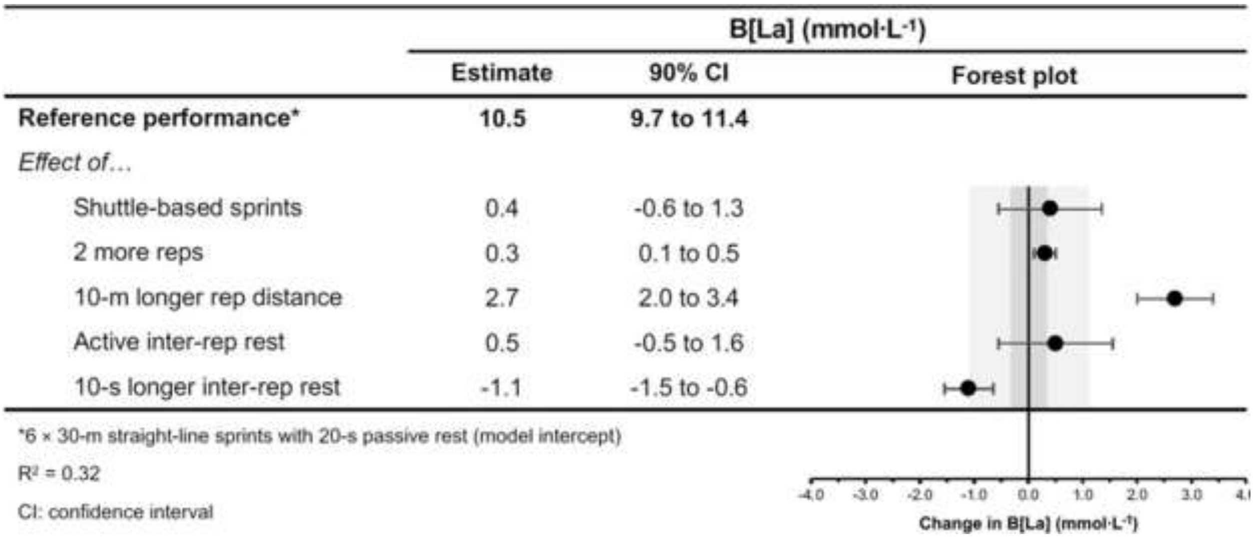
The Moderating Effects of (a) Sprint Modality; (b) Inter-Repetition Rest Mode; (c) Repetitions Per Set; d) Total Repetition Distance; and (e) Inter-Repetition Rest Time on Session Ratings of Perceived Exertion Following Repeated-Sprint Training with Team Sport Athletes



Note. Larger circles = greater study size.

Figure 15

The Moderating Effects of Programming Variables on End-Set Blood Lactate Following Repeated-Sprint Training with Team Sport Athletes



	B[La] (mmol·L⁻¹)		
	Estimate	**90% CI**	**Forest plot**
Reference performance*	**10.5**	**9.7 to 11.4**	
Effect of…			
Shuttle-based sprints	0.4	-0.6 to 1.3	
2 more reps	0.3	0.1 to 0.5	
10-m longer rep distance	2.7	2.0 to 3.4	
Active inter-rep rest	0.5	-0.5 to 1.6	
10-s longer inter-rep rest	-1.1	-1.5 to -0.6	

*6 × 30-m straight-line sprints with 20-s passive rest (model intercept)

$R^2 = 0.32$

CI: confidence interval

Note. Area outside the shaded zone represents the region of practical significance; B[La] = blood lactate

Figure 16

The Moderating Effects of (a) Sprint Modality; (b) Inter-repetition Rest Mode; (c) Repetitions Per Set; d) Total Repetition Distance; and (e) Inter-repetition Rest Time on End-Set Blood Lactate Following Repeated-sprint Training with Team Sport Athletes

Note. Larger circles = greater study size.

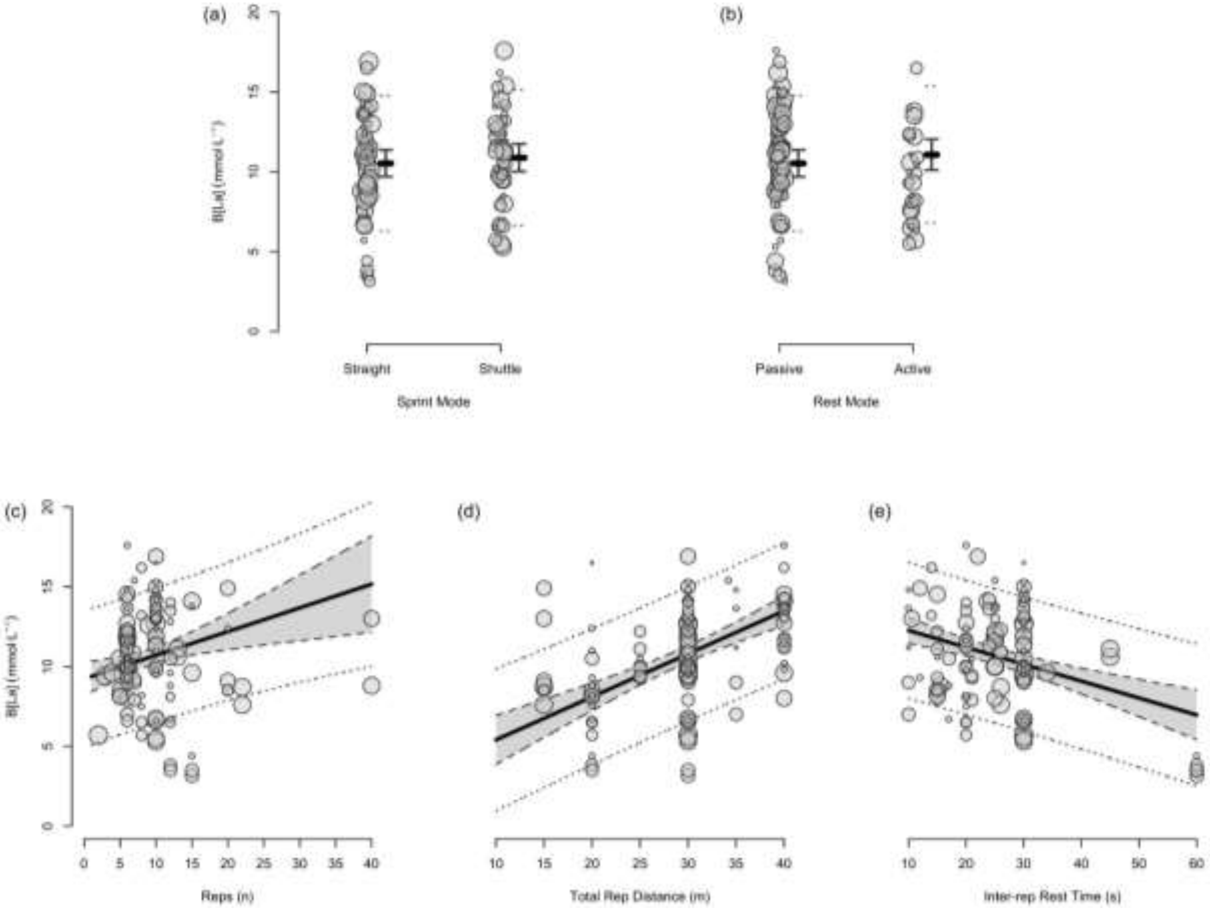
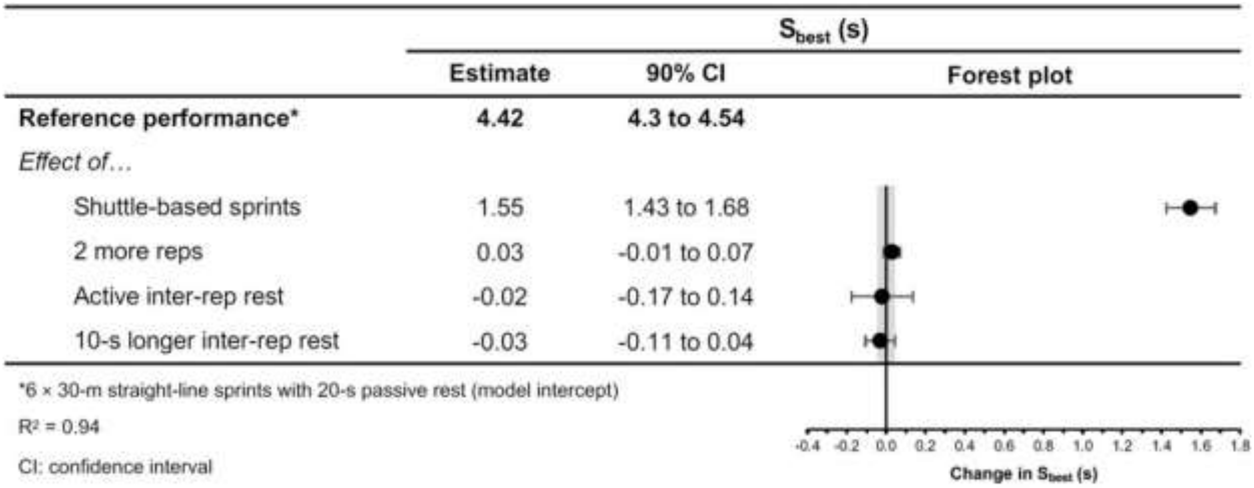


Figure 17

The Moderating Effects of Programming Variables on Best Sprint Time During Repeated-Sprint Training with Team Sport Athletes



	S_{best} (s)		
	Estimate	**90% CI**	**Forest plot**
Reference performance*	**4.42**	**4.3 to 4.54**	
Effect of…			
Shuttle-based sprints	1.55	1.43 to 1.68	
2 more reps	0.03	-0.01 to 0.07	
Active inter-rep rest	-0.02	-0.17 to 0.14	
10-s longer inter-rep rest	-0.03	-0.11 to 0.04	

*6 × 30-m straight-line sprints with 20-s passive rest (model intercept)

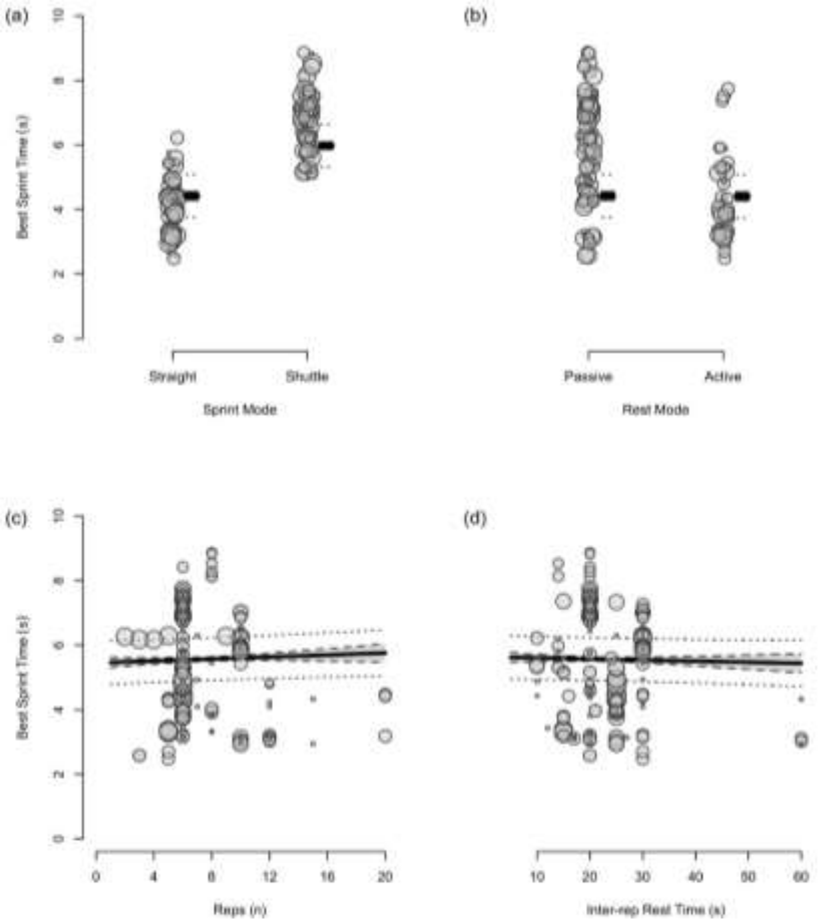
$R^2 = 0.94$

CI: confidence interval

Note. Area outside the shaded zone represents the region of practical significance; S_{best} = best sprint time.

Figure 18

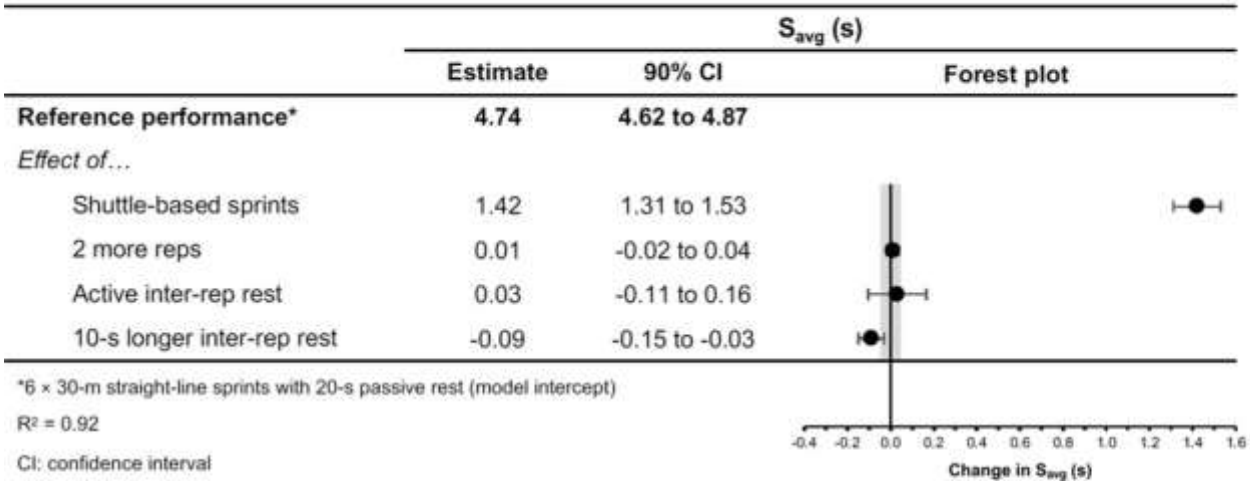
The Moderating Effects of (a) Sprint Modality; (b) Inter-repetition Rest Modality; (c) Repetitions Per Set; and (d) Inter-repetition Rest Time on Best Sprint Time During Repeated-Sprint Training with Team Sport Athletes



Note. Larger circles = greater study size.

Figure 19

The Moderating Effects of Programming Variables on Average Sprint Time During Repeated-Sprint Training with Team-sport Athletes



	S_{avg} (s)		
	Estimate	90% CI	Forest plot
Reference performance*	**4.74**	**4.62 to 4.87**	
Effect of…			
Shuttle-based sprints	1.42	1.31 to 1.53	
2 more reps	0.01	-0.02 to 0.04	
Active inter-rep rest	0.03	-0.11 to 0.16	
10-s longer inter-rep rest	-0.09	-0.15 to -0.03	

*6 × 30-m straight-line sprints with 20-s passive rest (model intercept)

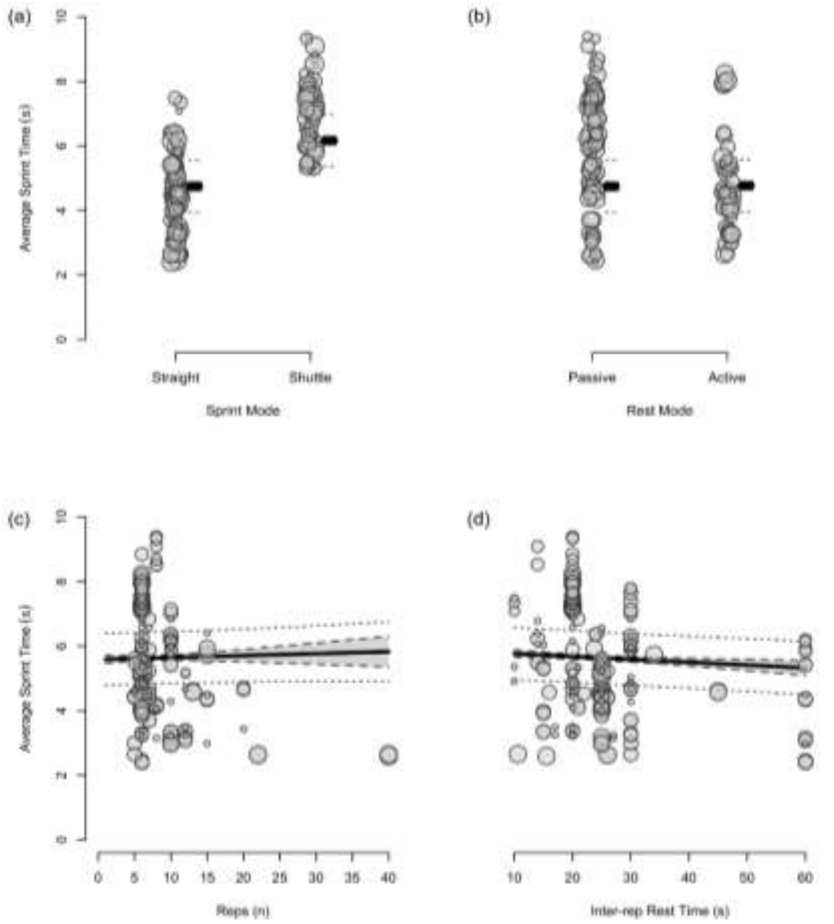
$R^2 = 0.92$

CI: confidence interval

Note. Area outside the shaded zone represents the region of practical significance; S_{avg} = average sprint time.

Figure 20

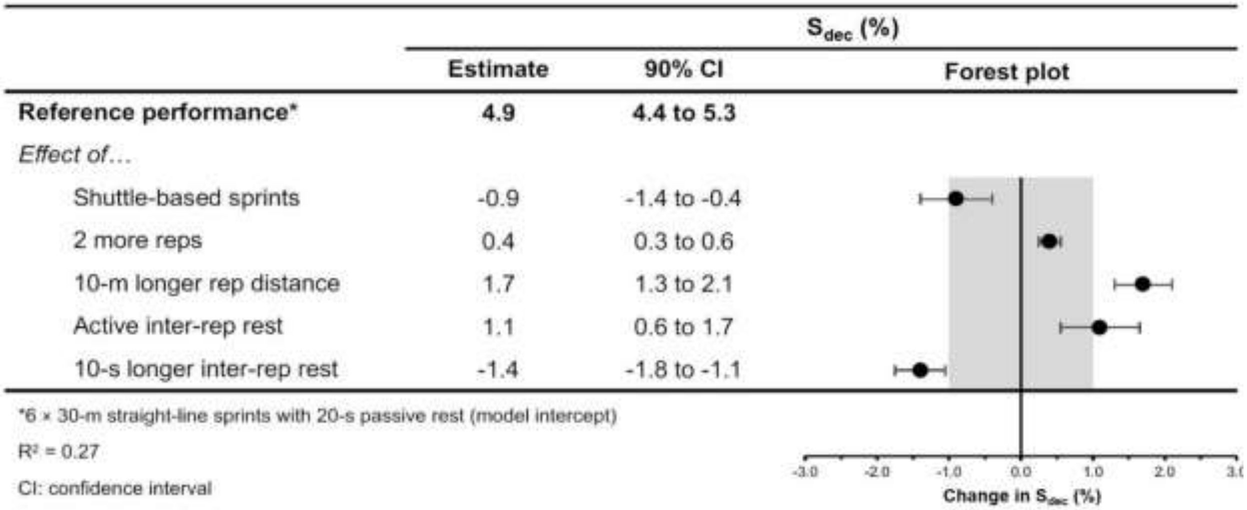
The Moderating Effects of (a) Sprint Modality; (b) Inter-repetition Rest Modality; (c) Repetitions Per Set; and (d) Inter-repetition Rest Time on Average Sprint Time During Repeated-sprint Training with Team Sport Athletes



Note. Larger circles = greater study size.

Figure 21

The Moderating Effects of Programming Variables on Sprint Time Decrement During Repeated-Sprint Training with Team Sport Athletes



	S_{dec} (%)		
	Estimate	**90% CI**	**Forest plot**
Reference performance*	**4.9**	**4.4 to 5.3**	
Effect of…			
Shuttle-based sprints	-0.9	-1.4 to -0.4	
2 more reps	0.4	0.3 to 0.6	
10-m longer rep distance	1.7	1.3 to 2.1	
Active inter-rep rest	1.1	0.6 to 1.7	
10-s longer inter-rep rest	-1.4	-1.8 to -1.1	

*6 × 30-m straight-line sprints with 20-s passive rest (model intercept)

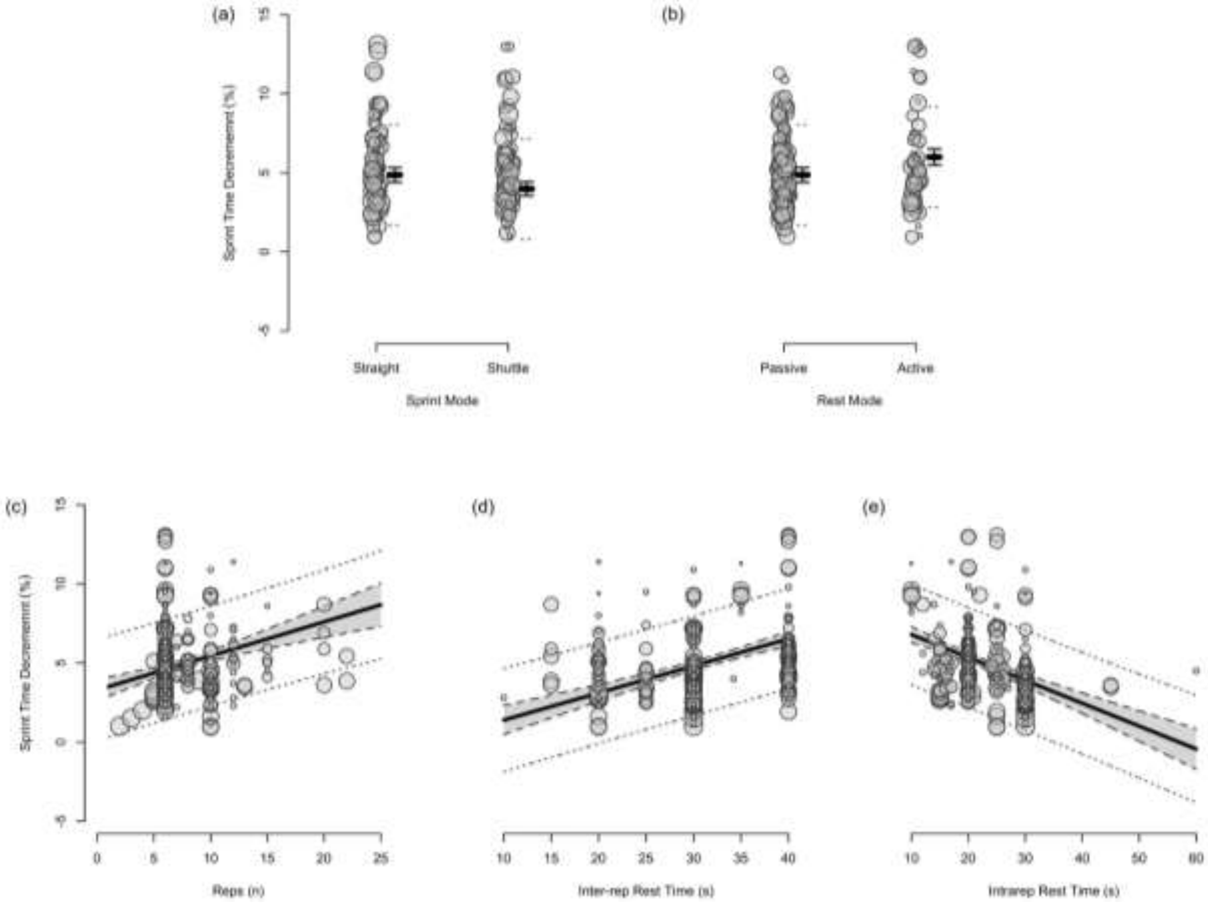
$R^2 = 0.27$

CI: confidence interval

Note. Area outside the shaded zone represents the region of practical significance; S_{dec} = sprint time decrement

Figure 22

The Moderating Effects of (a) Sprint Modality; (b) Inter-Repetition Rest Mode; (c) Repetitions Per Set; d) Total Repetition Distance; and (e) Inter-Repetition Rest Time on Sprint Time Decrement During Repeated-Sprint Training with Team Sport Athletes



Note. Larger circles = greater study size.

4.5.6 Acute Demands of Repeated-Sprint Training on Non-meta-analysed Outcomes

The acute demands of straight-line and shuttle RST on non-meta-analysed outcomes are as follows: total sprint time ranged from 7.82 to 86.09 s (number of studies = 102, number of samples =185), end-set heart rate (HR_{post}) ranged from 139 to 191 b·min^{-1} (n = 4 & 12), HR_{peak} as % HR_{max} ranged from 85 to 97% (n = 4 & 12), average VO_2 as a percentage of VO_{2max} ranged from 73 to 83% (n = 3 & 6) and creatine kinase measured 24 h post-session ranged from 354 to 1120 u·L^{-1} (n = 6 & 8). The absolute change in CMJ height ranged from 2.4 to -8.6 cm (n = 9 & 20) and the percent change ranged from 8 to -27% (n = 10 & 21). Results from studies that investigated SMM parameters (n = 2 & 2) and sprint force-velocity-power parameters (n = 1 & 1) are provided in Appendix 3.

4.5.7 Acute Demands of Multi-directional Repeated-sprint Training

The acute demands of multi-directional RST are as follows: S_{dec} ranged from 1 to 7% (number of studies = 13, number of samples = 24), S_{best} ranged from 4.36 to 8.21 s (n = 11 & 19), S_{avg} ranged from 4.14 to8.39 s (n = 12 & 22), total sprint time ranged from 32.22 to 83.99 s (n = 9 & 11), end-set B[La] ranged from 5.4 to 15.4 mmol·L^{-1} (n = 6 & 8), sRPE ranged from 5.5 to 9.1 au (n = 6 & 10), HR_{peak} ranged from 178 to 195 b·min^{-1} (n = 6 & 10).

4.6 DISCUSSION

This systematic review and meta-analysis provides the first comprehensive synthesis of the acute demands of RST in team sport athletes. It contains data from 215 studies, 282 repeated-sprint protocols and 4818 athlete inclusions. We demonstrate that physiological, neuromuscular, perceptual, and performance demands incurred during RST are consistently substantial across many RST protocols, sports, and athlete characteristics; a finding supported by both the meta-analysed point estimates and their 90% prediction intervals (Table 11). Moreover, the magnitude of these acute demands can be influenced by the manipulation of programming variables (Table 12). Prescribing longer sprint distances (> 30 m) and/or shorter (≤ 20 s) inter-repetition rest can increase physiological demands and performance decrement. Conversely, the most effective strategy to mitigate the acute decline in sprint performance is the prescription of longer inter-repetition rest times (≥ 30 s) and shorter sprint distances (15–25 m). The effects of performing two more repetitions per set on our outcomes was trivial, which suggests that prescribing a lower number of successive sprints (e.g., 4 as opposed to 6) may be a useful strategy to reduce sprint volume, while maintaining a high HR_{peak} and B[La]. The influence of shuttle-based protocols and inter-repetition rest modality remains largely inconclusive. These findings from our review and meta-analysis can be used to inform RST prescription and progression in team sport athletes.

Table 12

Summary of the Effects of Programming Variables on the Acute Demands of Repeated-Sprint Training in Team Sport Athletes

	HR_{peak}	B[La]	sRPE	S_{best}	S_{avg}	S_{dec}
Shuttle RST	?	?	=	↑	↑	=↓
2 more repetitions	=	=	=	=↑	=	=
10 m longer distance	=↑	↑	=	*	*	↑
Active rest	=↑	?	=↑	=↓	↓	=↑
10 s longer rest	=	↓	=	↓	↓	↓

Note. acute demands based on meta-analytic inferences and compared to the reference protocol of 6 × 30 m straight-line sprints with 20 s passive inter-repetition rest. ‘=’ indicates ‘trivial’; ‘↑↑’ substantial increase’; ‘↓’ indicates a ‘substantial decrease’; ‘=↓’ indicates ‘compatibility with both a trivial and substantial decrease’; ‘=#’ indicates ‘compatibility with both a trivial and substantial increase’; ‘?’ indicates ‘inconclusive’; ‘*’indicates that the effects were not evaluated; a decrease in S_{best} and S_{avg} indicates that sprint times are faster; RST = repeated-sprint training; HR_{peak} = peak heart rate; B[La] = blood lactate; sRPE = session ratings of perceived exertion; S_{best} = best sprint time; S_{avg} = average sprint time; S_{dec} = percentage sprint decrement.

Repeated-sprint training is one method among an array of training options that practitioners have at their disposal to enhance the physical performance of team sport athletes. The meta-analytic estimate of sRPE (Table 11) indicates that RST is perceived to be ‘very hard’ (90% PI: ‘moderate’ to ‘extremely hard’), which agrees with the intended prescription of this training modality and is similar to other HIIT methods (Buchheit & Laursen, 2013a, 2013b). Taking into account that a typical RST session lasts for between 10−20 min, the sRPE-training load (sRPE × training duration) is a fraction of that observed during team sport practice (Dalton-Barron et al., 2021; Harrison & Johnston, 2017; Malone et al., 2015), approximately 65−130 au (deciMax units). However, this should be considered alongside the physiological and neuromuscular stresses imposed by the RST session. The 10.1–11.3 $mmol{\cdot}L^{-1}$ reference estimate of B[La] is well above the second lactate threshold (~4 $mmol{\cdot}L^{-1}$) and therefore indicates that there is an intensive demand placed on the anaerobic system during RST (Gharbi et al., 2014). A high rate of anaerobic energy production, accompanied by a B[La] response exceeding 10 $mmol{\cdot}L^{-1}$, may be an important stimulus to elicit positive long-term changes in glycolytic enzymes (Bishop et al., 2011; Medbø & Burgers, 1990). Therefore, to potentially optimise the anaerobic adaptations to RST for team sport athletes, sessions that cause a B[La] demand of > 10 $mmol{\cdot}L^{-1}$ should be prescribed. Practitioners should also be conscious of the neuromuscular demands (i.e., impairment in the muscles ability to produce force) imposed by RST, with considerable decrements in CMJ height observed immediately after its implementation. However, while fatigue may be detrimental to acute performance, it also can be important for adaptation (Chiu & Barnes, 2003).

Athletes can reach VO_{2max} during RST (Dupont et al., 2005) and the average VO_2 demand is considerable (Table 11), corresponding to approximately 70–80% of VO_{2max} for the normal team sport athlete (Buchheit, 2010; M. Buchheit, D. Bishop, et al., 2010; T. J. Gabbett et al., 2011; T. A. Haugen et al., 2014; Higham et al., 2013; Madueno et al., 2018; Tønnessen et al., 2013). Although moderator analysis of VO_2 was not feasible due to a low number of samples, qualitative synthesis indicates that longer sprint distances (Dupont et al., 2005), active rest periods (Madueno et al., 2018), and shuttle-based RST (Buchheit, 2010; M. Buchheit, D. Bishop, et al., 2010) can amplify VO_2. Additionally, it would also be expected that performing more repetitions per set and more sets per session would increase the time spent under a high physiological stress, and this could have positive benefits for cardiovascular training adaptations such as an increase in stroke volume (Buchheit & Laursen, 2013a; Lepretre et al., 2004). However, long-bout HIIT, short-bout HIIT, and small-sided games elicit greater VO_2 demands (~ >8 min at or near VO_{2max}) (Buchheit & Laursen, 2013a, 2013b). Therefore, while improvement in aerobic fitness is achieved with RST, it is unlikely to be the best tool for eliciting time at or near VO_{2max} and ultimately, for enhancing aerobic fitness (Buchheit & Laursen, 2013a; Clemente et al., 2021). The prescription of protocols that amplify the aerobic stimulus but cause excessive levels of within-session fatigue could mitigate the improvement of other physical qualities (e.g., speed). Manipulating programming variables based on the goals of the training program is therefore crucial to regulate the acute demands of RST and optimise specific adaptations.

4.6.1 Moderating Effects of Programming Variables

4.6.1.1 Sprint modality

There were a greater number of RST protocols that prescribed straight-line sprints (n = 153, 54%) compared to shuttle RST (n = 105, 37%) and multi-directional RST (n = 24, 9%). Across the 24 protocols that prescribed multi-directional repeated-sprints (Aguiar et al., 2008; Almansba et al., 2019; Blasco-Lafarga et al., 2020; Brahim et al., 2016; Seifeddine Brini, Abderraouf Ben Abderrahman, et al., 2020; Brini, Boullosa, et al., 2021; Buchheit et al., 2012; Dellal & Wong, 2013; Gibson et al., 2013; Gonzalo-Skok et al., 2016; Joo, 2016; Kaplan, 2010; Perroni et al., 2013; Ruscello et al., 2013; Suarez-Arrones et al., 2014; Turki et al., 2020; Zagatto et al., 2017;

Zagatto et al., 2022), there were a variety of different designs and angles implemented, ranging from 45 to 135°, for 2–5 changes of direction. Given the multitude of programming variables to consider, meta-analysis of multi-directional RST was not feasible. Nonetheless, we found that consistently high HR_{peak} (178–195 $b \cdot min^{-1}$ and 92–100% HR_{max}), sRPE (5.5–9.1 au) and post-session B[La] (5.4–15.4 $mmol \cdot L^{-1}$) were reported across all multi-directional protocols. Multi-directional sequences were designed to replicate specific movement demands of team sports where rapid changes of direction are common (Brughelli et al., 2008; Sheppard & Young, 2006; Taylor et al., 2017). Moreover, previous research has identified that straight-line speed and COD ability are different physical qualities because of their distinct biomechanical determinants (Brughelli et al., 2008; Sheppard & Young, 2006). Greater application of multi-directional and shuttle-based RST may therefore be used to help develop COD ability, but practitioners should be aware of the acute demands of each modality.

Compared to straight-line RST, our meta-analytic estimates show that sprint times are clearly slower during shuttle-based RST (Figure 17 & 19), but S_{dec} can be less (Figure 21). Practitioners can therefore expect lower sprint velocities when changes of direction are implemented, but athletes may be able to better sustain their initial sprint performance. The effects on HR_{peak} and B[La] were inconclusive (Figure 11 & 15), while the effect on sRPE was mostly trivial (Figure 13), which may suggest that these physiological and perceptual demands of RST are independent of sprint modality. It should be noted however, that the acute demands of RST performed with changes of direction are conditional to the number and angle of direction changes, the distance between each direction change, and the duration of the sequence (Attene et al., 2016; M. Buchheit, D. Bishop, et al., 2010; Buchheit et al., 2012; Johnny Padulo et al., 2015; Zagatto et al., 2017). These factors affect the absolute speeds that are attained, and the muscular work performed during the sprint, propulsive and braking components. Additionally, by integrating changes of direction into RST, there is accumulation of acceleration and deceleration which can increase the neuromuscular demand (Buchheit et al., 2012). This seems evident by greater reductions in CMJ height following shuttle-based RST (Dal Pupo et al., 2013; Ruscello et al., 2013; Sánchez-Sánchez et al., 2014).

Shuttle-based sprints can be applied during a RST program to emphasise COD, while limiting absolute running speeds and inducing a similar physiological demand to straight-line RST. There may be instances, such as towards the end of season, where practitioners want to limit the physiological stress on the athlete during shuttle or multi-directional RST. In these cases, it has been demonstrated that decreasing the sprint duration through time-matched protocols is an effective strategy (Buchheit et al., 2012). Therefore, when designing RST, practitioners need to consider the influence of the direction changes on the duration of the sprint, rather than just the overall distance, as this can have a marked effect on the internal demands (Buchheit et al., 2012). Of course, straight-line sprints should be implemented if the goal is to expose athletes to higher speeds.

4.6.1.2 Number of sprint repetitions and sets

Repeated-sprint training is implemented in research and practice to target a broad range of outcomes, which is reflected by considerable variation in the number of sprint repetitions prescribed across studies (range: 2–40 repetitions per set). The majority of protocols (n = 257, 94%) implemented just one set, with six repetitions the most prescribed number of sprints per set (n = 122 protocols, 43%). Protocols that prescribed ≥ 12 repetitions per set (Abt et al., 2011; Clifford et al., 2016; Costello et al., 2021; Dellal et al., 2015; Dupont et al., 2005; Eliakim et al., 2012; Figueira et al., 2021b; T. Haugen et al., 2014; Haugen et al., 2015; Howatson & Milak, 2009; Iaia et al., 2017; Iaia et al., 2015; Little & Williams, 2007; Paulauskas et al., 2020; Russell et al., 2017b; Ulupınar, Hazır, et al., 2021; Ulupınar, Özbay, et al., 2021; Woolley et al., 2014) were often designed to induce a high degree of fatigue. Accordingly, high serum creatine kinase responses (542–1127 $u \cdot L^{-1}$) were reported 24 hours following RST in studies that prescribed high repetition protocols (Clifford et al., 2016; Howatson & Milak, 2009; Russell et al., 2017b; Woolley et al., 2014), despite longer inter-repetition rest times (≥ 30 s). These long-series of exhaustive efforts are counterintuitive to the movement demands of team sports, where sprint efforts are more likely to occur in small clusters (Dawson, 2012c; Spencer et al., 2004). While the moderating effects of the number of sets per session was not meta-analysed due to the low number of samples, it is worth noting that with an increasing number of sets, sprint times were impaired and heart rate was increased, but changes in B[La] were negligible (Dent et al., 2015; Paulauskas et al., 2020; Selmi et al., 2016). Further investigation is required to better understand the impact of the number of sets performed per session, as well as the overall session volume, on the acute demands of RST.

A substantial physiological demand is induced with the prescription of just six sprint repetitions, as demonstrated by the estimates and PI's for HR_{peak} and B[La] (Figure 11 & 15). A large cardiac demand, inferred by the 182 $b \cdot min^{-1}$ reference estimate of HR_{peak}, coupled with a B[La] response exceeding 10 $mmol \cdot L^{-1}$, provide a strong aerobic and anaerobic stimulus, which may underpin the improvements in intermittent running performance observed after RST interventions (Taylor et al., 2015; Taylor et al., 2016). Our meta-analytic estimates show that the effects of performing two more repetitions per set was trivial on all outcome measures except S_{best}, which was compatible with both meaningful and trivial effects (Figure 17). Therefore, other programming factors appear to have a greater effect on our physiological, perceptual, and performance outcomes. While increasing the number of repetitions per set would theoretically extend the time under a high physiological stress, increasing the number of sets per session would be a more effective strategy that would also allow for faster within-session sprint performance. Moreover, large numbers of successive repetitions can result in 'pacing' strategies that influence the maximal nature of RST, and accumulated fatigue reduces the effectiveness of later sprints (Vollaard et al., 2017). This is supported by our findings that show a S_{dec} of 1.2% would be expected to occur in studies (groups) performing 6 more repetitions (i.e., 12 repetitions per set in total) (Haugen & Buchheit, 2016). Therefore, excessive numbers of successive sprint repetitions increase fatigue and cause sub-optimal performance during RST.

A lower number of repetitions per set (e.g., ≤ 6 repetitions) may be a more effective programming approach during competition periods to reduce training volume while still providing a potent physiological stimulus and allowing for the quality of each repetition to be maintained. In this regard, the trivial reduction expected in each outcome measure when performing 4 versus 6 repetitions may be beneficial, when viewing from a risk-reward perspective. However, a one-size-fits-all approach regarding the RST prescription for team sport athletes can lead to some athletes being under-stimulated, while others can be overloaded, depending on the athletes' speed and fitness profile (Mendez-Villanueva et al., 2008; Sandford et al., 2021). When the number of repetitions performed is fixed, there is considerable inter-individual variation in the degree of fatigue experienced across the same group of athletes (Morcillo et al., 2015). This can be incurred despite two athletes having a similar MAS but different MSS (i.e., differences in anaerobic speed reserve) (Julio et al., 2020; Sandford et al., 2021). In our review, all studies, except one (Akenhead et al., 2017), prescribed a fixed number of repetitions. However, in the study by Akenhead et al. (2017) the level of relative sprint decrement (5%) was prescribed with a ‘flexible’ repetition scheme, which allowed more control over the magnitude of fatigue accrued by all participants. By prescribing a level of relative sprint decrement or relative performance threshold instead of a fixed number of repetitions, practitioners can individualise RST prescription. This could provide practitioners with the ability to autoregulate training load based on differences in physical capacities and fluctuations in prior fatigue.

4.6.1.3 Sprint distance

A sprint distance of 30 m was most implemented (n = 107 protocols, 38%), which is longer than the average sprint distance typically observed during field-based team-sports competitions (15–25 m) (Spencer et al., 2005). Additionally, 40 m was the longest sprint distance prescribed (n = 74, 26%). This distance is commonly used as a proxy measure of maximal speed in team sport athletes (Jiménez-Reyes, García-Ramos, et al., 2019; Jiménez-Reyes et al., 2022), as it can allow maximal velocity to be reached when it is applied in a straight-line format. Furthermore, both 30 and 40 m were often implemented as a shuttle format, with 1–2 changes of direction. A distance of 14 m was the shortest sprint effort prescribed, represented in two protocols (Mancha-Triguero et al., 2021), while 15 m was prescribed in 11 (4%) protocols. Compared to longer sprints (> 30 m), these shorter distances emphasise the acceleration phase of sprinting and were often applied with court-based athletes (i.e., basketball and handball) (Broderick et al., 2019; Izquierdo et al., 2002a; Mancha-Triguero et al., 2021; Paulauskas et al., 2020). Shorter distances may better reflect the competitive environment of court-based team sports where players are engaged in sprint efforts of 15 m and less (Conte et al., 2015; Figueira et al., 2021b; Manchado et al., 2013).

Despite the prevalence of studies implementing a sprint distance of 30 m, altering the distance of each sprint effort by 10 m had the largest moderating effect on B[La] (substantial increase), S_{dec} (substantial increase [more pronounced decline in sprint times]) and HR_{peak} (compatible with a trivial and substantial increase). Longer sprints increase phosphocreatine (PCr) depletion and glycolytic activity, while also resulting in an increased accumulation of metabolic by-products (e.g., hydrogen ions, inorganic phosphate) (Girard, Mendez-Villanueva, et al., 2011; Spencer et al., 2005). Furthermore, longer sprints provide exposure to faster absolute running speeds and higher vertical ground reaction forces that are attained via upright running mechanics (Higashihara et al., 2018; Mero et al., 1992). This is compared to shorter distances, where the athlete spends a high proportion of time in the acceleration phase, resulting in a greater horizontal propulsive force, but smaller braking force (Higashihara et al., 2018; Mero et al., 1992). Consequently, there can be a greater strain on the musculoskeletal system during longer sprints (Schache et al., 2012; Thelen et al., 2005; Timmins et al., 2014). This is evident through greater declines in sprint kinematics (i.e., vertical stiffness and centre of mass vertical displacement) when longer sprint distance (35 m vs 20 m) was prescribed in two studies that investigated SMM characteristics (Franck Brocherie et al., 2015a; Girard, Racinais, et al., 2011). Despite a greater physiological and neuromuscular demand imposed by longer sprints, the effect of a 10 m longer sprint on sRPE was trivial (Figure 13). This suggests that greater distances can be prescribed without inducing a practically substantial increase in perceived exertion.

When beginning a RST program, shorter distances (15–25 m) are a more conservative option that can be used to limit metabolic stress and neuromuscular strain. It may also be beneficial to prescribe shorter distances during maintenance/taper sessions or for athletes who may never be exposed to longer sprints during competition (e.g., court-based athletes, goalkeepers). Training progression and overload can then be achieved by gradually increasing distance (> 30 m) with a view to expose athletes to faster absolute running speeds, greater fatigue and a high physiological demand. This could be implemented during preparation phases before commencing high-intensity training drills and match-play, or during late-stage return to play following injury.

4.6.1.4 Inter-repetition rest duration

There was considerable heterogeneity in the distribution of inter-repetition rest duration across the protocols, which ranged from 10 to 60 s. This was partly due to differences in the approach to rest prescription, whereby pre-determined times, time-cycles and work-to-rest ratios were all employed in different literature. A 10 s rest duration was prescribed in 11 (4%) protocols, but such short rest may make it difficult for athletes to safely decelerate and make it back to the start-line in time for the next sprint. The most common rest durations were 20 s and 30 s, represented in 83 (29%) and 67 (24%) protocols, respectively. These rest durations are similar to the amount of recovery time typically afforded between intense bouts of sprinting during team sport competition (Dawson, 2012c; Spencer et al., 2004). A 60 s rest duration was implemented in 9 (3%) protocols.

Shorter rest times (e.g., 10 vs 20 s) are associated with slower sprint times, greater performance fatigue and an increased metabolic response. Additionally, shorter rest may lead to greater decrements in CMJ height following RST (J Padulo, M Tabben, LP Ardigò, et al., 2015). Inversely, longer inter-repetition rest times (e.g., 30 vs 20 s) have a clearly meaningful influence on the reduction of B[La] and allow for sprint performance to be better maintained across a set (i.e., faster S_{avg} and lower S_{dec}). This is likely due to greater clearance of metabolic by-products and increased PCr resynthesis (Girard, Mendez-Villanueva, et al., 2011; Little & Williams, 2007). An interesting finding of our study was that a 10 s longer inter-repetition rest had a trivial effect on HR_{peak} and sRPE. Longer inter-repetition rest may allow athletes to perform each repetition with greater speed (Balsom et al., 1992) and reduce the desire for pacing. Furthermore, longer rest would be expected to increase set duration, thereby allowing both heart rate and VO_2 to increase with time (Dupont et al., 2005; Paulauskas et al., 2020; Zagatto et al., 2017). It is possible, however, that the cardiorespiratory demand could be blunted if prolonged rest times (e.g., 60 s) are implemented. This has been shown in a group of well-trained university students where VO_2 was 9% less when 60 s rest times were used during RST, compared to 30 s rest (Balsom et al., 1992).

Collectively, our findings support the use of longer rest durations (≥ 30 s) to reduce within session fatigue and maintain repetition quality. Longer rest times could therefore be implemented during periods of fixture congestion to reduce player fatigue during RST, or used during the intensification stage of a pre-season to maximise sprint performance (Iaia et al., 2017). Additionally, longer rest times are recommended when longer sprint distances are prescribed, which can help account for the extended work duration of these sequences. However, longer rest durations reduce the metabolic demand of RST, which could limit certain physiological adaptations (e.g., maximal accumulated oxygen deficit, changes in glycolytic enzymes) (Bishop et al., 2011; Tabata et al., 1996) and performance in activities that require a substantial anaerobic component (Iaia et al., 2017). Therefore, shorter rest durations (≤ 20 s) can be prescribed to induce greater levels of fatigue, which could help prepare team-sport athletes for peak periods of a match, where sprint efforts can be interspersed with minimal rest (Dawson, 2012c; Spencer et al., 2004).

4.6.1.5 Inter-repetition rest modality

There were a higher number of protocols that implemented passive inter-repetition rest (n = 186, 66%), as opposed to an active rest period (n = 96, 34%). Active recovery protocols were commonly combined with inter-repetition rest durations of ≥ 25 s. Most protocols that prescribed an active recovery involved a slow jog at pre-defined running speeds (e.g., 2 $m \cdot s^{-1}$) or self-selected speeds, which were often returning to a one-way start line. Other active recovery protocols implemented faster running speeds such as 8 $km \cdot h^{-1}$ (Abt et al., 2011; Alemdaroğlu et al., 2018) and 50% of MAS (S Brini et al., 2020; Castagna et al., 2008; Dupont et al., 2005; Madueno et al., 2018)). When these faster running speeds were prescribed, the physiological demands (i.e., heart rate, VO_2, B[La]) were amplified and there was a greater S_{dec} compared to passive rest and active rest performed at a slow jog (S Brini et al., 2020; Castagna et al., 2008; Dupont & Berthoin, 2004; Madueno et al., 2018). Repeated jumps were performed during the inter-repetition rest period in two studies (Buchheit, 2010; J Padulo, M Tabben, G Attene, et al., 2015), which increased the cardiorespiratory and muscular demands (Buchheit, 2010; J Padulo, M Tabben, G Attene, et al., 2015). However, the internal demands are likely to be more varied compared to a precise running intensity.

The findings of our meta-analysis suggest that active rest may cause a meaningful increase in HR_{peak} (Figure 11), sRPE (Figure 13) and S_{dec} (Figure 21), although we acknowledge that these effects are also compatible with trivial values (i.e., there could be no meaningful influence). Active recovery limits the oxidative potential for PCr resynthesis before each sprint, which affects the maintenance of muscle power (Madueno et al., 2018; Mendez-Villanueva et al., 2008; J Padulo, M Tabben, LP Ardigò, et al., 2015). This leads to greater declines in anaerobic work capacity and subsequently, repeated-sprint performance. On the contrary, passive recovery is associated with an enhanced PCr resynthesis and as our results confirm, a smaller S_{dec} (Buchheit et al., 2009; Dupont et al., 2004). While there were no substantial differences in B[La] (Figure 15), our meta-analysis does not consider the intensity of the recovery period, which ultimately determines the extent of the acute demands (Buchheit, 2010; Buchheit et al., 2009; Castagna et al., 2008).

The prescription of active recovery might amplify RST physiological and perceptual demands, as well as performance decrement, without increasing the sprint volume. This could be achieved, for example, by prescribing active recovery at an intensity of ≥ 50% MAS. It would be practical to implement this with a standardised recovery-run distance and rest durations of ≥ 25 s to allow the athlete to gradually decelerate from the sprint component into the recovery running speed. Yet, once again, acknowledging that the influence of active recovery on HR_{peak}, sRPE, and S_{dec} were compatible with both meaningful and trivial effects, we advise practitioners to place more emphasis on recovery duration for manipulating RST acute demands at present. For this reason, future research should examine the effects of specific active recovery intensities on RST physiological, perceptual, neuromuscular and performance demands.

4.6.1.6 RST protocols with additional modifications

The use of additional modifications to RST can be applied to augment or attenuate internal demands. Short enforced deceleration zones (< 10 m) which were prescribed in two studies (Lakomy & Haydon, 2004; Woolley et al., 2014), reduce sprint performance and exacerbate the magnitude of muscle damage due to the large eccentric forces applied during rapid braking, which is further accentuated when higher numbers of repetitions are performed. Gradual deceleration zones (> 10 m) are therefore recommended to mitigate any undue muscular damage. Performing repeated jumps within the inter-repetition rest period may be an effective strategy to induce a greater physiological stimulus during RST, while exposing athletes to sport-specific actions, without an increase in the volume of high-intensity running (Buchheit, 2010; J Padulo, M Tabben, G Attene, et al., 2015). When jumps were prescribed in studies by Buchheit (2010) and J Padulo, M Tabben, G Attene, et al. (2015), very high B[La] (10.2‒13.1 m.mol^{-1}), HR_{peak} (96‒97% heart rate max), and sRPE (7.9‒8.0 au) were observed. The additional muscular work performed during the recovery period with jumps has previously been shown to increase muscle deoxygenation of the lower limbs, but it should be noted that these sequences are also likely to reduce acute sprint performance (Buchheit, 2010; J Padulo, M Tabben, G Attene, et al., 2015). Furthermore, with only two studies investigating the effects of jumps within the inter-repetition rest period, the optimal volume and intensity of these actions are yet to be elucidated. There is potential for other modifications to be implemented during RST, such as sport-specific skills (e.g., passing, shooting), grappling, push-ups, and tackling into contact bags. These types of explosive efforts typically precede or follow high-intensity runs/sprints during match play (Austin et al., 2011; Carling et al., 2012; Sirotic et al., 2009) and may help to better simulate the physiological demands associated with competition. Furthermore, flying sprints that incorporate a submaximal acceleration zone may provide exposure to repeated bouts of maximal velocity sprinting, without the neuromuscular demands of rapid acceleration (Beato & Drust, 2021).

4.6.7 Limitations

There are several important issues to consider when interpreting our findings. Depending on the outcome measure, a proportion of the variation in the meta-analysed acute demands of RST can be explained by factors other than the programming variables investigated (Appendix 4). Factors directly related to individual differences in human physiology have been shown to influence the acute demands to RST, such as age (Dellal & Wong, 2013; Gibson et al., 2013; Gustavo Jorge et al., 2020; Klatt et al., 2021; Robert G Lockie et al., 2016; Mujika et al., 2009; Rodríguez-Fernández et al., 2018; Turki et al., 2020), fitness level (Alizadeh et al., 2010), playing status (Brini, Boullosa, et al., 2021; Campa et al., 2019; García-Unanue et al., 2020; Impellizzeri et al., 2008; Ingebrigtsen et al., 2012; Keogh et al., 2003; Le Rossignol et al., 2014; Rampinini et al., 2009), gender (Delextrat et al., 2013; Dent et al., 2015; Mancha-Triguero et al., 2021; Tounsi et al., 2019) and ethnicity (Galy et al., 2015). Furthermore, a proportion of the variation in the acute demands may also be due to the impact of programming variables not investigated (e.g., number of sets), as well varied data collection methods, conditions and reporting. For example, there are inter- and intra-individual differences in B[La] accumulation depending on sampling procedures (time and site), hydration status, previous exercise and ambient temperature (Buchheit & Laursen, 2013b; Halson, 2014; Krustrup, Mohr, Steensberg, et al., 2006). Nevertheless, the influence of the latter factors on the present review are likely to be low considering that item ten in the inclusion-exclusion criteria ensures that RST must have been performed under normal conditions (e.g., hydrated state, ≤ 30° C) and without fatiguing exercise occurring in the previous

24 h. We also appreciate the concerns of comparing CMJ height between different methods and devices (McMahon et al., 2017), which is why CMJ outcomes were not meta-analysed.

When interpreting acute heart rate and VO_2 responses to training, it is important to consider the starting value at the commencement of exercise, which will influence the magnitude of change. However, the majority of studies did not present this information, and thus, we were unable to account for this in our analyses. Additionally, there was an insufficient number of samples to determine the moderating effects of programming variables on HR_{avg} and VO_2. There was also a low number of samples for HR_{peak} as % HR_{max}, creatine kinase, SMM parameters, and sprint FVP parameters, which meant we were unable to meta-analyse these outcomes. Therefore, in future, researchers may wish to investigate the effects of RST on these outcomes. Finally, it should be noted that while our elected reference adjustments of 10 m and 10 s allow for comparison between sprint distance and inter-repetition rest time, respectively, this will not always represent the same relative change (i.e., an increased sprint distance from 10 to 20 m represents a 100% change, while 30–40 m represents a 25% change). Therefore, this information should be treated with caution and used within the context of the programmed session.

4.6 CONCLUSIONS

Our systematic review and meta-analysis is the first to summarise the acute physiological, neuromuscular, perceptual and performance demands of RST in team sport athletes, while providing a quantitative synthesis of the effects of programming variables. RST provides a potent physiological stimulus for the physical development of team sport athletes, with the magnitude of the acute demands influenced by several programming variables (Table 12). Longer sprint distances and shorter inter-repetition rest periods are the most efficacious strategies to increase RST demands. When manipulated in combination, these factors are likely to have an even greater effect, from which the magnitude of within-session fatigue and acute training response can be expected to follow. Reducing the number of repetitions per set (e.g., 4 as opposed to 6) can maintain the physiological, perceptual and performance demands of RST while reducing sprint volume. When combined with shorter sprint distances and increased inter-repetition rest periods, this might be a useful strategy during strenuous training and competition periods (Laursen & Buchheit, 2019). Additionally, straight-line, shuttle and multi-directional repeated-sprints can be prescribed to target movement specific outcomes, depending on the aims of the training program. While there is a large quantity of evidence relating to acute performance outcomes of RST, there is a lack of literature on cardiorespiratory (e.g., VO_2) and neuromuscular demands. The insights from our review and meta-analysis provide practitioners with the expected demands of RST and can be used to help optimise training prescription through the manipulation of programming variables.

CHAPTER 5

STUDY 2

The Effects of Repeated-Sprint Training on Physical Fitness and Physiological Adaptation in Athletes: A Systematic Review and Meta-Analysis

This chapter is presented in the pre-publication format, adapted from:

Thurlow, F., Huynh, M., Townshend, A., McLaren, S. J., James, L. P., Taylor, J. M., ... & Weakley, J. (2023). The Effects of Repeated-Sprint Training on Physical Fitness and Physiological Adaptation in Athletes: A Systematic Review and Meta-Analysis. *Sports Medicine*, 1-22.

5.1 PRELUDE

Having comprehensively reviewed the acute demands of RST in Chapter 4, this chapter investigates the physical adaptations to RST. The moderating effects of programming variables on physical adaptations will also be synthesised, which provides practitioners with the most effective programming strategies to achieve optimal improvements in physical performance.

5.2 ABSTRACT

Background: Repeated-sprint training is a common training method for enhancing physical fitness in athletes. To advance RST prescription, it is important to understand the effects of programming variables on physical fitness and physiological adaptation.

Purpose: To (1) quantify the pooled effects of running-based RST on longitudinal changes in 10 and 20 m sprint time, VO_{2max}, Yo-Yo Intermittent Recovery Test Level 1 (YYIR1) distance, RSA, CMJ height, and COD ability in athletes, and, (2) examine the moderating effects of program duration, training frequency, weekly volume, sprint modality, repetition distance, number of repetitions per set, and number of sets per session on changes in these outcome measures.

Methods: Pubmed, SPORTDiscus, and Scopus databases were searched for original research articles up to July 4, 2023, investigating RST in healthy, able-bodied athletes, between 14–35 years of age, and a performance calibre of trained or above. RST interventions were limited to repeated, maximal running (land-based) sprints of ≤ 10 s duration, with ≤ 60 s recovery, performed for 2−12 weeks. A Downs and Black checklist was used to assess the methodological quality of the included studies. Eligible data were analysed using multi-level mixed-effects meta-analysis, with standardised mean changes determined for all outcomes. Standardised effects (Hedges G [G]) were evaluated based on coverage of their confidence (compatibility) intervals (CI), using a strength and conditioning specific reference value of G = 0.25 to declare an improvement (i.e., $G > 0.25$) or impairment (i.e., $G < -0.25$) in outcome measures. Applying the same analysis, the effects of programming variables were then evaluated against a reference RST program, consisting of three sets of 6 × 30 m straight-line sprints performed twice per week for six weeks (1200 m weekly volume).

Results: 40 publications were included in our investigation, with data from 48 RST groups (541 athletes) and 19 active control groups (213 athletes). Across all studies, the effects of RST were compatible with improvements in VO$_{2max}$ (G: 0.56; 90% CI: 0.32 to 0.80), YYIR1 distance (0.61; 0.43 to 0.79), RSA decrement (-0.61; -0.85 to -0.37), linear sprint times (10 m: -0.35; -0.48 to -0.22, 20 m: -0.48; -0.69, to -0.27), RSA average time (-0.34; -0.49 to -0.18), CMJ height (0.26; 0.13 to 0.39), and COD ability (-0.32; -0.52 to -0.12). Compared to the reference RST program, the effects of manipulating training frequency (+1 session per week), program duration (+ 1 extra training week), RST volume (+200 m per week), number of reps (+ 2 per set), number of sets per session (+1 set) or rep distance (+ 10 m per rep) were either non-substantial or comparable with an impairment in at least one outcome measure per programming variable.

Conclusions: Running-based RST improves speed, YYIR1 distance, VO$_{2max}$, RSA, COD ability, and CMJ height in trained athletes. Performing three sets of 6 × 30 m sprints, twice per week for six weeks is effective for enhancing physical fitness and physiological adaptation. Additionally, since our findings do not provide conclusive support for the manipulation of RST variables, further work is needed to better understand how programming factors can be manipulated to augment training-induced adaptations.

5.2.1 Key Points

- RST programs elicit moderate improvements in VO_{2max}, YYIR1 distance, and RSA decrement, as well as small improvements in 10 and 20 m linear sprint times, RSA average time, CMJ height, and COD ability.
- Compared to three sets per session, performing four sets per session may further enhance YYIR1 distance. Combined with a low number of repetitions (4−6 reps), this is a more effective training strategy to enhance physical qualities rather than long series of exhaustive efforts (e.g., two sets of 10−12 reps).
- Compared to the reference programs of three sets of 6 × 30 m straight-line sprints performed twice per week for six weeks (1200 m weekly volume), there was limited evidence to recommend increased training frequency (+1 session per week), program duration (+ 1 extra training week), RST volume (+200 m per week), number of reps (+ 2 per set) or rep distance (+ 10 m per rep) as beneficial to changes in physical qualities.

5.3 INTRODUCTION

Existing evidence suggests that RST improves several physical qualities relevant to sports competition, including speed, CMJ height, and intermittent running performance (Taylor et al., 2015). Physical adaptations from RST can be achieved with as few as 6 × 10–20 min sessions over two weeks (Taylor et al., 2016), which makes it particularly suitable in team sport environments, where there is a need for time-efficient, multi-component training methods. Furthermore, RST can be used to help prepare athletes for the intermittent, high-intensity demands of competition, with its frequent accelerations, decelerations and changes of direction (Brughelli et al., 2008; Sheppard & Young, 2006; Taylor et al., 2017). While RST is a potent training method, the magnitude of adaptations may depend on the methods of prescription as it is well documented that the manipulation of programming variables influences adaptation to other methods of training (e.g., resistance training) (Zatsiorsky et al., 2020).

Chapter 4 demonstrated that RST induces a considerable acute physiological, neuromuscular, perceptual, and performance demand in athletes. For example, average heart rate and VO_2 correspond to approximately 90% and 70–80% of max, respectively, while sessions are typically perceived as ’very hard’ and cause a reduction in countermovement jump height of ~4–5%. Therefore, RST could provide an effective stimulus to enhance aerobic capacity, but this is yet to be quantitively synthesised. A high level of aerobic fitness is essential for enhanced recovery between intermittent bouts of high-intensity exercise and has been associated with the ability to perform more work during team-sport competition (Stone & Kilding, 2009; Tomlin & Wenger, 2001). Due to the maximal intensity at which RST is performed, it also exerts a considerable demand on the metabolic system, demonstrated by blood lactate concentrations over 10 mmol·L^{-1} (Chapter 4). However, variation in the prescription of programming variables can influence the internal (i.e., psycho-physiological stress) and external (i.e., physical performance output) training load of RST, which subsequently have the potential to cause diverse training adaptations (Kalkhoven et al., 2021). It is therefore important to understand how the manipulation of programming variables affects the adaptations to RST in athletes.

Programming variables are the core, individual components of a training program (e.g., frequency of sessions, number of repetitions, sprint distance, etc.). In isolation and combination, they influence the exercise stimulus and the magnitude of physiological, neuromuscular, and musculoskeletal adaptations. Furthermore, the chronic effects of manipulating RST variables on physical adaptation are diverse. For example, when an average weekly sprint volume of ~800 m was completed during a six-week, shuttle-based RST intervention (Chtara et al., 2017), significant improvements in 10 m sprint time, repeated-sprint ability (RSA) average time and COD ability were achieved. Conversely, no change in these outcomes, as well as VO_{2max} and CMJ height, were observed when a volume of 1200 m per week was prescribed over a six-week, straight-line RST program (Krakan et al., 2020). There were no significant differences in adaptation were found when sprint modality (straight-line vs shuttle RST) (Beato et al., 2022; Taylor et al., 2016) and training frequency (1 vs 2 sessions per week) (Rey et al., 2019) were also compared. Due to the diverse responses observed throughout the literature, it is therefore important to determine the moderating effects of programming variables on chronic RST outcomes.

Since a review by Taylor et al. (Taylor et al., 2015), conducted in 2014, there has been a large increase in the available evidence on RST adaptations, and the moderating effects of programming variables on chronic changes in physical performance are yet to be quantitively synthesised. An updated review therefore seems timely and can provide practitioners with a greater understanding of the influence of RST prescription. Accordingly, our systematic review and meta-analysis aims to (1) quantify the pooled effects of running RST on changes in 10 and 20 m sprint time, VO_{2max}, YYIR1 distance, RSA, CMJ height, and COD ability in athletes, and, (2) examine the moderating effects of program duration, training frequency, weekly volume, sprint modality, repetition distance, number of repetitions per set, and number of sets per session on changes in these outcome measures.

5.4 METHODS

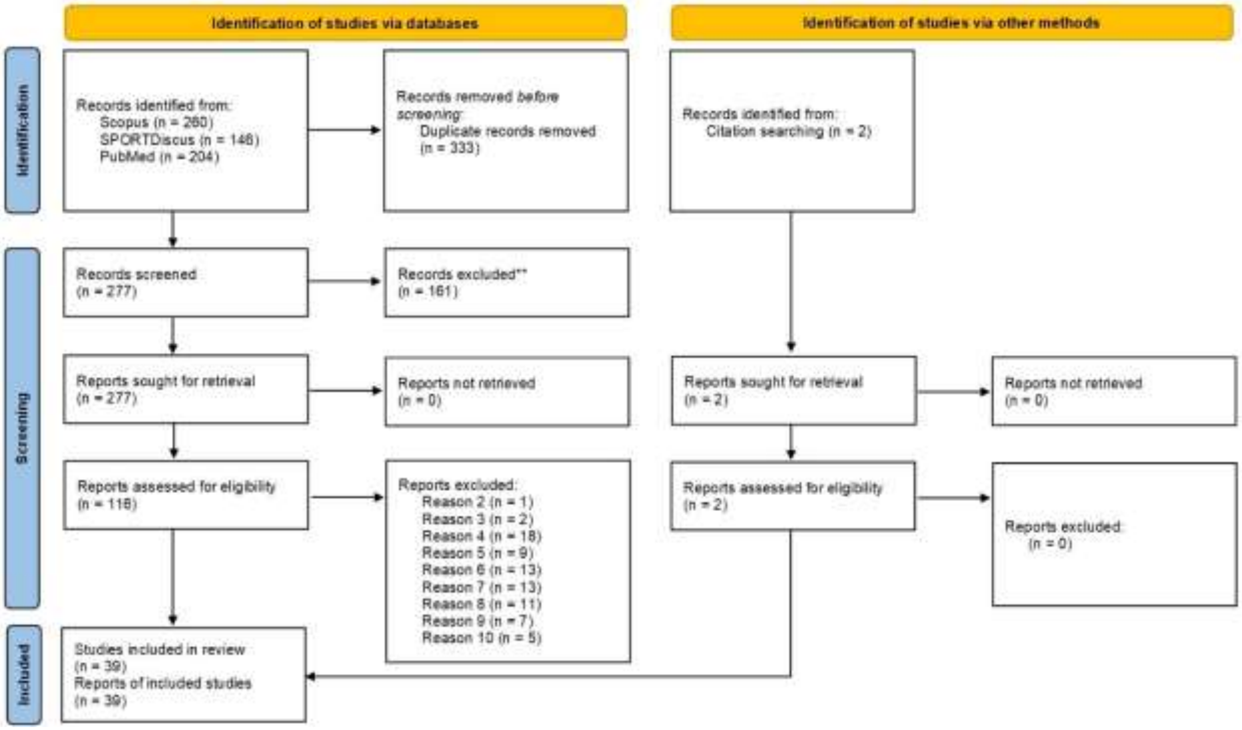
5.4.1 Search Strategy

Our study was conducted per the ‘Preferred Reporting Items for Systematic Reviews and Meta-analyses’ (PRISMA) guidelines (Moher et al., 2009) and registered on Open Science Framework (DOI: 10.17605/OSF.IO/RVNDW). A systematic search of the literature was conducted to find original research articles investigating the chronic effects of RST. The latest search was performed on July 4, 2023, using the electronic databases Pubmed, SPORTDiscus, and Scopus. No restrictions were imposed on the article language or the publication date. Relevant keywords for each search term were identified through pilot searching of titles/abstracts/full-texts of previously known articles. Key search terms were grouped and searched within the article title, abstract, and keywords using the search strategy outlined in Appendix 5 – 7.

Following the initial search of the literature, results were exported to Covidence (www.covidence.org, Melbourne, Australia) and duplicates were removed. The titles and abstracts were then independently screened by two authors (FT, JW), who were not blinded to journal names or manuscript authors. Full texts of the remaining articles were then screened by the same two authors to determine their final inclusion-exclusion status. Any disagreement between the two authors was resolved by a third author (AT). Furthermore, reference lists of all eligible articles and relevant reviews (Clemente et al., 2021; Taylor et al., 2015) were searched to retrieve any additional studies. Figure 23 displays the strategy for the study selection process used in our review.

Figure 23

Prisma Flow Diagram of the Study Selection Process in Chapter 5



5.4.3 Inclusion-Exclusion Criteria

The inclusion and exclusion criteria can be found in Table 13. Pilot scoping of the literature identified that two weeks (six sessions) was the shortest running-based RST program administered for this population, thus criteria 5 was determined accordingly.

Table 13

Study 2 Inclusion-Exclusion Criteria

Criteria	Inclusion	Exclusion
1	Original research article available in any language, including randomised and non-randomised, controlled and non-controlled experimental studies.	Reviews, surveys, opinion pieces, books, periodicals, editorials, case studies, observational studies, non-academic/non-peer-reviewed text, articles that repeated the results from a different article.
2	Healthy, able-bodied, non-injured athletes, aged 14–35 years, of any gender. Athletes' performance calibre was 'trained' or above.	Special populations (e.g., clinical, patients), people with a physical or mental disability, or people considered to be injured or returning from injury. Non-athletic populations or athletes competing at recreational level. Athletes under the age of 14 or over the age of 35 years.
3	A RST intervention, involving maximal intensity sprints, with a mean work duration of ≤ 10 s or equivalent distance, and a rest duration of ≤ 60 s.	A training intervention involving submaximal intensity, with a work duration of > 10 s or equivalent distance, and a rest duration of > 60 s.
4	RST was performed as an independent experimental training intervention. Usual training practice was permitted.	Studies incorporated combined experimental training interventions that were outside of their usual training practice (e.g., RST plus plyometric training).
5	RST was performed as a running, land-based intervention on a flat surface.	RST was performed on a slope, treadmill, bicycle, ergometer or any other implement.
6	RST intervention duration of 2–12 weeks (minimum six sessions).	RST intervention duration of < 2 weeks, < 6 sessions, or > 12 weeks.
7	Studies must have reported ≥ 1 outcome measure (outcome measures are described in section 2.3)	No relevant outcome measures were reported.
8	RST group must have performed the intervention under normal conditions (e.g., usual nutritional intake, normoxia, absence of ergogenic aids). Placebos permitted.	RST was performed under altered or abnormal conditions (e.g., hypoxia, heat stress, ergogenic aids, different diet).
9	Control groups must have performed their usual sports training under normal conditions without any additional interventions. Placebos permitted.	Additional training interventions were given to the control groups, outside of their usual training practice.

Note. RST = repeated-sprint training; y = years; s = seconds.

5.4.4 Selection of Outcome Measures and Programming variables

The outcome measures were selected based on consultation with elite sport practitioners and pilot scoping of the literature that identified the most common markers of physical fitness and physiological adaptation in athletes following a RST intervention, which also had a sufficient number of samples to quantitively synthesise. These outcome measures were: 10 m sprint time, 20 m sprint time, CMJ height, COD ability (i.e., time taken to complete the 5–0–5 test, T-test, modified T-test, 20 m agility test, zig-zag 20 m test, Illinois agility test), intermittent running performance (i.e., YYIR1 distance), RSA (mean time and percentage sprint decrement, as defined by Fitzsimons (Fitzsimons et al., 1993) and Glaister et al. (Glaister et al., 2008)) and VO_{2max} recorded during a graded exercise test with gas analysis on a motorised treadmill.

The primary programming variables recorded for the moderator meta-analysis were: program duration, average (i.e., across the intervention) training frequency, average weekly RST volume, sprint modality (i.e., straight-line, 180° shuttle or multi-directional), average number of repetitions per set, average number of sets per session and average sprint repetition distance. Secondary programming variables recorded, but not included in the moderator meta-analysis due to insufficient diversity in the data were: average inter-repetition rest duration, inter-repetition rest modality, inter-set rest duration and inter-set rest modality.

5.4.5 Extraction of Study Information

Mean and SD data were extracted directly from tables and the text of the included studies. To obtain data from studies where information was provided in figures, graph digitising software (WebPlotDigitizer, version 4.3, USA) was used. For studies where sprint duration was provided instead of sprint distance, the sprint distance was estimated using evidence from Chapter 4 and based on the average time taken to complete the prescribed distance. With regards to sprint modality, shuttle repeated-sprints were defined as RST where one or more 180° COD were performed. Multi-directional repeated-sprints involved RST where COD were performed with angles other than 180°. For rest modality, ‘passive’ included protocols where participants were required to walk back to a two-way start line (sprints alternating from both ends) in preparation for the next sprint. Where information relating to exercise protocols could not be found within the study or clarification was required, authors were contacted. The Participant Classification Framework (McKay et al., 2022) was used to define the training and performance calibre of the athletes included in our investigation.

5.4.6 Assessment of Reporting Quality and Risk of Bias

To assess the reporting quality and risk of bias within the studies included in our review, two authors (FT and JW) independently evaluated the literature using a modified version of the Downs and Black index (Downs & Black, 1998). This method is valid for assessing the methodological reporting quality of both randomised and non-randomised interventions, and has been used extensively in systematic reviews pertaining to sport science (Weakley, Cowley, et al., 2023; Weakley et al., 2021). If there was an absence of clear information to assess an item on either scale, it was scored as 0. Any disagreements between the two authors were resolved by discussion or a third author (AT).

5.4.7 Overall Certainty of Evidence

The overall certainty of evidence for each outcome was assessed by two authors (FT and JW) using the Recommendation, Assessment, Development and Evaluation (GRADE) tool (Higgins et al., 2019). The GRADE domains included inconsistency, heterogeneity, risk of bias, imprecision, indirectness, and publication bias, and were rated as ‘not serious’, ‘serious’ and ‘very serious’ as per the Cochrane recommendations. The overall certainty of evidence was then categorised as ‘very low’, ‘low’, ‘moderate’ or ‘high’ based on the level of confidence that the true effect was similar to the estimated effect for each outcome. Any disagreements between the two authors were resolved by discussion or a third author (AT).

5.4.8 Data Analysis

Meta-analysis was performed using the “metafor” (Viechtbauer, 2010) and “clubSandwich” (Pustejovsky, 2022) packages in the *R* programming language (R Core Team, 2021). The included studies reported outcomes across several subgroups (from repeated measures taken on the same sample). To account for this hierarchical structure, particularly the within-subject correlation, data were analysed using multi-level mixed-effects meta-analysis. Here, dependency was accounted for by replacing the variance with the variance-covariance matrix of the estimates for outcomes under the same study. Block-diagonal covariance-matrices were estimated with an assumed correlation of $r = 0.50$ (Chapter 4).

To conduct the meta-analysis, a simple model (intercept-only), using restricted maximum likelihood, was constructed to serve as a baseline model. In this model, we treated each study as a random effect, and grouped them within studies. Meta-regression was then used to determine how different programming variables influenced the outcomes, by adding the programming variables to the baseline model as fixed effects. The programming variables included were: training frequency (continuous, linear: sessions per week), program duration (continuous, linear: number of weeks), sprint modality (categorical: straight-line, 180° shuttle or multidirectional), sets per session (continuous, linear), repetitions per set (continuous, linear), repetition distance (continuous, linear) and weekly training volume (continuous, linear). Where continuous RST programming variables were altered across a study's intervention, the average value was used in our analyses (Attene et al., 2016; Attene et al., 2014; Brini et al., 2018; Seifeddine Brini, Nejmeddine Ouerghi, et al., 2020; M. Buchheit, A. Mendez-Villanueva, et al., 2010; Buchheit et al., 2008; Chtara et al., 2017; Gantois et al., 2019; Iaia et al., 2017; Kaynak et al., 2017b; Krakan et al., 2020; Lapointe et al., 2020; Le Scouarnec et al., 2022; Markovic et al., 2007; Nedrehagen & Saeterbakken, 2015; Ouergui et al., 2020; Rey et al., 2019; Selmi et al., 2018; Soares-Caldeira et al., 2014; Taylor et al., 2016; Taylor & Jakeman, 2021). For example, if six repetitions per set were applied in week one, but eight repetitions per set were applied in week two, the average number of repetitions across the intervention was set at seven per set. Therefore, as this occurred in 25 RST groups, some caution should be taken when interpreting the moderating effects of these programming variables.

Within the meta-regression, factors were re-scaled so that the reference (intercept) effect represented the response to the most common prescription of each programming variable found in our studies. Specifically, the reference response involved three sets of 6 × 30 m straight-line repeated sprints, performed twice per week for six weeks for a total weekly volume of 1200 m. The effects of programming variables were then evaluated at a magnitude deemed to be practically relevant for training prescription: performing one more session per week, one more week per program, one more set per session, two more repetitions per set, 200 m volume per week, and sprinting 10 m further per repetition. The effects of each programming variables were estimated while keeping all other factors constant. Maximum Likelihood and Correct Akaike Information Criteria were used to select the best model. We then explored different combinations of the programming factors in linear form and determined the importance value of each predictor by summing the weights and dividing it by the probabilities of the models where the variables appear. This importance value represents the overall support for each variable across all the candidate models. Finally, conclusions were made about the predictors by considering their relative weights and looking at all possible models. This helped us make informed inferences about the programming factors.

Standardised mean changes corrected for small sample bias (Hedges G) were analysed for all outcomes. Additionally, to aid the practical context of our results and accounting for the consistency of data collection methodology between different studies for 10 and 20 m sprint (s), VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) and YYIR1 (m), mean changes (i.e., raw units) were additionally analysed where appropriate. Uncertainty was expressed using 90% confidence intervals (CI), calculated based on a *t*-distribution, with denominator degrees of freedom given by the inner level of the random effects structure. Prediction intervals (PI) were computed alongside the estimates to convey the likely range of the true change in similar future studies. Between-study heterogeneity was estimated with Cochran’s Q and Higgins & Thompson’s I^2 statistics.

To provide interpretations on the effect of RST on changes in our outcomes and the moderating effects of programming variables, we visually scaled standardised effects (Hedges G) against threshold values reported specific to strength and conditioning outcomes, which were 0.25, 0.50, and 0.75 for small, moderate, and large effects, respectively (Swinton et al., 2022). Coverage of the upper and lower CI against these thresholds was considered when interpreting RST effects. When the upper and lower CI fell entirely or predominantly outside the trivial region (i.e., ≥ -0.25 [impairment], ≥ 0.25 [improvement]) we declared an effect substantial. When the upper and lower CI were inside the region bound by a trivial impairment and a trivial improvement (i.e., -0.25 to 0.25), the effect was deemed as non-substantial. If there was equal coverage between a non-substantial change and at least a small improvement or impairment, the effect was declared compatible with both (a trivial change and a substantial impairment/ improvement). When the width of the CI crossed both a small improvement and a small impairment (i.e., ≤ -0.25 and ≥ 0.25), the effect was deemed inconclusive (Curran-Everett, 2009; Williams et al., 2023). To facilitate consistent interpretation of standardised effects, the sign of time-based estimates and their CI were reversed, such that a negative value was indicative of an improvement and vice-versa.

5.5 RESULTS

Following the screening process (Figure 23), 40 publications were included in our investigation, with data from 48 RST groups and 19 active control groups. Across all studies, there were 754 athlete inclusions (541 from RST groups).

5.5.1 Study Characteristics

The most common study design across all studies was parallel-group, controlled trials (n = 27 studies, 68%), while parallel-group, non-controlled trials were represented in 13 (32%) studies. Where a control group was used, participants maintained ‘regular’ training throughout the intervention (i.e., active control group). Random allocation of participants was conducted in 33 (82%) of studies. The most investigated sport across all studies was soccer (n = 20, 50%), followed by basketball (n = 9, 23%), futsal, volleyball, and a mixture of sports (i.e., athlete were involved in a variety of different sports (n = 2, 5% respectively). Field hockey, tennis, handball, rugby, and taekwondo were represented in one study each. Nineteen (47.5%) studies involved highly trained/national level athletes, and 21 (52.5%) studies involved trained/development level athletes. Twenty-five (62.5%) studies involved adult athletes, while 15 (37.5%) studies involved youth athletes. Female athletes were represented in only four (10%) studies. A summary of the participants and study characteristics of included publications are provided in Appendix 10.

5.5.2 Outcomes for the Assessment of Reporting Quality and Risk of Bias

Appendix 8 summarises the outcomes of the modified Downs and Black scale for the assessment of reporting quality and risk of bias. Results ranged from 8−12, with a mean score of 10.5 ± 0.9.

5.5.3 Outcomes for the Overall Certainty of Evidence

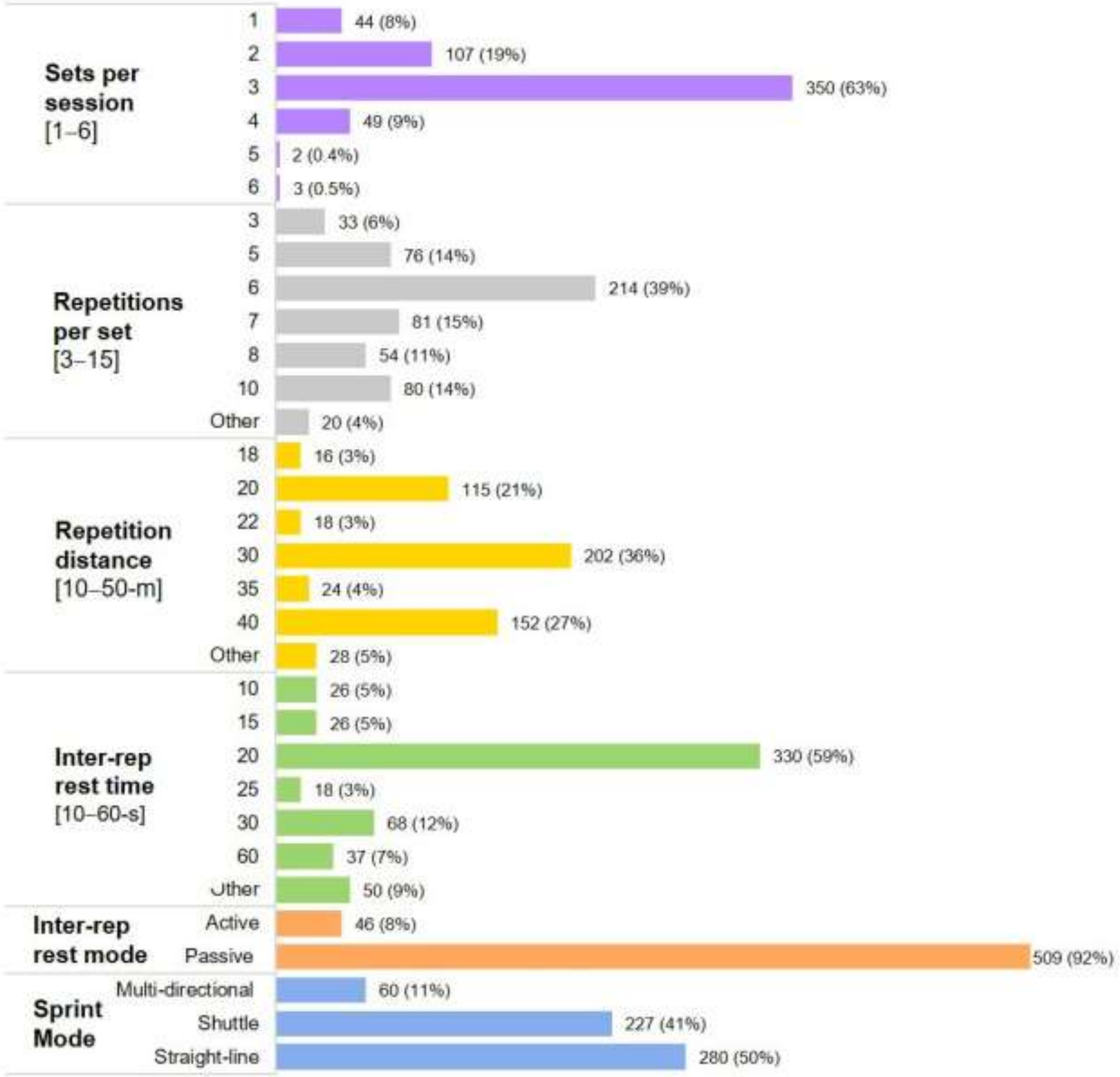
The GRADE tool for assessing the overall certainty of evidence is presented in Appendix 9. The certainty of evidence was downgraded to moderate (i.e., we believe that the true effect is probably close to the estimated effect) for 10 m sprint, 20 m sprint, VO_{2max}, RSA average, RSA decrement, CMJ height, and COD ability.

5.5.4 Study Outcomes

A summary of the training protocols and study outcomes of included publications are provided in Appendix 11. A RST program duration of six weeks was most implemented (n = 13 RST groups, 27%), while the most assigned training frequency was twice per week (n = 27, 56%). The average weekly training volume across all RST groups was 1200 m. Across all RST sessions (n = 567), the most common prescription for each programming variable were straight-line sprints (n = 268 RST sessions, 47%), performed over 30 m (n = 224, 40%), with a passive inter-repetition recovery (n = 521, 92%) lasting 20 s (n = 333, 59%). Three sets (n= 340, 60%) of six repetitions (n = 220, 39%) were most implemented. Multi-set protocols were prescribed across 537 sessions, with a passive inter-set recovery (n = 465, 87%) lasting four minutes (n = 295, 55%) most prescribed in these instances. The complete distribution of RST prescription across all sessions is presented in Figure 24.

Figure 24

The Distribution of Repeated-Sprint Training Prescription Across all 567 Sessions



Note. Data are given as the total number of protocols represented (percentage) [range]; ‘various’ indicates sessions that were prescribed with different combinations of a programming variable (e.g., 20 m sprints in set one, and 30 m sprints in set two).

5.5.5 Meta-Analysed Effects of Repeated-Sprint Training

The meta-analysed effects of RST on physical adaptation are presented in Table 14 (standardised units) and Table 15 (raw units). Individual forest plots for each outcome are presented in Figures 25–32. RST elicited moderate improvement in VO_{2max}, YYIR1 distance, and RSA decrement, as well as small improvements in short sprint performance (10 & 20 m sprint times), RSA average time, CMJ height and COD ability. Coverage of the prediction intervals for these effects suggested compatibility with improvements across the range of RST programs similar to those included in our meta-analysis, although 20 m sprint time, VO_{2max}, RSA, CMJ height and COD ability may have some compatibility with no substantial change.

Table 14

Meta-Analysed Effects of Repeated-Sprint Training on Physical Adaptation (Standardised Units)

Outcome	Number of…		Pooled Effects (Hedges G)		
	Studies	Samples	Estimate	90% CI	90% PI
10 m sprint	15	22	-0.34	-0.47 to -0.21	-0.5 to -0.19
20 m sprint	9	14	-0.45	-0.69 to -0.21	-0.99 to 0.09
VO_{2max}	8	8	0.63	0.36 to 0.91	0.14 to 1.13
YYIR1 distance	16	22	0.60	0.43 to 0.77	0.24 to 0.96
RSA average	23	27	-0.34	-0.49 to -0.18	-0.78 to 0.11
RSA decrement	17	21	-0.63	-0.86 to -0.40	-1.36 to 0.09
CMJ height	20	25	0.27	0.14 to 0.39	0.14 to 0.39
COD ability	13	20	-0.32	-0.53 to -0.12	-0.85 to 0.20

Note. CI = confidence interval; PI = prediction interval; VO_{2max} = maximal oxygen consumption; RSA = repeated-sprint ability; CMJ = countermovement jump; COD = change of direction; YYIR1 = Yo-Yo Intermittent Recovery Test Level 1.

Table 15

Meta-Analysed Effects of Repeated-Sprint Training on Physical Adaptation (Raw Units)

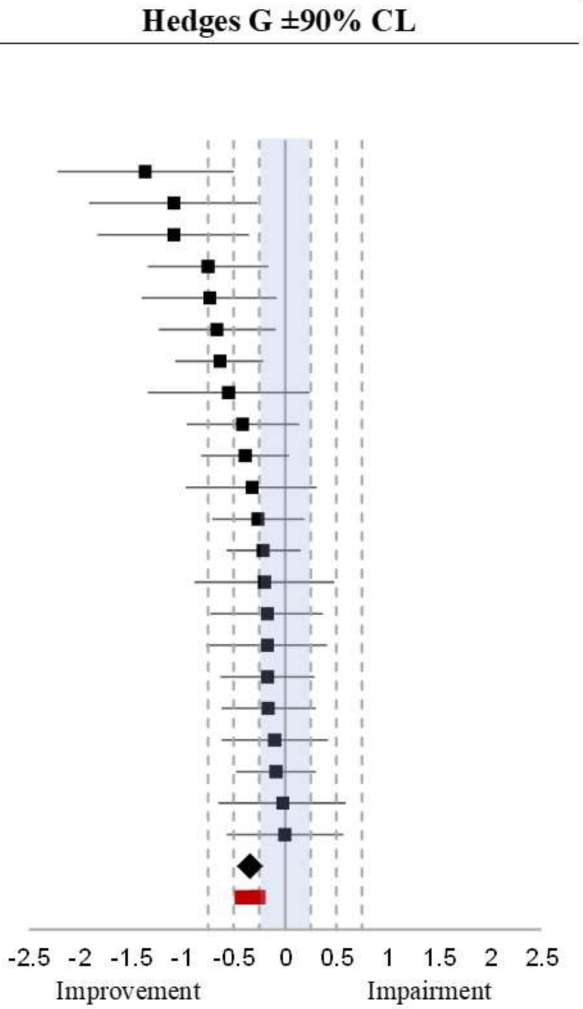
Outcome	Number of…		Pooled Effects (Raw Units)		
	Studies	Samples	Estimate	90% CI	90% PI
10 m sprint (s)	15	22	-0.04	-0.05 to -0.02	-0.08 to 0.00
20 m sprint (s)	9	14	-0.06	-0.09 to -0.02	-0.14 to 0.03
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	8	8	2.6	1.7 to 3.5	1.7 to 3.5
YYIR1 (m)	16	22	225	1534 to 296	3 to 447

Note. CI = confidence interval; PI = prediction interval; VO_{2max} = maximal oxygen consumption; YYIR1 = Yo-Yo Intermittent Recovery Test Level 1. Notes: Pooled effects (raw units) for RSA average time, RSA decrement, CMJ height and COD ability are unavailable due to the concerns of comparing results between different testing methods and protocols.

Figure 25

The Effects of Repeated-Sprint Training Programs on Change in 10 m Sprint Time

Study	Study statistics		
	Pre-training (s)	**Post-training (s)**	**Mean change (s)**
Taylor, J, 2016	1.73	1.62	-0.11
Chtara, 2017	1.90	1.82	-0.08
Taylor, J, 2016	1.75	1.64	-0.11
Negra, 2022	1.85	1.76	-0.09
Michailidis, 2022	1.96	1.90	-0.06
Negra, 2022	1.90	1.82	-0.08
Beato, 2019	1.78	1.70	-0.08
Maggioni, 2018	1.87	1.82	-0.05
Beato, 2022	1.86	1.82	-0.04
Arede, 2022	1.88	1.81	-0.07
Buchheit, 2010	1.96	1.93	-0.03
Rey, 2019	1.84	1.81	-0.03
Krakan, 2020	1.88	1.86	-0.02
Arede, 2022	2.07	2.03	-0.04
Taylor & Jakeman 2021	1.70	1.68	-0.02
Buchheit, 2008	1.88	1.86	-0.02
Rey, 2019	1.87	1.85	-0.02
Bravo, 2008	1.77	1.76	-0.01
Beato, 2022	1.80	1.79	-0.01
Beato, 2019	1.75	1.74	-0.01
Arede, 2022	2.18	2.17	-0.01
Le Scouarnec, 2022	2.12	2.12	0.00
Combined	1.87	1.83	-0.04
Prediction interval			

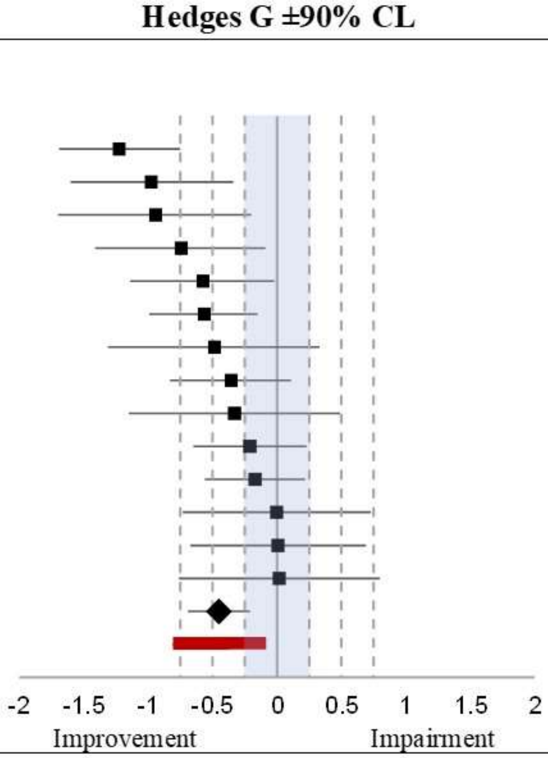


Note. The shaded zone indicates a trivial effect. Dashed lines indicate small, moderate, and large effects, respectively.

Figure 26

The Effects of Repeated-Sprint Training Programs on Change in 20 m Sprint Time

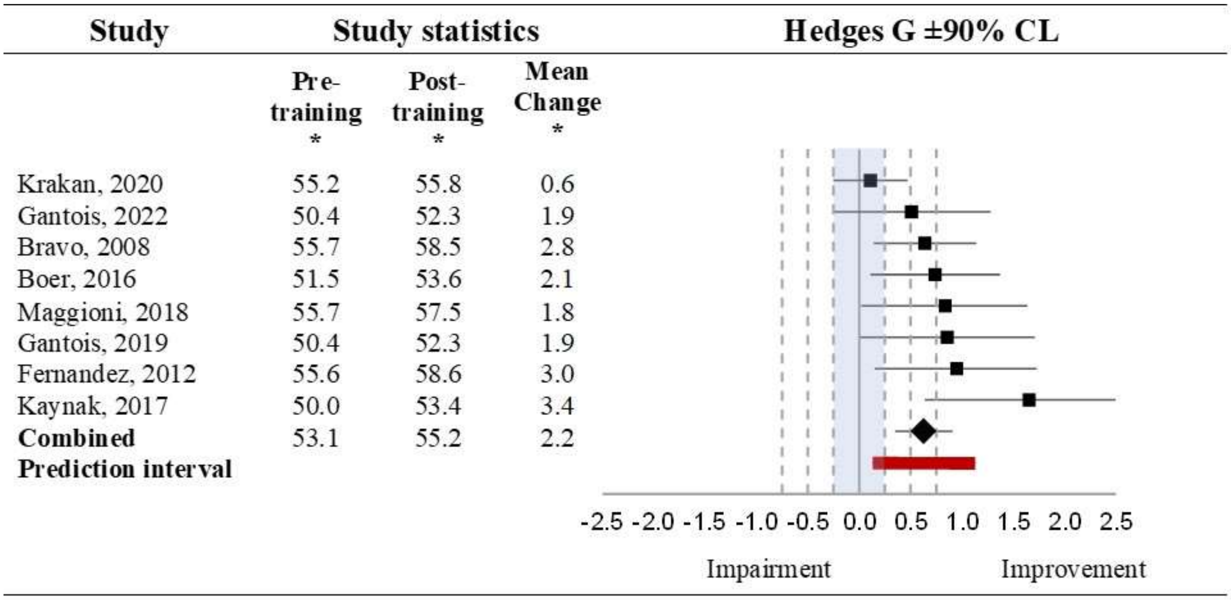
Study	Study statistics		
	Pre-training (s)	Post-training (s)	Mean change (s)
Markovic, 2007	3.23	3.13	-0.10
Negra, 2022	3.37	3.20	-0.17
Taylor, 2016	3.03	2.91	-0.12
Taylor, 2016	2.96	2.85	-0.11
Negra, 2022	3.28	3.14	-0.14
Beato, 2019	2.96	2.90	-0.06
Iaia, 2017	3.30	3.25	-0.05
Rey, 2019	3.31	3.23	-0.08
Iaia, 2017	3.29	3.21	-0.08
Rey, 2019	3.28	3.23	-0.05
Beato, 2019	2.94	2.92	-0.02
Fernandez, 2012	3.20	3.20	0.00
Le Scouarnec, 2022	3.43	3.44	0.01
Maggioni, 2018	3.20	3.22	0.02
Combined	3.20	3.13	-0.07
Prediction interval			



Note. The shaded zone indicates a trivial effect. Dashed lines indicate small, moderate, and large effects, respectively.

Figure 27

The Effects of Repeated-Sprint Training Programs on Change in Maximal Oxygen Consumption



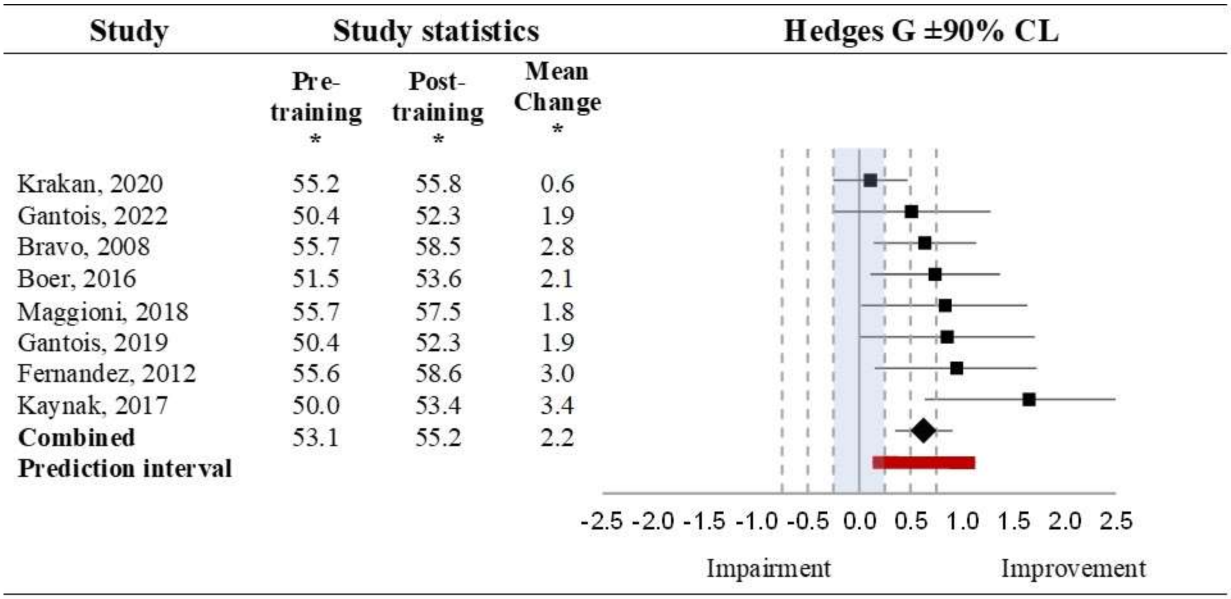
Study	Pre-training *	Post-training *	Mean Change *
Krakan, 2020	55.2	55.8	0.6
Gantois, 2022	50.4	52.3	1.9
Bravo, 2008	55.7	58.5	2.8
Boer, 2016	51.5	53.6	2.1
Maggioni, 2018	55.7	57.5	1.8
Gantois, 2019	50.4	52.3	1.9
Fernandez, 2012	55.6	58.6	3.0
Kaynak, 2017	50.0	53.4	3.4
Combined	53.1	55.2	2.2
Prediction interval			

Note. The shaded zone indicates a trivial effect. Dashed lines indicate small, moderate, and large effects, respectively. * = ml×kg^{-1}×min^{-1}.

Figure 28

The Effects of Repeated-sprint Training Programs on Change in Distance Achieved in the Yo-Yo Intermittent Recovery Test Level 1

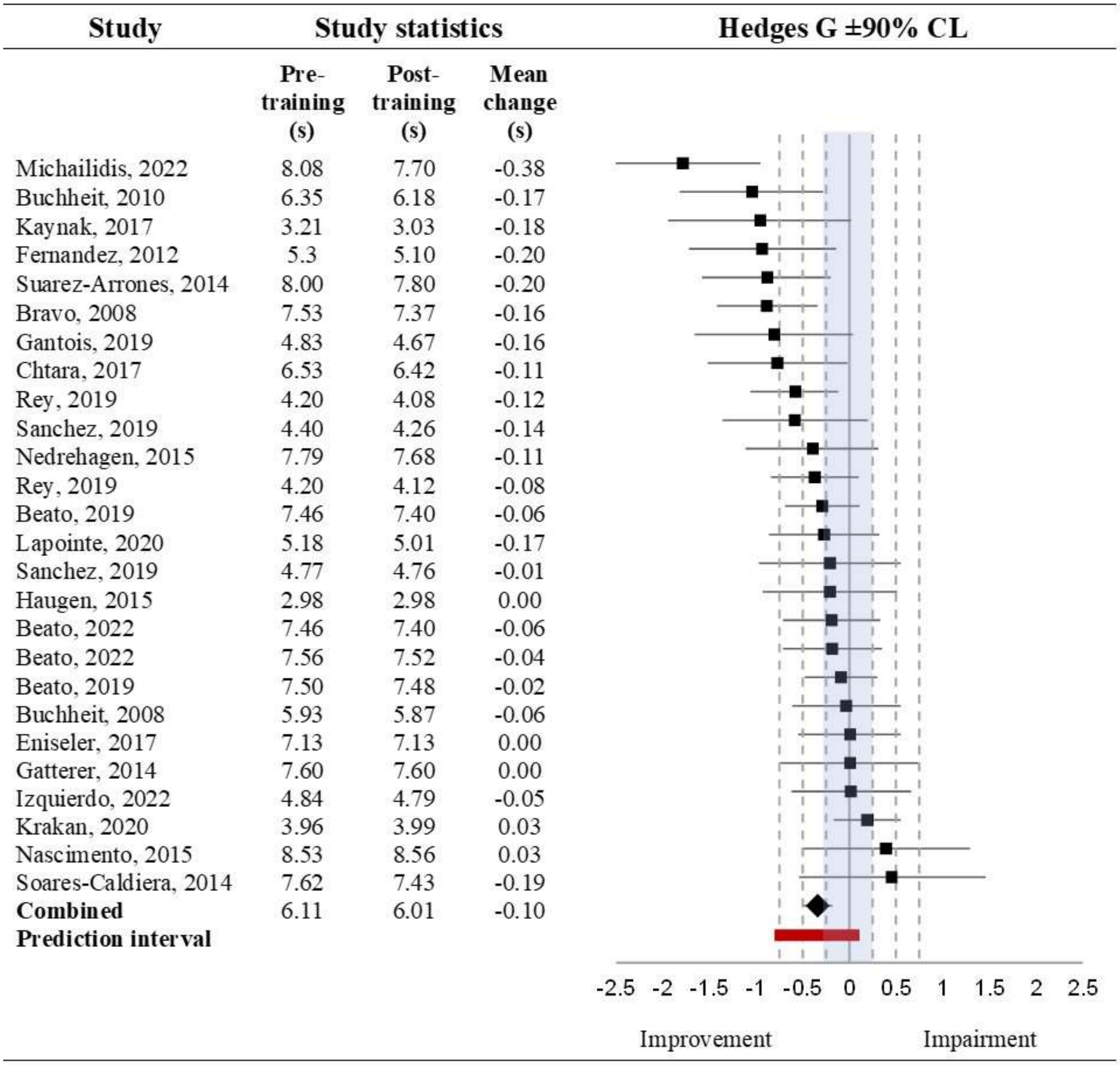
Note. The shaded zone indicates a trivial effect. Dashed lines indicate small, moderate, and large effects, respectively.



Study	Study statistics			Hedges G ±90% CL
	Pre-training *	Post-training *	Mean Change *	
Krakan, 2020	55.2	55.8	0.6	
Gantois, 2022	50.4	52.3	1.9	
Bravo, 2008	55.7	58.5	2.8	
Boer, 2016	51.5	53.6	2.1	
Maggioni, 2018	55.7	57.5	1.8	
Gantois, 2019	50.4	52.3	1.9	
Fernandez, 2012	55.6	58.6	3.0	
Kaynak, 2017	50.0	53.4	3.4	
Combined	53.1	55.2	2.2	
Prediction interval				

Figure 29

The Effects of Repeated-Sprint Training Programs on Change in Repeated-sprint Ability Average Time



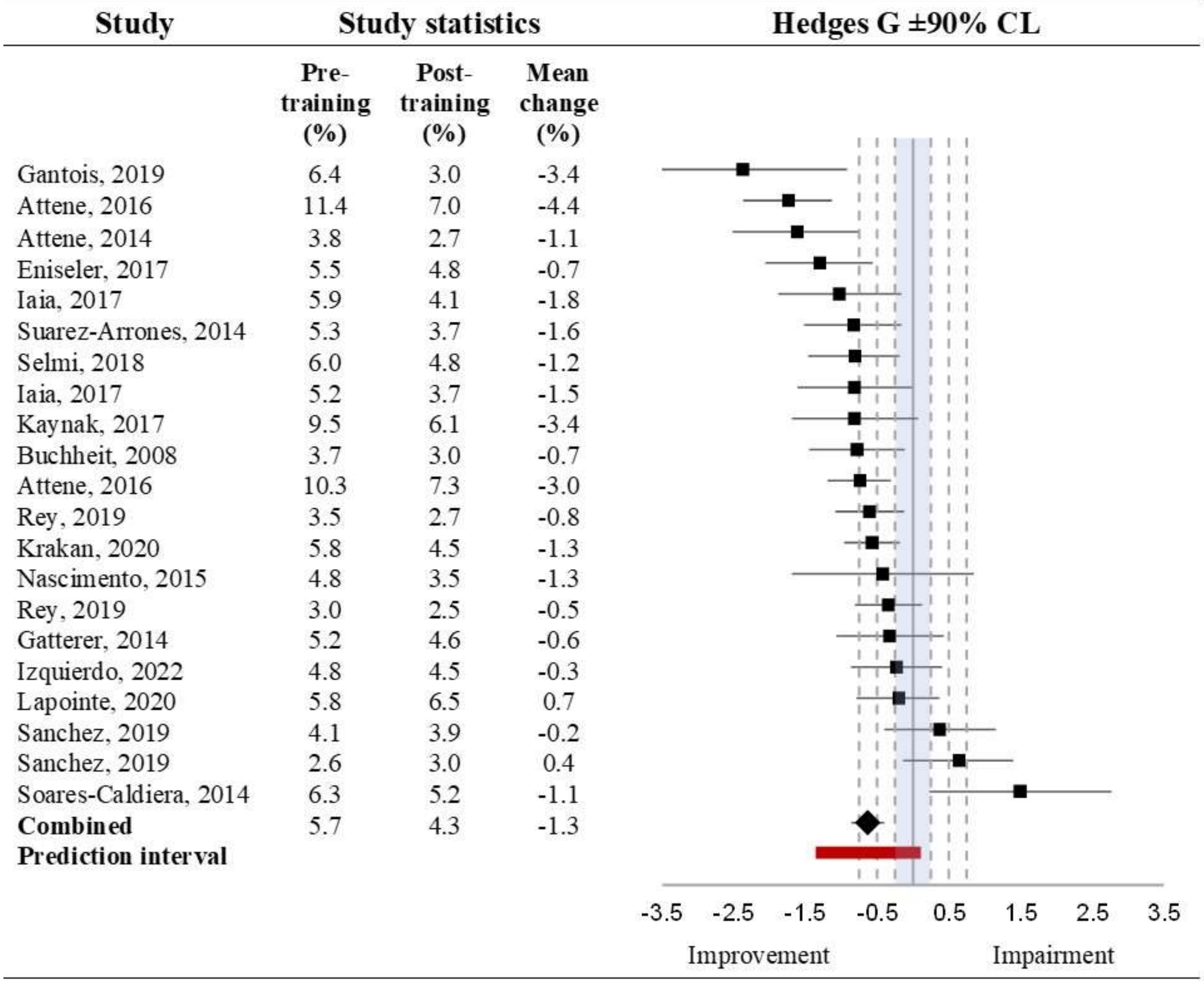
Study	Pre-training (s)	Post-training (s)	Mean change (s)
Michailidis, 2022	8.08	7.70	-0.38
Buchheit, 2010	6.35	6.18	-0.17
Kaynak, 2017	3.21	3.03	-0.18
Fernandez, 2012	5.3	5.10	-0.20
Suarez-Arrones, 2014	8.00	7.80	-0.20
Bravo, 2008	7.53	7.37	-0.16
Gantois, 2019	4.83	4.67	-0.16
Chtara, 2017	6.53	6.42	-0.11
Rey, 2019	4.20	4.08	-0.12
Sanchez, 2019	4.40	4.26	-0.14
Nedrehagen, 2015	7.79	7.68	-0.11
Rey, 2019	4.20	4.12	-0.08
Beato, 2019	7.46	7.40	-0.06
Lapointe, 2020	5.18	5.01	-0.17
Sanchez, 2019	4.77	4.76	-0.01
Haugen, 2015	2.98	2.98	0.00
Beato, 2022	7.46	7.40	-0.06
Beato, 2022	7.56	7.52	-0.04
Beato, 2019	7.50	7.48	-0.02
Buchheit, 2008	5.93	5.87	-0.06
Eniseler, 2017	7.13	7.13	0.00
Gatterer, 2014	7.60	7.60	0.00
Izquierdo, 2022	4.84	4.79	-0.05
Krakan, 2020	3.96	3.99	0.03
Nascimento, 2015	8.53	8.56	0.03
Soares-Caldiera, 2014	7.62	7.43	-0.19
Combined	6.11	6.01	-0.10
Prediction interval			

Note. The shaded zone indicates a trivial effect. Dashed lines indicate small, moderate, and large effects, respectively.

Figure 30

The Effects of Repeated-Sprint Training Programs on Change in Repeated-Sprint Ability Decrement

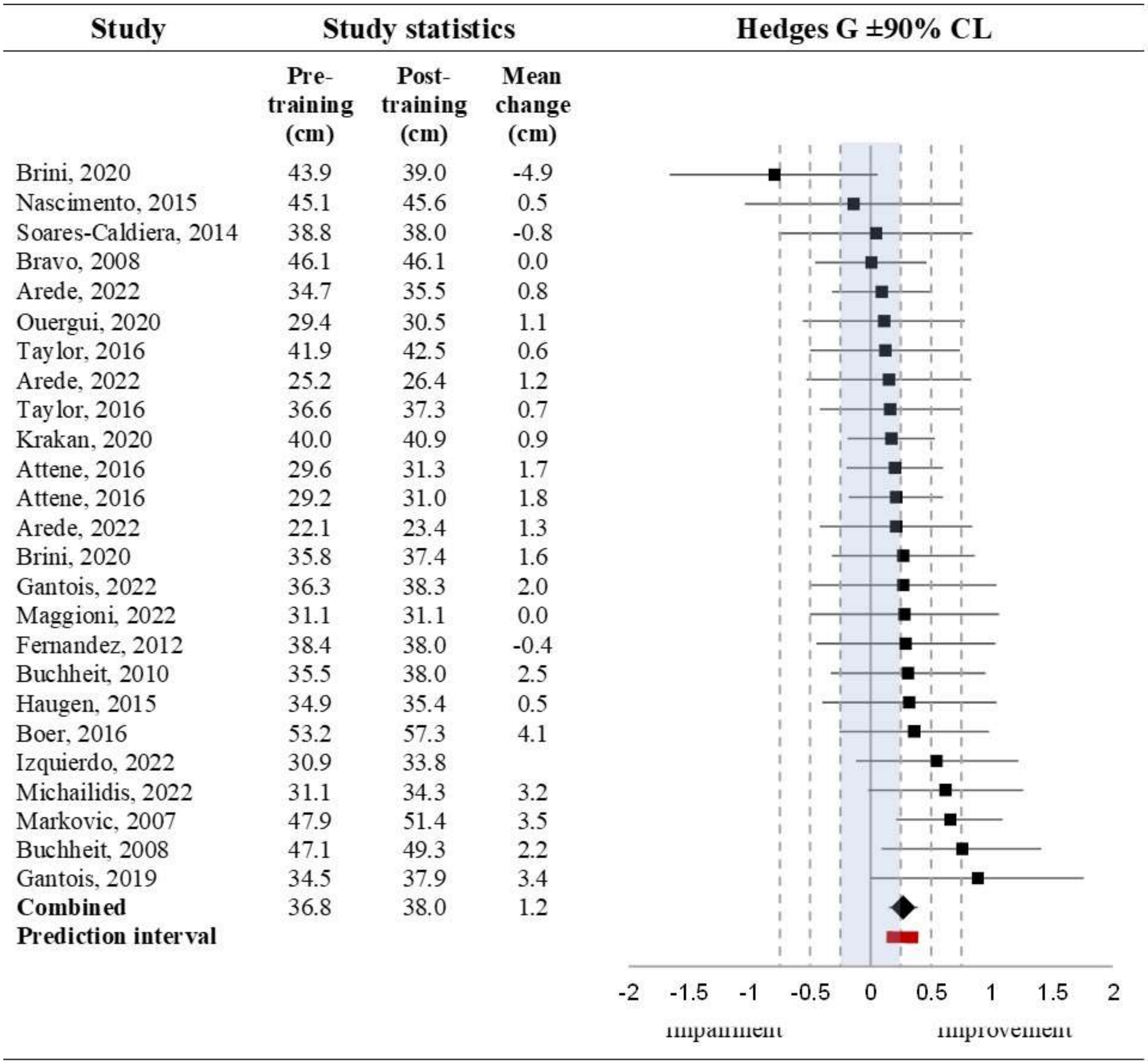
Note. The shaded zone indicates a trivial effect. Dashed lines indicate small, moderate, and large effects, respectively.



Study	Pre-training (%)	Post-training (%)	Mean change (%)
Gantois, 2019	6.4	3.0	-3.4
Attene, 2016	11.4	7.0	-4.4
Attene, 2014	3.8	2.7	-1.1
Eniseler, 2017	5.5	4.8	-0.7
Iaia, 2017	5.9	4.1	-1.8
Suarez-Arrones, 2014	5.3	3.7	-1.6
Selmi, 2018	6.0	4.8	-1.2
Iaia, 2017	5.2	3.7	-1.5
Kaynak, 2017	9.5	6.1	-3.4
Buchheit, 2008	3.7	3.0	-0.7
Attene, 2016	10.3	7.3	-3.0
Rey, 2019	3.5	2.7	-0.8
Krakan, 2020	5.8	4.5	-1.3
Nascimento, 2015	4.8	3.5	-1.3
Rey, 2019	3.0	2.5	-0.5
Gatterer, 2014	5.2	4.6	-0.6
Izquierdo, 2022	4.8	4.5	-0.3
Lapointe, 2020	5.8	6.5	0.7
Sanchez, 2019	4.1	3.9	-0.2
Sanchez, 2019	2.6	3.0	0.4
Soares-Caldiera, 2014	6.3	5.2	-1.1
Combined	5.7	4.3	-1.3
Prediction interval			

Figure 31

The Effects of Repeated-Sprint Training Programs on Change in Countermovement Jump Height

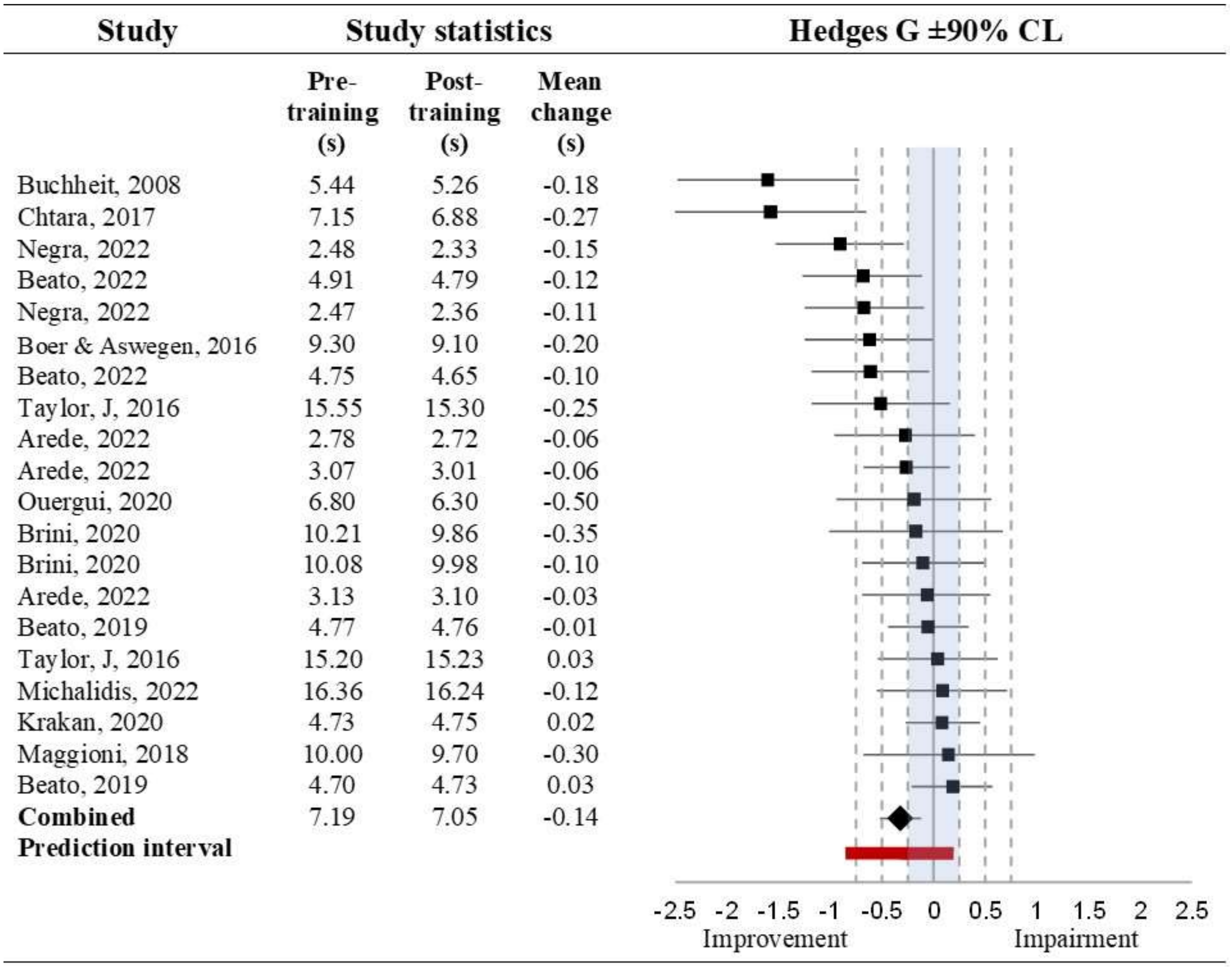


Study	Pre-training (cm)	Post-training (cm)	Mean change (cm)
Brini, 2020	43.9	39.0	-4.9
Nascimento, 2015	45.1	45.6	0.5
Soares-Caldiera, 2014	38.8	38.0	-0.8
Bravo, 2008	46.1	46.1	0.0
Arede, 2022	34.7	35.5	0.8
Ouergui, 2020	29.4	30.5	1.1
Taylor, 2016	41.9	42.5	0.6
Arede, 2022	25.2	26.4	1.2
Taylor, 2016	36.6	37.3	0.7
Krakan, 2020	40.0	40.9	0.9
Attene, 2016	29.6	31.3	1.7
Attene, 2016	29.2	31.0	1.8
Arede, 2022	22.1	23.4	1.3
Brini, 2020	35.8	37.4	1.6
Gantois, 2022	36.3	38.3	2.0
Maggioni, 2022	31.1	31.1	0.0
Fernandez, 2012	38.4	38.0	-0.4
Buchheit, 2010	35.5	38.0	2.5
Haugen, 2015	34.9	35.4	0.5
Boer, 2016	53.2	57.3	4.1
Izquierdo, 2022	30.9	33.8	
Michailidis, 2022	31.1	34.3	3.2
Markovic, 2007	47.9	51.4	3.5
Buchheit, 2008	47.1	49.3	2.2
Gantois, 2019	34.5	37.9	3.4
Combined	36.8	38.0	1.2
Prediction interval			

Note. The shaded zone indicates a trivial effect. Dashed lines indicate small, moderate, and large effects, respectively.

Figure 32

The Effects of Repeated-Sprint Training Programs on Change of Direction Ability



Study	Pre-training (s)	Post-training (s)	Mean change (s)
Buchheit, 2008	5.44	5.26	-0.18
Chtara, 2017	7.15	6.88	-0.27
Negra, 2022	2.48	2.33	-0.15
Beato, 2022	4.91	4.79	-0.12
Negra, 2022	2.47	2.36	-0.11
Boer & Aswegen, 2016	9.30	9.10	-0.20
Beato, 2022	4.75	4.65	-0.10
Taylor, J, 2016	15.55	15.30	-0.25
Arede, 2022	2.78	2.72	-0.06
Arede, 2022	3.07	3.01	-0.06
Ouergui, 2020	6.80	6.30	-0.50
Brini, 2020	10.21	9.86	-0.35
Brini, 2020	10.08	9.98	-0.10
Arede, 2022	3.13	3.10	-0.03
Beato, 2019	4.77	4.76	-0.01
Taylor, J, 2016	15.20	15.23	0.03
Michalidis, 2022	16.36	16.24	-0.12
Krakan, 2020	4.73	4.75	0.02
Maggioni, 2018	10.00	9.70	-0.30
Beato, 2019	4.70	4.73	0.03
Combined	7.19	7.05	-0.14
Prediction interval			

Note. The shaded zone indicates a trivial effect. Dashed lines indicate small, moderate, and large effects, respectively.

5.5.6 Moderating Effects of Study Design

There was a further small improvement 10 m sprint time (G: -0.48; 90% CI: -0.93 to -0.03) and further moderate improvement in VO_{2max} (0.57; 0.13 to 1.00) for randomised studies when compared to non-randomised studies. Conversely, compared to non-randomised studies, there was a small impairment in RSA decrement (0.34; -0.14 to 0.82) and moderate impairment in YYIR1 distance (-0.50; -0.90 to -0.10) for randomised studies. There was no substantial difference in RSA average time between randomised and non-randomised studies (-0.22; -0.55 to 0.10) and CMJ height (0.09; -0.16 to 0.33), and the differences between 20 m sprint time (-0.11; -0.64 to 0.41) and COD ability (-0.06; -0.46 to 0.35) were inconclusive.

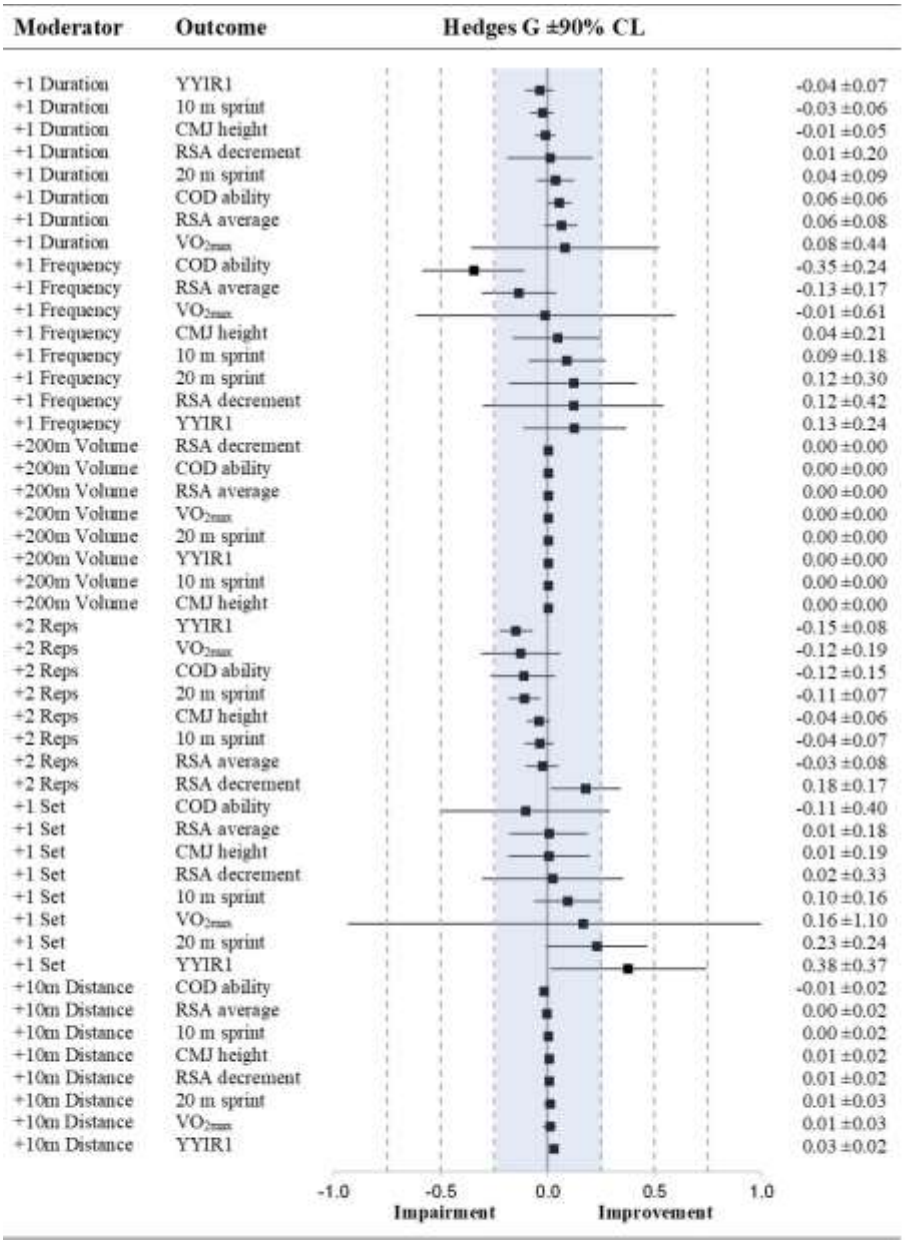
5.5.7 Moderating Effects of Programming Variables on the Effects of Repeated-Sprint Training

The moderating effects of programming variables on the RST outcomes when compared to the reference training program are presented in Figure 33. The efficacy of manipulating a single moderator was considered for all measures as a group, where compatibility with impairment in at least one outcome was considered as insufficient for recommendation.

The effect of increasing program duration by one week was non-substantial for all outcome measures, except for VO_{2max} and RSA decrement where effects were compatible with improvements. The effects of increasing weekly volume by 200 m were non-substantial for all outcome measures, apart from an improved RSA decrement. However, COD ability and RSA average were compatible with improvements. Increasing training frequency by one session per week, increasing sessions by one extra set, completing two more reps per set or extending rep distance by 10 m were either inconclusive or had effects compatible with impairments in at least one outcome measure.

Figure 33

The Moderating Effects of Programming Variables on Physical Adaptation Compared to the Reference Training Program



Note. Reference training program consists of three sets of 6 × 30 m straight-line repeated-sprints, performed twice per week for six weeks (1200 m weekly volume). The shaded zone indicates a trivial effect. Dashed lines indicate small, moderate, and large effects, respectively.

5.5.8 Model Selection

A comparison of univariate meta-regression models, naïve multivariate models, and the unconditional models for the effects of programming variables on the RST outcomes are provided in Appendices 8 – 13. In these tables, importance is a measure of how often a moderator appears relative to all candidate models, with higher values representing greater importance. The top five models for each outcome (excluding intercept-only models) are provided in Appendices 14 – 21. The number of repetitions per set appears in the top model for predicting change in five outcomes; 20 m sprint time, YYIR1 distance, RSA decrement, CMJ height and COD ability. Weekly volume, sprint modality and training frequency appear in the top models for predicting change in 10 m sprint time, VO_{2max}, and RSA average time, respectively.

5.6 DISCUSSION

From 754 athlete inclusions across 48 intervention groups and 19 active control groups, our systematic review and meta-analysis demonstrates that RST enhances a range of physical qualities that are fundamental to sports performance. Pooled effect estimates indicate that RST causes a moderate improvement in VO_{2max}, YYIR1 distance, and RSA decrement, as well as small improvements in10 and 20 m linear sprint time, RSA average time, CMJ height, and COD ability in athletes. Our meta-analysis is also the first to isolate the effects of manipulating programming variables on the physical adaptations to RST. Performing three sets of 6 × 30 m straight-line sprints with 20 s of passive inter-repetition rest, twice per week for six weeks, is an effective program to achieve the established benefits of RST. However, caution should be taken when manipulating programming variables, as the current evidence is suggestive of impairment in some physical qualities. Since our findings do not provide conclusive support for the manipulation of RST variables, further work is needed to better understand how programming factors can be manipulated to augment training-induced adaptations. Overall, our results support the application of RST as a time-efficient conditioning method that concurrently improves an array of distinct physical qualities.

A practical way to consider heterogeneity within meta-analysis is via a prediction interval, which provides the likely ES of a new (similar) study based on the included studies and informs practitioners about the expected results in future training interventions (Borg et al., 2023). Accordingly, prediction intervals for the meta-analysed effects of RST on physical adaptation are reported in Tables 14 and 15, and Figures 25–32. These largely concur with our interpretations of the ES, which are based on the point estimate and coverage of the upper and lower CI against threshold values reported specific to strength and conditioning outcomes. However, as is typical with prediction intervals, they are often wider than our CI's and therefore suggest less certainty in some outcomes. Specifically, based on our prediction intervals, the outcomes may have some compatibility with no substantial change. Given that none of our prediction intervals were compatible with an impairment in any outcome measure, practitioners can take confidence when interpreting our findings, which suggest a largely beneficial effect of RST for a multitude of physical qualities.

Our meta-analysis presents evidence of a substantial effect of running-based RST on aerobic capacity in athletes. From eight RST groups, there was a mean improvement from baseline of 4.0%, which equated to an increase in VO_{2max} of 2.2 $ml \cdot kg^{-1} \cdot min^{-1}$, from an average baseline of 52.9 $ml \cdot kg^{-1} \cdot min^{-1}$ (Figure 27). A considerable improvement (i.e., a standardised effect of ≥ 0.25) in aerobic capacity was observed in seven of the eight RST groups included in our investigation, with considerably greater improvements found compared to active control groups, which recorded an average decline in VO_{2max} of -1.2 $ml \cdot kg^{-1} \cdot min^{-1}$. (Boer & Van Aswegen, 2016; Fernandez-Fernandez et al., 2012; Gantois et al., 2019; Gantois et al., 2022a; Kaynak et al., 2017b; Maggioni et al., 2019). Evidence about the underlying physiological reasons for how increases in VO_{2max} are achieved with RST is lacking, but its brief duration may be insufficient to elicit significant increases in cardiac output, which tends to respond best to prolonged bouts of sub-maximal exercise (Blomqvist & Saltin, 1983; Clausen, 1977; Macpherson et al., 2011). Rather, RST induced improvement in VO_{2max} is more likely to arise from an enhanced ability to extract and utilise oxygen due to increased muscle oxidative handling capacity (i.e., a greater arterio-venous oxygen difference) (Macpherson et al., 2011; Sloth et al., 2013). We also found a substantial effect of RST on YYIR1 distance and RSA, two physical performance tests that require a large aerobic contribution (Girard, Mendez-Villanueva, et al., 2011; Kaufmann et al., 2020). These findings demonstrate that RST improves the ability to perform intermittent bouts of high-intensity running and sprinting. Thus, for practitioners who wish to develop high-intensity running ability in athletes, RST should be considered a productive method of conditioning.

A meta-analysis of the effects of RST on trained participants was conducted by Taylor et al. (2015). Since that time, 32 new studies have been included in our review, but several findings remain similar, despite the addition of new studies. These include the magnitude of improvement in linear sprint times, CMJ height, and YYIR1 distance. For the first time, we also investigated the effect of RST on COD ability, which is a key physical component of many sports (Brughelli et al., 2008). We found evidence for a small improvement, however, there was also compatibility with no substantial change. The wide disparity between COD tests included in our analysis (see section 2.3 for details) may have affected the precision of this outcome. Improvement in explosive physical qualities following RST likely arises from both neuromuscular and morphological adaptations. Neural adaptations may involve greater muscle fibre recruitment, firing frequency, and motor unit synchronisation (Creer et al., 2004; Ross et al., 2001), while morphological changes could include a shift toward type IIa muscle and an increase muscle cross-sectional area (Dawson et al., 1998; Ross & Leveritt, 2001). Collectively, our findings lend further support to the application of RST as a multi-component training method.

5.6.1 Moderating Effects of Programming Variables

As per sound training theory and in particular principles such as progressive overload, practitioners implementing RST will naturally seek to manipulate programming variables to maximise training outcomes across a program. Chapter 4 demonstrated that the manipulation of programming variables such as rest duration, rest modality, sprint modality, number of repetitions, and sprint distance have a substantial effect on acute RST demands. Since training load is a causal component of both acute and chronic training effects (Jeffries et al., 2021), it is reasonable to assume that the manipulation of programming factors may indeed influence RST outcomes.

To examine the effects of program duration, training frequency, weekly volume, repetition distance, number of repetitions per set, and number of sets per session on 10 and 20 m sprint time, VO_{2max}, YYIR1 distance, RSA, CMJ height, and COD ability, we used a multiple, multi-level mixed meta-regression against a reference program of three sets of 6 × 30 m straight-line sprints performed twice per week for six weeks. The effects of a single programming factor on a given outcome were then evaluated while holding all others constant. However, we opted for a pragmatic decision framework when interpreting moderators, considering each 'as a whole' on the entire set of outcome measures. For example, if the effects of a programming variable were compatible with at least a small improvement [$G >$ or < 0.25] in at least one outcome measure and not compatible with an impairment in any other, we intended to recommend its implementation for enhancing the effects of RST. However, if at least one programming factor was compatible with an impairment or inconclusive, we opted to not recommend its implementation based on the available evidence, even if some outcome measures showed compatibility with an improvement. Indeed, this was the case for our present findings.

It was not possible to include other programming factors such as sprint mode, rest mode, and rest duration within the multiple meta-regression models owing to limited heterogeneity in the range of levels for each variable. Therefore, these programming factors were mostly exampled via univariate meta-regression and qualitative synthesis. As such, consideration should be given to the likely lower strength of evidence and therefore recommendations via the aforementioned programming factors.

5.6.1.1 Program duration

Short RST programs (2−4weeks) are an effective strategy to enhance physical performance. Considerable improvements were found across all outcomes and in all studies that implemented a two-week (Beato et al., 2019; Gatterer et al., 2015a; Taylor et al., 2016) and four-week (Attene et al., 2016; Brini et al., 2018; Seifeddine Brini, Nejmeddine Ouerghi, et al., 2020; Galvin et al., 2013; Lapointe et al., 2020; Michailidis et al., 2022; Serpiello et al., 2012; Soares-Caldeira et al., 2014) RST intervention. Changes in enzyme activity related to aerobic and anaerobic metabolism can arise within two weeks of high-intensity training (Rodas et al., 2000), which may subtend rapid improvements in physical performance. A short block of RST could be applied immediately before the competitive season to prepare athletes for the intensity of competition or briefly inserted into the in-season training period to enhance fitness. Compared to the reference training program that consisted of a six-week duration, there were no substantial benefits of performing an additional week of RST (i.e., seven weeks). Therefore, it would seem that most adaptations to RST occur in the first six weeks of a RST program and then plateaux (Burgomaster et al., 2007; Sloth et al., 2013). Furthermore, longer program durations (10−12 weeks) that were employed in three studies (Seifeddine Brini, Abderraouf Ben Abderrahman, et al., 2020; M. Buchheit, A. Mendez-Villanueva, et al., 2010; Markovic et al., 2007), did not provide any meaningful benefits on physical performance and are often not feasible in practice given the condensed and concurrent training demands of many sports.

5.6.1.2 Training frequency

By manipulating session frequency, practitioners can appropriately manage weekly RST volume, with considerably lower average weekly volumes achieved when one (530 m) and two (1120 m) sessions per week were prescribed, compared to three (1610 m) and four (2100 m). Implementing one RST session per week is an effective in-season strategy to enhance sprint times, YYIR1 distance, CMJ height, and COD ability (M. Buchheit, A. Mendez-Villanueva, et al., 2010; Nedrehagen & Saeterbakken, 2015; Rey et al., 2019)), or at the least, maintain such attributes (Beato et al., 2022; Haugen et al., 2015). Two sessions per week is most common, and also most effective at eliciting the established benefits of RST. This prescription could be suitable during the preparation period when training opportunities are regular and higher volumes of sprinting are accumulated. Compared to the reference program that consisted of two sessions per week, an additional RST session per week (i.e., three sessions) causes an impairment in COD ability, without any conclusive benefits on other physical qualities. Three sessions per week may be effective during ‘shock’ two week mesocycles of RST, particularly when shuttle sprints are performed (Beato et al., 2019; Taylor et al., 2016), but they are not recommended under other circumstances. When weekly volume is matched (477 m per week), Rey et al. (2019) demonstrated that 6 weeks of RST significantly improves sprint performance and RSA to a similar extent with training frequencies of 1 or 2 times per week. While further evidence is required to draw more definitive conclusions on the influence of RST frequency when weekly volume is matched, it appears that one session per week could be used during congested competition fixtures or in periods when the emphasis should be placed on other physical qualities.

5.6.1.3 Training volume

The application of RST can help prepare athletes for the high-speed demands of competition but considering that RST is performed at or close to maximal intensity, controlling the volume of sprinting is important to ensure appropriate management of fatigue, as well as improvements in fitness. A wide range of weekly RST volumes (300–3150 m) were implemented across the studies in our investigation. Compared to the reference training program that consisted of 1200 m of weekly volume, there were no substantial effects of an additional 200 m of volume per week. It therefore appears that this programming manipulation is too modest to elicit meaningful benefits. Around 1200 m of volume per week appears is conducive for improving physical performance, but smaller weekly training volumes (< 800 m) could be prescribed at the beginning of a RST program to gradually expose athletes to maximal velocity or used during the in-season period to maintain sprint exposure.

5.6.1.4 Number of sprint repetitions

The number of sprint repetitions per set regularly appeared as a top five model for predicting future changes in performance (Appendix 20 – 27) and is commonly associated as a programming variable with high relevance across many of our RST outcomes (Appendix 12 – 19). However, compared to the reference training program that consisted of six repetitions per set, an additional two repetitions per set was not associated with any positive effects, and instead, had compatability with a small impairement in VO_{2max}. This evidence is further supported by visual inspection of the univariate meta-regression bubble plots (Appendix 28 – 35), which suggest that a greater number of repetitions per set has negative influence on physical fitness and physiological adaptation. While the number of repetitions is an important programming variable to consider for RST prescription, our results suggest that the prescription of 4–6 repetitions is most effective.

Improvements across all outcomes were also observed in the majority of studies that prescribed less than six repetitions per set on average (Attene et al., 2016; Brini et al., 2018; Seifeddine Brini, Nejmeddine Ouerghi, et al., 2020; M. Buchheit, A. Mendez-Villanueva, et al., 2010; Buchheit et al., 2008; Chtara et al., 2017; Kaynak et al., 2017b; Krakan et al., 2020; Lapointe et al., 2020; Nedrehagen & Saeterbakken, 2015; Rey et al., 2019; Rey et al., 2017; Selmi et al., 2018; Soares-Caldeira et al., 2014; Taylor & Jakeman, 2021). Findings from Chapter 4 suggested a lower number of successive repetitions (e.g., 4–6 repetitions) can allow for the quality of each sprint to be maintained while inducing a considerable cardiorespiratory response, which together with the findings from our study, lend support to the prescription of lower repetition sets. However, it is relevant to note, that our findings do not suggest that low RST volumes are more effective at improving performance. Rather, training sessions could be designed to incorporate small groups of repetitions performed over multiple sets (e.g., 4 sets of 5 repetitions). If larger repetition sets are prescribed, rest redistribution may permit the maintenance of acute sprint performance and internal physiological load (Weakley, Castilla, et al., 2022a). Furthermore, velocity loss thresholds can account for individual differences in RSA, and the capacity to recover between repetitions (Weakley, Castilla, et al., 2022a). Future research may wish to determine the effects of these prescriptive methods on changes in physical qualities.

5.6.1.5 Number of sets

It was common to alter the number of sets per session across the training program, which usually involved an initial period of a lower number of sets per session, corresponding with lower training volumes, and progression to a higher number of sets and greater training volumes (M. Buchheit, A. Mendez-Villanueva, et al., 2010; Buchheit et al., 2008; Chtara et al., 2017; Gantois et al., 2019; Iaia et al., 2017; Kaynak et al., 2017b; Krakan et al., 2020; Markovic et al., 2007; Nedrehagen & Saeterbakken, 2015; Ouergui et al., 2020; Rey et al., 2019; Rey et al., 2017; Selmi et al., 2018; Taylor et al., 2016). The current evidence demonstrates that two and three sets are effective at achieving the established benefits of RST, but one set may be insufficient. Compared to the reference training program that consisted of three sets per session, performing one more set per session (i.e., four sets) causes a substantial improvement in YYIR1 distance, as well as minor, non-substantial improvements in 10 and 20 m sprint times. Together with the evidence on the effect of the number of repetitions, these findings suggest that four sets of low repetitions (e.g., 4−6 reps) could be a more effective training strategy than long exhaustive sets (e.g., 2 sets of 10−12 reps). Although, given that our review did not directly compare these strategies, further investigation is needed. To maintain the time-efficient nature of RST when a higher number of sets are implemented, shorter inter-set rest times (e.g., 2 min) can be applied, without detriment to adaptation (M. Buchheit, A. Mendez-Villanueva, et al., 2010; Buchheit et al., 2008; Iaia et al., 2017). It can also be practical to integrate sets between technical drills, thus multiple sets can be completed across a training session.

5.6.1.6 Sprint distance

Longer sprint distances were associated with greater physiological demands and increased within-session fatigue in Chapter 4. These augmented internal responses to an acute exercise session could be expected to enhance the chronic physiological adaptations to a RST program. However, compared to the reference training program that consisted of a 30 m repetition distance, the effects of sprinting for an additional 10 m per repetition were non-substantial. It therefore seems that a sprint distance of 30 m is most suitable for the all-round development of physical performance in athletes during RST. While there was no conclusive evidence to suggest that longer sprint distances (e.g., 40 m) enhance chronic outcomes, they can increase exposure to faster running speeds, higher training volumes (Beato et al., 2019; Boer & Van Aswegen, 2016; Gatterer et al., 2015a; Maggioni et al., 2019; Ouergui et al., 2020) and greater metabolic stress (Chapter 4). Therefore, they may be beneficial to achieve process-oriented training goals, such as increased sprint volume exposure or to train under fatigue in team sport athletes (e.g., players not selected for the weekly competitive fixture, or during late-stage return-to-play following injury). Furthermore, it may be logical to assume that increasing repetition distance could improve maximum velocity, however, we did not find enough available data to assess this outcome. Conversely, it could be more practical to implement shorter repetition distances (e.g., 15–25 m) during competition phases, where a reduced sprint volume is desirable. The movement demands of specific sports, where the distance of sprint efforts varies considerably (Taylor et al., 2017), should also be considered when prescribing repetition distance.

5.6.1.7 Sprint modality

Visual inspection of univariate meta-regression bubble plots (Appendix 28 – 35) suggests that the adaptations to RST are largely independent of sprint modality and each respective modality (straight-line, shuttle and multi-directional) demonstrates the ability to enhance physical performance. Subsequently, sprint modality is associated with the least importance for influencing RST outcomes when compared to the other programming variables (Appendix 12 – 19). Both straight-line and shuttle-based RST are associated with an improvement in VO_{2max} (Appendix 30, C), but given the width of the CI's, the effect of straight-line RST was more uncertain. Furthermore, the meta-regression bubble plots rely on univariate analysis, and therefore, the influence of other programming variables may affect this outcome. For example, shuttle-based sprints were more commonly implemented with longer sprint distances (> 30 m) (Beato et al., 2022; Beato et al., 2019; Boer & Van Aswegen, 2016; Bravo et al., 2008; M. Buchheit, A. Mendez-Villanueva, et al., 2010; Buchheit et al., 2008; Chtara et al., 2017; Gatterer et al., 2015a; Gatterer et al., 2014; Lapointe et al., 2020; Maggioni et al., 2019; Selmi et al., 2018; Suarez-Arrones et al., 2014). It could have been expected that shuttle-based RST would improve COD ability to a greater extent than straight-line sprints and while there was some evidence for this to occur (Appendix 35), given the uncertainty of the effect (i.e., the width of the CI), and univariate analysis, this effect remains inconclusive. Original investigations are therefore required to compare the effects of straight-line, shuttle, and multi-directional sprints on COD ability, as well as other RST outcomes.

The different repeated-sprint modalities offer practitioners a variety of training options to challenge athletes in different ways. Shuttle-based RST can be implemented to emphasise change of direction while potentially optimising aerobic adaptations. Protocols with multiple changes of direction per repetition could be effective at improving COD ability, acceleration and deceleration, however, repetition distance should be limited to maintain the intensity of each effort. Straight-line sprints should be prescribed if the goal is to expose athletes to higher speed, here, it would be logical to gradually progress the repetition distance and volume of sprinting so athletes can become accustomed to maximal velocity efforts. One study (Lapointe et al., 2020) alternated between straight-line and shuttle-sprints across each session of the training program, which could be a practical strategy to incorporate both formats within a mesocycle.

5.6.1.8 Rest duration

Most RST sessions applied across our studies were implemented with a 20 s inter-repetition rest duration (n = 330, 59% of sessions) and a 4 min inter-set rest duration (n = 283; 55% of sessions). One study (Iaia et al., 2017) investigated the effects of inter-repetition rest duration on physical adaptation, with greater improvement in 20 m sprint time shown by the 30 s rest group compared to the 15 s rest group, as well as similar improvement in RSA decrement. Furthermore, enhanced sprint performance was more common in studies that prescribed longer inter-repetition rest durations (i.e., ≥ 30 s) (Galvin et al., 2013; Iaia et al., 2017; Markovic et al., 2007; Taylor & Jakeman, 2021), compared to shorter rest times (≤ 20 s) (M. Buchheit, A. Mendez-Villanueva, et al., 2010; Buchheit et al., 2008; Fernandez-Fernandez et al., 2012; Iaia et al., 2017), but the effects of rest duration on our other outcomes is equivocal. In Chapter 4, a 30 s inter-repetition rest period was shown to mitigate within-session fatigue and maintain repetition quality, which may explain why longer rest times augment sprint performance. We therefore recommend that longer rest times are prescribed if practitioners wish to prioritise the development of speed during RST, particularly when longer sprint distances (> 30 m) are implemented. While a 4 min inter-set rest period was most common, there is currently a lack of evidence to support the prescription of a particular inter-set rest time in relation to RST adaptations.

5.6.1.9 Rest modality

Passive rest was prescribed across most training programs, implemented in 509 (92%) and 453 (88%) of all training sessions for inter-repetition rest, and inter-set rest, respectively. Two studies (M. Buchheit, A. Mendez-Villanueva, et al., 2010; Buchheit et al., 2008) incorporated both passive and active rest into their RST program. In these interventions, passive rest was prescribed alongside shorter inter-repetition rest times (14 s) and active recovery was prescribed in conjunction with longer inter-repetition rest times (23 s), which involved a slow jog (M. Buchheit, A. Mendez-Villanueva, et al., 2010; Buchheit et al., 2008). One study (Fernandez-Fernandez et al., 2012) incorporated 8 min of sport-specific drills between sets as a form of inter-set active recovery, which was effective at increasing VO_{2max} and RSA average time by 5.4% and 3.7%, respectively, but there was no change in 20 m sprint time or CMJ height. Given the lack of long-term training interventions that have utilised active recovery or compared rest modalities, it would be misguided to present practical recommendations on this programming variable. Instead, we refer readers to Chapter 4 that guides the prescription of rest modality based on the acute responses to a RST session.

5.6.2 Limitations

There are several considerations when interpreting our findings. First, the inclusion of non-randomised and non-controlled trials within the analyse may have increased the risk of bias and imprecision of the results. However, our approach allows for a more comprehensive aggregation of the available evidence on RST and we have assessed the overall risk of bias to be low. Second, all RST interventions were performed alongside usual training; and therefore, the true (isolated) effects of RST are unknown. Furthermore, our analysis did not compare the effects against other training methods (e.g., interval training, resistance training), which can cause similar or greater improvement in certain physical qualities (Bravo et al., 2008; M. Buchheit, A. Mendez-Villanueva, et al., 2010; Fernandez-Fernandez et al., 2012). Third, due to the absence of real-world anchors for practically significant changes in our outcomes (e.g., VO_{2max}), we relied on standardised ES's to examine the magnitude of change in our outcomes and the moderating effects of programming variables. Even though we attempted to make these thresholds more specific to strength and conditioning (Swinton et al., 2022), we were not able to apply outcome-specific effect sizes (e.g., COD ability) due to a lack of reference across our entire range of meta-analysed physical qualities. Fourth, the effects of RST may vary according to an athlete's initial fitness. For example, in a study by (Sanchez-Sanchez et al., 2019), RST had a likely trivial effect on intermittent running performance in high-aerobic fitness soccer players, but a possibly beneficial effect in low-aerobic fitness soccer players. Therefore, our reference training program and programming variable manipulations may have a greater effect in athletes with a low fitness level, but less of an effect in highly fit athletes who are closer to their genetic ceiling. Practitioners should consider the physiological profiles of their individual athletes when designing RST. Lastly, as mentioned, we were able to consider the effects of many programming factors in combination with one another on RST outcomes via multiple, multi-level mixed meta-regression. However, we had insufficient data to include sprint modality or rest duration and modality in these models. Our 'naïve' interpretation of these effects came from univariate analysis and qualitative synthesis only and as such, may not be definitive at present.

5.7 CONCLUSIONS

The quantification of training adaptations allows practitioners to understand the relationship between the training stimuli imposed and the adaptations achieved (Taylor et al., 2015). Our meta-analysis presents both new and updated evidence on the physical adaptations to RST in athletes. True to its reputation as a multi-component training method (Taylor et al., 2015), our findings demonstrate that RST improves a range of physical qualities. Specifically, moderate improvements in VO_{2max}, YYIR1 distance, and RSA decrement were established, as well as small improvements in 10 and 20 m linear sprint times, RSA average time, CMJ height, and COD ability. The prescription of three sets of 6 × 30 m straight-line sprints, twice per week for six weeks, is an effective training program. Performing four sets per session is associated with additional improvement in YYIR1 distance and appears to be a more superior training strategy than long exhaustive sets (e.g., two sets of 10–12 reps). However, original investigations are needed to better understand how programming variables can be manipulated to augment training-induced adaptations as most of our findings could not differentiate their effects. The findings from our review and meta-analysis provide practitioners with the expected adaptations to RST in athletes and can be used to enhance the design of RST programs.

CHAPTER 6

STUDY 3

The Effects of Session Volume on Acute Demands During Repeated-Sprint Training and the Recovery Time-course of Neuromuscular Performance

This chapter is presented in the pre-publication format.

6.1 PRELUDE

Findings from Chapter 4 suggested that session volume may have an important influence on the acute demands of RST, but the extent is currently unknown. Therefore, Chapter 6 investigates the effect of different session volumes on acute physiological, perceptual, and performance demands, and the recovery time-course of neuromuscular performance. Furthermore, the influence of repetition distance and the number of repetitions will be compared.

6.2 ABSTRACT

Purpose: to examine the effects of manipulating session volume, sprint distance, and the number of repetitions on acute physiological, perceptual, and performance demands during RST, and the recovery time-course of neuromuscular performance.

Methods: using a randomised, cross-over design, 14 trained athletes completed two sets of: 10 × 40 m (10×40), 5 × 40 m (5×40), 10 × 20 m (10×20), and 5 × 20 m (5×20) sprints with 30 s rest between reps and 3 min rest between sets for all protocols. Heart rate, VO_2, RPE and sprint performance measures were recorded during each session. CMJ performance, lower-limb stiffness, and isometric hamstring strength were measured post-session, 24 hours, and 48 hours, and compared to pre-session.

Results: the 10×40 protocol induced the greatest internal and external training load compared to all other protocols ($p_{MET} < 0.05$), including *moderate* to *very large* differences in breathlessness RPE, *large* differences in S_{dec} and time > 90% VO_{2max}, and *very large* differences in session-RPE training load (sRPE-TL). The 5×20 protocol induced the lowest training load compared to all other protocols ($p_{MET} < 0.05$), including *moderate* to *large* differences in sRPE-TL and leg muscle RPE. Heart rate, VO_2, sRPE-TL, leg muscle RPE, and S_{dec}, were similar between 5×40 and 10×20 ($p_{MET} > 0.05$), but acceleration load was greater for 10×20 when compared to 5×40 ($p_{MET} < 0.001$), and this difference was *large*. Changes in neuromuscular performance across all time-points and all protocols were unclear.

Conclusions: larger session volumes increase the acute demands of RST and by manipulating volume, sprint distance, and the number of repetitions, practitioners can alter internal and external training load.

6.3 INTRODUCTION

Chapter 5 demonstrated that RST is an effective training method that can simultaneously improve a range of physical qualities. Furthermore, Chapter 4 showed that RST induces substantial acute physiological demands, including considerable increases in blood lactate, and mean and peak heart rate. However, acute responses are moderated by the manipulation of programming variables. For example, peak heart rate, blood lactate, and sprint performance are maintained during RST when four repetitions are completed per set compared to six, but a 10 m longer repetition distance (40 m vs 30 m) can amplify these demands and increase fatigue. Thus, to ensure the appropriate training load is imposed upon athletes, practitioners need to carefully consider the manipulation of programming variables.

One programming variable that has a large influence on the physiological demands of RST is session volume (i.e., repetition distance (m) × number of repetitions (n)). The volume of RST prescribed within the scientific literature typically ranges from 200–800 m per session and this appears to strongly influence the acute demands of RST. Larger session volumes (≥ 800 m) cause a peak heart rate of ≥ 90% of HR_{max} (Figueira et al., 2021a; Paulauskas et al., 2020). Additionally, Dupont et al. (2005) showed that players could reach VO_{2max} when a session volume of 600 m was implemented. Despite Chapter 4 identifying the importance of training volume, the effects of different session volumes on the physiological demands of RST have never been directly investigated. This information could provide coaches with strategies to amplify the training stimulus, which would be expected to enhance subsequent physiological adaptation.

Athletes require regular exposure to sprinting within the training environment to effectively prepare them for the high-speed demands of competition (Gabbett, 2016; Malone et al., 2017; Oakley et al., 2018). In team sports such as Australian Rules Football and soccer, players can achieve mean sprint (> 23 $\text{km}\cdot\text{h}^{-1}$) distances of 571 and 337 m per game, respectively (Coutts et al., 2010; Di Salvo et al., 2007). RST can provide controlled doses of near-to-maximal speed running (Edouard et al., 2019; Malone et al., 2017; Mendiguchia et al., 2020), but coaches need to consider the optimal volume of maximal velocity exposure so that excessive or insufficient volumes of sprint training do not hinder performance (Gabbett, 2016; Malone et al., 2017). Chapter 4 showed that there is considerable neuromuscular demand during RST due to its maximal intensity, which may be further increased by the prescription of larger session volumes (Buchheit & Laursen, 2013b). Previous studies have shown that greater RST volumes reduce CMJ performance and acute knee flexor strength (Baumert et al., 2021; Clifford et al., 2016; Timmins et al., 2014). Furthermore, these reductions may persist for up to 48 hours post-exercise (Baumert et al., 2021; Woolley et al., 2014). Given the possible effects of volume on fatigue and recovery time course, it is important to understand the effects of this programming variable, as well as the relationship between the two individual factors that constitute session volume (i.e., repetition distance and the number of repetitions). Therefore, the aims of our investigation were to, (1) examine the effects of manipulating session volume on acute physiological, perceptual, and performance demands during RST, and the recovery time-course of neuromuscular performance, and (2) determine whether repetition distance or the number of repetitions has a greater effect on the acute demands and the recovery time-course.

6.4 METHODS

6.4.1 Experimental Approach to the Problem

A randomised, crossover, counterbalanced design (Latin-square) was used to compare the effects of four different RST protocols. Heart rate, VO_2, dRPE, S_{dec}, acceleration load, and volume of sprinting > 90% of maximal sprint speed (MSS) were recorded during each session. Perceived muscle soreness, CMJ performance, lower-limb stiffness, and isometric hamstring strength were measured immediately pre- and post-session, 24 hours, and 48 hours, while sRPE were also recorded post-session. The study was conducted over 4 weeks for each participant and involved one RST session per week performed on Monday and two follow-up testing sessions 24 and 48 hours afterwards. In total, the athletes attended 13 sessions (i.e., familiarisation and 12 testing sessions). The RST protocols were prescribed with different combinations of the number of repetitions and sprint distance (i.e., 5 or 10 repetitions and 20 or 40 m distance), while all other programming variables were fixed across all sessions (Table 16). Together, the training protocols represent a practical range of session volumes (200–800 m) that were identified from Chapters 4 and 5.

Table 16

Prescription of the Repeated-Sprint Training Protocols used in Chapter 6

Protocol	Sets × Reps	Sprint distance	Inter-rep rest time	Inter-set rest time	Rest mode	Prescribed volume
10×40	2 × 10	40 m	30 s	180 s	Passive	800 m
10×20	2 × 10	20 m	30 s	180 s	Passive	400 m
5×40	2 × 5	40 m	30 s	180 s	Passive	400 m
5×20	2 × 5	20 m	30 s	180 s	Passive	200 m

6.4.2 Participants

Fourteen trained athletes, training at least three times per week with the purpose of competing at a local level or higher, were recruited from the Australian Catholic University to take part in our study. The physical characteristics of the athletes are presented in Table 17. Before initiating the study, athletes were informed of the procedures, risks and benefits and signed an institutionally approved informed consent form (Appendix 43). All athletes were injury-free for at least three months before the study. The study protocol adhered to the declaration of Helsinki and was approved by the Australian Catholic University Institutional Review Board.

Table 17

Physical Characteristics of the Athletes in Chapter 6

	Age (years)	Height (cm)	Weight (kg)	VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)
Males (n = 10)	24 ± 4	182 ± 9	83 ± 10	57 ± 6
Females (n = 4)	22 ± 1	169 ± 6	62 ± 3	45 ± 2

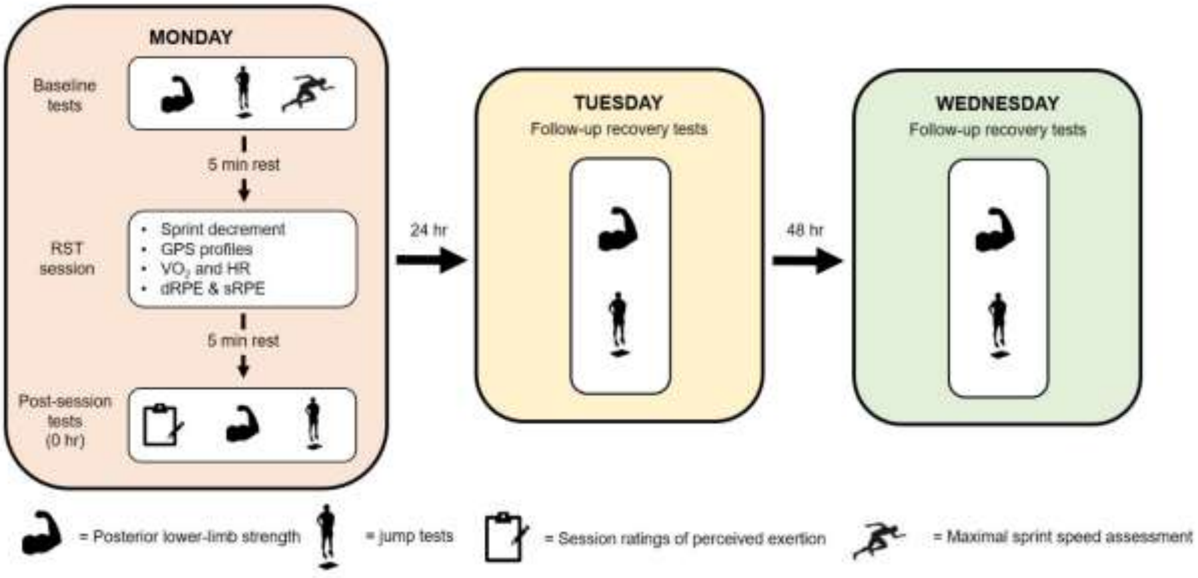
6.4.3 Procedures

All athletes attended a familiarisation session one week before the commencement of the study where they signed consent forms, practiced all testing procedures and had their height measured (Seca Alpha stadiometer, model 213, Hamburg, Germany). Additionally, the athletes completed a graded exercise test on a motorised treadmill (T22.1, Vertex Fitness, Abu Dhabi, United Arab Emirates) with respiratory gas analysis (K5, COSMED, Rome, Italy) to determine their VO_{2max} HR_{max}. All testing took place at the same time of day (±1 hour) to minimise any potential influence of diurnal or circadian variation. In the day preceding the familiarisation sessions, each RST session, as well as between each session and the follow-ups, the athletes were instructed to refrain from strenuous exercise involving the leg muscles (e.g., running, resistance training, sports activity) and from consuming alcohol. The athletes were also instructed to abstain from the consumption of food and beverage other than water within two hours of each session, and the consumption of caffeine six hours before each session. In addition to these restrictions, the athletes were also asked to maintain their usual nutritional habits during the intervention period. The sprints were performed on a grass sports oval, under similar environmental conditions (21–28°C, 54–78% humidity).

The experimental procedures for each RST session and its follow-up recovery sessions can be seen in Figure 34. At the beginning of each RST session, the athletes performed the same standardised warm-up (warm-up A), consisting of a series of dynamic movements performed over a distance of 10 m (e.g., walking lunges, heel sweeps, A-skips). Baseline testing was then performed in the following order: 1) a unilateral isometric strength test of the hamstring muscles, 2) a CMJ test, and 3) a double-leg hopping test. Following the baseline tests, the athletes performed an additional warm-up (warm-up B), which involved 4 × 40 m strides at an estimated 50%, 70%, 80% and 90% of maximal speed. Between each effort, the athletes slowly walked back to the starting point. Following the final stride, the athletes performed 1 × 40 m maximal sprint to determine their peak velocity for that day, which was identified via a 10 Hz GPS (Apex, STATSports, Newry, Northern Ireland) that was fitted within a vest on the athlete's upper thoracic region (Crang et al., 2021, 2022). The athletes were then provided a 5 min rest before beginning the RST session and during this rest period, they were fitted with the same automated, wearable, gas analysis system as used during the graded exercise test. Heart rate, VO_2, repetition times, and GPS data were recorded throughout the RST session. Differential ratings of perceived exertion were recorded at the end of set one and set two, while sRPE were recorded 5 min following the end of the RST session, with both having been used extensively throughout the literature to quantify the perception of effort that athletes experience during exercise (Dudley et al., 2023; Weakley, Castilla, et al., 2022b; Weakley, McLaren, et al., 2019). While we acknowledge that the collection of sRPE is typically taken 30 min post-session (McLaren, Graham, et al., 2016; McLaren et al., 2017), as follow-up tests were conducted 5 min post-session, sRPE was taken immediately before these. The post-session testing was conducted in the same order as baseline testing. For the 24- and 48-hour follow-up sessions, the athlete's perceived muscle soreness was recorded at the beginning of the session. The same standardised dynamic warm-up was performed (warm-up A) before commencing testing. Athletes wore the same footwear and were fitted with the same GPS unit across each session (Crang et al., 2021).

Figure 34

The Experimental Procedures for One Repeated-Sprint Training Session and its Follow-up Sessions



Note. This design is repeated for each of the four repeated-sprint training protocols, which are separated by one week. RST = repeated-sprint training; GPS = global positioning system; VO_2 = oxygen consumption; HR = heart rate; dRPE = differential ratings of perceived exertion.

6.4.3.1 Repeated-sprint training

The RST protocols are shown in Table 18. A 3 min rest period was provided between sets, from the end of set one (i.e., the moment the athlete crossed the finish line after the final sprint) to the start of the first sprint in set two. During the inter-set recovery period, athletes decelerated and walked back to the starting point, where they sat on a chair until the beginning of set two. Athletes started each sprint in a standing start position with their foot 0.3 m behind the first timing gate (Weakley, McCosker, et al., 2022). A 10 s warning and 3 s countdown was provided for each repetition. Athletes were instructed to give maximal effort and sprint through the finish line. Loud verbal encouragement was given to all athletes during each repetition. During the recovery period between sprints, athletes decelerated and walked back to the starting point. Two sets of single-beam timing gates (TCi, Brower Timing Systems, Draper, USA) were used that worked in both directions, which allowed the athletes to start each sprint at the end they finished the previous sprint. The timing gates were used to determine the sprint times of each repetition, while GPS was used to determine acceleration load and the volume of sprinting > 90% of each individuals MSS during each session (Murray et al., 2018). The fastest peak velocity derived from the GPS achieved during baseline testing (1 × 40 m maximal sprint) for each athlete on each training day was used as the reference MSS. This approach allowed for daily individual fluctuations in sprint performance to be accounted for. To calculate the decline in sprint speed across each set, S_{dec} was used (average of both sets), with its calculation comprehensively detailed in Chapter 3 (3.3.6).

6.4.3.2 Hamstring strength

Assessment of isometric hamstring strength was performed on a portable force plate (ForceDecks, VALD Performance, Brisbane, Australia). The test was performed on the athletes' dominant limb at knee angles of 90° and 30°. Its methods are extensively detailed in Chapter 3 (3.3.4), but briefly, the athlete was instructed to push the heel of their working leg into the force platform as hard as possible as though they were trying to perform a hamstring curl, without lifting their hips, hands or head off the mat. The contraction was performed for 3 s and repeated three times at each angle with 30 s rest between trials. The highest peak force (N) from the three trials was recorded for analysis.

6.4.3.3 Jump testing

Jump testing was performed on the same portable force plates as the hamstring strength assessment. Its methods are extensively detailed in Chapter 3 (3.3.2 and 3.3.3). Briefly, for the CMJ, three maximal trials were performed without arm swing and from a self-selected depth. For the double leg hopping test, athletes completed one trial of 20 consecutive hops with the average of hops 6–15 used for analysis. Leg stiffness was calculated through Dalleau’s equation (Dalleau et al., 2004).

6.4.3.4 Perceptual measures

Immediately following the completion of each RST set, athletes provided dRPE for breathlessness (RPE-B) and leg exertion (RPE-L) by considering verbal anchors on a Borg CR100 Scale® (Borg, 2010). Athletes were instructed that their ratings should reflect the perceptions of effort experienced for the preceding set only (McLaren et al., 2020) and they were informed about the definition of perceived exertion and its scaling, including the importance of separating rating of perceived exertion from other exercise-related sensations such as pain, discomfort and fatigue (McLaren et al., 2020). Instructions were also given to athletes on how to appraise dRPE, such that RPE-B depends mainly on breathing rate and/or heart effort, and RPE-L depends mainly on the strain and exertion in the leg muscles (McLaren et al., 2020). The average of both sets for dRPE was used for analysis. Five minutes after the RST session, athletes also provided a global sRPE by considering verbal anchors on a modified version (Foster et al., 2001) of the Borg CR10 Scale® (Borg, 2010), which was multiplied with the session duration to determine sRPE-training load (sRPE-TL) (Foster et al., 2001).

6.4.3.5 Oxygen consumption and heart rate

During the familiarisation session, athletes completed a graded exercise test on a motorised treadmill with respiratory gas exchange data collected via a portable metabolic system and heart rate measured using a chest strap monitor (HRM-Dual, Garmin Australasia Pty Ltd, New South Wales, Australia), which was integrated with the metabolic system. The methods of the graded exercise test are extensively detailed in Chapter 3 (3.3.5)

For the RST sessions, heart rate and respiratory gas exchange were continuously recorded from the start of the first repetition to 30 s following the final repetition, using the same equipment as the graded exercise test. Erroneous fluctuations in raw data were removed if they were considered to be higher or lower than physiologically possible. Heart rate and VO_2 data were averaged for each repetition, set and the overall RST session (excluding the inter-rest recovery period). Peak heart rate was identified from the highest value during each set and the overall RST session. Heart rate and VO_2 data from the inter-set rest period were also analysed, which included the value at the end of set one (from the moment the athlete passed the timing gate after the last sprint), and the decline after 1 min, 2 min and 3 min. For the analysis of VO_2 during the inter-set rest period, a 15 s average was used, so that the VO_2 decline at 1 min, 2 min and 3 min were recorded from 45–60 s, 105–120 s, and 165–180 s, respectively.

6.4.4 Statistical Analyses

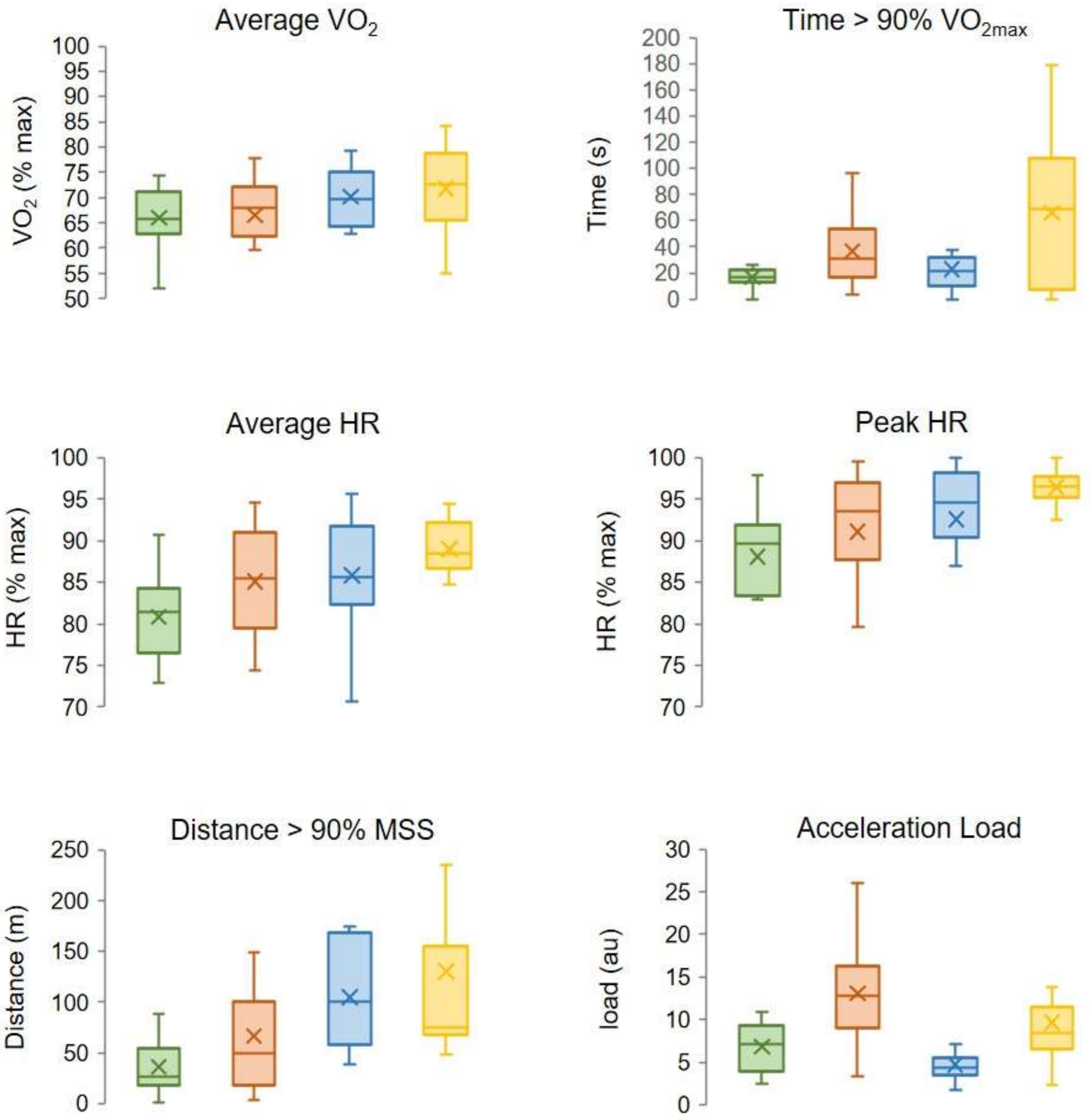
The mean ± SD was calculated for all outcomes. The Shapiro-Wilk test confirmed all variables were normally distributed. A univariate ANOVA was used to compare between protocol differences in physiological, perceptual, and sprint performance outcomes, and within protocol differences (pre-post, pre-24 hours, pre-48 hours) in recovery outcomes. To aid with data interpretation, all effects were expressed as an ES by dividing the estimate and its CL by the pooled between-subject SD of each protocol (subsequently adjusted for small sample bias) and day-to-day variability. Values of 0.2, 0.6, 1.2 and 2.0 represent thresholds for small, moderate, large, and very large differences for the standardised difference in means (Batterham & Hopkins, 2006). A difference was declared when the upper and lower confidence interval fell entirely or predominantly outside the non-substantial region (i.e., outside -0.2 to 0.2). When this was visually apparent, a MET was used to provide a probabilistic description of the CL's disposition relative to the threshold for a non-substantial effect. Given that this study was not powered for definitive conclusions, we elected to present probability values for the one-sided tests (p_{MET}) as continuous estimates only, rather than declaring a fixed alpha level representing 'practical significance'. Data analysis was conducted using SPSS 29 program for Windows (SPSS, Inc, Chicago, IL, USA).

6.5 RESULTS

Descriptive data on the acute physiological, perceptual, and performance demands of each RST protocol are presented in Figure 35 and Appendix 36 and 37. Additionally, Figure 36 displays the change in heart rate and VO_2 across the inter-set recovery period for each RST protocol.

Figure 35

The Acute Demands of Each Repeated-Sprint Training Protocol



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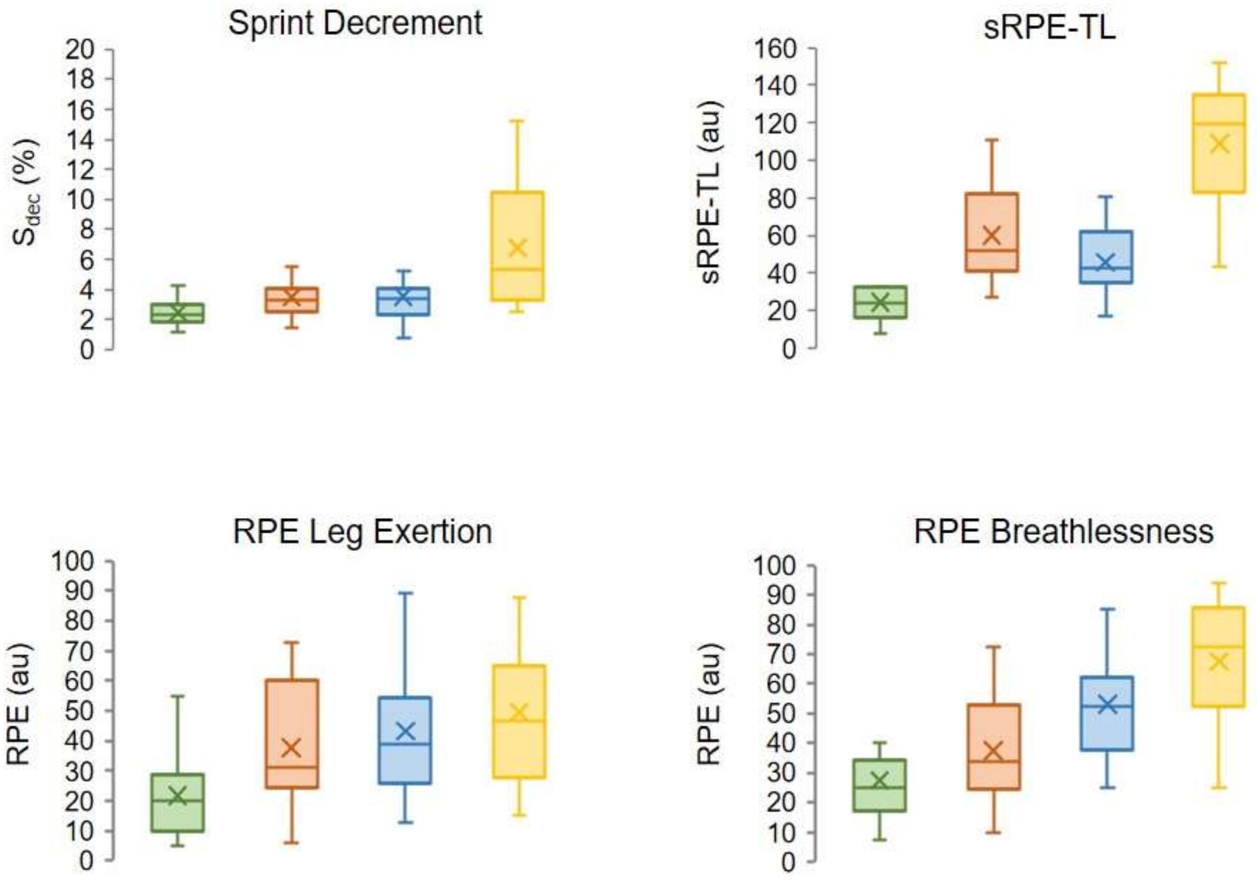

Sprint Decrement

sRPE-TL

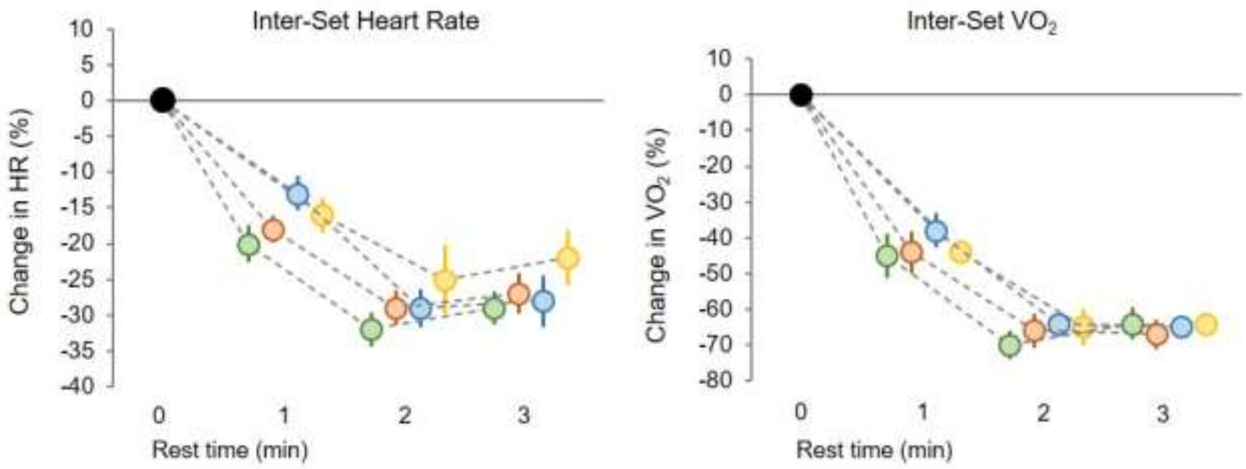
RPE Leg Exertion

RPE Breathlessness

Note. Green = 5×20; orange = 10×20; blue = 5×40; yellow = 10×40; × = mean; VO_2 = oxygen consumption; VO_{2max} = maximal oxygen consumption; HR = heart rate; S_{dec} = percentage sprint decrement; RPE = rating of perceived exertion; sRPE-TL = session RPE-training load; au = arbitrary units.

Figure 36

Change in Heart Rate and Oxygen Consumption Across the Inter-Set Recovery Period Between Set One and Set Two for Each Repeated-Sprint Training Protocol



Note. Data presented as mean ±90% CL. The interest recovery period is the time between the end of the last sprint repetition in set one (0 min) and the start of the first sprint repetition in set two (3 min); Green = 5×20; orange = 10×20; blue = 5×40; yellow = 10×40.

6.5.1 Training Load

6.5.1.1 Physiological and perceptual measures (internal training load)

Session average heart rate was higher for 10×40 and 5×40 when compared to 5×20 (p_{MET} = 0.002 & 0.059, respectively), and these differences were *large* and *moderate* (ES: 1.38 ±0.65 & 0.80 ±0.64, respectively). Additionally, the session peak heart rate was higher for 10×40 when compared to 5×20 and this difference was *moderate* (ES: 1.10 ±0.83; p_{MET} = 0.011). Time >90% VO_{2max} was greater for 10×40 when compared to 5×40 (p_{MET} = 0.002) and 5×20 ($p_{MET} < 0.001$), and these differences were *large* (ES: 1.29 ±0.62 & 1.47 ±0.63, respectively).

Differential RPE-L was greater for 10×40 (p_{MET} = 0.001), 5×40 (p_{MET} = 0.013), and 10×20 (p_{MET} = 0.063) when compared to 5×20, and these differences were *large, moderate, and moderate* (ES: 1.37 ±0.63, 1.06 ±0.63 & 0.78 ±0.63, respectively). RPE-B was greater for 10×40 when compared to 5×40 (p_{MET} = 0.064), 10×20 ($p_{MET} < 0.001$), and 5×20 ($p_{MET} < 0.001$), and these differences were *moderate*, *large,* and *very large* (ES: 0.79 ±0.64, 1.64 ±0.64 & 2.19 ±0.64). Furthermore, RPE-B was greater for 5×40 when compared to 10×20 (p_{MET} = 0.046) and 5×20 (p_{MET} = 0.001), and these differences were *moderate* and *large* (ES: 0.85 ±0.64 & 1.41 ±0.64, respectively).

Session RPE-TL was greater for 10×40 when compared to 5×40 ($p_{MET} < 0.001$), 10×20 ($p_{MET} < 0.001$), and 5×20 ($p_{MET} < 0.001$), and these differences were *very large* (ES: 2.59 ±0.63, 2.00 ±0.63 & ES: 3.47 ±0.63, respectively). Session RPE-TL was also greater for 5×40 (p_{MET} = 0.039) and 10×20 ($p_{MET} < 0.001$) when compared to 5×20, and these differences were *moderate* and *large* (ES: 0.88 ±0.63 & 1.47 ±0.63, respectively). All other comparisons of internal training load were not definitive and can be found in Appendix 38 and 39.

6.5.1.2 External training load

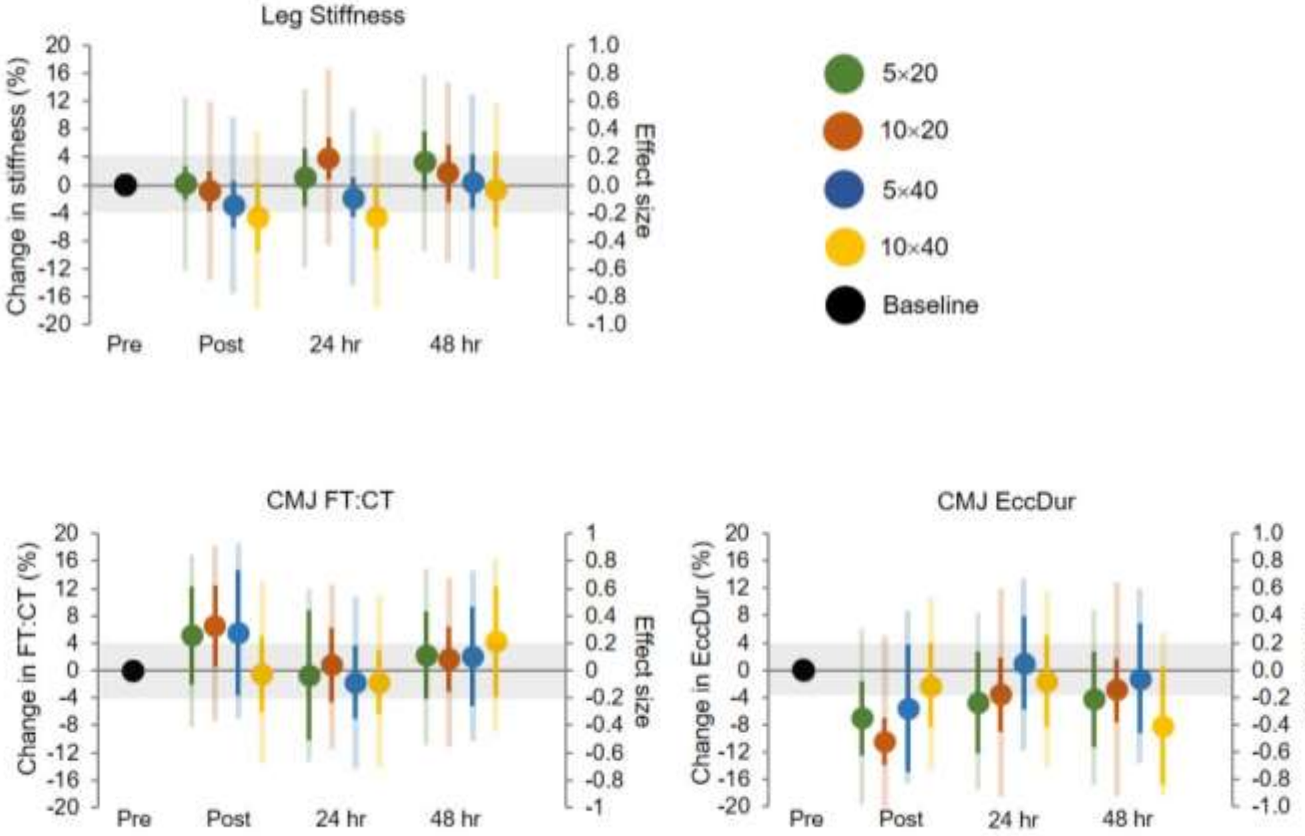
Sprint decrement was greater for 10×40 when compared to 5×40 ($p_{MET} = 0.002$), 10×20 ($p_{MET} = 0.001$), and 5×20 ($p_{MET} < 0.001$), and these differences were *large* (ES: 1.37 ±0.64, 1.39 ±0.64 & 1.79 ±0.64, respectively). Session distance >90% MSS was greater for 10×40 when compared to 10×20 ($p_{MET} = 0.029$) and 5×20 ($p_{MET} = 0.001$), and these differences were *moderate* and *large* (ES: 0.94 ±0.64 & 1.38 ±0.63, respectively). Additionally, session distance >90% MSS was greater for 5×40 when compared to 5×20 ($p_{MET} = 0.018$), and this difference was *moderate* (ES: 1.05 ±0.66). Session acceleration load was greater for 10×40 when compared to 5×40 ($p_{MET} = 0.013$), and this difference was *moderate* (ES: 1.07 ±0.64). Furthermore, session acceleration load was greater for 10×20 when compared to 5×40 ($p_{MET} < 0.001$), and this difference was *large* (ES: 1.83 ±0.63). All other comparisons of external training load were not definitive and can be found in Appendix 40.

6.5.2 Recovery Measures

The effects of RST on the recovery time course of neuromuscular performance are presented in Figure 37 and Appendix 41. Changes in neuromuscular performance across all time points and all protocols were unclear.

Figure 37

The Recovery Time-Course of Neuromuscular Performance Within Each Repeated-Sprint Training Protocol



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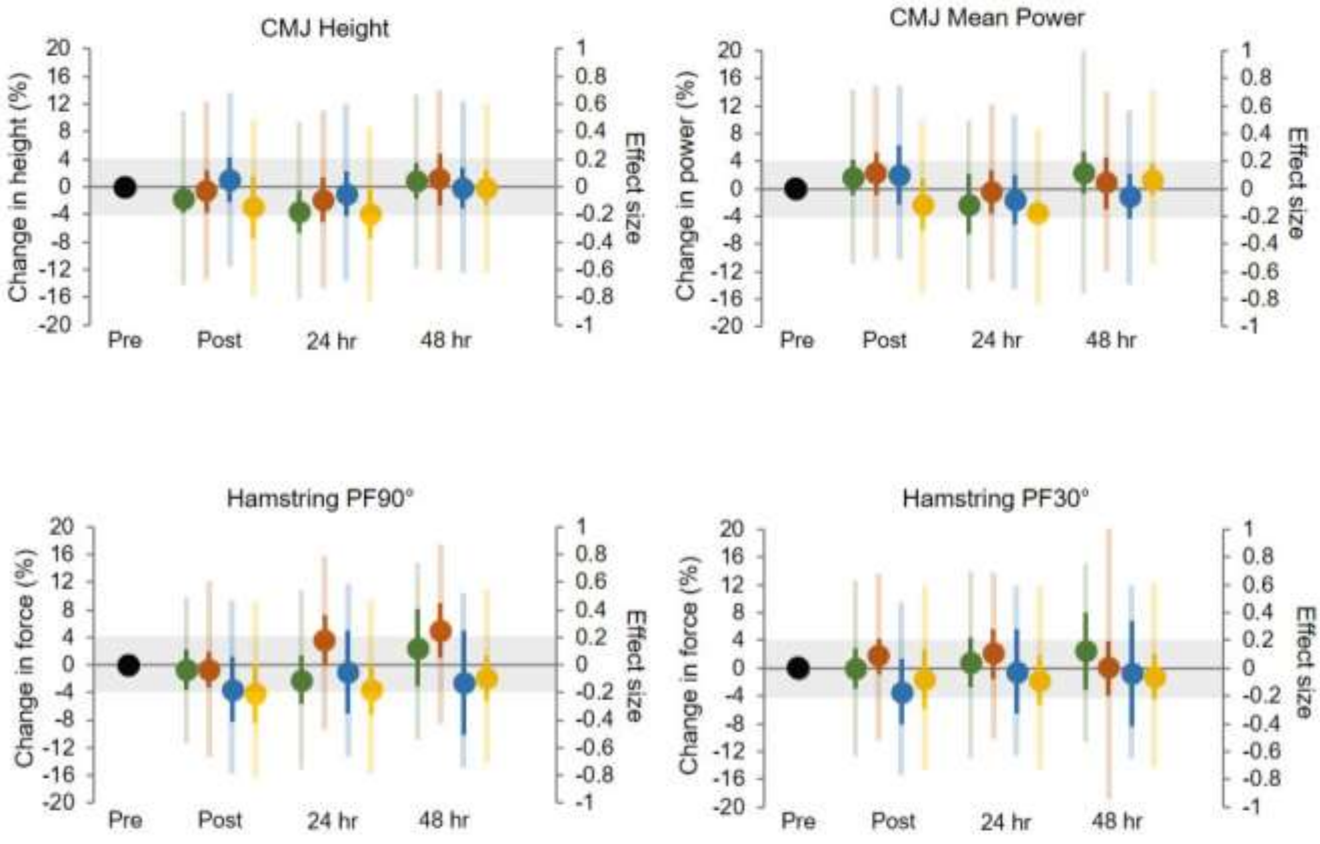


Note. Green = 5×20; orange = 10×20; blue = 5×40; yellow = 10×40. Dark error bar represents the 90% CL for the percent change in performance; shaded colour represents the 90% CL for the standardised difference; grey shaded zone represents a trivial effect. PF90° = peak force at 90° of knee flexion; PF30° = peak force at 30° of knee flexion; CMJ = countermovement jump; FT:CT = flight-time to contraction-time ratio; EccDur = eccentric duration.

6.6 DISCUSSION

Our study aimed to investigate the effects of manipulating RST session volume on acute physiological, perceptual, and performance demands, as well as the recovery time course of neuromuscular performance. The 10×40 protocol induced the greatest physiological and perceptual demands, which was demonstrated by a session average heart rate and VO_2 of 89 ±3% and 72 ±8% of max, respectively, while dRPE were rated hard to very hard on average. Additionally, the 10×40 protocol also had the greatest S_{dec} and incurred a sRPE-TL that was higher than all other protocols by a *very large* magnitude. Conversely, the acute demands of the 5×20 protocol were considerably less than all other protocols. When session volume was matched at 400 m, the internal training load was similar, but the acceleration load was greater for the 10×20 protocol, whereas sprint volume (> 90% MSS) was higher for the 5×40 protocol. However, across all protocols, there was substantial inter-individual variation in neuromuscular function, and subsequently, the return to baseline of neuromuscular performance was unclear. The findings from our investigation demonstrate that larger session volumes increase the acute demands of RST and by manipulating volume, sprint distance, and the number of repetitions, practitioners can alter internal and external training load.

This is the first investigation to directly examine time above 90% of VO_{2max} during RST. Specifically, we found that 66 ± 56 s was spent above 90% of VO_{2max} during the 10×40 protocol, which was greater than the other protocols by a *large* magnitude. Time above 90% of VO_{2max} has been suggested to be an important stimulus to elicit both maximal cardiovascular and peripheral adaptations (Billat, 2001b; Laursen & Jenkins, 2002; Midgley et al., 2006). Performing more repetitions in succession increases time above 90% of VO_{2max} and HR_{max} by extending the duration of the session and amplifying within session fatigue, as demonstrated by a greater S_{dec} with a large effect for the 10×40 protocol. However, other high-intensity conditioning methods, such as short- and long-intervals, may elicit > 10 min above 90% of VO_{2max} (Buchheit & Laursen, 2013b). Compared to these other conditioning methods, time above 90% of VO_{2max} was low for all four RST protocols. Therefore, the strategy of implementing high repetition protocols to increase time above 90% of VO_{2max} during RST is likely futile because increases will be relatively minimal. Furthermore, compared to sets prescribed with five repetitions, performing ten repetitions did not substantially increase the average VO_2 demands when sprint distance was matched (e.g., 10×40 vs. 5×40). Therefore, rather than prescribing high repetition protocols, practitioners are encouraged to increase sprint distance or manipulate other RST variables, such as rest time, to enhance the acute aerobic stimulus. Future research should investigate the acute and chronic effects of manipulating sets and repetitions within volume-matched protocols (i.e., 2 sets of 10 repetitions vs. 4 sets of 5 repetitions) as this could also be an effective strategy to increase the physiological responses.

Chapter 4 found that sprint distance has a substantial influence on physiological demands during RST. Our present investigation lends further support to this premise, showing that 40 m sprints caused greater VO_2 and heart rate demands compared to 20 m sprints, although this was only definitive for average heart rate with a *moderate* effect. Additionally, a greater volume of sprinting above 90% of MSS was achieved with 40 m sprints. The 10×40 and 5×40 protocols elicited over 100 m of sprinting per session, compared to 67 ±64 m and 36 ±27 m for the 10×20 and 5×20 protocols, respectively. Sprint training above 90% of MSS has been proposed as a key component of hamstring injury risk management (Edouard et al., 2023) and our findings suggest that the prescription of RST with a repetition distance of 40 m can provide a concurrent sprint and physiological stimulus that is substantial. Alternatively, acceleration load was increased during the 20 m sprint protocols, while dRPE was lower compared to the 40 m protocols, by *moderate* to *large* magnitudes. Therefore, shorter sprint protocols may reduce the perceptual demand on athletes during RST and target the development of acceleration performance.

The 10×40 protocol tended to cause greater decrements in neuromuscular performance following the RST sessions, particularly for leg stiffness, CMJ height, and CMJ mean power (Figure 37). However, given the width of the effect size CL's these, and all other recovery outcomes were unclear. The certainty in these results was affected by considerable inter-individual variation, with athletes demonstrating a decrement, no change, or potentiation of neuromuscular performance following RST. Furthermore, the training volumes may have been insufficient to induce consistent change in neuromuscular performance across the athletes, but these were considered to be the lower (200 m) and upper (800 m) limits of volume that are prescribed within applied training environments. While practitioners are encouraged to consider the individual fatigue responses to RST, future research may benefit from using more sensitive measures to detect neuromuscular fatigue and a larger sample size to form more definitive conclusions.

Our study provides evidence of the acute effects of RST volume, but it has some limitations. First, given the altered sprint distances across our protocols, we acknowledge that the work-to-rest ratios were subsequently different, and this would influence the recovery between sprints and subsequent physiological demands. However, the application of work-to-rest ratios in a sporting environment is logistically difficult because the time taken to perform each sprint varies between repetitions and athletes. Accordingly, standardised rest times were selected because these are more common within scientific literature and practical within real-world training environments. Second, we used measures of neuromuscular recovery that are frequently implemented within sports settings, but recognise that there is no single ideal model to study fatigue (Cairns et al., 2005), and other disruptions to homeostasis may have occurred. Additionally, we did not assess changes in eccentric hamstring strength or muscle activity. Considering the eccentric demands of sprint activity on the hamstring muscles (Mendiguchia et al., 2020), this may provide different results to our isometric hamstring strength assessment, which reduced the potential influence of testing fatigue on our recovery outcomes and is highly practical within sporting environments (McCall et al., 2015; O'Keefe, 2020).

In conclusion, the findings from Chapter 6 demonstrate that larger session volumes increase the acute demands of RST. A session volume of 800 m induces the greatest aerobic stimulus but also causes substantially greater within-session fatigue (i.e., S_{dec}), sRPE-TL, and dRPE. When session volume is matched at 400 m, the physiological and perceptual demands are similar, but the external training loads (i.e., acceleration load and volume > 90% MSS) are dependent on the sprint distance. A session volume of 200 m elicits a low physiological stimulus but could be useful to introduce or maintain exposure to maximal sprinting. Practitioners can use our findings to alter the acute training stimulus, based on the aims of the training program.

6.6.1 Practical Applications

Session volumes of 200 m, prescribed as two sets of 5 × 20 m sprints, could be applied at the beginning of a RST program to introduce athletes to maximal acceleration, while limiting training load, before progressing to larger volumes such as 400 m. If 400 m of volume is implemented, prescribing this session as two sets of 5 × 40 m sprints will provide athletes with exposure to maximal sprinting (~100 m > 90% of MSS), whereas the prescription of two sets of 10 × 20 m sprints will emphasise acceleration load. To maximise the acute physiological and neuromuscular demands of RST, which may result in a greater stimulus for adaptation, larger session volumes (i.e., 800 m) are recommended and these are best achieved by implementing longer sprint distances (i.e., 40 m). Lastly, we administered 3 min inter-set rest periods and found that there were no differences in heart rate and VO_2 recovery between the 2nd and 3rd minute mark (Figure 36). Therefore, during congested training sessions, to reduce session duration while providing adequate recovery of cardiorespiratory function, 2 min passive rest periods can be prescribed.

CHAPTER 7

STUDY 4

The Effects of Repeated-Sprint Training vs Short-Bout High-Intensity Interval Training on Hamstring Muscle Architecture and Physical Fitness in Rugby League Players

This chapter is presented in the pre-publication format.

7.1 PRELUDE

Chapter 5 demonstrated that RST enhances a range of physical qualities that are important to sports performance. However, comparison between RST and other HIIT methods is lacking, and several important outcomes, such as their effects on specific neuromuscular and morphological outcomes are yet to be investigated. Therefore, Chapter 7 compares changes in hamstring muscle architecture and physical fitness between RST and short-bout HIIT in rugby league players.

7.2 ABSTRACT

Purpose: To quantify and compare the effects of RST vs short-bout HIIT on hamstring architecture and physical fitness in rugby league players.

Methods: In a parallel, two-group, pre-post design, 24 representative U20 players were assigned to either RST (*n* = 12) or short-bout HIIT (*n* = 12) for a six-week intervention delivered alongside usual team training. Assessments of biceps femoris long-head (BFlh) muscle thickness, pennation angle, and fascicle length, CMJ performance, eccentric hamstring strength, sprint FVP profile, and a 1200 m time trial (i.e., aerobic fitness) were performed pre- and post-intervention.

Results: Compared to baseline, the RST group had *moderate* improvements in aerobic fitness and maximal theoretical velocity, as well as a *moderate* increase in BFlh fascicle length, a *small* increase in BFlh muscle thickness, and a *moderate* reduction in BFlh pennation angle. The short-bout HIIT group had *moderate* improvement in aerobic fitness and a *small* improvement in CMJ peak power, as well as a *large* increase in BFlh fascicle length, a *moderate* increase in BFlh muscle thickness, and a *small* reduction in BFlh pennation angle. Changes in aerobic fitness were greater for short-bout HIIT when compared to RST and this difference was *moderate*. Conversely, changes in eccentric knee flexor strength, 10, 20, and 30 m sprint times, as well as certain FVP characteristics, were greater for RST and these differences were *moderate*. All other effects were inconclusive.

Conclusions: Both groups increased fascicle length, but RST was more effective at improving hamstring strength and linear speed, while short-bout HIIT was more effective for improving aerobic fitness. These findings may be useful to inform running-based training for physical fitness, injury prevention and rehabilitation.

7.3 INTRODUCTION

High-intensity interval training is one of the most effective means of improving the physical performance of athletes (Billat, 2001b; Buchheit & Laursen, 2013a; Gibala, 2021; Laursen & Jenkins, 2002). It involves repeated short-to-long bouts of exercise, performed at a perceived effort of “hard” or greater, and interspersed by periods of low-intensity exercise or passive rest (Billat, 2001b; Laursen & Buchheit, 2019). This method of exercise prescription allows for greater volumes of training to be accomplished at high-intensity, and with its frequent accelerations and decelerations, can be used to help prepare an athlete’s cardiorespiratory, metabolic, and musculoskeletal systems for the rigorous demands of sport (Laursen & Jenkins, 2002). High-intensity interval training is also time-efficient, which makes it particularly suitable for application within team sport environments, where technical, tactical, and physical training is concurrently implemented (Laursen & Buchheit, 2019). However, there are several different modalities of HIIT, which share both similarities and distinct differences (Buchheit & Laursen, 2013a).

Repeated-sprint training and short-bout HIIT are two HIIT modalities that are commonly implemented at similar stages of an athlete’s season to enhance physical conditioning. They are often used during the intensification period of an athlete’s pre-season to improve specific physical qualities (e.g., speed, aerobic fitness), or applied during the playing season to promote performance maintenance (Laursen & Buchheit, 2019; Thurlow et al., 2023). Both HIIT formats are completed in a similar duration, and often use comparable set and repetition schemes (e.g., 1–3 sets of 6–12 reps). Furthermore, they have been shown to induce improvements in aerobic capacity, intermittent running performance, repeated-sprint ability, sprint times, and CMJ height, although results can at times be conflicting (Clemente et al., 2021) and several important training outcomes are yet to be quantified and compared.

Repeated-sprint training simultaneously targets both the metabolic and neuromuscular systems, inciting improvement in a range of physical qualities, including both speed and endurance. However, its effectiveness versus ‘isolated’ training contents (i.e., neuromuscular or metabolic orientated sessions) has been questioned (Martin Buchheit, 2012), as such sessions may promote a greater stimulus that could lead to enhanced adaptation in specific fitness qualities. Only one study has compared RST and short-bout HIIT (Buchheit et al., 2008). In a nine-week intervention involving adolescent handball players, there was a 10.9% improvement in aerobic fitness (measured via a 30:15 intermittent fitness test) for the short-bout HIIT group and a 5.5% improvement for the RST group (Buchheit et al., 2008). Additionally, the short-bout HIIT group increased their CMJ height by 6.1%, in comparison to a 4.7% increase by the RST group (Buchheit et al., 2008). Improvements in sprint times for both conditioning methods are usually within the range of 1–4% (Faude et al., 2014; Jastrzebski et al., 2014), but evidence of their effects on the mechanical effectiveness of sprinting (i.e., sprint FVP profiles (Samozino et al., 2016) is lacking. Knowledge regarding the effects of HIIT modality on physical performance can be used by practitioners to achieve specific training adaptations.

Hamstring strain injuries are one of the most prevalent injuries in team sport, resulting in considerable time loss from training and competition (Maniar et al., 2023; Opar et al., 2012). Short biceps femoris long head (BFlh) fascicles and eccentric knee flexor weakness are two modifiable risk factors that have been strongly linked to hamstring strain injury risk (Opar et al., 2015; R. G. Timmins et al., 2016). Sprinting has been identified as a training method which can improve these factors (Freeman et al., 2019; Mendiguchia et al., 2020; Sancese et al.) and potentially mitigate the risk of such injuries (Edouard et al., 2023; Malone et al., 2017). Chapter 5 demonstrated that RST can provide controlled doses of maximal effort running and thus, it may produce a stimulus to increase fascicle length and eccentric hamstring strength (Edouard et al., 2019; Malone et al., 2017; Mendiguchia et al., 2020). On the contrary, it has been suggested that athletes who have only or mostly been exposed to high, but not maximal running velocity, may not have obtained the sprinting-specific mechanical requirements needed for adequate preparation of the hamstrings (Edouard et al., 2023). Considering the sub-maximal running velocities in which short-bout HIIT is performed (typically between 110–140% MAS), the biomechanical strain on the hamstrings may be inadequate to cause significant architectural and strength adaptations. Therefore, investigation is required to determine the hamstring architectural and strength adaptations to RST and short-bout HIIT, which may be of insightful information for hamstring strain injury prevention and rehabilitation practices. Accordingly, we aimed to quantify and compare the effects of RST vs short-bout HIIT on BFlh architecture, aerobic fitness, eccentric knee flexor strength, CMJ performance, and sprint FVP profiles in rugby league players.

7.4 METHODS

7.4.1 Participants

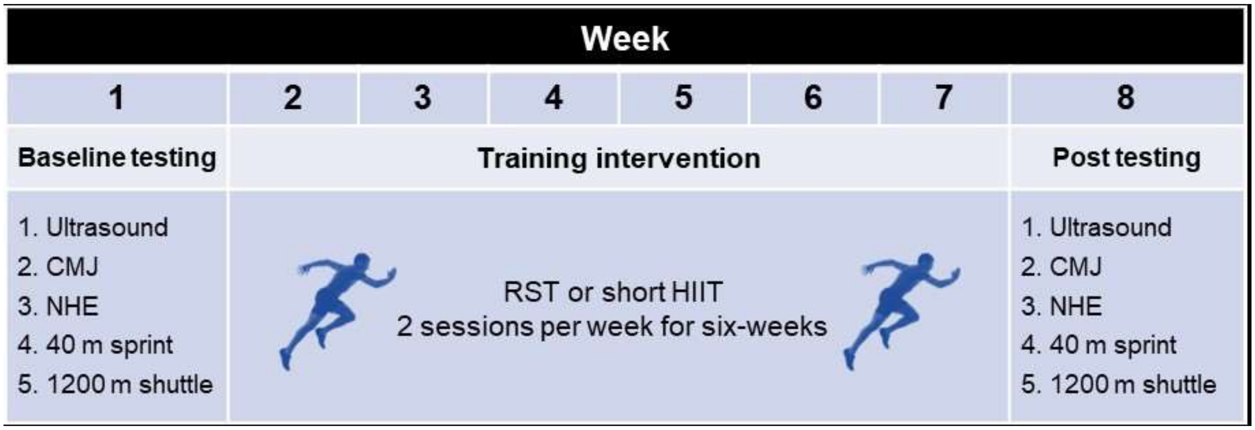
Thirty male rugby league players from an under 20's team, which participates in the Queensland competition (i.e., the elite level competition for under 20 players in Queensland, Australia), were recruited for this study. All available players from the team were recruited, but six players (three from each training group) were excluded from the final analysis due to missed follow-up tests, injuries, or absence from more than two training sessions. None of the injuries occurred during the experimental training or testing sessions. Thus, 24 players (mean ± standard deviation (SD); age: 20 ±0.8 y; stature: 1.82 ±0.05 m; body mass: 90.4 ±13.4 kg) were included in the final analysis. All included players had at least five years of playing experience. Prior to initiating the study, the players were informed of the procedures, risks and benefits and signed an institutionally approved informed consent form (Appendix 43). All players were required to be injury free for at least three months prior to the study. The study protocol adhered to the declaration of Helsinki and was approved by the Australian Catholic University Institutional Review Board. It was also registered on Open Science Framework:
(DOI: https://doi.org/10.17605/OSF.IO/PU6ER). We used the CONSORT checklist when writing our report (Schulz et al., 2010).

7.4.2 Study Design

A parallel, two-group, longitudinal (pre-test – post-test) design was used to compare the effects of RST and short-bout HIIT on BFlh architecture, eccentric hamstring strength and physical fitness. The study was conducted over an eight-week period during the team's preseason (January to February) and involved a six-week training intervention that was delivered alongside the teams usual training practice. A single two-hour testing session was held at the players rugby club, exactly one week before and after the training intervention. In order of delivery, testing comprised of, (1) ultrasonography of the BFlh to determine muscle architecture (muscle thickness, pennation angle, fascicle length), (2) the countermovement jump (CMJ (height, peak power)), (3) eccentric knee-flexor strength during the Nordic hamstring exercise, (4) sprint FVP profiling, and (5) the 1200 m shuttle run time trial (Bronco test). Following baseline measurements and using an allocation ratio of 1:1, players were assigned to one of two training groups by an investigator (FT): RST (n = 12) or short-bout HIIT (n = 12). Players within each group were matched according to their MAS (± 0.2 $m \cdot s^{-1}$), which subsequently resulted in both groups having the same baseline level of MAS (4.1 $m \times s^{-1}$), as well as peak velocity (8.7 $m \times s^{-1}$) and CMJ height (37.2 cm). Out of request by the rugby club, a control group was not applied in this study due to the ethical consideration of withholding players from training interventions that are known to enhance physical performance (Clemente et al., 2021). A description of the study design is provided in Figure 38.

Figure 38

Design of the Experimental Training Intervention



Week							
1	2	3	4	5	6	7	8
Baseline testing	Training intervention						Post testing
1. Ultrasound 2. CMJ 3. NHE 4. 40 m sprint 5. 1200 m shuttle	RST or short HIIT 2 sessions per week for six-weeks						1. Ultrasound 2. CMJ 3. NHE 4. 40 m sprint 5. 1200 m shuttle

Note. CMJ = counter-movement jump; NHE = Nordic hamstring exercise; RST = repeated-sprint training; HIIT = high-intensity interval training.

The players completed two training sessions per week across the six-week intervention that were dedicated to their respective conditioning method (i.e., RST or short-bout HIIT). The players were informed that both training methods were similar, with RST performed at a higher intensity and short-bout HIIT performed for higher volume, but the outcomes were expected to be similar. On Monday evenings, both groups were taken through the same 10 min warm-up by the team's strength and conditioning coach (BL), followed by the experimental training intervention. On Thursday evenings, all players performed a 90–120 min field-based rugby session that consisted of warm-up, the experimental training intervention, technical and tactical drills. The experimental training intervention was always performed at the beginning of training, following the warm-up. On Friday evenings, all players participated in a second field-based rugby session, that lasted for 60–90 min and involved warm-up, technical and tactical drills. The players were also assigned two full-body resistance training sessions per week, one which was completed by themselves on a

Tuesday, and one which was completed as a team after the Thursdays field-based session. Within the resistance training program, the lower-body exercises consisted of the back squat (4 sets of 2 repetitions at 90–95% of one repetition maximum), as well as 3–4 sets of 3–8 repetitions at a self-selected load for the step up, Bulgarian split squats, landmine squat, heavy sled push and bodyweight squat jump. No specific hamstring exercises (e.g., Nordics, Romanian dead lifts, leg curls) were intentionally prescribed during the intervention.

Pre- and post-intervention testing was conducted at the same time of day and running tests were performed on an outdoor, grass rugby field. There was minimal influence of wind across both testing sessions and temperature was consistent (±1°C). In the day preceding each testing session, the players were instructed to refrain from strenuous exercise involving the leg muscles (e.g., running, resistance training) and from consuming alcohol. The players were also instructed to abstain from the consumption of food and beverage other than water in the two hours prior to each testing session, and the consumption of caffeine six hours before each testing session. In addition to these restrictions, players were asked to maintain their usual nutrition during the intervention period and to wear the same footwear across both testing sessions.

To monitor external field training load, total distance, high-speed running distance, and sprint distance were recorded during each field-based training session using 10 Hz GPS units (Apex, STATSports, Newry, Northern Ireland) (Beato et al., 2018; Beato & de Keijzer, 2019; McLaren, Macpherson, et al., 2018). Relative (individualised) speed thresholds were used for each player (Murray et al., 2018), which were determined from the maximal 40 m sprint performed during baseline testing. To attain the distance of running in each speed zone, relative speed thresholds were based on the following categories: high (55–74.99%), very high (75–89.99%), and sprinting (≥ 90%) (Murray et al., 2018). There was an inadequate number of GPS units for all players, thus the same nine players from each group were selected to wear the same GPS unit across each session (Crang et al., 2021). These players were matched according to their MAS (±0.2 $m \cdot s^{-1}$), with at least one player selected from each playing position.

Internal training load was monitored via sRPE, which were recorded for each field-based training session and the wrestling sessions. The sRPE was then multiplied by the duration of each entire session to determine sRPE-training load (Dudley et al., 2023; Foster et al., 2001). The sum of all training loads for a given training week represented the weekly training load (Foster et al., 2001; McLaren, Smith, et al., 2018). The collection of sRPE was taken ~15 min after each training session (McLaren, Smith, et al., 2018) on the same players that wore the GPS units. The players provided sRPE by considering verbal anchors on a modified version (Foster et al., 2001) of the Borg CR10 Scale® (Borg, 2010). Before the first session, players were informed about the definition of perceived exertion and its scaling, including the importance of separating perceived exertion from other exercise related sensations such as pain, discomfort and fatigue (McLaren et al., 2020). Compliance to RPE data collection was 100%. Volume load (kg) and repetition counts (n) were recorded for all lower-body resistance exercises.

7.4.3 Training Programs

Full details of the training programs for both groups are provided in Table 18. Evidence from Chapters 4–6 was used to optimise the training program design. Each experimental training session was matched for duration, and the number of sets and repetitions completed, but differed in running intensity and the repetition work and rest durations. Both groups also performed straight-line efforts only and were given the same type of rest (passive) and the same inter-set rest duration (2 min). The training programs were periodised so that session volume was gradually increased across each week of the intervention, until the final week, when a reduction in volume was prescribed to optimise performance. The RST sessions were performed at maximal intensity, while the short-bout HIIT sessions were performed at sub-maximal intensity and prescribed using a proportion of the players ASR. Each player's ASR was calculated from two landmarks; peak velocity attained during the 40 m sprint, and MAS, which was established from performance in the 1200 m shuttle run test and through the use of a corrective equation (Baker & Heaney, 2015). The prescription of intensity based on the ASR has previously been shown to reduce the inter-subject variability in the acute responses to short-bout HIIT in rugby players (Julio et al., 2020). When an intensity of 25% of the ASR was applied for rugby players (Julio et al., 2020), time to exhaustion was equivalent to the completion of approximately 6 × 15 s repetitions. Therefore, short-bout HIIT was prescribed as 6 × 15 s repetitions at 25% of the ASR for training week one. To accommodate for a potential increase in fitness across the intervention period, and in observance of the players response to training, weeks 3–4 and 5–6 were prescribed at an intensity of 27.5% and 30% of the baseline ASR, respectively. To determine the distance of each 15 s interval that each player was required to run, the following calculation was performed:

$$\text{interval distance (m) at 25\% of ASR} = ((\text{peak velocity} - \text{MAS}) \times 0.25) + \text{MAS}) \times 15$$

$$\text{interval distance (m) at 27.5\% of ASR} = ((\text{peak velocity} - \text{MAS}) \times 0.275) + \text{MAS}) \times 15$$

$$\text{interval distance (m) at 30\% of ASR} = ((\text{peak velocity} - \text{MAS}) \times 0.30) + \text{MAS}) \times 15$$

where both peak velocity and MAS are given in m·s^{-1}. Players in the short-bout HIIT group were then divided into small groups based on the distance they were required to run each interval, with cones placed 1 m of each players calculated interval distance.

Each experimental training session was supervised by the investigators. To ensure that players gave maximal effort during the RST sessions, consistent, verbal encouragement was provided alongside the finishing times of each sprint. Players in the short-bout HIIT group were informed of the time throughout each run (i.e., at 7, 10, 13, 14, and 15 s) so that they would complete their assigned interval distance in 15 s, which was adhered to by all players.

Table 18

Training Program for the Repeated-sprint and Short High-intensity Interval Training Groups

	RST	Short-bout HIIT	Duration (min)
Week 1	2 × 6 × 30 m	2 × 6 × 15:15 @ 25% ASR	8
Week 2	2 × 8 × 30 m	2 × 8 × 15:15 @ 25% ASR	10
Week 3	2 × 8 × 40 m	2 × 8 × 15:15 @ 27.5% ASR	10
Week 4	3 × 6 × 40 m	3 × 6 × 15:15 @ 27.5% ASR	13
Week 5	3 × 6 × 40 m	3 × 6 × 15:15 @ 30% ASR	13
Week 6	2 × 6 × 30 m	2 × 6 × 15:15 @ 30% ASR	8

Note. RST = repeated-sprint training; short-bout HIIT = short-duration high-intensity interval training; ASR = anaerobic speed reserve. RST format = sets × repetitions × distance, on 30 s passive inter-repetition rest; short-bout HIIT format = sets × repetitions × work duration: inter-repetition rest duration (passive), with the work duration performed at a proportion of each players ASR; inter-set rest was 2 min and passive for both groups.

7.4.4 Muscle Architecture

The methods to assess BFlh architecture has been previously reported (Pollard et al., 2019; R. Timmins et al., 2016; Timmins et al., 2017). Briefly, muscle thickness, pennation angle, and fascicle length of the BFlh were determined from ultrasound images taken along the longitudinal axis of the muscle belly utilizing a two-dimensional, B-mode ultrasound (frequency, 12Mhz; depth, 8 cm; field of view, 14 x 47 mm) (GE Versana, Wauwatosa, U.S.A). The scanning site was determined as the halfway point between the ischial tuberosity and the knee joint fold, along the line of the BFlh. Once the scanning site was determined, the distance of the site from various anatomical landmarks were recorded to ensure reproducibility of the scanning site for future testing sessions. These landmarks included the ischial tuberosity, fibula head and the posterior knee joint fold at the mid-point between BF and ST tendon. All architectural assessments were performed with the participant prone on a massage plinth, after 5 mins of inactivity. The orientation of the probe was then manipulated by the assessor (RT) whose reliability has been previously reported (intraclass correlations: > 0.95, coefficient of variation: < 5.0%) (Timmins et al., 2015).

To gather ultrasound images, the linear array ultrasound probe, with a layer of conductive gel was placed on the skin over the scanning site, aligned longitudinally and perpendicular to the posterior thigh. Care was taken to ensure minimal pressure was placed on the skin by the probe as this may influence the accuracy of the measures (Klimstra et al., 2007). Finally, the orientation of the probe was manipulated slightly by the sonographer if the superficial and intermediate aponeuroses were not parallel. Once the images were collected, analysis was undertaken offline (MicroDicom, Version 0.7.8, Bulgaria). Muscle thickness was defined as the distance between the superficial and intermediate aponeuroses of the BFlh. Pennation angle was defined as the angle between the inferior aponeurosis and a fascicle of interest. The aponeurosis angle for both aponeuroses was determined as the angle between the line marked as the aponeurosis and an intersecting horizontal reference line across the captured image (Kellis et al., 2009). As the entire fascicle was not visible in the field of view of the probe, its length was estimated via the following equation (Kellis et al., 2009):

$$FL = \sin(AA + 90^\circ) x \; MT / \sin(180^\circ - (AA + 180^\circ - PA))$$

where FL = fascicle length, AA = aponeurosis angle, MT = muscle thickness, and PA = pennation angle. Fascicle length was reported in absolute terms (cm). The extrapolation measure and equation, while first used in quadriceps, has been validated against cadaveric BFlh tissue and as such is considered a robust way of estimating fascicle lengths (Kellis et al., 2009). The same assessor (RT) collected and analyzed all scans and was blinded to participant identifiers during the analysis. Results given are the average of both limbs.

7.4.5 Eccentric Knee Flexor Strength

The assessment of eccentric knee flexor strength during the Nordic hamstring exercise has been previously reported (Bourne et al., 2017; R. Timmins et al., 2016; Timmins et al., 2021). It demonstrates very good reliability (intraclass correlation coefficient =0.83–0.90; typical error, 21.7–27.5 N; typical error as a coefficient of variation, 5.8%–8.5%; minimal detectable change at a 95% confidence level, 60.1–76.2 N) (Opar et al., 2013). Athletes knelt on the device (Nordbord, Vald Performance, Albion, Australia) and had their ankles secured superior to the lateral malleolus by individual braces. Players first completed a standardised warm-up protocol (Timmins et al., 2021) and then were asked to perform three maximal repetitions by gradually leaning forward at the slowest possible speed and maximally resisting this movement with both limbs, while maintaining a neutral trunk and hips position, with their hands across their chest (Opar et al., 2013). Only the eccentric phase of the Nordic hamstring exercise was completed. Investigators ensured strict adherence to technique and athletes received verbal encouragement throughout each repetition to ensure maximal effort. The highest of the three peak values (in Newtons (N)) was used for analysis (Timmins et al., 2021).

7.4.6 Countermovement Jump

The CMJ is a common and reliable test within rugby athletes (Owen et al., 2023; Weakley, Black, et al., 2022). The assessment of CMJ performance was performed on a portable force plate (ForceDecks, VALD Performance, Brisbane, Australia). Athletes began in a standing position and were instructed to jump as high as possible while keeping their hands on their hips. The depth of the countermovement was self-selected by the athlete (Cormack et al., 2008; Pérez-Castilla et al., 2021). Participants first completed a standard warm-up protocol consisting of one repetition at 50, 75, and 90% of their perceived maximal effort, followed by three maximal trials. Jump height was analysed using the impulse-momentum method (Linthorne, 2001) and the highest jump from the three trials was used for analysis.

7.4.7 Sprint Performance

Following the assessment of muscle architecture, CMJ performance and eccentric knee flexor strength, all players completed a standardised, ~10 min, field-based warm-up, consisting of a series of dynamic movements and athletic drills (e.g., walking lunges, high-knee skips, side skips), followed by 4 × 40 m run throughs at increasing intensity (i.e., 50, 70, 80 and 90% of self-perceived maximal speed). Each player then performed two maximal 40 m sprints from a standing start position, with ~5 min rest between trials. The players were informed that no backward movement was allowed when starting (i.e., rocking to build up additional momentum), to begin each sprint at their own convenience and to give maximal effort. Loud verbal encouragement was given to all players during each sprint. To determine sprint performance, instantaneous velocity-time data was collected using a laser testing system (LaserSpeed, MuscleLab, Stathelle, Norway) sampling at 1000 Hz. The laser was positioned on a tripod 10 m behind the player and at a height of 1 m, corresponding approximately to the players centre of mass (Cross et al., 2018). It was operated remotely through connection to a laptop to limit the possible variability introduced by manual operation (Simperingham et al., 2019). Analysis of the raw data was conducted via a custom-made code in R Studio (RStudio: Integrated Development for R. Version 4.2.3, Boston, USA) with the fastest of the two trials from each athlete used for analysis. The processed data was used to determine 10, 20, and 30 m sprint times, as well as the following sprint FVP characteristics: maximal theoretical power (P_{max}), maximal theoretical force (F_0), maximal theoretical velocity (V_0), maximal ratio of horizontal force (RF_{max}), and rate of decrease in the ratio of force (D_{rf}).

7.4.8 Aerobic Fitness

To evaluate aerobic fitness, a 1200 m shuttle run test was performed, which is commonly used in rugby (Mayo et al., 2018; Vachon et al., 2021) and was part of the teams usual testing battery. The 1200 m shuttle run test has been shown to be a valid and reliable field-based measure of aerobic performance (Brew & Kelly, 2014; Kelly & Wood, 2013), and when used in conjunction with a corrective equation, can provide an estimate of MAS (Baker & Heaney, 2015). The corrective equation accounts for the time taken to change direction during the test, with 1 s per turn provided for athletes weighing over 100 kg, and 0.7 s provided for athletes weighing under 100 kg (Baker & Heaney, 2015):

Athletes over 100 kg: MAS ($m \cdot s^{-1}$) = 1200 / (time in seconds – 29)

Athletes under 100 kg: MAS ($m \cdot s^{-1}$) = 1200 / (time in seconds – 20.3)

The test was performed 5 min after the 40 m sprint and consists of a continuous 20, 40, and 60 m straight shuttle run (i.e., 20 m up and back, 40 m up and back, 60 m up and back), completed five times at a maximal effort for a total distance of 1200 m (Kelly et al., 2014). Players were required to touch each 0–20–40–60 m line with their foot, with adherence closely monitored by coaches. A hand-held stopwatch was used by the investigator to record the total time taken.

7.4.9 Statistical Analysis

The mean ± SD for pre- and post-testing sessions were calculated for all outcomes. The Shapiro-Wilk test confirmed all variables were normally distributed. Paired sample T-tests were performed to determine the within group changes for each outcome, and ANCOVA were performed to determine the between-group differences of the within group changes for each outcome, with the pre-test score entered as a covariate (Vickers & Altman, 2016). Between-group differences in training load were analysed using linear mixed models, with training group added as a fixed factor and player added as a random intercept. To aid with data interpretation, all effects were expressed as an ES corrected for small sample bias (Hedges G). Values of G = 0.2, 0.6, 1.2 and 2.0 were applied to represent small, moderate, large, and very large differences (Batterham & Hopkins, 2006). A difference was declared when the upper and lower compatibility limits (90%)

fell entirely or predominantly outside the non-substantial region (i.e., outside -0.2 to 0.2). When this was visually apparent, a MET was used to provide a probabilistic description of the CI disposition relative to the threshold for a non-substantial effect. Given that this study was not powered for definitive conclusions, we elected to present probability values for the one-sided tests (p_{MET}) as continuous estimates only, rather than declaring a fixed alpha level representing 'practical significance'. Data analysis was conducted using SPSS 29 program for Windows (SPSS, Inc, Chicago, IL, USA).

7.5 RESULTS

7.5.1 Training Load

The average weekly training loads across the interventions are presented in Table 19. Additionally, the acute demands (i.e., sRPE and external intensity metrics) of each RST and short-bout HIIT session are presented in Supplementary Tables 1 and 2. High-speed running distance was greater for short-bout HIIT and this difference was *very large*. Conversely, very-high-speed running distance and sprint distance was greater for RST, and this difference was *very large*.

Table 19

Average Weekly Training Loads Across the Intervention

	RST	Short-bout HIIT	Between group comparisons	
			p_{MET}	ES ± 90% CI
Field sessions				
sRPE-TL (au)	1574 ± 283	1599 ± 316	0.857	0.08 ± 0.19
TD (m)	9688 ± 1731	10572 ± 1837	0.281	0.50 ± 0.96
HSR (m)	1536 ± 638	2974 ± 790	0.001	2.00 ± 0.66
VHSR (m)	708 ± 163	333 ± 71	0.002	2.99 ± 1.16
SPD (m)	94 ± 25	27 ± 12	0.001	3.40 ± 1.16
Resistance training				
VL (kg)	8612 ±18	8641 ± 28	0.535	0.15 ± 1.18
Rep count (n)	113 ± 3	113 ± 4	0.723	0.12 ± 0.25

Note. RST = repeated-sprint training group; short-bout HIIT = short high-intensity interval training group; CI = compatibility interval; sRPE-TL = session rating of perceived exertion-training load; TD = total distance; HSR = high-speed running distance; VHSR = very high-speed running distance; SPD = sprint distance; VL = volume load; n = number.

7.5.2 Within-group Changes

Within-group changes in physical fitness outcomes and hamstring architecture are presented in Table 20. The RST group had a *moderate* improvement in aerobic fitness (p_{MET} = 0.07) and V_0 (p_{MET} = 0.09) when compared to baseline. Additionally, the RST group had a *moderate* increase in BFlh fascicle length (p_{MET} = 0.002) and a *small* increase in BFlh muscle thickness (p_{MET} = 0.12), as well as a *moderate* reduction in BFlh pennation angle (p_{MET} = 0.05) when compared to baseline. The short-bout HIIT group had a *moderate* improvement in aerobic fitness (p_{MET} = 0.003) and a *small* improvement in CMJ peak power (p_{MET} = 0.153) when compared to baseline. Additionally, the short-bout HIIT group had a *large* increase in BFlh fascicle length (p_{MET} < 0.001) and a *moderate* increase in BFlh muscle thickness (p_{MET} = 0.03), as well as a *small* reduction in BFlh pennation angle (p_{MET} = 0.13) when compared to baseline. All other within-group effects were inconclusive (i.e., the width of the CI crossed both a small improvement and a small impairment [≤ -0.20 and ≥ 0.20]).

Table 20

Within-group Changes in Hamstring Architecture and Physical Fitness Outcomes

	RST (*n* = 12)				Short-bout HIIT (*n* = 12)			
	Pre ±SD	Post ±SD	△ ±90% CI	ES ±90% CI	Pre ±SD	Post ±SD	△ ±90% CI	ES ±90% CI
BFlh architecture								
MT (cm)	2.72 ±0.30	2.84 ±0.24	0.12 ±0.16	0.53 ±0.48	2.83 ±0.24	2.98 ±0.29	0.15 ±0.13	0.69 ±0.51
FL (cm)	10.08 ±0.84	11.13 ±0.86	1.05 ±0.46	1.12 ±0.61	10.28 ±0.80	11.27 ±0.70	0.99 ±0.44	1.54 ±0.70
PA (°)	16.19 ±1.17	15.34 ±1.38	-0.85 ±0.64	0.69 ±0.54	16.53 ±0.91	15.86 ±1.26	-0.67 ±0.50	0.52 ±0.51
NHE (N)	375 ±70	389 ±76	14 ±25	0.26 ±0.46	409 ±61	375 ± 64	-34 ±35	-0.48 ±0.50
1200 m shuttle (s)	310 ±24	306 ±18	-4 ±5	-0.60 ±0.20	311 ± 23	301 ± 20	-10 ±4	-1.16 ±0.64
CMJ								
JH (cm)	38.5 ±6.4	39.4 ±6.2	0.9 ±1.4	0.35 ±0.51	37.5 ± 5.1	38.5 ± 4.8	1.0 ±1.2	0.42 ±0.47
PP (W·kg^{-1})	55.1 ±8.1	55.6 ±8.7	0.5 ±1.7	0.18 ±0.50	53.5 ± 5.4	54.9 ± 5.8	1.4 ±1.4	0.49 ±0.48
Sprint performance								
10 m (s)	2.16 ±0.12	2.14 ±0.09	-0.02 ±0.03	-0.34 ±0.48	2.11 ±0.05	2.14 ±0.05	0.03 ±0.04	0.41 ±0.47
20 m (s)	3.47 ±0.19	3.43 ±0.14	-0.04 ±0.04	-0.44 ±0.49	3.41 ±0.07	3.45 ±011	0.04 ±0.05	0.42 ±0.47
30 m (s)	4.69 ±0.26	4.64 ±0.20	-0.05 ±0.05	-0.49 ±0.50	4.61 ±0.12	4.67 ±0.17	0.06 ±0.06	0.45 ±0.48
Sprint characteristics								
F_0 (N·kg^{-1})	6.26 ±0.47	6.36 ±0.26	0.10 ±0.21	0.26 ±0.50	6.52 ±0.31	6.37 ±0.39	-0.35 ±0.21	-0.31 ±0.50
V_0 (m·s^{-1})	8.36 ±0.53	8.47 ±0.50	0.11 ±0.10	0.61 ±0.54	8.64 ±0.65	8.59 ±0.65	-0.05 ±0.08	-0.33 ±0.50
P_{max} (W·kg^{-1})	13.1 ±1.6	13.4 ±1.2	0.3 ±0.5	0.34 ±0.50	14.1 ±1.5	13.7 ±1.6	-0.4 ±0.5	-0.35 ±0.50
D_{rf} (%)	-7.0 ±0.5	-6.9 ±0.6	-0.1 ±0.4	-0.17 ±0.49	46.8 ±1.8	46.0 ±1.9	-0.8 ±0.4	-0.29 ±0.48
RF_{max} (%)	45.4 ±2.4	46.0 ±1.4	0.6 ±1.2	0.31 ±0.50	-7.0 ±0.8	-6.9 ±0.4	-0.1 ±0.9	-0.33 ±0.50

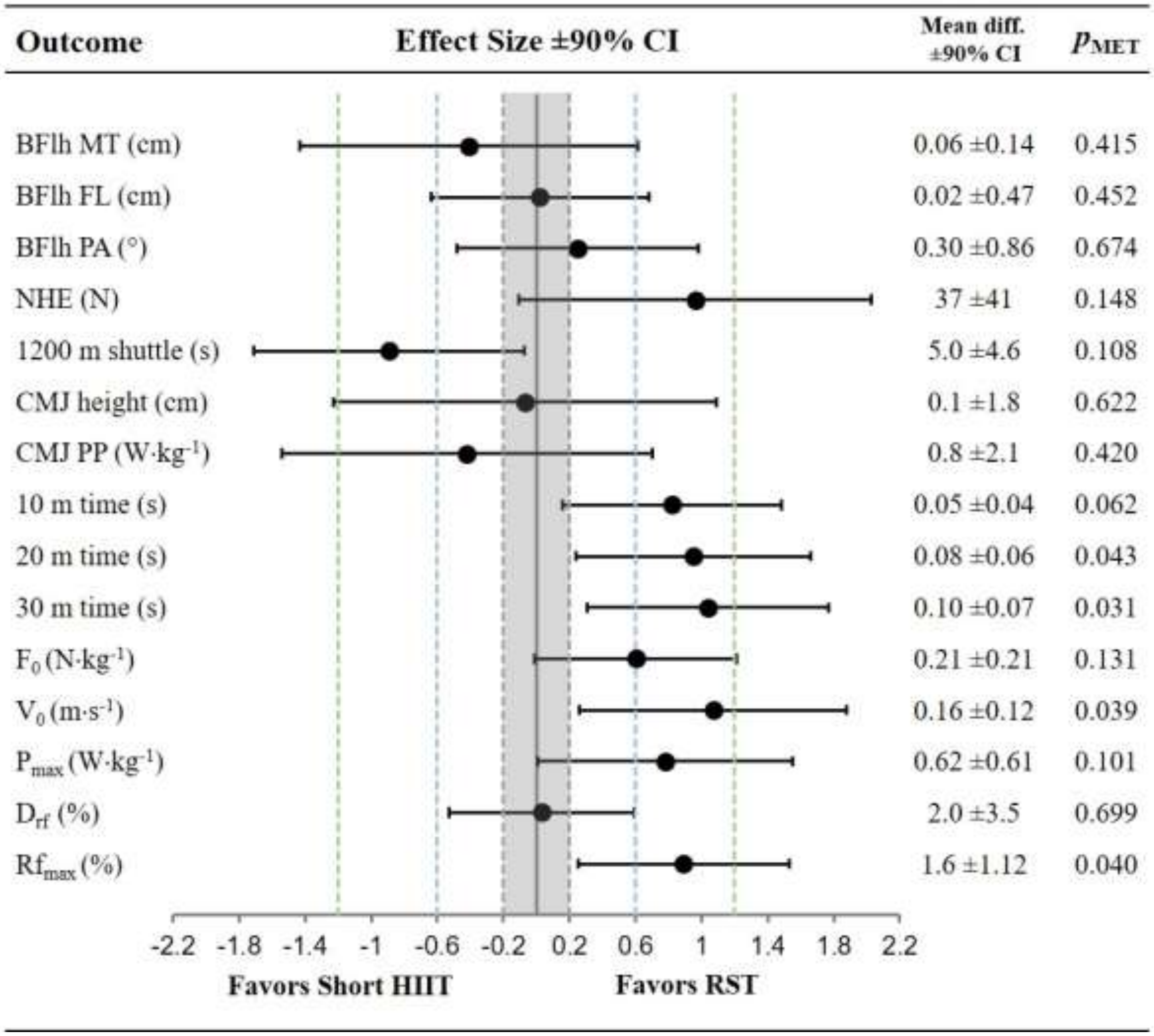
Note. RST = repeated-sprint training; HIIT = high-intensity interval training; NHE = Nordic hamstring exercise; CMJ = counter-movement jump; JH = jump height; PP = relative peak power; F_0 = maximal theoretical relative force; V_0 = maximal theoretical velocity; P_{max} = maximal theoretical relative power; RF_{max} = maximal ratio of horizontal force; D_{rf} = rate of decrease in the ratio of force; ES = effect size; CI = compatibility interval; SD = standard deviation; r = change; ° = degrees

7.5.3 Between-group Differences

Between-group differences of the within-group change in hamstring architecture and physical fitness outcomes are presented in Figure 39 (ES, 90% CI and p_{MET}). The change in aerobic fitness was greater for short-bout HIIT and this difference was *moderate.* Conversely, changes in eccentric knee flexor strength, 10 m sprint time, 20 m sprint time, 30 m sprint time, V_0, P_{max}, and RF_{max} were greater for RST (sprint times were faster) compared to short-bout HIIT, and these differences were *moderate.* All other effects were inconclusive.

Figure 39

Between Group Differences of the Within-group Change in Hamstring Architecture and Physical Fitness Outcomes



Outcome	Mean diff. ±90% CI	p_{MET}
BFlh MT (cm)	0.06 ±0.14	0.415
BFlh FL (cm)	0.02 ±0.47	0.452
BFlh PA (°)	0.30 ±0.86	0.674
NHE (N)	37 ±41	0.148
1200 m shuttle (s)	5.0 ±4.6	0.108
CMJ height (cm)	0.1 ±1.8	0.622
CMJ PP ($W \cdot kg^{-1}$)	0.8 ±2.1	0.420
10 m time (s)	0.05 ±0.04	0.062
20 m time (s)	0.08 ±0.06	0.043
30 m time (s)	0.10 ±0.07	0.031
F_0 ($N \cdot kg^{-1}$)	0.21 ±0.21	0.131
V_0 ($m \cdot s^{-1}$)	0.16 ±0.12	0.039
P_{max} ($W \cdot kg^{-1}$)	0.62 ±0.61	0.101
D_{rf} (%)	2.0 ±3.5	0.699
Rf_{max} (%)	1.6 ±1.12	0.040

Note. CI = compatibility interval; MET = minimum effects test; diff. = difference; NHE = Nordic hamstring exercise; CMJ = countermovement jump; PP = peak power; V_0 = maximal theoretical velocity; F_0 = maximal theoretical force; P_{max} = maximal theoretical power; RF_{max} = maximal ratio of horizontal force; D_{rf} = rate of decrease in the ratio of force; BFlh = biceps femoris long-head; MT = muscle thickness; FL = fascicle length; PA = pennation angle; HIIT = high-intensity interval training; RST = repeated-sprint training. Notes: grey zone = trivial effect

7.6 DISCUSSION

The aim of our study was to quantify and compare the physical adaptations between RST and short-bout HIIT, when these conditioning methods were added to a six-week pre-season training program in under 20 rugby league players. Changes in strength, sprint, and endurance performance were different for the two groups. Specifically, the improvement in aerobic fitness was greater for short-bout HIIT when compared to RST and this difference was *moderate.* Conversely, changes in eccentric knee flexor strength, linear sprint times and sprint FVP characteristics (i.e., V_0, P_{max}, RF_{max}) were greater for RST compared to short-bout HIIT, and these differences were *moderate*. Furthermore, despite the absence of specific eccentric strength training during the intervention period, increases in BFlh fascicle length were observed in both training groups (increase of ~1 cm, ~10%), but the between-group differences in hamstring architecture were inconclusive. Our findings demonstrate the diverse effects of RST and short-bout HIIT on physical performance, while providing new insights into the potential benefits of these training methods on hamstring architecture.

This is the first study to assess changes in BFlh muscle architecture in response to a training program involving RST or short-bout HIIT. Formal between-group comparisons were inconclusive (Figure 39), with similar changes within both groups, including a *large* and *moderate* increase in fascicle length for short-bout HIIT and RST, respectively, as well as *small* to *moderate* changes in muscle thickness and pennation angle. Changes in fascicle length were greater than the minimum detectable change at a 95% confidence interval, as previously assessed by Timmins et al. (40), although recognising that this was across a shorter time-period. Nonetheless, these findings may align with the work of Mendiguchia et al. (Mendiguchia et al., 2020), who demonstrated that six-weeks of conventional sprint training in addition to normal soccer preseason increased BFlh muscle thickness by 5.8 ±2.1% and BFlh fascicle length by 16.2 ±10.3%. Furthermore, these increases were substantially greater than the soccer only group, which displayed only trivial changes (BFlh muscle thickness: 1.4 ±2.0; BFlh fascicle length: -0.3 ±1.7) (Mendiguchia et al., 2020). These findings and our preliminary evidence may have implications for hamstring injury prevention and rehabilitation, with previous evidence demonstrating that athletes with prior history of BFlh strain injury have shorter fascicles and greater pennation angles on their previously injured limb when compared with the contralateral uninjured limb (Timmins et al., 2015). Furthermore, soccer players with shorter BFlh fascicles are more likely to sustain a future hamstring injury, and the probability of injury is reduced by ~ 21% for every 1 cm increase in fascicle length, which was the magnitude of change associated with both of our conditioning groups (Timmins et al., 2016).

The RST group had an increase in eccentric knee flexor strength (mean: 4% ±; 90% CI: 6%), while short-bout HIIT had a decrease (-7 ±9%). Between-group comparison of these changes suggested an effect that was mostly compatible in favour of RST (ES: 0.66 ±; 90% CI: 0.74, Figure 39). This discrepancy may be due to the diverse locomotor demands, and subsequent muscular requirements of the two training methods. The RST group attained substantially greater volumes of sprinting and very-high-speed running across the intervention (Table 19). In comparison, the short-bout HIIT group only attained 27 ±11 m of sprinting per week. At slower speeds, such as those performed during short-bout HIIT (i.e., 4.8–6.1 $m \cdot s^{-1}$), peak hamstring forces are low, but substantially increase as speeds of over 7 $m \cdot s^{-1}$ are reached (Dorn et al., 2012). Therefore, despite an absence of eccentric strength training during the intervention period, through the addition of RST, but not short-bout HIIT, the hamstrings were exposed to the necessary forces required to improve strength by a small magnitude for some players. A small, significant benefit of sprint training on eccentric hamstring strength was found by Freeman et al. (2019), with this collective evidence suggesting that RST could be used in conjunction with hamstring strength training to form part of a multi-faceted injury prevention program.

Aerobic fitness is important for performance in rugby league, given the duration of a match, the considerable distances covered at low speeds, and the need for quick recovery following high-intensity efforts (Johnston et al., 2014). Both RST and short-bout HIIT have previously been associated with substantial improvements in aerobic fitness (Clemente et al., 2021), and in our investigation, *moderate* improvements in both groups were observed (RST: -4; ±5 s vs HIIT: -10; ±4 s). Between group comparison indicated that greater improvement was associated with short-bout HIIT (ES: 0.63 ±; 90% CI: 0.59, Figure 39), which together with previous evidence, suggests that it is a more superior training method than RST for maximising aerobic fitness. Substantially greater high-speed running distances were attained with short-bout HIIT (Table 19) and cardiorespiratory demands are typically higher (Buchheit & Laursen, 2013a), with these factors appearing to stimulate enhanced adaptations of the aerobic system. We therefore recommend the application of short-bout HIIT during the general preparation stages of pre-season when greater volumes of high-speed running are accumulated and maximal improvements in running capacity are desired.

Repeated-sprint training may be best suited to the specific preparation stage of pre-season when an increase in intensity is often applied and an improvement in explosive physical qualities are sought after. Changes in sprint performance were compatible with small improvements for the RST group, whereas small impairments were compatible in the HIIT group (Table 20). Between-group comparison revealed a moderate effect in favour of RST for sprint performance when compared to HIIT (Figure 39). Furthermore, a *moderate* increase in V_0 was also found for RST vs HIIT (0.11 ±0.10 $m \cdot s^{-1}$ vs -0.05 ±0.08 $m \cdot s^{-1}$, Figure 39), which suggests that the ability to reach greater velocities during sprint acceleration may underpin the improvement in sprint times following RST. It therefore seems that the running speeds attained during short-bout HIIT (predominately 55–75% of MSS), as well as other training content, were insufficient to improve sprint performance. Together, the results from both groups support conventional wisdom that running inventions should be performed at near-to-maximal speeds to enhance sprint performance.

While an improvement in CMJ performance may not be the main target of RST and short-bout HIIT, previous evidence, including analysis from Chater 5, has demonstrated that when these training methods are implemented alongside normal training practice, small improvements are often achieved (Buchheit et al., 2008). Within our investigation, small improvements were again observed, although changes were compatible with trivial values. Between group comparisons in CMJ height and CMJ peak power were unclear (Figure 39), which may be attributed to unclear differences in resistance training load (Table 19), which would be expected to have a considerable influence on CMJ outcomes.

Our study presents evidence on the chronic effects of RST and short-bout HIIT, but there are several limitations that should be noted. First, this study was performed in conjunction with the teams normal training practice, which may influence the extent of change in our outcomes. Additionally, due to the applied nature of the study, we were not able to include a pure (no intervention) control group, meaning the observed withing-group changes of each training method may be an overestimation of their true effectiveness. Second, due to the small transducer field of view being unable to capture an entire BFlh fascicle, the measure of fascicle length is an estimation made from a validated equation (Kellis et al., 2009). However, the methodology and equation employed have been validated against cadaveric samples and show excellent agreement between dissection and estimation methods (Kellis et al., 2009).

7.7 CONCLUSIONS

For the first time, we observed positive changes in hamstring architecture with RST and short-bout HIIT, which were achieved despite an absence of eccentric hamstring strength training during a rugby league pre-season. However, it is not yet clear if the effects were augmented by other training content, if they are greater than the normal variation in hamstring muscle architecture over a 6-week period or how they differ between RST and short-bout HIIT. The RST group also had *small* to *moderate* improvements in aerobic fitness, linear sprint performance, and some sprint FVP characteristics. Short-bout HIIT on the other hand, had *greater* increases in aerobic fitness compared to RST, but had impairments in sprint performance and sprint FVP characteristics. Collectively, our findings demonstrate the benefits of these low-volume, time-efficient conditioning methods, which can be used to attain morphological, physiological, and neuromuscular adaptations in athletes when applied alongside usual training practice. Future research should investigate the effects of different RST and short-bout HIIT training programs on our outcomes, such as the inclusion of change of direction during each repetition or various training volumes. Furthermore, the application of these conditioning programs during the in-season would provide practitioners with more robust training solutions.

CHAPTER 8

FINAL DISCUSSION AND CONCLUSIONS

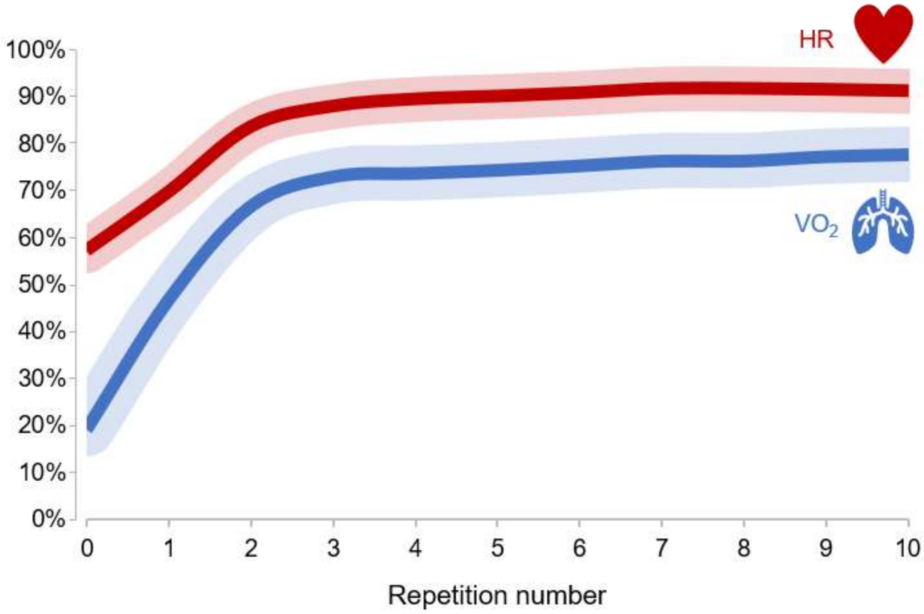
The overarching aim of this thesis was to examine the acute demands and physical adaptations of RST, while also investigating the moderating effects of programming variables. Prior to this thesis, there was a breadth of data on certain acute (i.e., heart rate, B[La], RPE, S_{dec}, S_{best}, S_{avg}) and chronic (i.e., RSA, YYIR1 distance, CMJ height, COD ability, sprint times) training outcomes. Furthermore, it was identified that there were many different RST protocols, where the application of programming variables varied considerably. Due to this variation, there was a lack of consensus on the effects of RST on the above-mentioned outcomes, while evidence on other outcomes (e.g., VO_2, sprint FVP profiles) was limited. Additionally, the moderating effects of programming variables had yet to synthesised. Therefore, Chapters 4 and 5 synthesized the acute demands and physical adaptations of RST. From these chapters, training volume was identified as programming variable that is important to the application of RST and thus, Chapter 6 explored its effects on acute physiological, perpetual, and performance demands, as well as the recovery time course of neuromuscular performance. Finally, having thoroughly investigated the effects of RST in Chapters 4–6 of this thesis, Chapter 7 compared the physical adaptations between a RST and short-bout HIIT intervention. While discussions are encompassed within each individual study, the aim of this final discussion chapter is to link the findings together. Furthermore, practical recommendations, future research suggestions and final conclusions will be provided.

8.1 THE ACUTE DEMANDS OF REPEATED-SPRINT TRAINING

Chapters 4 and 6 established that the acute physiological, neuromuscular, perceptual, and performance demands incurred during RST are substantial. RST elicits an intensive anaerobic response, as implied by a B[La] that is regularly above 10 $\mathrm{mmol \cdot L^{-1}}$. Furthermore, Chapter 4 demonstrated that coaches can expect an average VO_2 of between 70–80% of max and a HR_{avg} of 90% of max during RST. Similar findings were observed in Chapter 6, which also identified that there is an abrupt increase in VO_2 and heart rate during the first 3–4 repetitions of a set as the aerobic system attempts to maintain energy supply (Figure 40). However, likely due to the extended rest times of RST compared to its short work durations, the cardiorespiratory demands plateau as more repetitions are completed. Therefore, time above 90% of VO_{2max} is limited ($\leq$ 1 min) (Buchheit & Laursen, 2013a), which may explain why the improvement in aerobic capacity following RST is often less than other HIIT methods (Bravo et al., 2008; Clemente et al., 2021).

Figure 40

Average Heart Rate and Oxygen Consumption as a Percentage of Maximal Values Across a Set of 10 × 40 m Straight-line Repeated-Sprints



Note. Thick lines indicate the mean and the shaded zones indicate the standard deviation. The set was performed with performed with 30 s inter-repetition rest. HR = hear rate; VO_2 = oxygen consumption.

Chapter 4 established that RST is a conditioning method that is typically perceived as 'very hard' (i.e., 6.5 on a CR10 rating of perceived exertion scale). Chapter 6 investigated the perceptual demands of RST in further detail to differentiate between exertion signals and found that the dRPE for breathlessness and leg muscle exertion are similar but range from 'moderate' to 'very hard' on average, depending on the prescription of volume, sprint distance, and the number of repetitions. A sensation of exercise induced hyperventilation is common during RST, which may be the body's attempt to compensate for lactic acidosis during such intense anaerobic work and this would have a large influence on the perception of breathlessness and leg-muscle exertion.

The effects of RST on acute fatigue are diverse and depending upon the design of the training session, the fatigue response can be drastically different. Chapters 4 and 6 identified that there is often substantial within-session fatigue during RST, that causes a steep decline in sprint times across a set. Furthermore, these chapters found that the differences in CMJ height immediately following RST range from +8 to -27%. Although typically, coaches can expect a decline of around ~4–5%. Alterations in the mechanical effectiveness of sprinting may also occur during RST with reductions in maximal velocity and power (Jiménez-Reyes, Cross, et al., 2019). Additionally, leg-spring behavior is impaired during RST, as evidenced by a progressively lower vertical stiffness and an increased center of mass vertical displacement over a set of six sprints (Franck Brocherie et al., 2015b; Girard, Racinais, et al., 2011). This is accompanied by altered stride parameters (e.g., increased contact time and stride duration, reduced stride frequency and length) and ultimately, slower sprint times (Franck Brocherie et al., 2015b; Girard, Racinais, et al., 2011). While fatigue can be important for adaptation (Chiu & Barnes, 2003), adopting programming strategies to help maintain mechanical efficiency during RST would be beneficial to enhance acute sprint performance.

Table 21

Summary of the Acute Demands of Repeated-Sprint Training

Average VO_2	**Average HR**	**Peak HR**	**T > 90% VO_{2max}**
70% of max	90% of max	95% of max	≤ 1 min
B[La]	**S_{dec}**	**sRPE**	**T > 90% HR_{max}**
10.8 $mmol \cdot L^{-1}$	-5.0%	6.5 au	2.5 min

Note. Evidence adapted from Chapters 4 & 6. VO_2 = oxygen consumption; VO_{2max} = maximal oxygen consumption; HR = heart rate; HR_{max} = maximal heart rate; B[La] = blood lactate; S_{dec} = percentage sprint decrement; sRPE = session ratings of perceived exertion; au = arbitrary units; T = time.

8.2 THE PHYSICAL ADAPTATIONS OF REPEATED-SPRINT TRAINING

Chapters 5 and 7 of this thesis demonstrate that RST enhances a range of physiological, neuromuscular, and morphological qualities, which are important to athletic performance. As sprints often occur at decisive moments of competition (Faude et al., 2012; Martínez-Hernández et al., 2022), speed is crucial to many athletes. Chapter 5 found that RST consistently improves 10, 20, and 30 m sprint times by 2–3% (Taylor et al., 2015). This improvement is substantial considering that the smallest worthwhile change in short sprint performance is 1–2% (Haugen & Buchheit, 2016). RST is yet to be compared to specific sprint training methods (e.g., free, resisted or assisted sprint training), which typically enhance sprint times by 3–5% (Rumpf et al., 2016). However, Chapter 7 demonstrated that greater improvements in linear sprint times and certain sprint FVP characteristics were achieved with six-weeks of RST when compared to short-bout HIIT. Furthermore, compared to small-sided games, long HIIT, plyometric training and agility training, greater improvements in linear sprint times have also been observed with RST (Bravo et al., 2008; M. Buchheit, A. Mendez-Villanueva, et al., 2010; Chtara et al., 2017; Maggioni et al., 2019)

Beyond linear speed, RST can enhance several other explosive physical capacities, including CMJ height and COD ability. Increases in CMJ height tend to be smaller with RST compared to plyometric training (M. Buchheit, A. Mendez-Villanueva, et al., 2010), similar to short-bout HIIT (Buchheit et al., 2008) and greater than small-sided games (Seifeddine Brini, Nejmeddine Ouerghi, et al., 2020). Given the multi-directional nature of small-sided games and agility training, coaches may expect these training methods to have a larger beneficial effect on COD ability, yet similar improvements with RST have been demonstrated, which may be related to the rapid accelerations and decelerations that athletes complete with RST (Seifeddine Brini, Nejmeddine Ouerghi, et al., 2020; Buchheit et al., 2008; Chtara et al., 2017; Maggioni et al., 2019). Coaches can therefore use RST in addition, or as a replacement to agility training to improve COD ability and can incorporate shuttles or turns to replicate the biomechanical requirements of COD activity.

Morphological adaptations are attained following RST, which may enhance the force generating capacity of the leg extensor muscles. Novel evidence from Chapter 7 demonstrated a moderate increase in BFlh fascicle length (10.4 ± 8.4%), a small increase in muscle thickness (4.3 ± 9.1%), and moderate reduction in pennation angle (-5.3 ± 7.0%) following six-weeks of RST integrated into a normal rugby league pre-season. This was despite the absence of specific eccentric hamstring strength training, but recognising that other training content (e.g., field-based training), may have impacted on these results. Nonetheless, it seems that the high-speed demands of RST contribute to positive architectural changes, which may have important implications for hamstring injury prevention and rehabilitation programs (R. G. Timmins et al., 2016).

For an optimal physiological stimulus during HIIT, it is suggested that athletes should spend at least several minutes per session above 90% of VO_{2max} (Billat, 2001b; Buchheit & Laursen, 2013a; Laursen & Jenkins, 2002; Midgley et al., 2007; Midgley et al., 2006). Yet, Chapter 5 demonstrated that substantial improvements in aerobic capacity are still attained through RST despite not achieving this. From baseline, coaches can expect an increase in VO_{2max} of 2.1 $ml \cdot kg^{-1} \cdot min^{-1}$, which equates to an improvement of ~4%. While considerable, this improvement has been shown to be less than long HIIT (Bravo et al., 2008) and small-sided games (Maggioni et al., 2019), which typically elicit substantially greater time at or near VO_{2max} (Buchheit & Laursen, 2013b). Evidence about the underlying physiological reasons for how increases in VO_{2max} are achieved with RST is lacking, but there are several theories derived from investigation into sprint interval training, which refer to the role of exercise intensity being a key driver of aerobic training adaptations (Macpherson et al., 2011; Vollaard et al., 2017). The 'all out' intensity of sprint training causes the rapid depletion of phosphocreatine and glycogen after just a few repetitions, while also resulting in the accumulation of metabolic by-products (e.g., hydrogen ions, inorganic phosphate) (Girard, Mendez-Villanueva, et al., 2011; Spencer et al., 2005). Repeated exposure to these acute demands ultimately results in chronic adaptations, including mitochondrial biogenesis, and metabolic adaptations of all three energy systems (Burgomaster et al., 2008; Granata et al., 2016; Ross & Leveritt, 2001; Scalzo et al., 2014; Serpiello et al., 2012). Although, the brief duration of RST may be insufficient to induce significant increases in cardiac output, which tends to respond best to prolonged bouts of sub-maximal exercise (Blomqvist & Saltin, 1983; Clausen, 1977; Macpherson et al., 2011). Therefore, improvements in VO_{2max} with RST may predominantly arise from an enhanced ability to extract and utilise oxygen due to increased muscle oxidative handling capacity (i.e., a greater arterio-venous oxygen difference) (Macpherson et al., 2011; Sloth et al., 2013).

The ability to perform repeated intermittent bouts of high-intensity running is enhanced through RST, with moderate improvements in RSA and the YYIR1. Performance during these field-based fitness tests are associated with physical (e.g., high-speed running distance, total distance) (Black et al., 2018; Krustrup & Bangsbo, 2001; Krustrup et al., 2003; Krustrup et al., 2005; Ermanno Rampinini et al., 2007; Souhail et al., 2010; Veale et al., 2010) and game related (e.g., number of tackles, number of assists) (Cunningham et al., 2018; Fort-Vanmeerhaeghe et al., 2016a; Rampinini et al., 2008) performance during team sport competition. Evidence from Chapter 5 showed that athletes achieved a mean improvement of 252 m in the YYIR1, which is the equivalent of six shuttles. When directly compared to long HIIT and small-sided games, YYIR1 improvement is considerably greater following RST (Bravo et al., 2008; Brini et al., 2018; Eniseler et al., 2017a; Maggioni et al., 2019). Furthermore, RSA is also enhanced to a greater extent with RST when compared to long HIIT (Bravo et al., 2008), plyometric training and agility training (Chtara et al., 2017), with similar improvements compared to short-HIIT (Buchheit et al., 2008). The YYIR1 and RSA tests heavily tax both the aerobic and anerobic systems (Girard, Mendez-Villanueva, et al., 2011; Kaufmann et al., 2020; Krustrup et al., 2003), thus the substantial improvement in these tests with RST reflects its ability to concurrently enhance both energy pathways.

Table 22

Summary of the Physical Improvements Following Repeated-sprint Training

VO_{2max}	YYIR1	10 m	20 m
4.0%	16.0%	2.1%	2.2%
RSA average	**RSA decrement**	**CMJ height**	**COD ability**
1.6%	24.6%	3.3%	2.0%

Note. Evidence adapted from Chapter 5.VO_{2max} = maximal oxygen consumption; YYIR1 = Yo-Yo Intermittent Recovery Test Level 1; RSA = repeated-sprint ability; CMJ = countermovement jump; COD = change of direction.

8.3 THE EFFECT OF PROGRAMMING VARIABLES ON THE ACUTE DEMANDS AND PHYSICAL ADAPTATIONS OF REPEATED-SPRINT TRAINING

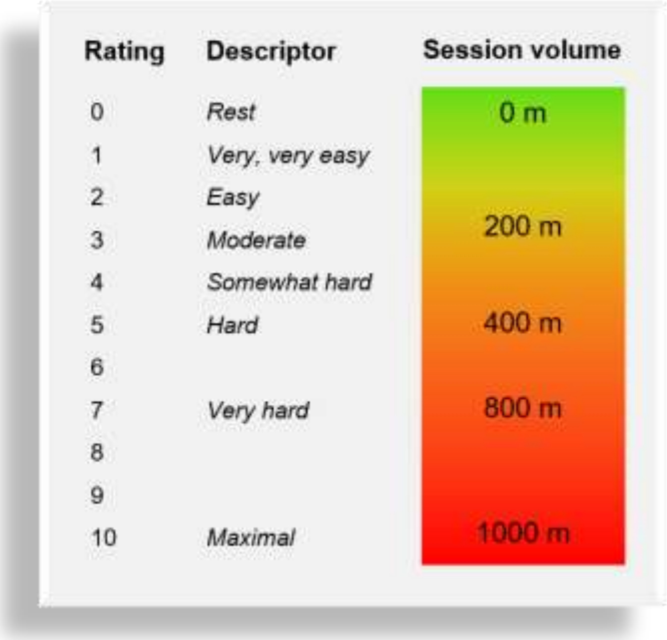
While the acute and chronic responses to RST are consistent across many protocols, findings from this thesis also demonstrate that they can also be altered through the manipulation of programming variables. The following sub-sections summarise the acute and chronic effects of manipulating RST volume, frequency, program duration, the number of repetitions per set, the number of sets per session, sprint repetition distance, rest time, rest modality, and sprint modality. Furthermore, a visual summary of the effects of programming variables on the acute demands and physical adaptations of RST are presented in Figure 44 and Table 23, respectively.

8.3.1 Volume

Chapters 4 and 5 demonstrated that RST volumes usually range from 200−1000 m per session and 400–2000 m per week. Improvements in physical performance can be achieved with low weekly volumes (400−1000 m) (Arede et al., 2022; Beato et al., 2022; M. Buchheit, A. Mendez-Villanueva, et al., 2010; Buchheit et al., 2008; Chtara et al., 2017; Galvin et al., 2013; Gantois et al., 2019; Gantois et al., 2022b; Gatterer et al., 2014; Iaia et al., 2017; Negra et al., 2022a; Rey et al., 2019), which when prescribed as individual sessions, which are typically perceived as moderate to hard and incur minimal neuromuscular fatigue (Chapter 6). This makes the application of low training volumes more useful during the in-season or at the beginning of a RST intervention. Higher volumes increase the acute physiological, neuromuscular, and perceptual demands of RST. For example, average VO_2 and heart rate was 8% higher when sessions with 800 m volume were prescribed, compared to 200 m in Chapter 6. Furthermore, Chapter 5 showed that higher weekly volumes of around 1200–1400 m per week appear to maximise physical adaptation. Coaches should consider that larger volume sessions (e.g., 800 m) are more perceptually demanding and can induce greater fatigue, thus their application is more suited to the pre-season period when greater training load is desired and tolerated (Figure 41).

Figure 41

The Approximate Relationship Between Session Volume and Ratings of Perceived Exertion During Repeated-Sprint Training



Rating	Descriptor	Session volume
0	*Rest*	0 m
1	*Very, very easy*	
2	*Easy*	
3	*Moderate*	200 m
4	*Somewhat hard*	
5	*Hard*	400 m
6		
7	*Very hard*	800 m
8		
9		
10	*Maximal*	1000 m

Note. Evidence adapted from Chapter 6.

8.3.2 Training Frequency

One RST session per week can enhance physical performance and physiological adaptation (M. Buchheit, A. Mendez-Villanueva, et al., 2010; Nedrehagen & Saeterbakken, 2015; Rey et al., 2019), or at the least, maintain fitness attributes (Beato et al., 2022; Haugen et al., 2015). However, Chapter 5 demonstrated that two RST sessions per week is more effective at improving linear speed and aerobic fitness, particularly during pre-season periods when greater sprint volumes are accumulated. Three sessions per week can be beneficial during short mesocycles, with Taylor et al. (Taylor et al., 2016) demonstrating that just six RST sessions in two weeks can lead to improvements in speed and high-intensity running performance in soccer players. Other than this application, three sessions per week is not advised and Chapter 5 found that it can have a negative influence on the development of COD ability.

8.3.3 Program Duration

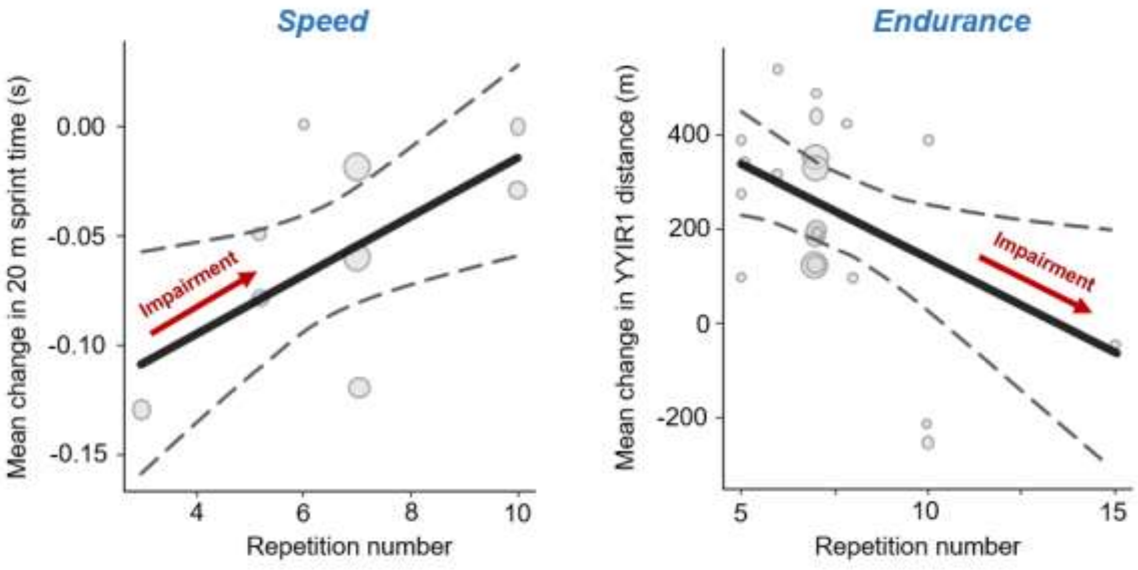
Performance improvements from RST have been observed after just two weeks (Taylor et al., 2016). However, longer program durations are more optimal to enhance adaptation, with six-weeks sufficient to achieve the established benefits of RST. Beyond this time-frame, evidence from Chapter 5 demonstrated that there are no meaningful benefits of an additional week of RST (i.e., seven weeks) on physical fitness and physiological adaptation. While original investigations are required to examine the time course of RST adaptations for programs up to 12 weeks long, current evidence from this thesis suggests that 2–6 week is a sufficient program duration for the application of RST.

8.3.4 Number of Repetitions

There are likely no additional benefits of prescribing high-repetition sets, with Chapters 4 and 5 showing that they have trivial effects on the acute physiological demands of RST (i.e., heart rate, VO_2, blood lactate), and can attenuate physical adaptations. This is due to high-repetition sets eliminating the improvements in speed and endurance that are attained with RST (Figure 42), because they tend to result in pacing strategies and/or an excessive sprint decrement, which influences the maximal nature of sprinting. Low-repetition sets (e.g., 4–6 reps) are recommended for most athletes as they support the maintenance of running velocity while still inducing a substantial metabolic and cardiorespiratory response (Gharbi et al., 2014; Weakley, Castilla, et al., 2022a), provided that RST volume is maintained through an increased number of sets or sprint distance. However, there may be an exception for endurance-based athletes, who can often sustain consistent sprint performance for 8–12 repetitions and may benefit from higher repetition sets.

Figure 42

The Effects of Manipulating the Number of Repetitions Per Set Within a Repeated-sprint Training Program on Chronic Changes in 20 m Sprint Time (Left) and Distance Achieved in the Yo-Yo Intermittent Recovery Test level One (Right)



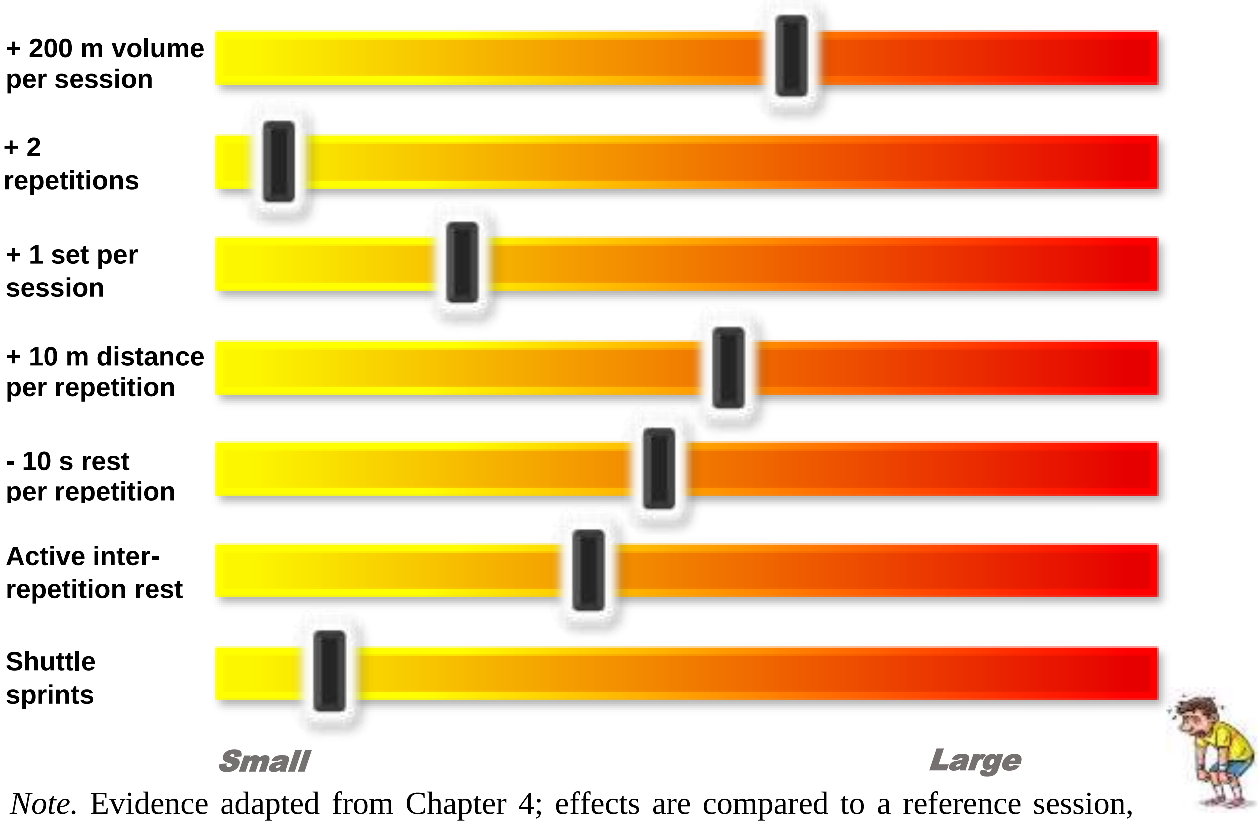
Note. Thick black lines indicate the mean change, dashed lines indicate 90% confidence intervals, and circles indicate each studies mean change with thicker circles indicating a greater sample size.

8.3.5 Number of Sets

Chapter 6 demonstrated that with an increasing number of sets during a RST session, there is a greater systemic physiological demand (Dent et al., 2015; Paulauskas et al., 2020). Most notable is the increase in time above 90% of maximal heart rate, which rises by an additional minute when a 2nd set is performed. Evidence suggests that one set per session is insufficient to attain meaningful improvements in performance (Haugen et al., 2015; Taylor & Jakeman, 2021). Therefore, to augment the acute physiological demands of RST and maximise physical adaptation, 2–3 sets per session is generally recommended. Although, four sets may be advantageous when low numbers of repetitions are prescribed (e.g., 4–6 reps), or used to increase session volume during the preparation period. To maintain the time-efficient nature of RST when a higher number of sets are implemented, Chapter 6 showed that shorter inter-set rest times (e.g., 2 min) can be applied, which allow for similar recovery of cardiorespiratory function compared to 3 min sets.

Figure 43

A Summary of the Effects of Programming Variables on Acute Physiological, Perceptual, and Neuromuscular Demands During Repeated-Sprint Training



Note. Evidence adapted from Chapter 4; effects are compared to a reference session, consisting of one set of 6 × 30 m straight-line sprints, with 20 s passive inter-repetition rest.

8.3.6 Sprint Distance

Chapters 4 and 5 found that the distance of each sprint repetition ranges from 10–40 m. Short distances (e.g., 20 m) incur greater acceleration loads and allow for consistent sprint times across each set, while increased volumes of near-to-maximal velocity sprinting were attained with longer distances (e.g., 40 m) in Chapter 6. The manipulation of sprint distance also has a considerable influence on the acute physiological demands of RST (Figure 43). For example, Chapter 4 demonstrated that sprinting 10 m further per repetition (i.e., 40 vs 30 m) increases peak heart rate by 2.5 ±2.7 b·min^{-1} and blood lactate by 2.7 ±1.2 mmol·L^{-1}. Longer sprints are also associated with increased perceived exertion, sprint decrement and neuromuscular fatigue. While sprint distance has substantial effects on the acute demands of RST, evidence from Chapter 5 indicates that it has a minor influence on physical adaptation. This is perhaps cause for a pragmatic interpretation of its role. Shorter sprints (10–20 m) may be more applicable to the in-season period and for court-based athletes, where confined spaces mean that quick linear and multi-directional movement is essential. Conversely, longer sprint distances are highly suitable during the pre-season and off-season periods, and for team sport athletes who require faster top speeds and a well-developed level of aerobic fitness.

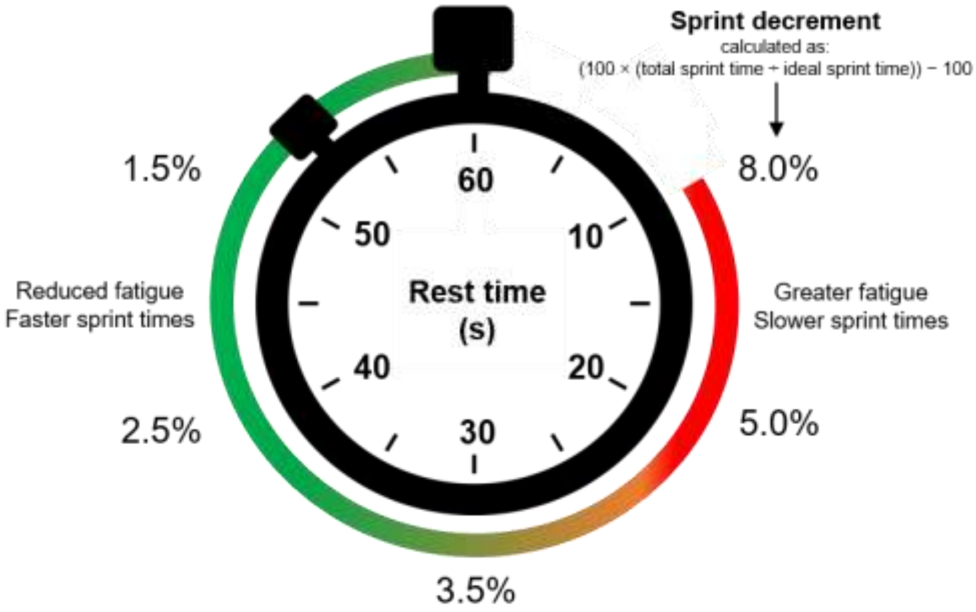
8.3.7 Rest Time

The prescription of both short (≤ 20 s) and long (≥ 30 s) inter-repetition rest times are effective during RST, but coaches can increase or reduce rest time to elicit specific acute responses and prioritise the development of certain physical qualities. Chapter 4 found that short rest times cause a higher blood lactate and greater sprint decrement. Furthermore, when short rest times are implemented over the duration of a training program, they lead to greater improvements in intermittent running performance and 200 m sprint time, compared to long rest times (Iaia et al., 2017). Longer rest times enhance the clearance of metabolic by-products and allow for increased phosphocreatine resynthesis, which assists power output (Girard, Mendez-Villanueva, et al., 2011; Little & Williams, 2007). Consequently, faster and more consistent within-session sprint times are achieved when long rest times are implemented (Figure 44), while neuromuscular fatigue is mitigated (J Padulo, M Tabben, LP Ardigò, et al., 2015). Despite the addition of a 10 s longer inter-repetition rest (i.e., 30 vs 20 s), there is no substantial change in peak heart rate (-0.7 ±1.8

b·min^{-1}). Therefore, providing athletes with a 30 s rest between repetitions maintain the physiological demands of RST while permitting faster within-session sprint performance. In the long term, this may translate into greater improvements in explosive physical qualities, with faster 20 m sprint times and improved RSA demonstrated, compared to short rest times (Iaia et al., 2017).

Figure 44

The Acute Effects of Inter-repetition Rest Time on Within Session Performance Fatigue During Repeated-Sprint training

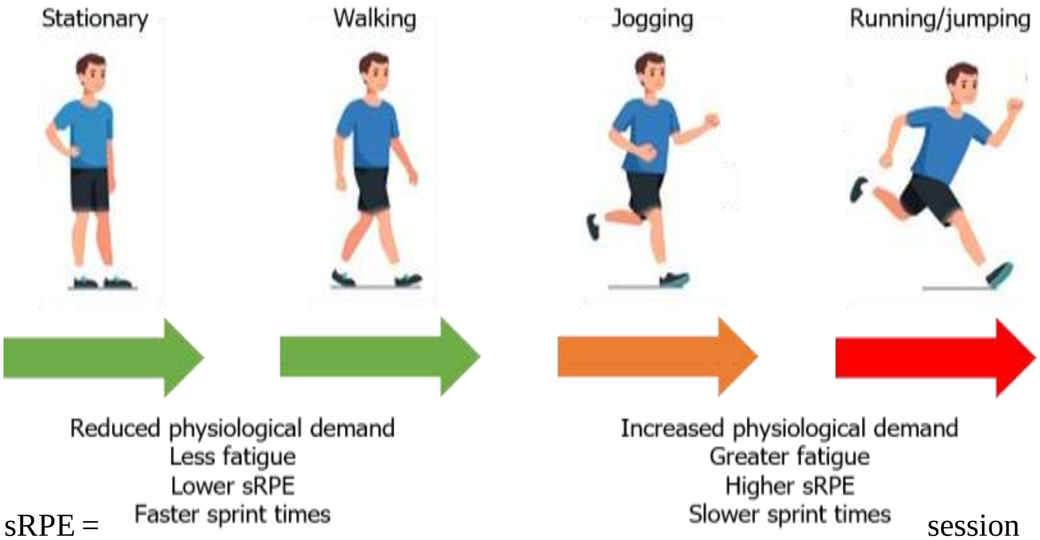


8.3.8 Rest Modality

The chronic effects of passive vs active rest on physical adaptation is yet to be compared within the literature. However, during RST, passive rest periods reduce perceived exertion and are associated with enhanced phosphocreatine resynthesis between sprints, which allows for faster sprint times across the set (Buchheit et al., 2009; Dupont et al., 2004). The acute demands of RST with active recovery are dependent on the intensity of the auxiliary activity and thus, their effects are broad. However, in general, active recovery can be used to amplify the physiological and muscular demands, without increasing sprint volume, but coaches should also be aware that higher ratings of perceived exertion and greater declines in acute sprint performance will be induced (Figure 45) (Buchheit, 2010; Buchheit et al., 2009; J Padulo, M Tabben, G Attene, et al., 2015).

Figure 45

The Effect of Exercise Intensity During the Recovery Periods of Repeated-sprint Training



Note. sRPE = session ratings of perceived exertion.

8.3.9 Sprint Modality

Evidence from Chapters 4 and 5 suggest that coaches can expect the acute demands and chronic adaptations of the different sprint running modalities to be similar, and each respectively modality can enhance physical performance. Therefore, all three sprint modalities (i.e., straight-line, shuttle, and multi-directional running) can be applied with similar results, but minor differences may be observed, such as an improved COD ability when shuttle RST programs are implemented. Additionally, shuttle sprints can elicit a slightly greater systemic physiological, metabolic, and neuromuscular load (Figure 43), which may maximise improvement in aerobic capacity. However, these responses are conditional to the number and angle of direction changes, the distance between each direction change, and the duration of each repetition (Attene et al., 2016; M. Buchheit, D. Bishop, et al., 2010; Buchheit et al., 2012; Johnny Padulo et al., 2015; Zagatto et al., 2017), which affects the absolute speeds that are attained and the muscular work performed during acceleration and deceleration.

Table 23

A Summary of the Effects of Programming Variables on the Physical Adaptations to Repeated-Sprint Training

Programming variable	Endurance	Speed	CMJ	RSA	COD
+ 1 week program duration	**o**	**o**	**o**	**o**	**o**
+ 1 session per week	**o**	**o**	**o**	**o**	**-**
+ 200 m volume per week	**o**	**o**	**o**	**o**	**o**
+ 2 repetitions per set	**o**	**o**	**o**	**o**	**o**
+ 1 set per session	**+**	**o**	**o**	**o**	**o**
+ 10 m distance per repetition	**o**	**o**	**o**	**o**	**o**
+ 10 s rest per repetition	**o**	**+**	**NA**	**o**	**NA**
Shuttle sprints	**+**	**o**	**o**	**o**	**+**

Note: Effects compared to a reference program, consisting of three sets of 6 × 30 m straight-line sprints, with 20 s inter-repetition rest, performed twice per week for six weeks (1200 m volume per week). There was insufficient evidence to summarise the effects of rest modality. CMJ = countermovement jump; RSA = repeated-sprint ability; COD = change of direction ability**.**
+ = small improvement; **-** = small impairment; **o** = no substantial change; NA = not applicable (insufficient evidence).

8.4 PRACTICAL APPLICATIONS

There are several situations where blocks of RST are useful and feasible within the training program. The following sections utilise the scientific findings from this thesis to describe these situations in detail so that they can be applied in practice. Furthermore, Tables 24 to 27 provide examples of RST prescription that can be implemented by coaches in real-world training environments.

8.4.1 Off-season

The off-season is a time for athletes to rest, recover, and regenerate from the physical and psychological demands of the previous season (Mujika et al., 2018). However, it is important that athletes maintain fitness levels during this time so that they are prepared for the elevated training demands of preseason (Mujika et al., 2018). To mitigate loss in physical capacity during the off-season, Silva et al. (2016) suggested the prescription of simple training tools in order to facilitate compliance to offseason programs and recommended a ‘minimum effective training dose’ to maintain or at least attenuate the loss of physiological and neuromuscular qualities. RST can be used during the off-season to maintain exposure to maximal velocity, acceleration, deceleration and COD, while enhancing aerobic and anaerobic fitness qualities. Because RST is a training method that provides both a considerable physiological and neuromuscular stimulus, it may reduce the necessity for the frequent prescription of isolated training contents during the off-season (e.g., traditional strength or endurance training). Furthermore, given that the application of RST requires minimal equipment, time and space, it is ideal for when athletes are away from their usual training environments. To maintain exposure to various movement patterns, coaches can prescribe different sprint modalities across the same session, week or program (Eniseler et al., 2017a; Lapointe et al., 2020). For example, straight-line sprints could be assigned to set 1, shuttle sprints assigned to set 2 and multi-directional sprints assigned to set 3 (Table 24). Multi-directional sprints can incorporate a range of different sequences (i.e., various angles and courses; Figure 46) and may be particularly beneficial for team sports that are played under 360° conditions, such as American

Football, soccer, hockey, and Australian Rules Football. As athletes are often training unsupervised during the offseason period, prescribing recovery on time-cycles will allow athletes to easily manage their own session (e.g., sprints starting every 30 s).

Figure 46

Programming Options for the Application of Multi-directional Repeated-Sprint Training

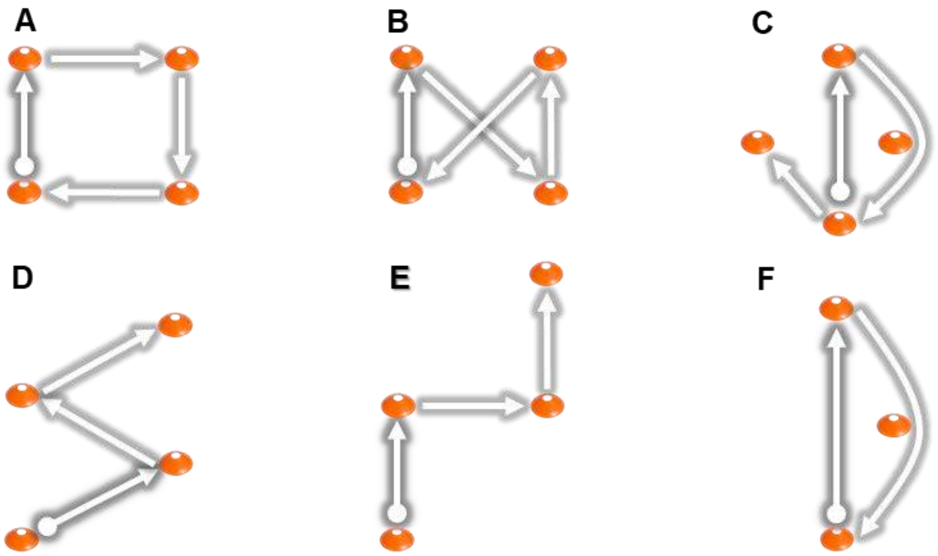


Table 24

Example of a One Week Repeated-Sprint Training Program During the Off-season

Training content	Session 1	Session 2

Aim	Enhance physical performance + expose athletes to various movement demands	Enhance physical performance + expose athletes to various movement demands
Sets × repetitions	3 × 6	3 × 6
RST modality	Set 1: Straight-line Set 2: Shuttle (1 × COD) Set 3: Multi-directional	Set 1: Straight-line Set 2: Shuttle (2 × COD) Set 3: Multi-directional
Repetition distance	30 m	30 m
Inter-repetition rest	On 30 s, passive	On 30 s, active (see Figure 47 for options)
Inter-set rest	3 min, passive	3 min, passive
Session duration	15 min	15 min
Prescribed volume	540 m	540 m
Est. volume >90% MSS	200 m	0 m
Physiological demand	Moderate	High
Neuromuscular demand	Moderate	Moderate
Perceptual demand	Moderate	High
Progression	+10 m distance, +1 set,	+10 m distance, +1 set

Note. RST = repeated-sprint training; COD = change of direction; MSS = maximal sprint speed; min = min; m = metre; s = second

8.4.2 Preparation Period

The preparation period or 'pre-season' is a crucial time for athletes to improve their fitness and physical preparation for the upcoming season. Following a general preparation block, RST can be administered during the specific preparation phase, where there is often a small reduction in volume and an increase in training intensity (Joyce & Lewindon, 2014). Sessions that are more demanding on the physiological and neuromuscular systems can be prescribed during this time to maximise adaptation (Table 25). This may include longer sprints (30–40 m), active recovery, and a greater weekly RST volume (1200–1600 m). Coaches may wish to implement sets between technical and tactical drills or include additional modifications during or after sprint efforts (Figure 47). The objective of administering additional modifications is to provide a further physiological stimulus and/or execute movement patterns that are transferable to sport-specific actions.

Figure 47

Additional Modifications to Repeated-Sprint Training that can Alter the Training Stimulus

Between sets and repetitions:

- Jumps/skipping
- Squats
- Lateral shuffling
- Push-ups
- Planks and sit-ups
- Medicine ball throws
- Tackling
- Wrestling/grappling
- Passing
- Shooting
- Dribbling
- Small-sided games

Within repetitions:

- Short deceleration zones
- Decision making
- Velocity-loss thresholds
- Curved-linear sprints
- Hill sprints
- Wearable resistance
- Three-point starts
- Kneeling starts
- Beach starts
- Flying starts
- Side starts
- Lateral shuffling starts

Table 25

Example of a One Week Repeated-Sprint Training Program During the Pre-season

Training content	Session 1	Session 2

Aim	Enhance physical performance + expose athletes to max velocity	Enhance physical performance + expose athletes to COD
Sets × repetitions	4 × 5	4 × 5
RST modality	Straight-line	Shuttle (2 × COD)
Repetition distance	40 m	30 m (10 + 10 + 10)
Inter-repetition rest	On 30 s, passive	On 30 s, passive
Inter-set rest	2 min, passive	2 min, passive
Session duration	18 min	18 min
Prescribed volume	800 m	600 m
Est. volume >90% MSS	200 m	0 m
Physiological demand	High	High
Neuromuscular demand	High	High
Perceptual demand	Moderate	Moderate
Progression	Active recovery with sport specific actions, +2 repetitions,	Active recovery with sport specific actions, +2 repetitions

Note. RST = repeated-sprint training; COD = change of direction; MSS = maximal sprint speed; min = min; m = metre; s = second

8.4.3 Competition Period

Consistent performance across a season is crucial to the success of the team, and as such, recovery between games is paramount (Mujika et al., 2018). Additionally, technical and tactical practice is prioritised to fine-tune elements of match-play (Gamble, 2006). The time assigned for isolated physical training is subsequently reduced during the competitive season, which makes the need for efficient and effective training methods even more important (Gamble, 2006). While a reduction in training load is necessary to help manage the in-season stress on athletes, intensity should be maintained to avoid a slump in performance (Connolly & White, 2017; Slattery et al., 2012). Given that RST is time-efficient, low volume, high-intensity, and quickly recovered from, its application during the competition period is highly suitable. Low volume (< 820 m), in-season RST interventions have been shown to significantly improve a range of physical qualities (M. Buchheit, A. Mendez-Villanueva, et al., 2010; Chtara et al., 2017; Iaia et al., 2017; Nedrehagen & Saeterbakken, 2015; Rey et al., 2019). Furthermore, when training and competition schedules are particularly congested, just one low-volume RST session per week, administered for 6–8 weeks, maintained (Beato et al., 2022) and improved (Rey et al., 2019) 10 and 20 m sprint times, RSA, intermittent running performance, and COD ability in young soccer players. Therefore, coaches may wish to implement RST at the beginning of in-season training sessions when athletes are least fatigued (i.e., as part of an extended warm-up), with just two sets of 4–6 repetitions × 20–30 m sprints (Table 26) providing a sufficient stimulus for adaptation.

For players who are not selected in the weekly team or for those playing limited minutes, ‘top-up’ conditioning sessions are required to maintain a state of preparedness. In these instances, RST can provide adequate exposure to the intensity of competition and required volume of high-speed running. Within a single 10 min RST session consisting of two sets of 5 × 40 m straight-line sprints with 30 s rest, Chapter 6 demonstrated that athletes attain 130 ±101 m of sprinting (> 90% of maximal speed) and 454 ±30 m of high-speed running (> 55% of MSS). Additional modifications to RST for top-up conditioning sessions could be easily implemented by coaches to permit the practice of movement skills under accumulating fatigue and incorporate physical contact into the session.

Table 26

Example of a One Week Repeated-Sprint Training Program During the Competition Period

Training content	Session 1	Session 2
Aim	Maintain physical performance + exposure to max acceleration	Maintain physical performance + exposure to COD
Sets × repetitions	2 × 5	2 × 5
RST modality	Straight-line	Shuttle (1 × COD)
Repetition distance	20 m	20 m (10 + 10)
Inter-repetition rest	On 30 s, passive	On 30 s, passive
Inter-set rest	2 min, passive	2 min, passive
Session duration	7 min	7 min
Prescribed volume	300 m	200 m
Est. volume >90% MSS	80 m	0 m
Physiological demand	Low	Low
Neuromuscular demand	Low	Low
Perceptual demand	Low	Low
Progression	+ 1 set, +10 m distance	+10 m distance, +1 COD, + 1 set

Note. RST = repeated-sprint training; COD = change of direction; MSS = maximal sprint speed; min = min; m = metre; s = second

8.4.4 Return to Competition from Injury

The return to sport following injury is a multifactorial process that requires an athlete to meet a number of individually tailored criteria before they can safely and effectively resume competition (Blanch & Gabbett, 2016; Joyce & Lewindon, 2015). An important component of this process is the return to competition phase, where the athlete must successfully progress through a period of training involving sport-specific loading, including volumes of high-speed running and sprinting which could be expected during matches (Blanch & Gabbett, 2016; Gabbett et al., 2021; Gabbett, 2020; Whiteley et al., 2021). RST can be administered during this phase to help prepare an athlete for the intensity of competition and may transfer to the performance of repeated-high intensity efforts, which appear frequently at critical times during a game (Austin et al., 2011; McLaren, Weston, et al., 2016; Serpiello et al., 2018). Shorter sprint distances (e.g., 20 m) and longer rest times (≥ 30 s) are initially advised to limit the physiological stress and musculoskeletal strain on the athlete (Table 27). Sessions can then be progressively increased in volume and complexity through the incorporation of longer sprint distances, changes of direction, physical contact and sport-specific actions. Coaches should also consider that high-intensity efforts usually occur in small clusters within a game (Austin et al., 2011; Barron et al., 2016; M.-v. Buchheit et al., 2010; Dawson, 2012c; Serpiello et al., 2018; Spencer et al., 2004), thus it is more beneficial to administer multiple sets of low repetitions (e.g., 4 sets of 3–5 reps), rather than long series of exhaustive sprints that are more likely to exacerbate fatigue.

Table 27

Training content	Session 1	Session 2

Aim	Introduce max effort sprinting and sport skills under fatigue	Introduce COD and sport skills under fatigue
Sets × repetitions	3 × 4	3 × 4
RST modality	Straight-line	Multi-directional
Repetition distance	20 m	20 m (5 + 5 + 5 + 5)
Inter-repetition rest	30 s, passive	30 s, passive
Inter-set rest	4 min, active (sport-specific skills)	4 min, active (sport-specific skills)
Session duration	15 min	15 min
Prescribed volume	240 m	240 m
Est. volume >90% MSS	50 m	0 m
Physiological demand	Moderate	Moderate
Neuromuscular demand	Moderate	Moderate
Perceptual demand	Moderate	Moderate
Progression	+10 m distance, + 1 set, + contact	+ 10 m distance, + 1 set, + contact

Example of a One Week Repeated-Sprint Training Program for an Athlete Returning to Competition from Injury

Note. RST = repeated-sprint training; COD = change of direction; MSS = maximal sprint speed; min = min; m = metre; s = second

8.5 LIMITATIONS

The four studies within this thesis contribute extensively to the body of literature on RST, but they also have some limitations. The following paragraphs describe these limitations with the hope that future research can benefit and be guided from their acknowledgement.

A key issue that influences the results of all studies within this thesis is that both the acute and chronic responses to RST may vary according to individual differences in athlete physiology (e.g., muscle fibre typology, energy substrate utilization, aerobic fitness) and these effects were not investigated. Athletes with a lower level of fitness have been shown to fatigue more quickly during RST (Alizadeh et al., 2010), but also achieve greater improvements in aerobic performance (Sanchez-Sanchez et al., 2019). This has implications for the prescription of RST programs, where athletes of a lower fitness level, or have a greater propensity for speed, may benefit most from performing slightly less volume [120], divided across fewer successive repetitions and over additional sets with longer inter-repetition rest times (e.g., 4 sets of 4 reps with 30 s rest). Conversely, endurance athletes would favour a higher volume [120] and higher repetition session with short inter-repetition rest (e.g., 3 sets of 8 reps with 15 s rest), while those in between could be prescribed a more traditional protocol (e.g., 3 sets of 6 reps with 20 s rest).

The interpretation of the results of both meta-analysis (Chapters 4 & 5) were affected by the absence of real-world anchors for practically significant changes in our outcomes (e.g., B[La], VO_{2max}). Furthermore, the magnitude of practically significant change in some other outcomes, such as heart rate, lacks clear consensus within the literature. Therefore, we relied on standardised

ES or (at times) limited data to examine the magnitude of change in our outcomes and the moderating effects of programming variables. Investigation into the magnitude of change in acute (i.e., B[La], heart rate, VO_2) and chronic outcomes (i.e., VO_{2max}), that is practically important in athletes, would enhance the application of RST in the future.

Building upon the work of Chapter 4, Chapter 6 investigated the acute effects of session volume, sprint distance and the number of repetitions in detail. These three programming variables were manipulated to provide four different RST conditions, that represented a broad range of RST volumes and protocols used in practice. Rest times was subsequently standarised across all four conditions so that 30 s recovery periods were provided between sprints. This amount of time was chosen as Chapter 4 demonstrated that it allowed for an improved acute sprint performance, while maintaining physiological demands. However, this approach meant that the work to rest ratios of the conditions were subsequently different, and this is expected to influence the acute demands. The application of work to rest ratios in a sporting environment is logistically difficult because the time taken to perform each sprint varies between repetitions and athletes. However, practitioners should consider the effects of different work to rest ratio’s when designing RST programs. It is also important to note that while our elected reference adjustments of 10 m and 10 s allow for comparison between sprint distance and inter-repetition rest time in Chapters 4 and 5, this will not always represent the same relative change and will also alter the work to rest ratio.

8.6 RECOMMENDATIONS FOR FUTURE RESEARCH

The current thesis has examined and answered a range of research questions. However, with this improved understanding of RST, further research questions are now apparent. The following paragraphs suggest future research which would benefit the field of exercise and sports science.

There is an abundance of evidence on the acute effects of RST on certain outcomes (e.g., B[La], sRPE, S_{dec}) but there are other important outcomes which require greater investigation. Chapter 4 identified that acute neuromuscular outcomes were represented in just 13 studies, with 10 of these investigating the change in CMJ height following RST (Figure 9), and due to the diverse methodological approaches to jump measurement (e.g., different testing equipment and protocols), the findings were heterogeneous and could only be qualitatively synthesised. While Chapter 6 of this thesis added to the body of literature on this topic, the findings were inconclusive and further research with larger sample sizes would be useful to better understand the effects of RST on neuromuscular fatigue. Furthermore, sprint FVP profiling and the assessment of SMM parameters provide evidence of the underlying neuro-mechanical factors that are influenced by fatigue during RST, but these outcomes were represented in just one and two studies, respectively (Figure 9). Given the maximal intensity in which RST is performed, a potential barrier for its application within sporting settings are its acute effects on the neuromuscular and musculoskeletal systems. Despite Chapter 6 demonstrating that neuromuscular fatigue is typically low, further research in this area would strengthen the body of evidence, which could potentially increase the application of RST.

The body of research on the chronic effects of RST on physical performance is now extensive, with Chapters 5 and 7 of this thesis highlighting the effectiveness of RST as a multi-component training method. However, underlying physiological reasons for the improvements in aerobic capacity and intermittent running performance that is often observed after RST interventions is lacking, and this thesis has only been able to speculate on these mechanisms. Specifically, chronic changes in cardiac output and the arterio-venous difference following RST is unknown, and this knowledge could be used to optimise the prescription of RST, particularly if different training protocols were compared.

The moderating effects of programming variables have been comprehensively studied within this thesis. Although, there are several programming variables that require further investigation. The effects of passive vs active recovery on physical adaptations is yet to be examined, while the acute and chronic effects of manipulating rest time is also limited. Due to the dearth of additional modifications that can be made to RST (Figure 47), knowledge regarding their influence would allow coaches to select the most effective modifications to meet training aims. One important finding of this thesis has been that the prescription of small groups of repetitions is generally a more effective training prescription than large repetition sets. However, as training volume is important to adaptation, future research should investigate the acute and chronic effects of manipulating sets and repetitions within volume-matched protocols (i.e., 2 sets of 10 repetitions vs 4 sets of 5 repetitions).

8.7 THESIS CONCLUSIONS AND KEY FINDINGS

Repeated-sprint training is a highly effective and time-efficient training method that can be used to prepare athletes for the intensity of competition and enhances a range of physical performance outcomes. To summarise the main findings from this thesis:

- The substantial acute physiological demands of RST are demonstrated by an end-set blood lactate of 10.8 $\text{mmol}\cdot\text{L}^{-1}$, an average heart rate of ~90% of max and an average VO_2 of ~70% of max. Sessions are perceived to be hard, but given they are short in duration, sRPE-TL is low, between 25–135 au.
- RST may incur a temporary reduction in neuromuscular performance, which is commonly demonstrated by a ~ 4–5% decline in CMJ height. However, restoration of muscle strength and power is often restored by 24 hours, irrespective of session volume.
- Shorter inter-repetition rest periods (≤ 20 s) and longer repetition distances (> 30 m) increase physiological demands and cause greater reductions in acute sprint performance. Conversely, longer inter-repetition rest periods (≥ 30 s) and shorter repetition distances (≤ 20 m) enhance acute sprint performance and reduce the physiological demands.
- RST concurrently improves a range of physiological, neuromuscular, morphological, and performance outcomes. It is associated with an improvement in linear and multi-directional sprint times by 2–3%, CMJ height and eccentric hamstring strength by 3%, aerobic capacity by 4%, biceps-femoris fascicle length by 9%, and YYIR1 distance by 16%.

- The prescription of three sets of 6 × 30 m sprints, twice per week for 6 weeks is an effective training program to achieve the established benefits of RST. Performing an additional set per session may further enhance improvement in YYIR1 distance without compromise to other physical qualities.

- Higher repetition sets (e.g., 8–12 reps) are not associated with any beneficial effects on acute demands or chronic adaptations and may impair some outcomes. Training sessions that incorporate small groups of repetitions performed over multiple sets (e.g., 3–4 sets of 4–6 repetitions) appear to be a more effective programming strategy.
- RST can be effectively implemented across all phases of the annual training plan (i.e., off-season, preparation period, competition period and return to competition from injury) by manipulating programming variables to achieve desired outcomes.

CHAPTER 9

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CHAPTER 10

APPENDICES

APPENDIX 1. Modified Downs and Black scale outcomes for the assessment of reporting quality and risk of bias in Study 1.

Study	Item number														Total score (out of 14)
	1	2	3	6	7	10	12	15	16	18	20	22	23	25	
Abt et al. (2011)	1	1	0	1	1	1	0	0	1	1	1	0	0	1	9
AbuMoh'd and Abubaker (2020)	1	1	0	1	1	1	0	1	1	1	1	0	1	1	11
Aguiar et al. (2008)	1	1	1	1	1	0	0	0	1	1	1	0	1	0	9
Akenhead et al. (2017)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Alemdaroğlu et al. (2018)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Almansba et al. (2019)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Alizadeh et al. (2010)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Altimari et al. (2021)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Archiza et al. (2018)	1	1	1	1	1	1	0	1	1	1	1	0	1	1	12
Attene et al. (2016)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Ayarra et al. (2018)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Aziz et al. (2000)	1	1	1	1	1	0	0	0	1	1	1	0	0	0	8
Baldi et al. (2016)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Balsalobre-Fernández et al. (2014)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Beato et al. (2019)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	10
Beato et al. (2022)	1	1	1	1	1	0	0	0	1	1	1	0	1	0	9
Beato and Drust (2021)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	9
Beaven et al. (2018)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Binnie et al. (2014)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Martyn J Binnie et al. (2013)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
M. J. Binnie et al. (2013)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Blasco-Lafarga et al. (2020)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
J. H. Borges et al. (2016)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10
Brahim et al. (2016)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
S Brini et al. (2020)	1	1	0	1	1	0	0	0	1	1	1	0	0	1	8
Seifeddine Brini, Abderraouf Ben Abderrahman, et al. (2020)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Brini et al. (2018)	1	1	1	1	1	0	0	0	1	1	1	0	1	0	9
Brini, Delextrat, et al. (2021)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Brini, Boullosa, et al. (2021)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Brocherie et al. (2014)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Franck Brocherie et al. (2015a)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
F. Brocherie et al. (2015)	1	1	1	1	1	1	0	1	1	1	1	0	1	1	12
Broderick et al. (2019)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
M Buchheit (2012)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Buchheit (2010)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
M. Buchheit, D. Bishop, et al. (2010)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Buchheit et al. (2012)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Campa et al. (2019)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Campos et al. (2021)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Campos-Vazquez et al. (2015)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	10
Caprino et al. (2012)	1	1	1	1	1	0	0	0	1	1	1	0	0	0	8
Castagna et al. (2008)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Castagna et al. (2007)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Chaouachi et al. (2010)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Charlot et al. (2016)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Chen et al. (2019)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Clifford et al. (2016)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Corrêa et al. (2016)	1	1	1	1	1	0	0	0	1	1	1	0	0	0	8
Costello et al. (2021)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Cuadrado-Peñafiel et al. (2014)	1	1	1	1	1	0	0	0	1	1	1	0	0	0	8

Study	**Item number**														**Total score (out of 14)**
	1	**2**	**3**	**6**	**7**	**10**	**12**	**15**	**16**	**18**	**20**	**22**	**23**	**25**	
da Silva et al. (2010)	1	1	1	1	1	0	0	0	1	1	1	0	0	0	8
Dal Pupo et al. (2013)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Dal Pupo et al. (2017)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Daneshfar et al. (2018)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Dardouri et al. (2014)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
de Andrade et al. (2021)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Delextrat et al. (2014)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Delextrat and Kraiem (2013)	1	1	1	1	1	1	1	0	1	1	1	0	0	1	11
Delextrat et al. (2013)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Dellal et al. (2015)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Dellal and Wong (2013)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Dent et al. (2015)	1	1	0	1	1	0	0	0	1	1	1	0	0	1	8
Donghi et al. (2021)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Doyle et al. (2020)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Dupont et al. (2010)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Dupont et al. (2005)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	10
Eliakim et al. (2012)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Elias et al. (2012)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Elias et al. (2013)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Eniseler et al. (2017b)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Eryılmaz and Kaynak (2019)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Eryılmaz et al. (2019)	1	1	1	1	1	0	0	0	1	1	1	0	0	0	8
Essid et al. (2021)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Farjallah et al. (2020)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Figueira et al. (2021b)	1	1	1	1	1	0	0	0	1	1	1	0	0	0	8
Fornasier-Santos et al. (2018)	1	1	1	1	1	0	0	1	1	1	1	0	1	0	10
Fort-Vanmeerhaeghe et al. (2016b)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Fortin and Billaut (2019)	1	1	1	1	1	0	0	1	1	1	1	0	0	1	10
Freitas et al. (2016)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Gabbett (2010)	1	1	0	1	1	1	0	0	1	1	1	0	0	0	9
T. J. Gabbett et al. (2011)	1	1	0	1	1	1	0	0	1	1	1	0	0	0	8
T. Gabbett et al. (2011)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Gabbett et al. (2008)	1	1	0	1	1	1	0	0	1	1	1	0	0	0	9
Galvin et al. (2013)	1	1	1	1	1	1	0	1	1	1	1	0	1	1	12
Galy et al. (2015)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Gantois et al. (2017)	1	1	0	1	1	0	0	0	1	1	1	0	0	0	7
Gantois et al. (2019)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Gantois et al. (2018)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
García-Unanue et al. (2020)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Gatterer et al. (2015b)	1	1	1	1	1	1	0	1	1	1	1	0	1	1	12
Gharbi et al. (2014)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Gharbi et al. (2015)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Gibson et al. (2013)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10
Girard et al. (2018)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Girard, Racinais, et al. (2011)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
González-Frutos et al. (2022)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Gonzalo-Skok et al. (2016)	1	1	1	1	1	0	0	0	1	1	1	0	1	1	10
Goodall et al. (2015a)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Hamlin (2007)	0	1	1	1	1	0	0	0	1	1	1	0	1	1	9
Hamlin et al. (2017)	1	1	1	1	1	0	0	1	1	1	1	0	1	1	11
Hammami et al. (2019)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
T. Haugen et al. (2014)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Haugen et al. (2015)	1	1	1	1	1	0	0	0	1	1	1	0	1	1	10
Hermassi et al. (2018)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Higham et al. (2013)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9

Study	**Item number**														**Total score (out of 14)**
	1	**2**	**3**	**6**	**7**	**10**	**12**	**15**	**16**	**18**	**20**	**22**	**23**	**25**	
Hollville et al. (2018)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Howatson and Milak (2009)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Iaia et al. (2015)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Iaia et al. (2017)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Impellizzeri et al. (2008)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Ingebrigtsen et al. (2014)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Ingebrigtsen et al. (2012)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Iacono et al. (2016)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10
Izquierdo et al. (2002a)	1	1	1	1	1	0	0	1	1	1	1	0	1	1	11
Jang and Joo (2020)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Jiménez-Reyes, Cross, et al. (2019)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Johnston and Gabbett (2011)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Joo Joo (2016)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
G. Jorge et al. (2020)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Kaplan (2010)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Keir et al. (2013)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Keogh et al. (2003)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Kilduff et al. (2013)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Klatt et al. (2021)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Krakan et al. (2020)	1	1	0	1	1	1	0	0	1	1	1	0	0	0	8
Krueger et al. (2020)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Lakomy and Haydon (2004)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Lapointe et al. (2020)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Le Rossignol et al. (2014)	1	1	1	1	1	0	0	0	1	1	1	0	0	0	8
Little and Williams (2007)	1	1	0	1	1	0	0	0	1	1	1	0	0	0	7
Robert G. Lockie et al. (2016)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Lockie et al. (2020)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Lockie et al. (2019)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Lombard et al. (2021)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Madueno et al. (2018)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Maggioni et al. (2019)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10
Mancha-Triguero et al. (2021)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Marcelino et al. (2016)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Matzenbacher et al. (2016)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
McGawley and Andersson (2013)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Meckel et al. (2018)	1	1	0	1	1	0	0	0	1	1	1	0	0	1	8
Meckel, Gottlieb, et al. (2009)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Meckel, Machnai, et al. (2009)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Meckel et al. (2015)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Meckel et al. (2014)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Michalsik et al. (2015)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Mohr et al. (2016)	1	1	1	1	1	0	0	0	1	1	1	0	1	1	10
Mohr and Krustrup (2016)	1	1	1	1	1	0	0	0	1	1	1	0	1	1	10
Mohr et al. (2012)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Moncef et al. (2012)	1	1	1	1	1	0	0	0	1	1	1	0	0	0	8
Morcillo et al. (2015)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Moreira et al. (2015)	1	1	1	1	1	0	0	0	1	1	1	0	0	0	8
Mujika et al. (2009)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Müller et al. (2021)	1	1	0	1	1	1	0	0	1	1	1	0	0	0	8
Okuno et al. (2013)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Nakamura et al. (2009)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Nascimento et al. (2015)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10
Nedrehagen and Saeterbakken (2015)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10
Nikolaidis et al. (2015)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Padulo et al. (2016)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10

Study	Item number														Total score (out of 14)
	1	2	3	6	7	10	12	15	16	18	20	22	23	25	
Padulo et al. (2014)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Johnny Padulo et al. (2015)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
J Padulo, M Tabben, G Attene, et al. (2015)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
J Padulo, M Tabben, LP Ardigò, et al. (2015)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Paulauskas et al. (2020)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Perroni et al. (2013)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Petisco et al. (2019)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Purkhús et al. (2016)	1	1	1	1	1	0	0	0	1	1	1	0	1	0	9
Pyne et al. (2008)	1	1	1	1	1	0	0	0	1	1	1	0	0	0	8
Ramírez-Campillo et al. (2016)	1	1	1	1	1	0	0	1	1	1	1	0	1	1	11
E. Rampinini et al. (2007)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Rampinini et al. (2009)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Rey et al. (2017)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Rodríguez-Fernández et al. (2018)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Rodríguez-Fernández et al. (2016)	1	1	1	1	1	0	0	0	1	1	1	0	0	0	8
Røksund et al. (2017)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Ruscello et al. (2017)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Ruscello et al. (2013)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Russell et al. (2017b)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Salleh et al. (2017)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Sánchez-Sánchez et al. (2014)	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
Sánchez-Sánchez et al. (2019)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Sanchez-Sanchez et al. (2018)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Sanders et al. (2017)	1	1	1	1	1	1	0	0	1	1	0	0	0	0	8
Scanlan and Madueno (2016)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Scanlan et al. (2021)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Selmi et al. (2016)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Selmi et al. (2018)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Shalfawi et al. (2014)	1	1	1	1	1	0	0	0	1	1	1	0	0	0	8
Shalfawi et al. (2012)	1	1	1	1	1	0	0	0	1	1	1	0	1	0	9
Shalfawi et al. (2013)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10
Silva et al. (2019)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Soares-Caldeira et al. (2014)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10
Spineti et al. (2015)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10
Stojanovic et al. (2012)	1	1	1	1	1	0	0	0	1	1	1	0	0	0	8
Suarez-Arrones et al. (2014)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Taylor et al. (2016)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Teixeira et al. (2019)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Thomassen et al. (2010)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Tønnessen et al. (2011)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10
Torreblanca-Martinez et al. (2020)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Tounsi et al. (2019)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Trecroci et al. (2020)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Turki et al. (2020)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Ulupınar, Özbay, et al. (2021)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Ulupınar, Hazır, et al. (2021)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
van den Tillaar (2018)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Vasquez-Bonilla et al. (2021)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Wadley and Le Rossignol (1998)	1	1	1	1	1	0	0	0	1	1	1	0	0	0	8
West et al. (2016)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Woolley et al. (2014)	1	1	1	1	1	0	0	0	1	1	1	0	0	0	8
Yanci et al. (2017)	1	1	1	1	1	0	0	0	1	1	1	0	1	0	9
Zagatto et al. (2017)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10

Study	**Item number**														**Total score (out of 14)**
	1	**2**	**3**	**6**	**7**	**10**	**12**	**15**	**16**	**18**	**20**	**22**	**23**	**25**	
Zagatto et al. (2021)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Zagatto et al. (2022)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9

Notes: 0 = no; 1 = yes; U = unable to determine. Item 1: clear aim/hypothesis; Item 2: outcome measures clearly described; Item 3: patient characteristics clearly described; Item 6: main findings clearly described; Item 7: measures of random variability provided; Item 10: actual probability values reported; Item 12: participants prepared to participate representative of the entire population; Item 15: blinding of outcome measures; Item 16: analysis completed was planned; Item 18: appropriate statistics; Item 20: valid and reliable outcome measures; Item 22: participants recruited over the same period; Item 23: randomised; Item 25: adjustment made for confounding variables.

APPENDIX 2. Summary of participant and study characteristics from Study 1.

Study	**Participants**						**Experimental Approach**		
	N$^{\#}$	**Sport**	**Level**	**Age (yrs)**	**Stature (cm)**	**Body mass (kg)**	**Design**	**Type**	**Details**
Abt et al. (2011)	11 (NR)	SOC	TRA	NR	NR	NR	NC	CRO (ran)	6 different, time-matched RS protocols (~60 s), performed twice each on an indoor synthetic sports floor, separated by 3–7 days.
AbuMoh'd and Abubaker (2020)	18	SOC	NAT	NR	NR	NR	C	PAG (r)	Baseline RS test on an athletics track, before an intervention.
Aguiar et al. (2008)	34	SOC	NAT	INT: 27 ± 5 CON: 27 ± 5	INT: 175 ± 5 CON: 175 ± 6	INT: 73 ± 5 CON: 73 ± 7	NC	PAG (r)	RS test before an intervention
Akenhead et al. (2017)	9	SOC	NAT	26 ± 3	172 ± 6	71 ± 7	NC	OBS	RS test performed in an indoor sports hall. Test ends when S_{dec} = 5% for 2 consecutive trials.
Alemdaroğlu et al. (2018)	9	SOC	TRA	18 ± 1	177 ± 5	74 ± 7	NC	CRO (ran)	4 different RS tests performed twice each on an AG pitch, separated by 48 hrs.
Alizadeh et al. (2010)	41	SOC	NAT	High: 17 ± 1 Med: 18 ± 1 Low: 17 ± 1	High: 177 ± 3 Med: 174 ± 5 Low: 171 ± 5	High: 71 ± 4 Med: 66 ± 5 Low: 67 ± 5	NC	OBS	Single RS test. Results according to the criterion of VO_{2max}
Almansba et al. (2019)	17	SOC	NAT	16 ± 0	175 ± 1	67 ± 9	NC	CRO (ran)	2 RS tests performed on AG, separated by 72 hrs.
Altimari et al. (2021)	46	SOC	NAT	18 ± 0	174 ± 5	64 ± 4	NC	OBS	RS test on a SOC field. U17 group only, birth tertiles combined.
Archiza et al. (2018)	18 (0%)	SOC	NAT	Sham: 20 ± 2 INT: 22 ± 4	Sham: 160 ± 0 INT: 160 ± 0	Sham: 55 ± 5 INT: 56 ± 6	C	PAG (r)	Baseline RS test on a grass field, before an intervention.
Attene et al. (2016)	36 (39%)	BB	NAT	M: 16 ± 1; F: 16 ± 1	M: 178 ± 1 F: 165 ± 1	M: 66 ± 6 F: 56 ± 7	NC	PAG (r)	2 different baseline RS tests on an indoor court, as part of a testing battery, before a RST intervention.
Ayarra et al. (2018)	40	FUT	TRA	22 ± 5	176 ± 7	70 ± 10	NC	OBS	Single RS test on an indoor wooden surface.
Aziz et al. (2000)	40	MIX	INTL	23 ± 4	173 ± 1	64 ± 6	NC	OBS	RS test on NG, as part of a testing battery.
Baldi et al. (2016)	26	SOC	NAT	23 ± 4	178 ± 6	72 ± 8	NC	OBS	RS test on outdoor NG, as part of a testing battery.
Balsalobre-Fernández et al. (2014)	11	BB	NAT	25 ± 6	200 ± 11	99 ± 9	NC	OBS	RS test in an indoor hall.

Study	Participants						Experimental Approach		
	N$^{\#}$	Sport	Level	Age (yrs)	Stature (cm)	Body mass (kg)	Design	Type	Details
Beato et al. (2019)	36	SOC	TRA	21 ± 2	179 ± 7	74 ± 7	NC	PAG (r)	Baseline RS test before an intervention and RS training data
Beato et al. (2022)	20	SOC	NAT	18–21	177 ± 6	71 ± 7	NC	PAG (r)	Baseline RS test before an intervention and RS training data
Beato and Drust (2021)	16	SOC	TRA	21 ± 1	179 ± 8	71 ± 8	NC	CRO (ran)	RS test on a synthetic outdoor track. Sub-maximal RS test excluded from the review.
Beaven et al. (2018)	12	RUG	NAT	22 ± 1	185 ± 4	96 ± 9	C	CRO (ran)	RS test on an indoor running track.
Binnie et al. (2014)	24 (0%)	HOC	NR	SAN: 19 ± 7 GRA: 21 ± 4	SAN: 168 ± 12 GRA: 167 ± 67	SAN: 66 ± 9 GRA: 63 ± 6	NC	PAG (r)	Baseline RS test in a gymnasium, before an intervention. Participant's pair-matched by VO$_{2max}$.
Martyn J Binnie et al. (2013)	10 (70%)	HOC/ NET	NAT	M: 23 ± 3 F: 20 ± 3	M: 182 ± 5 F: 176 ± 11	M: 83 ± 6 F: 69 ± 15	NC	CRO (ran)	Baseline RS test in a gymnasium.
M. J. Binnie et al. (2013)	10 (80%)	HOC/ NET	NR	M: 22 ± 2 F: 21 ± 1	M; 181 ± 5 F: 179 ± 14	M: 78 ± 6 F: 74 ± 18	NC	CRO (ran)	Baseline RS test in a gymnasium
Blasco-Lafarga et al. (2020)	13	SOC	NAT	18 ± 1	172 ± 4	68 ± 6	NC	CRO	RS test on a SOC pitch.
J. H. Borges et al. (2016)	20	SOC	NAT	17 ± 1	175 ± 7	69 ± 9	NC	PAG (r)	Baseline RS test before an intervention.
Brahim et al. (2016)	27	SOC	NAT	DEF: 18 ± 1 MID: 18 ± 1 FWD: 17 ± 1	DEF: 183 ± 6 MID: 178 ± 5 FWD: 180 ± 5	DEF: 75 ± 9 MID: 70 ± 7 FWD: 72 ± 4	NC	OBS	3 different RS tests on NG, separated by > 1 day.
S Brini et al. (2020)	16	BB	NR	23 ± 3	186 ± 10	78 ± 8	NC	CRO (ran)	4 different RS protocols, separated by 48-hrs.
Seifeddine Brini, Abderraouf Ben Abderrahman, et al. (2020)	16	BB	NAT	22 ± 3	186 ± 10	78 ± 8	C	PAG (r)	RS test before an intervention.
Brini et al. (2018)	16	BB	NR	23 ± 2	186 ± 9	78 ± 11	C	PAG (r)	RS test before an intervention.
Brini, Delextrat, et al. (2021)	16	BB	NAT	23 ± 2	186 ± 10	78 ± 8	NC	CRO (ran)	2 different RS tests on a BB court, separated by > 48-hrs.
Brini, Boullosa, et al. (2021)	40	BB	NAT	27 ± 3	192 ± 9	88 ± 9	NC	OBS	RS test on a wooden BB court.

Study	Participants						Experimental Approach		
	$N^{\#}$	Sport	Level	Age (yrs)	Stature (cm)	Body mass (kg)	Design	Type	Details
Brocherie et al. (2014)	16	SOC	INTL	27 ± 4	177 ± 4	72 ± 5	NC	OBS	RS test on indoor AG, as part of a testing battery.
Franck Brocherie et al. (2015a)	8	SOC	INTL	28 ± 5	176 ± 4	72 ± 3	NC	OBS	RS test on indoor AG.
F. Brocherie et al. (2015)	36	HOC	NAT	25 ± 5	178 ± 6	76 ± 8	C	PAG (r)	Baseline RS test on an indoor synthetic floor, before an intervention.
Broderick et al. (2019)	19	MIX	TRA	21.0 ± 2.0	178.8 ± 7.2	8.1 ± 8.9	C	CRO (ran)	RS tests in an indoor gymnasium, separated by 7 days.
M Buchheit (2012)	27	MIX	NAT	HB: 23 ± 3 TS3: 23 ± 4	HB: 188 ± 7 TS3: 180 ± 8	HB: 88 ± 11 TS3: 77 ± 9	NC	OBS	RS tests were performed by different groups of athletes on an indoor synthetic track.
Buchheit (2010)	13	MIX	NR	22 ± 3	179 ± 5	75 ± 5	NC	CRO (ran)	4 different RS protocols on an indoor synthetic track, separated by > 48-hrs.
M. Buchheit, D. Bishop, et al. (2010)	13	MIX	NR	22 ± 3	179 ± 5	75 ± 5	NC	CRO (ran)	2 different RS protocols on an indoor synthetic track, separated by > 48-hrs.
Buchheit et al. (2012)	12	MIX	NAT	22 ± 2	178 ± 8	76 ± 4	NC	CRO (ran)	4 different RS protocols on an indoor synthetic track, separated by > 48-hrs.
Campa et al. (2019)	36	SOC	NAT	17 ± 1	EL: 177 ± 6 S-EL: 178 ± 6	EL: 69 ± 4 S-EL: 70 ± 7	NC	OBS	RS test on NG.
Campos et al. (2021)	11	FUT	NAT	19 ± 1	178 ± 7	71 ± 6	NC	PAG	Baseline RS test on an indoor FUT court before an intervention.
Campos-Vazquez et al. (2015)	21	SOC	NAT	18 ± 1	177 ± 6	70 ± 7	NC	PAG (r)	Baseline RS test on AG, before an intervention.
Caprino et al. (2012)	10	BB	TRA	16 ± 1	184 + 7	77 + 8	NC	OBS	RS test before an official BB match.
Castagna et al. (2008)	16	BB	TRA	17 ± 1	181 ± 6	73 ± 10	NC	OBS (ran)	2 different RS tests on an indoor wooden BB court, separated by > 48-hrs, as part of a testing battery.
Castagna et al. (2007)	18	BB	TRA	17 ± 1	181 ± 6	73 ± 10	NC	OBS	RS test on an indoor wooden BB court, separated by > 48-hrs.
Chaouachi et al. (2010)	23	SOC	NAT	19 ± 1	181 ± 6	73 ± 4	NC	CRO (ran)	RS test on an indoor synthetic track.
Charlot et al. (2016)	10	FUT	NAT	26 ± 4	170 ± 7	70 ± 9	NC	OBS*	RS test before a FUT tournament

Study	**Participants**						**Experimental Approach**		
	$N^{\#}$	**Sport**	**Level**	**Age (yrs)**	**Stature (cm)**	**Body mass (kg)**	**Design**	**Type**	**Details**
Chen et al. (2019)	26	SOC	NAT	21 ± 1	173 ± 4	65 ± 5	C	PAG (r)	RS test on an indoor synthetic surface.
Clifford et al. (2016)	20	MIX	NAT	CON: 21 ± 2 INT: 23 ± 3	CON: 177 ± 1 INT: 183 ± 1	CON: 73 ± 12 INT: 77 ± 10	C	PAG (r)	Baseline RS test before an intervention period.
Corrêa et al. (2016)	10	SOC	TRA	19 ± 1	179 ± 0	71 ± 7	NC	OBS*	Baseline RS test on outdoor NG.
Costello et al. (2021)	24	RUG	NAT	21 ± 2	182 ± 5	88 ± 9	C	CRO (ran)	RS protocol (session 1 & day 1 only)
Cuadrado-Peñafiel et al. (2014)	37	SOC/ FUT	NAT	SOC: 29 ± 1 FUT: 27 ± 5	SOC: 178 ± 1 FUT: 179 ± 1	SOC: 73 ± 12 FUT: 75 ± 7	NC	OBS	Single RS test
da Silva et al. (2010)	29	SOC	NAT	18 ± 1	179 ± 5	74 ± 7	NC	OBS	Single RS test.
Dal Pupo et al. (2013)	14	FUT	TRA	U17	170 ± 6	63 ± 8	NC	OBS (ran)	2 different RS tests on a FUT court, separated by 48-hrs.
Dal Pupo et al. (2017)	7	FUT	TRA	16 ± 1	172 ± 9	65 ± 8	NC	OBS (ran)	2 different RS tests on a concrete floor, separated by 48-hrs.
Daneshfar et al. (2018)	20	HB	INTL	16 ± 1	185 ± 5	83 ± 6	NC	OBS (ran)	2 different RS tests were performed indoors, separated by 48-hrs, as part of a testing battery.
Dardouri et al. (2014)	29	MIX	NR	23 ± 2	180 ± 10	69 ± 9	NC	OBS	RS test, indoors, as part of a testing battery.
de Andrade et al. (2021)	16	MIX	NAT	22 ± 3	186 ± 10	79 ± 23	NC	OBS	Single RS test on an indoor rigid surface.
Delextrat et al. (2014)	17 (53%)	BB	TRA	M: 22 ± 3 F: 21 ± 3	M: 19 ± 9 F: 176 ± 8	M: 91 ± 10 F: 74 ± 10	C	CRO (ran) (r)	Baseline RS test, before an intervention.
Delextrat and Kraiem (2013)	31	BB	TRA	FWD: 16 ± 1 G: 17 ± 1 CEN: 16 ± 1	FWD: 183 ± 5 G: 175 ± 6 CEN: 191 ± 8	FWD: 75 ± 7 G: 69 ± 5 CEN: 81 ± 3	NC	OBS (ran)	RS test, as part of a testing battery.
Delextrat et al. (2013)	16 (50%)	BB	TRA	M: 23 ± 3 F: 22 ± 2	M: 191 ± 9 F: 179 ± 9	M: 90 ± 10 F: 78 ± 9	C	PAG (ran) (r)	Baseline RS test, before an intervention.
Dellal et al. (2015)	22	SOC	INTL	24 ± 4	178 ± 6	80 ± 6	NC	OBS	3 different RS protocols performed indoors, separated by > 48-hrs, as part of a testing battery.

Study	Participants						Experimental Approach		
	N[#]	Sport	Level	Age (yrs)	Stature (cm)	Body mass (kg)	Design	Type	Details
Dellal and Wong (2013)	39	SOC	NAT	Open age to U17	PRO: 180 ± 4 U19: 178 ± 7 U17: 180 ± 6	PRO: 72 ± 4 U19: 69 ± 6 U17: 67 ± 5	NC	OBS	2 different RS tests on AG, separated by 1 week.
Dent et al. (2015)	15 (47%)	SOC	TRA	M: 20 ± 2 F: 19 ± 2	NR	M: 79 ± 11 F: 62 ± 7	NC	CRO	Single RS protocol.
Donghi et al. (2021)	12	SOC	NAT	17 ± 1	178 ± 6	69 ± 4	C	CRO (ran)	Baseline RS test in an indoor gym,
Doyle et al. (2020)	25 (0%)	SOC	INTL	19 ± 3	167 ± 6	63 ± 7	NC	OBS	RS test performed on an indoor surface.
Dupont et al. (2010)	12	SOC	TRA	23 ± 4	179 ± 6	72 ± 7	NC	OBS	RS test on an indoor tartan track.
Dupont et al. (2005)	11	SOC	TRA	25 ± 4	176 ± 6	68 ± 4	NC	OBS	RS test on an indoor tartan track.
Eliakim et al. (2012)	12	BB	NAT	16 ± 1	186 ± 10	76 ± 6	C	CRO (ran)	RS test on a BB court, CON condition only.
Elias et al. (2012)	14	ARF	NAT	21 ± 3	186 ± 7	80 ± 7	NC	CRO (ran)	Baseline RS test on an indoor, wooden surface.
Elias et al. (2013)	24	ARF	NAT	20 ± 3	186 ± 6	81 ± 8	NC	PAG (r)	Baseline RS test on an indoor wooden sprung floor, before an intervention.
Eniseler et al. (2017b)	19	SOC	NAT	17 ± 1	174 ± 5	66 ± 6	C	PAG (r)	Baseline RS test on NG before an intervention
Eryılmaz and Kaynak (2019)	16	VB	TRA	21 ± 1	184 ± 5	74 ± 8	NC	OBS	RS test on an indoor VB court.
Eryılmaz et al. (2019)	12	MIX	TRA	24 ± 4	179 ± 6	73 ± 9	NC	SG	Data extracted from one session during a RST intervention.
Essid et al. (2021)	18	HB	NAT	17 ± 0.3	190 ± 10	78 ± 10	NC	CRO (ran)	RS test (morning session only)
Farjallah et al. (2020)	20	SOC	NAT	19 ± 1	180 ± 10	70 ± 11	C	PAG	RS test on a SOC field, before an intervention.
Figueira et al. (2021b)	12	BB	NAT	21 ± 2	190 ± 7	86 ± 6	NC	CRO (ran)	2 different RS tests.
Fornasier-Santos et al. (2018)	35	RUG	NAT	18 ± 1	182 ± 7	95 ± 15	C	PAG (r)	Baseline RS test on an indoor, concrete floor and RS training data from the control group.

Study	Participants						Experimental Approach		
	N$^{\#}$	Sport	Level	Age (yrs)	Stature (cm)	Body mass (kg)	Design	Type	Details
Fort-Vanmeerhaeghe et al. (2016b)	11	HB (0%)	NAT	17 ± 1	182 ± 7	70 ± 8	NC	OBS	RS test on a BB court
Fortin and Billaut (2019)	15	AF	TRA	21 ± 2	188 ± 19	82 ± 3	NC	PAG	Baseline RS test before an intervention.
Freitas et al. (2016)	9	BB	NAT	21 ± 3	198 ± 8	93 ± 15	NC	CRO (r)	Baseline RS test in an indoor centre.
Gabbett (2010)	19 (0%)	SOC	NAT / INTL	18 ± 3	NR	NR	NC	OBS	Same RS test, repeated twice.
T. J. Gabbett et al. (2011)	58	RUG	NAT	24 ± 4	184 ± 6	97 ± 10	NC	OBS	RS test on a synthetic surface, as part of a testing battery.
T. Gabbett et al. (2011)	86	RUG	NAT	ST: 25 ± 4 N-ST: 23 ± 4 N-SEL: 22 ± 4	ST: 185 ± 5 N-ST: 182 ± 6 N-SEL: 183 ± 7	ST: 96 ± 8 N-ST: 99 ± 12 N-SEL: 96 ± 11	NC	OBS	RS test on a synthetic surface, as part of a testing battery.
Gabbett et al. (2008)	16 (0%)	SOC	NAT / INTL	18.3 ± 2.8	NR	NR	NC	PAG	Baseline RS test, before an intervention.
Galvin et al. (2013)	42	RUG	NAT	18 ± 2	183 ± 7	88 ± 9	C	PAG (r)	RS test performed outdoors, before an intervention.
Galy et al. (2015)	22	FUT	INTL	MG: 24 ± 4 N-MG: 23 ± 5	MG: 173 ± 5 | N-MG: 180 ± 8	MG: 72 ± 7 N-MG: 74 ± 12	NC	OBS	RS test on an indoor synthetic court, as part of a testing battery.
Gantois et al. (2017)	20	BB	NAT	18-24	180 ± 6	81 ± 13	NC	OBS	RS test on a BB court.
Gantois et al. (2019)	20	BB	NAT	21 ± 2	181 ± 8	74 ± 9	C	PAG (r)	RS test on a BB court, before an intervention.
Gantois et al. (2018)	12	BB	NAT	22 ± 3	180 ± 2	81 ± 14	NC	SG	Baseline RS test, before an intervention.
García-Unanue et al. (2020)	33	FUT	NAT / TRA	23 ± 4	176 ± 6	73 ± 6	NC	OBS	RS test on a FUT field. Results according to playing level.
Gatterer et al. (2015b)	14	SOC	TRA	24 ± 2	178 ± 7	77 ± 7	C	PAG	Baseline RS test, before an intervention.
Gharbi et al. (2014)	20	MIX	TRA	22 ± 3	178 ± 7	71 ± 8	NC	CRO (ran)	Series of RS protocols on an indoor synthetic surface, separated by >24 hrs.

Study	**Participants**						**Experimental Approach**		
	N$^{\#}$	**Sport**	**Level**	**Age (yrs)**	**Stature (cm)**	**Body mass (kg)**	**Design**	**Type**	**Details**
Gharbi et al. (2015)	16	MIX	TRA	23 ± 2	178 ± 4	72 ± 3	C	OBS (ran)	RS test on an indoor synthetic surface
Gibson et al. (2013)	32	SOC	TRA	18 ± 1	179 ± 5	177 ± 5	NC	OBS	RS test on an indoor synthetic surface
Girard et al. (2018)	12	SOC	INTL	28 ± 5	176 ± 4	64 ± 5	NC	OBS	RS test on indoor AG, wearing normal football boots with plantar pressure insoles inserted.
Girard, Racinais, et al. (2011)	13	SOC	NAT	18 ± 1	190 ± 10	83 ± 10	NC	OBS	RS test on indoor AG, wearing normal football boots with plantar pressure insoles inserted.
González-Frutos et al. (2022)	13 (0%)	HOC	INTL	25 ± 6	167 ± 4	59 ± 4	NC	OBS	Single RS test
Gonzalo-Skok et al. (2016)	22	BB	NAT	16 ± 1	180 ± 6	81 ± 13	C	PAG (r)	2 different RS tests were performed on an indoor BB court, as part of a testing battery, before an intervention.
Goodall et al. (2015a)	12	MIX	NR	25 ± 6	180 ± 7	77 ± 7	NC	OBS	Single RS protocol.
Hamlin (2007)	20 (85%)	RUG	NAT	19 ± 1	180 ± 10	85 ± 14	NC	CRO (r)	Baseline RS protocol, before an intervention.
Hamlin et al. (2017)	19	RUG	TRA	CON: 22 ± 4 INT: 20 ± 2	CON: 178 ± 5 INT: 174 ± 5	CON: 88 ± 14 INT: 77 ± 10	C	PAG (r)	Baseline RS test in an indoor stadium, on 2 separate occasions, 4–5 days apart.
Hammami et al. (2019)	28	HB	NAT	INT: 17 ± 0 CON: 17 ± 0	INT: 163 ± 4 CON: 164 ± 4	INT: 61 ± 5 CON: 60 ± 4	C	PAG (r)	Baseline RS test before an intervention
T. Haugen et al. (2014)	25 (52%)	SOC	TRA	INT: 17 ± 1 CON: 17 ± 1	INT: 174 ± 8 CON: 173 ± 6	INT: 65 ± 8 CON: 62 ± 7	C	PAG (r)	Baseline RS test before an intervention
Haugen et al. (2015)	42	SOC	TRA	17 ± 1	178 ± 6	66 ± 9	C	PAG (r)	Baseline RS test before an intervention
Hermassi et al. (2018)	22	HB	NAT	19 ± 0	179 ± 2	83 ± 1	NC	OBS (ran)	2 different RS tests, separated by 3–7 days, as part of a testing battery.
Higham et al. (2013)	18	RUG	INTL	22 ± 2	183 ± 6	90 ± 8	NC	OBS	RS test on an indoor synthetic track, as part of a testing battery.
Hollville et al. (2018)	10	HOC	NAT	19 ± 1	180 ± 6	72 ± 5	NC	OBS	RS test on AG. Results from the 1st set only.

Study	**Participants**						**Experimental Approach**		
	$N^{\#}$	**Sport**	**Level**	**Age (yrs)**	**Stature (cm)**	**Body mass (kg)**	**Design**	**Type**	**Details**
Howatson and Milak (2009)	20	MIX	NAT	22 ± 2	178 ± 7	85 ± 14	NC	OBS	Single RS protocol performed on an outdoor track.
Iaia et al. (2015)	18	SOC	NAT	19 ± 1	180 ± 7	74 ± 7	NC	PAG (r)	Baseline RS test on AG, as part of a testing battery, performed by 2 different groups.
Iaia et al. (2017)	29	SOC	NAT	17 ± 1	178 ± 10	69 ± 8	C	PAG (r)	Data extracted from baseline RS tests on AG and the 1st RS training session of an intervention.
Impellizzeri et al. (2008)	22	SOC	NAT	22 ± 1	177 ± 4	73 ± 5	NC	OBS	Same RS test on NG, performed twice on different occasions
Impellizzeri et al. (2008)	30	SOC	NAT	25 ± 5	181 ± 5	78 ± 8	NC	OBS*	RS test on NG, performed at different timepoints across a regular season.
Impellizzeri et al. (2008)	108	SOC	NAT / TRA	24 ± 4	75 ± 7	179 ± 5	NC	OBS*	RS test on NG. Results according to player level.
Ingebrigtsen et al. (2014)	57	SOC	NAT	22 ± 5	181 ± 5	75.2 ± 7.6	NC	OBS	RS test on indoor AG, as part of a testing battery
Ingebrigtsen et al. (2012)	51	SOC	NAT	PRO: 26 ± 7 SEMI: 20 ± 3	PRO: 183 ± 5 SEMI: 181 ± 5	NR	NC	OBS	RS test. Results according to player level.
Iacono et al. (2016)	18	HB	NAT	25 ± 4	188 ± 7	91 ± 9	NC	PAG (r)	RS test on an indoor court before an intervention
Izquierdo et al. (2002a)	19	HB	NAT	INT: 21 ± 5 PLA: 24 ± 5	INT: 182 ± 8 PLA: 190 ± 8	INT: 79 ± 8 PLA: 87 ± 12	C	PAG (r)	Baseline RS test on an indoor HB court, before an intervention.
Jang and Joo (2020)	12	SOC	NAT	23 ± 2	175 ± 6	71 ± 5	NC	CRO (r)	Single RS test.
Jiménez-Reyes, Cross, et al. (2019)	20	RUG	INTL	24 ± 4	188 ± 5	96 ± 7	NC	OBS	RS test on an indoor synthetic athletics track.
Johnston and Gabbett (2011)	12	RUG	NR	23 ± 2	179 ± 10	85 ± 11	NC	CRO (ran)	The same RS test was performed twice on different occasions.
Joo Joo (2016)	11	SOC	TRA	22 ± 2	174 ± 6	NR	NC	SG	Baseline RS test before an intervention.
G. Jorge et al. (2020)	43	SOC	NAT	18 ± 1	178 ± 8	74 ± 10	NC	OBS*	RS test on NG, performed at different timepoints across a season.

Study	Participants						Experimental Approach		
	$N^{\#}$	Sport	Level	Age (yrs)	Stature (cm)	Body mass (kg)	Design	Type	Details
Kaplan (2010)	85	SOC	TRA	21 ± 3.8	176 ± 6	69 ± 7	NC	OBS	RS test on NG as part of a testing battery.
Keir et al. (2013)	8	SOC	NAT	21 ± 2	176 ± 5	75 ± 4	NC	OBS (ran)	Single RS test.
Keogh et al. (2003)	74 (0%)	HOC	TRA	REP: 19 ± 1 Club: 20 ± 2	REP: 165 ± 1 Club: 164 ± 1	REP: 59 ± 1 Club: 57 ± 1	NC	OBS	RS test as part of a testing battery
Kilduff et al. (2013)	20	RUG	NAT	26 ± 2	185 ± 4	96 ± 8	C	CRO (ran)	Baseline RS test on an indoor synthetic track, before an intervention.
Klatt et al. (2021)	29	HB	NAT	U20: 18 ± 1 SEN: 27 ± 6	U20: 182 ± 8 SEN: 192 ± 9	U20: 79 ± 9 SEN 90 ± 14	NC	OBS*	Single RS protocol
Krakan et al. (2020)	41 (NR)	MIX	TRA	NR	RS-G, 181 ± 7 PLY, 175 ± 6	RS-G, 81 ± 8 PLY, 77 ± 9	NC	PAG	RS test before an intervention
Krueger et al. (2020)	18	HOC	INTL	17 ± 1	182 ± 6	74 ± 8	C	PAG (r)	Baseline RS test, before an intervention.
Lakomy and Haydon (2004)	18	HOC	NAT	24 ± 4	179 ± 5	77 ± 4	C	CRO (ran) (r)	2 different RS protocols on AG
Lapointe et al. (2020)	17 (71%)	BB	NAT	22	186 ± 12	89 ± 17	C	PAG (r)	Baseline RS test before an intervention.
Le Rossignol et al. (2014)	20	ARF	NAT	22 ± 2	188 ± 6	88 ± 8	NC	OBS	RS test on an outdoor synthetic track, as part of a testing battery
Little and Williams (2007)	6	SOC	NAT	18–27	NR	NR	NC	CRO (ran)	4 different RS protocols, performed on non-consecutive days.
Robert G. Lockie et al. (2016)	17	SOC	INTL	20 ± 2	181 ± 6	78 ± 7	NC	OBS	RS test on outdoor NG, as part of a testing battery.
Lockie et al. (2020)	19 (0%)	SOC	INTL	20 ± 1	164 ± 6	61 ± 8	NC	OBS	RS test on outdoor NG, as part of a testing battery.
Lockie et al. (2019)	18	SOC	INTL	21 ± 2	181 ± 6	78 ± 6	NC	OBS	RS test on outdoor NG, as part of a testing battery. Results are for all players.
Lombard et al. (2021)	23	HOC	NAT / INTL	24 ± 3	178 ± 3	77 ± 5	NC	OBS	RS test on AG, as part of a testing battery. Results are for all players.
Madueno et al. (2018)	8 (75%)	BB	NAT	20 ± 2	183 ± 10	78 ± 17	NC	CRO (ran)	2 different RS protocols on an indoor hardwood floor, separated by 2–7 days.

Study	Participants						Experimental Approach		
	N#	Sport	Level	Age (yrs)	Stature (cm)	Body mass (kg)	Design	Type	Details
Maggioni et al. (2019)	36	BB	NAT	19 ± 1	182 ± 7	74 ± 10	C	PAG (r)	RS training data from an intervention.
Mancha-Triguero et al. (2021)	61	BB	NAT	U18	M: 195 F: 168	M: 85 F: 57	NC	OBS	RS test on BB court.
Marcelino et al. (2016)	12	BB	TRA	19 ± 1	193 ± 7	89 ± 15	NC	CRO	Same 2 baseline RS tests, separated by 24-hrs, before an intervention.
Matzenbacher et al. (2016)	9	FUT	TRA	17 ± 0	176 ± 7	68 ± 9	NC	OBS *	RS test performed at the beginning and end of the season.
McGawley and Andersson (2013)	18	SOC	NAT	23 ± 4	180 ± 8	76 ± 6	NC	PAG	Baseline RS test on AG, before an intervention.
Meckel et al. (2018)	18	SOC	NAT	22-32	NR	77 ± 8	NC	OBS *	RS test performed at different timepoints across a season.
Meckel, Gottlieb, et al. (2009)	12	BB	NAT	17 ± 1	187 ± 9	78 ± 6	NC	CRO (ran)	RS test on a BB court, after a game day warm-up.
Meckel, Machnai, et al. (2009)	33	SOC	NAT	16-18	175 ± 4	67 ± 7	NC	OBS (ran)	2 different RS tests on NG, separated by ~1 week, as part of a testing battery.
Meckel et al. (2015)	16	VB	NAT	26 ± 5	192 ± 6	84 ± 7	NC	OBS (ran)	RS test in a sports arena, as part of a testing battery.
Meckel et al. (2014)	20	SOC	NAT	17 ± 1	174 ± 7	67 ± 7	NC	CRO (ran)	RS test on a SOC pitch, after a match warm up.
Michalsik et al. (2015)	26	HB	INTL	26 ± 3	189 ± 6	91 ± 9	NC	OBS	RS test on an indoor HB court. Results are all players combined.
Mohr et al. (2016)	40	SOC	NAT	22 ± 0	177 ± 1	73 ± 1	C	PAG (r)	Baseline RS test on NG, before an intervention.
Mohr and Krustrup (2016)	18	SOC	TRA	19 ± 1	179 ± 6	79 ± 4	NC	PAG (r)	Baseline RS test on AG, before an intervention.
Mohr et al. (2012)	17	SOC	NAT	27 ± 1	184 ± 1	80 ± 2	C	CRO	Baseline RS test on indoor AG, before an intervention.
Moncef et al. (2012)	44	HB	NAT	22 ± 3	182 ± 6	85 ± 2	NC	OBS	RS test, as part of a testing battery.
Morcillo et al. (2015)	18	SOC	NAT	27 ± 4	180 ± 5	78 ± 5	NC	OBS	Single RS test.
Moreira et al. (2015)	10	FUT	NAT	24 ± 3	174 ± 5	73 ± 9	C	CRO (ran)	Baseline RS test before an intervention.

Study	Participants						Experimental Approach		
	N[#]	**Sport**	**Level**	**Age (yrs)**	**Stature (cm)**	**Body mass (kg)**	**Design**	**Type**	**Details**
Mujika et al. (2009)	28	SOC	TRA	U17 & U18	U17: 178 ± 6 U18: 179 ± 9	U17: 70 ± 7 U18: 72 ± 8	NC	OBS	RS test on indoor AG.
Müller et al. (2021)	12	RUG	TRA	25 ± 4	177 ± 5	92 ± 12	NC	CRO (ran)	Single RS test.
Nakamura et al. (2009)	13	HB	NAT	24 ± 4	187 ± 7	88 ± 3	NC	OBS	RS test in a gymnasium.
Nascimento et al. (2015)	18	FUT	TRA	17 ± 1	177 ± 5	69 ± 7	C	PAG (r)	Baseline RS test before a long-term RS intervention.
Nedrehagen and Saeterbakken (2015)	22 (41%)	SOC	TRA	INT: 20 ± 3 CON: 22 ± 3	INT: 20 ± 3 CON: 22 ± 3	69 ± 10	C	PAG (r)	Baseline RS test on indoor AG before an intervention
Nikolaidis et al. (2015)	36	SOC	TRA	22 ± 5	180 ± 6	75 ± 8	NC	OBS	RS test on AG, as part of a testing battery.
Okuno et al. (2013)	12	HB	NAT	19 ± 2	185 ± 87	85 ± 10	NC	CRO	Single RS test
Padulo et al. (2016)	18	SOC	NAT	16 ± 0	174 ± 10	65 ± 10	NC	CRO (ran)	Same RS test, repeated twice, on AG, separated by > 6 days.
Padulo et al. (2014)	17	SOC	NAT	17 ± 1	179 ± 5	69 ± 7	NC	CRO (ran)	Same 2 RS tests and 1 different RS test on AG, separated by 3 days.
Johnny Padulo et al. (2015)	18	BB	NAT	16 ± 1	178 ± 10	66 ± 9	NC	CRO	2 different RS tests on an indoor BB court, repeated twice, separated by > 48-hrs, as part of a testing battery.
J Padulo, M Tabben, G Attene, et al. (2015)	18	SOC	NAT	16 ± 0	174 ± 10	65 ± 10	NC	CRO	The same RS test was repeated twice, and 1 different RS test, on AG, separated by 1-week.
J Padulo, M Tabben, LP Ardigò, et al. (2015)	17	SOC	INTL	16 ± 0	181 ± 10	66 ± 10	NC	CRO	3 different RS tests on AG, separated by 5 days.
Paulauskas et al. (2020)	12	BB	NAT	21 ± 2	190 ± 7	86 ± 6	NC	CRO (ran)	2 different RS protocols, on an indoor wooden BB court, separated by 1-week.
Perroni et al. (2013)	12	SOC	TRA	23 ± 6	177 ± 6	75 ± 7	NC	SG	Baseline RS test on AG, before an intervention.
Petisco et al. (2019)	10	SOC	NAT	22 ± 3	178 ± 4	70 ± 3	C	CRO (ran)	RS test following the regular warm-up protocol.
Purkhús et al. (2016)	25 (0%)	VB	NAT	18 ± 4	172 ± 7	63 ± 11	C	PAG (r)	Baseline RS test on an indoor HB court, before an intervention.

Study	Participants						Experimental Approach		
	N$^{\#}$	Sport	Level	Age (yrs)	Stature (cm)	Body mass (kg)	Design	Type	Details
Pyne et al. (2008)	60	ARF	NAT	18 ± 0	188 ± 7	82 ± 8	NC	OBS	RS test on an indoor sprung wooden floor, as part of a testing battery.
Ramírez-Campillo et al. (2016)	30 (0%)	SOC	TRA	CON: 23 ± 2 PLA: 23 ± 2 INT: 23 ± 3	CON: 161 ± 6 PLA: 164 ± 9 CR: 162 ± 4	CON: 60 ± 8 PLA: 57 ± 5 INT: 60 ± 8	C	PAG (r)	Baseline RS test, before an intervention.
E. Rampinini et al. (2007)	18	SOC	NAT	26 ± 5	182 ± 4	81 ± 8	NC	OBS	RS test on outdoor NG.
Rampinini et al. (2009)	23	SOC	NAT / TRA	PRO: 25 ± 4 AM: 26 ± 6	PRO: 180 ± 3 AM: 177 ± 5	PRO: 74 ± 5 AM: 71 ± 8	NC	OBS	RS test on outdoor NG.
Rey et al. (2017)	19	SOC	TRA	INT: 24 ± 3 CON: 24 ± 2	INT: 179 ± 5 CON: 178 ± 5	INT: 74 ± 7 CON: 75 ± 7	C	PAG (r)	Baseline RS test on an indoor court, before an intervention.
Rodríguez-Fernández et al. (2018)	33	SOC	NAT	PRO: 24 ± 3 YTH: 18 ± 1	PRO: 180 ± 2 YTH: 174 ± 10	PRO: 75 ± 5 YTH: 65 ± 1	NC	SG	Baseline RS test before an intervention.
Rodríguez-Fernández et al. (2016)	24	SOC	TRA	19 ± 2	176 ± 6	67 ± 9	NC	SG	Baseline RS test before an intervention
Røksund et al. (2017)	75	SOC	NAT	19 ± 3	181 ± 6	75 ± 10	NC	OBS	Single RS test as part of a testing battery.
Ruscello et al. (2017)	15 (0%)	SOC	NAT	23 ± 6	165 ± 6	59 ± 9	NC	CRO (r)	2 different RS tests on AG, separated by > 48-hrs.
Ruscello et al. (2013)	17	SOC	NAT	22 ± 4	177 ± 6	72 ± 10	NC	CRO (r)	2 different RS tests on AG, separated by > 48-hrs.
Russell et al. (2017b)	14	SOC	NAT	18 ± 2	178 ± 5	75 ± 6	NC	CRO (ran)	Baseline RS test before an intervention.
Salleh et al. (2017)	24	SOC	TRA	21 ± 2	173 ± 3	65 ± 3	NC	OBS	Single RS test.
Sánchez-Sánchez et al. (2014)	18	SOC	TRA	22 ± 2	175 ± 6	74 ± 9	NC	OBS	RS test on 4 different AG pitches, separated by 72 hrs.
Sánchez-Sánchez et al. (2019)	21	SOC	NAT	U18	NR	NR	NC	OBS	Single RS test.
Sanchez-Sanchez et al. (2018)	16	SOC	NAT / TRA	21 ± 1	69 ± 5	177 ± 5	C	PAG	Baseline RS test before an intervention
Sanders et al. (2017)	20 (50%)	SOC	INTL	M: 21 ± 1 F: 20 ± 1	M: 178 ± 7 F: 168 ± 6	M: 75 ± 5 F: 63 ± 5	NC	OBS	Single RS test.
Scanlan and Madueno (2016)	9 (67%)	MIX	TRA	22 ± 4	171 ± 6	73 ± 12	NC	CRO (ran)	Two different RS protocols on an indoor, sprung, hardwood surface.

Study	**Participants**						**Experimental Approach**		
	N$^{\#}$	**Sport**	**Level**	**Age (yrs)**	**Stature (cm)**	**Body mass (kg)**	**Design**	**Type**	**Details**
Scanlan et al. (2021)	8 (75%)	BB	TRA	20 ± 1	183 ± 10	78 ± 17	NC	CRO	RS protocol an indoor, hardwood BB court.
Selmi et al. (2016)	24	SOC	NAT	17 ± 0	172 ± 9	68 ± 7	NC	CRO (ran)	3 different RS tests on outdoor AG, separated by > 48-hrs.
Selmi et al. (2018)	30	SOC	NAT	18 ± 1	178 ± 5	70 ± 7	C	PAG (r)	Baseline RS test before an intervention
Shalfawi et al. (2014)	30 (0%)	SOC	NAT	19 ± 4	167 ± 4	58 ± 7	NC	OBS	RS test in an indoor arena.
Shalfawi et al. (2012)	15	SOC	NAT	16 ± 1	179 ± 7	68 ± 9	C	PAG (r)	RS test on indoor AG before an intervention
Shalfawi et al. (2013)	17 (0%)	SOC	TRA	21 ± 3	1769 ± 5	64 ± 6	C	PAG (r)	RS test on an indoor Mondo track
Silva et al. (2019)	22	SOC	NAT	18 ± 1	175 ± 6	71 ± 5	NC	SG	Baseline RS test before an intervention.
Soares-Caldeira et al. (2014)	14	FUT	NAT	INT: 25 ± 8 CON: 21 ± 5	172 ± 6	72 ± 9	C	PAG (r)	RS test on an indoor synthetic floor, before an intervention.
Spineti et al. (2015)	22	SOC	NAT	18 ± 0	180 ± 8	70 ± 9	NC	PAG (r)	RS test before an intervention
Stojanovic et al. (2012)	24	BB	NAT	22. ± 3	197 ± 6	96 ± 9	NC	OBS	RS test on a BB court, as part of a testing battery.
Suarez-Arrones et al. (2014)	16	RUG	TRA	27 ± 5	180 ± 7	91 ± 16	C	PAG (r)	Data extracted from baseline RS tests (both groups) and training data (RST group).
Taylor et al. (2016)	15	SOC	TRA	24 ± 4	179 ± 6	77 ± 8	NC	PAG	Data extracted from a RST intervention.
Teixeira et al. (2019)	20 (0%)	FUT	NAT	19 ± 2	162 ± 5	59 ± 8	NC	PAG (r)	Baseline RS test on an indoor FUT court, as part of a testing battery, before a long-term training intervention.
Thomassen et al. (2010)	18	SOC	NAT	23 ± 1	182 ± 2	79 ± 2	NC	PAG (r)	Baseline RS test on an indoor wooden surface.
Tønnessen et al. (2011)	20	SOC	NAT	16 ± 1	176 ± 7	67 ± 9	C	PAG (r)	Baseline RS test before an intervention.
Torreblanca-Martinez et al. (2020)	18 (0%)	SOC	NAT	18 ± 2	162 ± 5	56 ± 7	NC	SG	RS test on outside AG.

Study	Participants						Experimental Approach		
	N[#]	Sport	Level	Age (yrs)	Stature (cm)	Body mass (kg)	Design	Type	Details
Tounsi et al. (2019)	33	SOC	NAT	17 ± 0	NR	NR	NC	CRO (ran)	RS test on NG
Trecroci et al. (2020)	9	SOC	NAT	17–19	177 ± 2	66 ± 6	NC	CRO (r)	Baseline RS test on NG, before an intervention.
Turki et al. (2020)	19	SOC	NR	18 ± 1	175 ± 7	70 ± 8	C	CRO (ran) (r)	Baseline RS test.
Ulupınar, Özbay, et al. (2021)	18	SOC	TRA	20 ± 2	178 ± 5	72 ± 6	NC	CRO (ran)	2 different RS protocols on outdoor NG, separated by > 48 hrs
Ulupınar, Hazır, et al. (2021)	16	SOC	TRA	19 ± 2	176 ± 5	70 ± 6	NC	CRO (ran)	4 different RS protocols on indoor AG, separated by > 48 hrs
van den Tillaar (2018)	17 (0%)	SOC	NR	17 ± 1	168 ± 5	62 ± 7	NC	OBS	Single RS test on a track.
Vasquez-Bonilla et al. (2021)	38 (0%)	SOC	NAT	23 ± 4	165 ± 11	61 ± 7	NC	OBS	Single RST test on an indoor court
Wadley and Le Rossignol (1998)	17	ARF	NAT	21 ± 2	182 ± 5	81 ± 10	NC	OBS	RS test on an asphalt surface, as part of a testing battery.
West et al. (2016)	15	RUG	NAT	28 ± 3	188 ± 6	99 ± 9	C	CRO (ran)	RS test on an indoor sprint track.
Woolley et al. (2014)	10	MIX	NR	27 ± 3	178 ± 6	78 ± 8	NC	CRO (ran)	RS protocol on a non-slip indoor surface
Yanci et al. (2017)	39	FUT	TRA	23 ± 5	170 ± 10	69 ± 10	C	PAG (r)	Baseline RS test before an intervention
Zagatto et al. (2017)	20	BB	NAT	17 ± 1	191 ± 8	84 ± 12	NC	CRO (ran)	2 different RS tests on an indoor court, separated by 2–4 days.
Zagatto et al. (2021)	12	BB	NAT	25 ± 7	200 ± 10	97 ± 9	C	CRO (r)	RS test on a BB court, CON condition only.
Zagatto et al. (2022)	10	BB	NAT	17 ± 1	191 ± 7	87 ± 15	C	CRO (ran)	Single RS protocol on a BB court

Study	Participants						Experimental Approach		
	N[#]	Sport	Level	Age (yrs)	Stature (cm)	Body mass (kg)	Design	Type	Details

Data are presented as mean ± standard deviation.

Abbreviations: N[#] = number of participants (unless stated, the proportion of males was 100%). M = male; F = female; NR = not reported; NA = not applicable; OBS = observational design; CRO = crossover design; SG = single group pre-test post-test design; ran = experimental treatment or measurements delivered in a randomised order; r = random assignment of participants to experimental groups; C = controlled study; NC = non-controlled study; PLA = placebo; SOC = soccer, FUT = futsal; RUG = rugby; HOC = field hockey; BB = basketball; AF = American football; ARF = Australian rules football; VB = volleyball; HB = handball; NET = netball; MIX = mixture of team sports; TRA = trained/developmental athletes; INT = international/elite athletes; NAT = national/highly trained athletes; PRO = professional; SEMI = semi-professional; AM = amateur; YTH = youth; CON = control group; INT = intervention group; Sham = sham group; RS = repeated-sprint; RS-G = repeated-sprint group; PLY = plyometric group; REP = representative players; Club = club players; MID = midfielders; FWD = forwards; DEF = defenders; G = guards; CEN = centres; U17 = under 17 players; U18 = under 18 players; U20 = under 20 players; SEN = senior players; VO_{2max} = maximal oxygen consumption; High = high $V0_2$max group; Med = medium VO_{2max} group; Low = low VO_{2max} group; SAN = sand training group; GRA = grass training group; TS3 = team sport 3; ST = starting players; N-ST = non-starting players; N-SEL = non-selected players; MG = Melanesian group; N-MG = Non-Melanesian group; S_{dec} = percentage sprint decrement; yrs = years; hrs = hours; AG = artificial grass; NG = natural grass; cm = centimetre; kg = kilogram; ~ = approximately; * = single group time series.

APPENDIX 3. Summary of exercise protocol information and outcomes from Study 1.

Study	Exercise protocol						Outcomes			
	RST Mode	Sets × Reps	Distance / Duration	Rest Time	Rest Mode	I-set Rest	Performance	Perceptual	Neuromuscular	Physiological
Abt et al. (2011)	STR	1 × 22	15 m	1:10^{N} (~26 s)	A^{H}	-	S_{avg}: 2.64 ± 0.06 s	-	-	$B[La]_{peak}$: 1.3 ± 0.2 to 7.6 ± 0.6 mmol·L^{-1}
	STR	1 × 22	15 m	1:10^{N} (~26 s)	P	-	S_{avg}: 2.63 ± 0.07 s	-	-	$B[La]_{peak}$: 1.0 ± 0.1 to 8.7 ± 0.9 mmol·L^{-1}
	STR	1 × 22	30 m	1:10^{N} (~45 s)	A^{H}	-	S_{avg}: 4.57 ± 0.22 s	-	-	$B[La]_{peak}$: 1.2 ± 0.2 to 10.6 ± 0.7 mmol·L^{-1}
	STR	1 × 22	30 m	1:10^{N} (~45 s)	P	-	S_{avg}: 4.59 ± 0.15	-	-	$B[La]_{peak}$: 1.3 ± 0.2 to 11.1 ± 0.8 mmol·L^{-1}
AbuMoh'd and Abubaker (2020)	STR	1 × 7	30 m	30 s	P	-	INT, S_{avg}: 3.71 ± 0.05; PLA, S_{avg}: 3.70 ± 0.05	-	-	INT, $B[La]^{5'}$: 9.0 ± 0.1 mmol·L^{-1}; PLA, $B[La]^{5'}$: 9.2 ± 0.2 mmol·L^{-1}
Akenhead et al. (2017)	SHU	1 × 12	25 m (12.5 + 12.5)	20 s	P	-	S_{dec}: 5.3%	-	-	-
Aguiar et al. (2008)	MD^{A}	1 × 7	34.2 m	25 s	A^{K}	-	INT, S_{avg}: 6.69 ± 0.20 s CON, S_{avg}: 7.31 ± 0.34 s	-	-	-
Alemdaroğlu et al. (2018)	SHU	1 × 6	40 m	On 25 s (~17 s)	A^{H}	-	S_{best}: 7.35 ± 0.17 s; S_{total}: 45.93 ± 0.84 s; S_{dec}: 4.13 ± 1.81%	-	-	$B[La]^{3'}$: 9.3 ± 2.5 mmol·L^{-1}
	STR	1 × 6	40 m	On 25 s (~19 s)	A^{H}	-	S_{best}: 5.68 ± 0.20 s; S_{total}: 34.90 ± 1.21 s; S_{dec}: 2.42 ± 1.43%	-	-	$B[La]^{3'}$: 7.6 ± 1.4 mmol·L^{-1}
	SHU	1 × 8	30 m (15 + 15)	On 25 s (~19 s)	A^{H}	-	S_{best}: 5.64 ± 0.16 s; S_{total}: 46.41 ± 1.32 s; S_{dec}: 2.85 ± 1.51%	-	-	$B[La]^{3'}$: 7.9 ± 2.1 mmol·L^{-1}
	STR	1 × 8	30 m	On 25 s (~20 s)	A^{H}	-	S_{best}: 4.50 ± 0.15 s; S_{total}: 37.21 ± 1.23 s; S_{dec}: 3.29 ± 0.91%	-	-	$B[La]^{3'}$: 8.1 ± 1.4 mmol·L^{-1}
Alizadeh et al. (2010)	STR	1 × 6	35 m	10 s	P	-	High, S_{best}: 5.34 ± 0.13 s; S_{total}: 33.47 ± 0.99 s; S_{dec}: 9.6 ± 0.1%; Med, S_{best}: 5.39 ± 0.14 s; S_{total}: 34.77 ± 0.56 s; S_{dec}: 9.3 ± 0.2%; Low, S_{best}: 6.22 ± 0.39 s; S_{total}: 40.56 ± 3.50 s; S_{dec}: 9.2 ± 0.3%	-	-	High, $\triangle B[La]^{3'}$: 1.73 to 6.97 mmol·L^{-1}; MED, $\triangle B[La]^{3'}$: 1.9 to 9.0 mmol·L^{-1}
Almansba et al. (2019)	MD^{Y}	1 × 6	40	20 s	P	-	S_{best}: 7.97 ± 0.39 s; S_{avg}: 8.37 ± 0.30 s; S_{dec}: 4.8 ± 2.0%	6–20: 15.2 ± 1.6 au	-	$B[La]^{2'}$: 12.9 ± 1.5 mmol·L^{-1} ; HR_{peak}: 189 ± 7 b·min^{-1} HRav: 195 ± 8 b·min^{-1}

Study	Exercise protocol						Outcomes			
	RST Mode	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
	STR	1 × 6	40	20 s	P	-	S_{best}: 5.75 ± 0.28 s; S_{avg}: 6.16 ± 0.29 s; S_{dec}: 6.7 ± 3.1%	6–20: 13.9 ± 1.8 au		$B[La]^{2'}$: 11.6 ± 1.2 $mmol \cdot L^{-1}$; HR_{peak}: 185 ± 6 $b \cdot min^{-1}$; HR_{avg}: 178 ± 9 $b \cdot min^{-1}$
Altimari et al. (2021)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	1TR, S_{avg}: 7.08 ± 0.27 s; S_{dec}: 5.3 ± 1.3%; 2TR, S_{avg}: 7.16 ± 0.25 s; S_{dec}: 5.4 ± 1.2%; 3TR, S_{avg}: 7.08 ± 0.27 s; S_{dec}: 5.6 ± 1.5%	-	-	-
Archiza et al. (2018)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	Sham, S_{best}: 7.50 ± 0.20 s; S_{avg}: 7.90 ± 0.20 s; S_{dec}: 6.3 ± 3.0%; INT, S_{best}: 7.60 ± 0.30 s; S_{avg}: 8.20 ± 0.30 s; S_{dec}: 7.9 ± 2.4%	-	-	-
Attene et al. (2016)	SHU	1 × 10	30 m (15 + 15)	30 s	P	-	S_{best}: 6.41 ± 0.43 s; S_{total}: 67.27 ± 4.43 s; S_{dec}: 10.9 ± 4.3%	CR10: 8.6 ± 0.5 au	-	$B[La]^{3'}$: 9.5 ± 1.6 $mmol \cdot L^{-1}$
Ayarra et al. (2018)	STR	1 × 6	30 m	25 s	A	-	S_{total}: 26.03 ± 2.09 s; S_{dec}: 1.7 ± 3%	-	-	-
Aziz et al. (2000)	STR	1 × 8	40 m	30 s	A^{1}	-	S_{best}: 5.45 ± 0.23 s; S_{total}: 45.90 ± 1.64 s; S_{dec}: 5.4 ± 2.7%		-	-
Baldi et al. (2016)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	S_{best}: 7.13 ± 0.24 s; S_{dec}: 5.2 ± 1.6%		-	$B[La]_{peak}$:17.6 ± 2.6 $mmol \cdot L^{-1}$
Balsalobre-Fernández et al. (2014)	STR	1 × 6	35 m	10 s	P	-	-	-	△ CMJ^{AA}: -4.2 cm (-9.2 ± 4.8%)	-
Beato et al. (2019)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	STR-G, S_{best}: 7.13 ± 0.17 s, S_{avg}:7.46 ± 0.19 s; SHU-G group, S_{best}: 7.14 ± 0.18 s, S_{avg}:7.50 ± 0.21 s	-	-	-
	STR	3 × 7	30 m	20 s	P	4 min P	-	CR10: 6.3 ± 0.5 au	-	-
	SHU	3 x 7	40 m	20 s	P	4 min P	-	CR10: 6.4 ± 0.6 au	-	-
Beato et al. (2022)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	STR-G, S_{best}: 7.30 ± 0.15 s; S_{avg}: 7.56 ± 0.20 s SHU-G, S_{best}: ± 7.23 ± 0.32 s; S_{avg}: 7.46 ± 0.31 s	-	-	-
	STR	3 × 7	30 m	20 s	P	4 min P	-	CR10: 6.1 ± 0.8 au	-	-

Study	**Exercise protocol**						**Outcomes**			
	RST Mode	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
	SHU	3 × 7	40 m (20 + 20)	20 s	P	4 min p	-	CR10: 6.4 ± 0.7	-	-
Beato and Drust (2021)	STR	3 × 7	30 m	25 s	A^{Q}	3 min P	-	-	-	HR$_{peak}$: 192 ± 12 b·min^{-1}
Beaven et al. (2018)	STR	1 × 5	40 m	On 30 s (~24 s)	P	-	S$_{total}$: 27.58 ± 1.58 s		-	HR$_{post}$: 139 ± 8 b·min^{-1}
Binnie et al. (2014)	STR	1 × 8	20 m	20 s	A^{W}	-	SAN, S$_{total}$: 30.97 ± 1.58 s; S$_{dec}$: 4.8 ± 2.1%; GRA, S$_{total}$: 29.56 ± 1.69 s; S$_{dec}$: 4.5 ± 2.2%	-	-	SAN, B[La]$_{peak}$: 6.5 ± 2.3 mmol·L^{-1}; GRA, B[La]$_{peak}$: 5.7 ± 2.5 mmol·L^{-1}
Martyn J Binnie et al. (2013)	STR	1 × 8	20 m	20 s	A^{K}	-	S$_{best}$: 3.31 s; S$_{total}$: 27.46 s; S$_{dec}$: 3.7%		-	B[La]$_{post}$: 8.2 mmol·L^{-1} HR$_{peak}$: 160 b·min^{-1}
M. J. Binnie et al. (2013)	STR	1 × 8	20 m	20 s	A^{K}	-	S$_{best}$: 3.34 s; S$_{total}$: 27.94 s; S$_{dec}$: 4.4%	-	-	B[La]$_{post}$: 7.5 mmol·L^{-1} HR$_{peak}$: 163 b·min^{-1}
Blasco-Lafarga et al. (2020)	MD^{C}	1 × 7	34.2 m	25 s	A^{K}	-	S$_{best}$: 5.72 ± 0.13 s; S$_{avg}$: 5.91 ± 0.14 s; S$_{total}$: 41.41 ± 0.99 s; S$_{dec}$: 3.5 ± 1.6%	CR10: 9.1 ± 2.2 au	-	B[La]$^{3'}$: 8.5 ± 1.4 mmol·L^{-1}
J. H. Borges et al. (2016)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	RES, S$_{best}$: 7.35 ± 0.07 s; S$_{avg}$: 7.70 ± 0.14 s; PLY, S$_{best}$: 7.21 ± 0.18 s; S$_{avg}$: 7.55 ± 0.22 s	-	-	-
Brahim et al. (2016)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	S$_{dec}$: 2.7 ± 1.3%		-	-
	MD^{B}	1 × 12	20 m	40 s	P	-	S$_{dec}$: 3.8 ± 2.3%		-	-
	MD^{A}	1 × 7	34.2 m	25 s	A^{K}	-	S$_{dec}$: 4.3 ± 3.4%		-	-
S Brini et al. (2020)	SHU	1 × 10	30 m	30 s	P	-	S$_{best}$: 5.80 ± 0.21 s; S$_{total}$: 58.99 ± 1.67 s	CR10: 4.3 ± 0.5 au	-	B[La]$_{post}$: 5.3 ± 1.7 mmol·L^{-1}; HR$_{peak}$: 194 ± 2 b·min^{-1}
	SHU	1 × 10	30 m	30 s	A^{X}	-	S$_{best}$: 5.88 ± 0.15 s; S$_{total}$: 59.58 ± 1.36 s	CR10: 5.0 ± 0.6 au		B[La]$_{post}$: 5.5 ± 2.1 mmol·L^{-1}; HR$_{peak}$: 195 ± 2 b·min^{-1}
	SHU	1 × 10	30 m	30 s	A^{Y}	-	S$_{best}$: 5.91 ± 0.15 s; S$_{total}$: 60.02 ± 1.11 s	CR10: 7.4 ± 0.8 au	-	B[La]$_{post}$: 6.8 ± 2.2 mmol·L^{-1}; HR$_{peak}$: 195 ± 2 b·min^{-1}
	SHU	1 × 10	30 m	30 s	A^{Z}	-	S$_{best}$: 5.92 ± 0.11 s; S$_{total}$: 60.10 ± 0.94 s	CR10: 8.2 ± 0.8 au	-	B[La]$_{post}$: 6.6 ± 2.1 mmol·L^{-1}; HR$_{peak}$: 196 ± 2 b·min^{-1}

	Exercise protocol						**Outcomes**			
Study	**RST Mode**	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
Brini et al. (2018)	SHU	1 × 10	30 m (15 + 15)	30 s	P	-	SSG, S_{best}: 5.90 ± 0.11 s; S_{avg}: 5.98 ± 0.68 s; S_{total}: 59.78 ± 0.68 s; RS, S_{best}: 5.88 ± 0.13 s; S_{avg}: 5.97 ± 1.14 s; S_{total}: 59.72 ± 1.14 s	-	-	SSG, HR_{peak}: 186 ± 4 b·min^{-1}; RS, HR_{peak}: 189 ± 3 b·min^{-1}
Brini, Delextrat, et al. (2021)	SHU	1 × 10	30 m (15 + 15)	30 s	P	-	S_{best}: 5.89 ± 0.10 s; S_{total}: 59.60 ± 0.90 s; S_{dec}: 1.2 ± 0.5%	CR10: 7 ± 1 au	-	B[La]$^{3'}$: 6.6 ± 2.1 mmol·L^{-1}; HR_{peak}: 191 ± 1 b·min^{-1}
	MD	1 × 10	30 m	30 s	P	-	S_{best}: 5.90 ± 0.10 s; S_{total}: 59.80 ± 0.90 s; S_{dec}: 1.3 ± 0.5%	CR10: 8 ± 1 au	-	B[La]$^{3'}$: 6.8 ± 2.2 mmol·L^{-1}; HR_{peak}: 195 ± 1
Seifeddine Brini, Abderraouf Ben Abderrahman, et al. (2020)	MD	1 × 10	30 m	30 s	P	-	INT, S_{best}: 6.91 ± 0.1s; S_{total}: 70.90 ± 0.98 s; CON, S_{best}: 6.87 ± 0.12 s; CON, S_{total}: 69.81 ± 0.62 s	INT, CR10: 5.6 ± 1.4 au; CON, CR10: 6.0 ± 1.3 au	-	INT, B[La]$^{3'}$: 5.4 ± 2.1 mmol·L^{-1}; HR_{peak}: 187 ± 3 b·min^{-1}; CON, B[La]$^{3'}$: 5.8 ± 2.4 mmol·L^{-1}; HR_{peak}: 187 ± 6 b·min^{-1}
Brini, Boullosa, et al. (2021)	MD^{A}	1 × 10	30 m	30 s	P	-	PRO, S_{best}: 8.07 ± 0.03 s; S_{total}: 83.35 ± 2.19 s; SEMI, S_{best}: 8.21 ± 0.16 s; S_{total}: 83.56 ± 2.17 s;	PRO, CR10: 6.8 ± 0.6 SEMI, CR10: 6.9 ± 0.6	-	PRO, B[La]$^{3'}$: 8.0 ± 2.0 mmol·L^{-1}; HR_{peak}: 187 ± 2 b·min^{-1} SEMI, B[La]$^{3'}$: 9.5 ± 0.6 mmol·L^{-1}; HR_{peak}: 189 ± 1 b·min^{-1}
Brocherie et al. (2014)	STR	1 × 6	35 m	10 s	P	-	S_{best}: 4.87 ± 0.14 s; S_{total} 31.73 ± 1.13 s; S_{dec}: 8.7 ± 2.3%		-	-
Franck Brocherie et al. (2015a)	STR	1 × 6	35 m	10 s	P	-	S_{avg}: 5.34 ± 0.25 s; S_{dec}: 9.5 ± 2.4%	6–20: 15.9 ± 0.9 au	△ sprint 1–6: Δ*L*: 17.5 ± 2.5 to 18.0 ± 2.9 cm; Δz: 1.9 ± 0.3 to 2.7 ± 0.3 cm; F_{z}max: 2.36 ± 0.18 to 2.41 ± 0.14 N; K_{vert}: 127.6 ± 17.7 to 91.4 ± 10.4 kN·m^{-1}; K_{leg}: 13.7 ± 1.7 to 13.8 ± 2.7 kN·m^{-1}	B[La]$^{4'}$: 10.5 ± 2.0 mmol·L^{-1}
F. Brocherie et al. (2015)	STR	1 × 8	20 m	On 20 s (~17 s)	P	-	HYP, S_{total}: 27.23 ± 1.15 s; S_{dec}: 4.0 ± 1.7%; NOR, 27.05 ± 0.81 s; S_{dec}: 4.3 ± 1.9%; CON, 26.98 ± 1.03 s; S_{dec}: 5.2 ± 2.1%	-	-	-

	Exercise protocol						**Outcomes**			
Study	**RST Mode**	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
Broderick et al. (2019)	STR	1 × 3	15 m	20 s	P	-	INT, S$_{best}$: 2.58 ± 0.10 s; S$_{total}$: 7.82 ± 0.32 s; CON, S$_{best}$: 2.58 ± 0.10 s; S$_{total}$: 7.84 ± 0.31 s	-	-	-
M Buchheit (2012)	STR	1 × 6	30 m	20 s	P	-	S$_{best}$: 5.73 ± 0.27 s; S$_{avg}$: 5.90 ± 0.27 s; S$_{dec}$: 2.8 ± 0.9%	-	-	-
	SHU	1 × 6	25 m	25 s	A^{L}	-	S$_{best}$: 3.96 ± 0.15 s; S$_{avg}$: 4.09 ± 0.17 s; S$_{dec}$: 3.2 ± 1.3%			
Buchheit (2010)	STR	1 × 6	25 m	On 25s (~21 s)	A^{L}	-	S$_{best}$: 3.97 ± 0.15 s; S$_{avg}$: 4.09 ± 0.16 s S$_{dec}$: 2.8 ± 1.2%	CR10: 7 ± 1 au	-	B[La]$^{3'}$: 9.4 ± 2.4 mmol·L^{-1}; VO$_{2avg}$: 38.1 ± 5.0 ml·min^{-1}·kg^{-1} (% VO$_{2max}$: 76 ± 10%); HR$_{peak}$: 175 ± 11 b·min^{-1} (% HR$_{max}$: 95 ± 6%)
	SHU	1 × 6	25 m (12.5 + 12.5)	On 25 s (~20 s)	A^{L}	-	S$_{best}$: 5.186 ± 0.16 s; S$_{avg}$: 5.29 ± 0.17 s; S$_{dec}$: 2.5 ± 1.0%	CR10: 7 ± 1 au	-	B[La]$^{3'}$: 9.9 ± 2.0 mmol L^{-1}; VO$_{2avg}$: 39.7 ± 5.0 ml·min^{-1}·kg^{-1} (% VO$_{2max}$: 79 ± 10%); HR$_{peak}$: 177 ± 11.0 b·min^{-1} (% HRmax: 96 ± 6%)
	STR	1 × 6	25 m	On 25 s (~21 s)	A^{M}	-	S$_{best}$: 3.98 ± 0.14 s; S$_{avg}$: 4.14 ± 0.17 s S$_{dec}$: 3.9 ± 1.5%	CR10: 8 ± 1 au	-	B[La]$^{3'}$: 10.2 ± 2.4 mmol·L^{-1}; VO$_{2avg}$: 40.2 ± 4.5 ml·min^{-1}·kg^{-1} (% VO$_{2max}$: 80 ± 9%); HR$_{peak}$: 176 ± 11 b·min^{-1} (% HRmax: 96 ± 6%)
	SHU	1 × 6	25 m (12.5 + 12.5)	On 25 s (~20 s)	A^{M}	-	S$_{best}$: 5.18 ± 0.18 s; S$_{avg}$: 5.43 ± 0.18 s S$_{dec}$: 3.4 ± 2.3%	CR10: 8 ± 1 au	-	B[La]$^{3'}$: 10.4 ± 2.1 mmol·L^{-1}; VO$_{2avg}$: 42.2 ± 5.0 ml·min^{-1}·kg^{-1} (% VO$_{2max}$: 84 ± 10%); HR$_{peak}$: 178 ± 11 b·min^{-1} (% HRmax: 97 ± 6%)
M. Buchheit, D. Bishop, et al. (2010)	STR	1 × 6	25 m	On 25 s (~21 s)	A^{L}	-	S$_{best}$: 3.96 ± 0.15 s; S$_{avg}$: 4.09 ± 0.17 s S$_{dec}$: 3.2 ± 1.3%	CR10: 7.2 ± 1.4 au	-	△ B[La]$^{3'}$: 2.2 ± 0.2 to 9.3 ± 2.4 mmol·L^{-1}; VO$_{2avg}$: 35.8 ± 4.7 ml·min^{-1}·kg^{-1} (% VO$_{2max}$: 77.4 ± 9.3%); HR$_{peak}$: 173 ± 9 b·min^{-1} (% HRmax: 94 ± 5%)

Study	Exercise protocol						Outcomes			
	RST Mode	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
	SHU	1 × 6	25 m (12.5 + 12.5)	On 25 s (~20 s)	A^{L}	-	S_{best}: 5.16 ± 0.17 s; S_{avg}: 5.30 ± 0.17 s S_{dec}: 2.6 ± 1.2%	CR10: 7.2 ± 0.8 au	-	△ B[La]$^{3'}$: 2.2 ± 0.2 to 10.0 ± 1.7 mmol·L^{-1}; VO$_{2avg}$: 40.4 ± 5.2 ml·min^{-1}·kg^{-1} (% VO$_{2max}$: 80.5 ± 10.3%); HR$_{peak}$: 173 ± 10 b·min^{-1} (% HRmax: 94 ± 5%)
Buchheit et al. (2012)	STR	1 × 6	30 m	On 25 s (~20 s)	A^{L}	-	S_{best}: 4.37 ± 0.17 s; S_{avg}: 4.69 ± 0.20 s S_{dec}: 6.7 ± 2.5%	CR10: 7.4 ± 1.5 au	-	△ B[La]$^{3'}$: ↑ 10.1 ± 2.2 mmol·L^{-1}; HR$_{peak}$: 184 ± 7 b·min^{-1}
	MD^{D}	1 × 6	~27.6 m	On 25 s (~20 s)	A^{L}	-	S_{best}: 4.38 ± 0.17 s; S_{avg}: 4.61 ± 0.29 s S_{dec}: 4.8 ± 3.6%	CR10: 6.9 ± 1.7 au	-	△ B[La]$^{3'}$: ↑ 8 ± 2.3 mmol·L^{-1}; HR$_{peak}$: 181 ± 8 b·min^{-1}
	MD^{E}	1 × 6	~21.2 m	On 25 s (~20 s)	A^{L}	-	S_{best}: 4.36 ± 0.15 s; S_{avg}: 4.69 ± 0.16 s S_{dec}: 7.0 ± 3.2%	CR10: 6.0 ± 1.6 au	-	△ B[La]$^{3'}$: ↑ 6.1 ± 2.5 mmol·L^{-1}; HR$_{peak}$: 178 ± 9 b·min^{-1}
	MD^{F}	1 × 6	~ 19.2 m	On 25 s (~20 s)	A^{L}	-	S_{best}: 4.39 ± 0.19 s; S_{avg}: 4.73 ± 0.19 s S_{dec}: 7.1 ± 3.0%	CR10: 6.0 ± 1.1 au	-	△ B[La] $^{3'}$: ↑ 7.4 ± 2.3 mmol·L^{-1}; HR$_{peak}$: 180 ± 8 b·min^{-1}
Campa et al. (2019)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	EL, S_{best}: 7.00 ± 0.30 s; S_{avg}: 7.50 ± 0.40 s; S_{dec}: 6.3 ± 3.1%; S-EL, S_{best}: 7.70 ± 0.20 s; S_{avg}: 7.90 ± 0.20 s; S_{dec}: 3.4 ± 1.1%	-	-	-
Campos et al. (2021)	SHU	1 × 8	40m (10 + 20 + 10)	20 s	P	-	IT$_{100}$, S_{best}: 8.12 ± 0.20 s; S_{avg}: 8.69 ± 0.36 s; IT$_{86}$, S_{best}: 8.28 ± 0.24 s; S_{avg}: 8.50 ± 0.18 s	-	-	-
Campos-Vazquez et al. (2015)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	SQ, S_{best}: 6.99 ± 0.11 s; S_{avg}: 7.40 ± 0.18 s; TG, S_{best}: 7.07 ± 0.18 s; S_{avg}: 7.42 ± 0.15 s	-	-	-
Caprino et al. (2012)	SHU	1 × 10	30 m (15 + 15)	30 s	P	-	S_{total}: 58.80 ±2.10 s; S_{dec}: 2.3 ± 1.0%	-	-	△ B[La] $^{3'}$: 5.1 ± 1.4 mmol·L^{-1} to 12.4 ± 2.8 mmol·L^{-1}
Castagna et al. (2008)	SHU	1 × 10	30 m (15 + 15)	30 s	P	-	S_{avg}: 6.17 ± 0.10 s; S_{total}: 60.56 ± 1.60 s; S_{dec}: 3.4 ± 2.3%	-	-	△ B[La]$^{3'}$: 2.5 ± 0.7 mmol L^{-1} to 14.1 ± 3.5 mmol·L^{-1}
	SHU	1 × 10	30 m (15 + 15)	30 s	A^{Z}	-	S_{avg}: 6.32 ± 0.10 s; S_{total}: 62.15 ± 2.99 s S_{dec}: 5.0 ± 2.4%	-	-	△ B[La]$^{3'}$: 2.4 ± 0.5 to 13.2 ± 2.9 mmol·L^{-1}

Study	Exercise protocol						Outcomes			
	RST Mode	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
Castagna et al. (2007)	SHU	1 × 10	30 m (15 + 15)	30 s	P	-	S_{dec}: 3.4 ± 2.3%	-	-	$\triangle$ B[La]$_{post}$: 2.5 ± 0.7 to 13.6 ± 3.1 mmol·L^{-1}; $\triangle$ B[La]$^{3'}$: 2.5 ± 0.7 to 14.2 ± 3.5 mmol·L^{-1}
Chaouachi et al. (2010)	STR	1 × 7	30 m	25 s	A^{Q}	-	S_{avg}: 4.50 ± 0.13 s; S_{total}: 31.21 ± 1.13 s; S_{dec}: 6.0 ± 2.5%	-	-	-
Charlot et al. (2016)	STR	1 × 6	25 m	25 s	A^{K}	-	S_{avg}: 3.84 ± 0.17 s: S_{total}: 23.10 ± 1.10 s; S_{dec}: 7.4 ± 3.9%	-	-	-
	SHU	1 × 6	25 m (12.5 + 12.5)	25 s	A^{K}	-	S_{avg}: 5.32 ± 0.17 s: S_{total}: 30.50 ± 2.30 s; S_{dec}: 4.1 ± 1.3%	-	-	-
Chen et al. (2019)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	S_{best}: 7.50 ± 0.50 s; S_{total}: 45.9 ± 3.34 s; S_{dec}: 3.5 ± 2.5%	6–20: 15 ± 3.6 au	-	B[La]$_{post}$: 9.8 ± 2.1 mmol·L^{-1}; HR$_{peak}$:171 ± 12 b·min^{-1}
Clifford et al. (2016)	STR	1 × 20	30 m	30 s	P	-	INT, S_{best}: 4.41 ± 0.23 s; S_{avg}: 4.65 ± 0.25 s; PLA: 4.48 ± 0.14 s; S_{avg}: 4.70 ± 0.15 s	INT, 6–20: 15 ± 1 au; PLA, 6–20: 14 ± 2 au	INT, $\triangle$ CMJ^{AA}: -11.8 ± 8.9%; PLA, $\triangle$ CMJ^{AA}: -9.6 ± 4.8%	INT, CK 24 h: 188 ± 62 to 542 ± 461 u·L^{-1} (188%); PLA, CK 24 h: 318 ± 145 to 592 ± 321 u·L^{-1} (86%)
Corrêa et al. (2016)	STR	1 × 6	35 m	10 s	P	-	S_{total}: 31.17 ± 1.03 s; S_{dec}: 8.2 ± 2.77%	-	-	-
Costello et al. (2021)	STR	1 × 20	20 m	20 s	A	-	S_{avg}: 3.43 ± 0.2 s	CR10: 9 ± 1.1	-	B[La]$_{post}$: 12.4 ± 2.6 mmol·L^{-1}: HR$_{avg}$: 178 ± 8 b·min^{-1}
Cuadrado-Peñafiel et al. (2014)	SHU	1 × 6	40 m (20 + 20)	30 s	P	-	SOC, S_{best}: 7.01 ± 0.22 s; S_{dec}: 2.7 ± 0.6%; FUT: 7.26 ± 0.19 s; S_{dec}: 4.4 ± 1.2%	-	-	SOC, B[La]$_{post}$: 13.7 ± 2.8 mmol·L^{-1}; FUT, B[La]$_{post}$: 14.3 ± 3.4 mmol·L^{-1}
da Silva et al. (2010)	SHU	1 × 7	34.2 m	25 s	P	-	S_{best}: 6.30 ± 0.24 s; S_{avg}: 6.56 ± 0.23 s; S_{dec}: 4.0 ± 1.9%	-	-	B[La]$_{peak}$: 15.4 ± 2.2 mmol·L^{-1}
Dal Pupo et al. (2013)	STR	1 × 6	25 m	15 s	A	-	S_{best}: 3.80 ± 0.18 s; S_{avg}: 3.98 ± 0.20 s; S_{dec}: 4.7 ± 2.0%	-	$\triangle$CMJ^{AB}: 43.52 ± 1.48 to 41.68 ± 1.25 cm (-4.2%)	B[La]$_{peak}$: 11.1 ± 2.4 mmol·L^{-1}
	SHU	1 × 6	25 m (12.5 + 12.5)	15 s	A	-	S_{best}: 5.17 ± 0.23 s; S_{avg}: 5.34 ± 0.23 s; S_{dec}: 3.2 ± 1.4%	-	$\triangle$ CMJ^{AB}: 43.52 ± 1.48 to 40.37 ± 1.28 cm (-7.2%)	B[La]$_{peak}$: 12.2 ± 3.3 mmol·L^{-1}

Study	**Exercise protocol**						**Outcomes**			
	RST Mode	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
Dal Pupo et al. (2017)	STR	1 × 6	25 m	15 s	A	-	S_{best}: 3.73 ± 0.12 s; S_{avg}: 3.91 ± 0.15 s; S_{dec}: 4.7 ± 1.8%	-	-	-
	SHU	1 × 6	25 m (12.5 + 12.5)	15 s	A	-	S_{best}: 5.13 ± 0.22 s; S_{avg}: 5.30 ± 0.20 s; S_{dec}: 3.3 ± 0.9%	-	-	-
Daneshfar et al. (2018)	SHU	1 × 10	30 m (15 + 15)	30 s	P	-	Test, S_{best}: 6.35 ± 0.08 s; S_{total}: 68.97 ± 0.23 s; S_{dec}: 9.1 ± 1.1% Retest, S_{best}: 6.30 ± 0.08 s; S_{total}: 69.25 ± 0.24 s; S_{dec}: 9.3 ± 1.1%	CR10: 8.8 ± 0.1 au	-	$B[La]^{3'}$: 10.0 ± 0.1 mmol·L^{-1}
Dardouri et al. (2014)	SHU	1 × 10	30 m (15 + 15)	30 s	P	-	S_{best}: 6.15 ± 0.25 s; S_{total}: 63.90 ± 2.50 s; S_{dec}: 4.1 ± 1.4%	-	-	$B[La]^{3'}$: 14.8 ± 0.4 mmol·L^{-1}
de Andrade et al. (2021)	STR	1 × 6	35 m	10 s	P	-	S_{best}: 4.43 ± 0.17 s; S_{avg}: 4.91 ± 0.23 s; S_{total}: 29.45 ± 1.39 s; S_{dec}: 11.3 ± 7.6%	-	-	$B[La]_{peak}$: 13.7 ± 2.4 mmol·L^{-1}
Delextrat et al. (2014)	SHU	1 × 10	30 m (15 + 15)	30 s	P	-	M, S_{total}: 58.40 ± 2.80 s; S_{dec}: 4.3 ± 0.4%; F, S_{total}: 63.50 ± 2.20 s; S_{dec}: 3.6 ± 0.9%	-	-	-
Delextrat and Kraiem (2013)	SHU	1 × 6	20 m (10 + 10)	On 20 s (~15 s)	P	-	S_{total}: 29.00 ± 2.10 s; S_{dec}: 4.0 ± 2.7%	-	-	-
Delextrat et al. (2013)	SHU	1 × 10	30 m (15 + 15)	30 s	P	-	M, S_{total}: 58.01± 3.01 s; S_{dec}: 4.3 ± 1.5%; F, S_{total}: 63.34 ± 2.38 s; S_{dec}: 3.6 ± 0.3%	-	-	-
Dellal et al. (2015)	STR	1 × 10	20 m	30 s	A^{K}	-	-	-	-	HR_{peak}:191 b·min^{-1} (% HRmax: 91%)
	STR	1 × 10	30 m	30 s	A^{K}	-	-	-	-	HR_{peak}:198 b·min^{-1} (% HRmax: 95%)
	STR	1 × 15	20 m	30 s	A^{K}	-	-	-	-	HR_{peak}:198 b·min^{-1}; (% HRmax: 95%)
Dellal and Wong (2013)	MD^{X}	1 × 10	20 m	25 s	A^{K}	-	U17, S_{best}: 5.39 ± 0.03 s; S_{avg}: 5.47 ± 0.04 s; S_{total}: 32.76 ± 0.24 s; S_{dec}: 1.4 ± 0.6%; U19, S_{best}: 5.34 ± 0.03 s; 5.39 ± 0.04 s; S_{total}: 32.25 ± 0.26 s; S_{dec}: 1.0 ± 0.4%; PRO, S_{best}: 5.31 ± 0.05 s; S_{avg}: 5.37 ± 0.07 s; S_{total}: 32.22 ± 0.42 s; S_{dec}: 1.2 ± 0.5%	-	-	-

Study	**Exercise protocol**						**Outcomes**			
	RST Mode	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
Dent et al. (2015)	STR	4 × 6	30 m	On 30 s (~25 s)	A^{K}	7 min P	M, S_{best}: set 1, 4.29 ± 0.05 s; set 2, 4.35 ± 0.02 s; set 3, 4.45 ± 0.10 s; set 4, 4.49 ± 0.11 s; S_{avg}: set 1, 4.47 ± 0.9 s; set 2, 4.54 ± 0.12 s; set 3, 4.60 ± 0.13 s; set 4, 4.54 ± 0.12 s; S_{dec}: set 1, 4.7 ± 1.4%; set 2, 4.9 ± 1.4%; set 3, 5.4 ± 2.0%; set 4, 4.3 ± 1.1% F, S_{best}: set 1, 4.74 ± 0.18 s; set 2, 4.87 ± 0.14 s; set 3, 4.96 ± 0.27 s; set 4, 4.97 ± 0.22 s S_{avg}: set 1, 5.09 ± 0.21 s; set 2, 5.17 ± 0.31 s; set 3, 5.24 ± 0.27 s; set 4, 5.23 ± 0.31 s; S_{dec}: set 1, 7.1 ± 2.1%; set 2, 6.6 ± 2.8%; set 3, 7.2 ± 1.3%; set 4, 7.2 ± 2.8%	-	-	M: set 1, △ B[La]$^{3'}$: 0.9 ± 0.4 to 10.0 ± 1.6 mmol·L^{-1}; set 2, B[La]$^{3'}$: 11.9 ± 2.9 mmol·L^{-1}; set 3, 11.6 ± 3.3 mmol·L^{-1}; set 4, 11.6 ± 4.0 mmol·L^{-1}; HR$_{post}$: set 1, 179 ± 20 b·min^{-1}; set 2, 175 ± 38 b·min^{-1}, set 3, 188 ± 10 b·min^{-1}; set 4, 189 ± 10 b·min^{-1}; F: set 1, △ B[La]$^{3'}$: 0.8 ± 0.3 to 10.0 ± 3.5 mmol·L^{-1}; set 2, B[La]$^{3'}$: 12 ± 3.6 mmol·L^{-1}; set 3, 12.0 ± 3.3 mmol·L^{-1}; set 4, 12.2 ± 3.7 mmol·L^{-1} HR$_{post}$: set 1, 189 ± 9 b·min^{-1}; set 2, 190 ± 8 b·min^{-1}; set 3, 191 ± 6 b·min^{-1}; set 4, 190 ± 8 b·min^{-1}
Donghi et al. (2021)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	-	CR10: 5 ± 1.2 au	-	-
Doyle et al. (2020)	STR	1 × 6	20 m	On 15 s (~12 s)	A^{W}	-	S_{best}: 3.43 ± 0.16 s; S_{total}: 21.42 ± 0.97 s; S_{dec}: 4.4 ± 0.3%	-	-	-
Dupont et al. (2010)	STR	1 × 7	30 m	20 s	A	-	S_{avg}: 4.60 ± 0.14 s	-	-	-
Dupont et al. (2005)	STR	1 × 15	40 m	25 s	A^{Z}	-	S_{avg}: 6.41 ± 0.31 s; S_{dec}: 8.6 ± 3.2%	-	-	B[La]$^{3'}$: 13.8 ± 3.1 mmol·L^{-1}; VO$_{2avg}$: 60.5 ± 4.3 ml·min^{-1}·kg^{-1}
Eliakim et al. (2012)	STR	1 × 12	20 m	On 20 s (~ 17 s)	P	-	S_{best}: 3.23 ± 0.17 s; S_{avg}: 3.24 ± 0.04 s; S_{total}: 38.91 ± 0.52 s; S_{dec}: 2.3 ± 0.6	CR10: 7 ± 1 au	-	HR$_{avg}$: 177 ± 6 b·min^{-1} HR$_{post}$: 181 ± 4 b·min^{-1}
Elias et al. (2012)	STR	1 × 6	20 m	On 30 s (~27 s)	P	-	PAS, S_{total}: 18.53 ± 0.28 s; COL, S_{total}: 18.62 ± 0.46 s; CWT, S_{total}: 18.63 ± 0.45 s	-	-	-
Elias et al. (2013)	STR	1 × 6	20 m	On 30 s (~27 s)	P	-	PAS, S_{total}: 18.66 ± 0.37 s; COL, S_{total}: 18.50 ± 0.47 s; CWT, S_{total}: 18.68 ± 0.39 s	-	-	-
Eniseler et al. (2017b)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	RS, S_{best}: 6.75 ± 0.19 s; S_{avg}: 7.13 ± 0.17 s; S_{dec}: 5.5 ± 0.8% SSG, S_{best}: 6.73 ± 0.19 s; S_{avg}: 7.12 ± 0.17 s; S_{dec}: 5.8 ± 1.1%	-	-	-

Study	**Exercise protocol**						**Outcomes**			
	RST Mode	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
Eryılmaz and Kaynak (2019)	STR	1 × 10	20 m	20 s	A^K	-	S_{best}: 2.97 ± 0.10 s; S_{avg}: 3.21 ± 0.10 s; S_{dec}: 8.0 ± 2.7%	-	-	-
Eryılmaz et al. (2019)	STR	1 × 10	20 m	20 s	A^K	-	S_{avg}: 4.28 ± 0.10 s	-	-	-
Essid et al. (2021)	SHU	1 × 6	30 m (15 + 15)	On 20 s (~14 s)	P	-	S_{best}: 6.19 ± 0.03 s; S_{avg}: 6.78 ± 0.03; S_{dec}: 8.7 ± 0.0%	-	-	-
Farjallah et al. (2020)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	INT, S_{avg}: 7.18 ± 0.23 s; PLA, S_{avg}: 7.34 ± 0.03 s	-	-	-
Figueira et al. (2021b)	SHU	3 × 10	30 m (15 + 15)	30 s	P	5 min P	S_{total}: 59.22 ± 2.10 s; S_{dec}: 3.6 ± 1.6%	-	-	$B[La]^{3'}$: 13.0 ± 2.3 $mmol \cdot L^{-1}$; HR_{peak}: 174 ± 7 $b \cdot min^{-1}$
	STR	3 × 20	15 m	15 s	P	5 min P	S_{total}: 53.66 ± 1.56 s; S_{dec}: 4.9 ± 2.1%	-	-	$B[La]^{3'}$: 8.5 ± 3.4 $mmol \cdot L^{-1}$ HR_{peak}: 174 ± 7 $b \cdot min^{-1}$
Freitas et al. (2016)	SHU	1 × 10	30 m (15 + 15)	30 s	P	-	S_{total}: 57. 50 ± 2.89 s; S_{dec}: 2.9 ± 1.0%	-	-	-
Fornasier-Santos et al. (2018)	STR	1 × 10	40 m	On 30 s (~25 s)	P	-	-	HYP, CR10: 9.2 ± 0.7 au NOR, CR10: 9.2 ± 0.7 au	-	HYP: 13.7 ± 4.3 $mmol \cdot L^{-1}$ NOR: 13.0 ± 4.2 $mmol \cdot L^{-1}$
	STR	2 × 8	40 m	NR	P	3 min P	-	CR10: 8.3 ± 0.5	-	10.2 ± 3.3 $mmol \cdot L^{-}$
Fort-Vanmeerhaeghe et al. (2016b)	SHU	1 × 10	30 m (15 + 15)	30 s	P	-	S_{best}: 6.20 ± 0.20 s; S_{avg}: 6.34 ± 0.19 s	-	-	-
Fortin and Billaut (2019)	STR	1 × 12	20 m	20 s	A^K	-	Sham, S_{best}: 3.07 ± 0.13 s; S_{total}: 39.69 ± 1.34 s; INT, S_{best}: 3.05 ± 0.08 s; S_{total}: 39.79 ± 1.65 s	-	-	-
Gabbett (2010)	STR	1 × 6	20 m	On 15 s (~12 s)	A^J	-	S_{total}: 21.50 ± 1.20 s; S_{dec}: 5.6 ± 1.6%	-	-	$B[La]_{post}$: 9.3 ± 2.0 $mmol \cdot L^{-1}$ HR_{peak}: 182 ± 6 $b \cdot min^{-1}$
T. J. Gabbett et al. (2011)	STR	1 × 12	20 m	On 20 s (~17 s)	P	-	S_{total}: 38.70 ± 2.30 s	-	-	-
T. Gabbett et al. (2011)	STR	1 × 12	20 m	On 20 s (~17 s)	P	-	ST, S_{total}: 38.30 ± 2.80 s; N-ST, S_{total}: 38.90 ± 3.20; N-SEL, S_{total}: 39.10 ± 3.30	-	-	-

Study	Exercise protocol						Outcomes			
	RST Mode	Sets × Reps	Distance / Duration	Rest Time	Rest Mode	I-set Rest	Performance	Perceptual	Neuromuscular	Physiological
Gabbett et al. (2008)	STR	1 × 6	20 m	On 15 s (~12 s)	A^{J}	-	INT, S_{total}: 21.16 ± 1.06 s; CON, S_{total}: 20.71 ± 0.52 s	-	-	-
Galvin et al. (2013)	STR	1 × 10	30 m	30 s	P	-	HYP, S_{total}: 32.20 ± 1.10 s; S_{dec}: 4.0 ± 3.0%; NOR, S_{total}: 32.70 ± 1.20 s; S_{dec}: 5.1 ± 3 .9%	-	-	-
Galy et al. (2015)	STR	1 × 6	25 m	25 s	A^{K}	-	MG, S_{best}: 3.77 ± 0.19 s; S_{avg}: 3.99 ± 0.17 s; S_{total}: 23.96 ± 1.05 s; S_{dec}: 5.9 ± 3.1%; N-MG, S_{best}: 3.92 ± 0.19 s; S_{avg}: 4.09 ± 0.17 s; S_{total}: 24.55 ± 1.01 s; S_{dec}: 4.4 ± 1.8%	-	-	-
	SHU	1 × 6	25 m (12.5 + 12.5)	25 s	A^{K}	-	MG, S_{best}: 5.29 ± 0.19 s; S_{avg}: 5.47 ± 0.19 s; S_{total}: 32.79 ± 1.14 s; S_{dec}: 3.4 ± 1.0%; N-MG, S_{best}: 5.31 ± 0.18 s; S_{avg}: 5.53 ± 0.15 s; S_{total}: 33.21 ± 0.92 s; S_{dec}: 4.3 ± 0.8%	-	-	-
Gantois et al. (2017)	STR	1 × 6	30 m	20 s	P	-	S_{best}: 4.59 ± 0.24 s; S_{avg}: 4.82 ± 0.31 s; S_{total}: 27.60 ± 6.77 s; S_{dec}: 5.3 ± 2.9%	-	-	-
Gantois et al. (2019)	STR	1 × 6	30 m	20 s	P	-	RS, S_{best}: 4.56 ± 0.24 s; S_{avg}: 4.83 ± 0.38 s; S_{total}: 29.00 ± 2.30; S_{dec}: 6.4 ± 3.5%; CON, S_{best}: 4.64 ± 0.24 s; S_{avg}: 4.87 ± 0.22; S_{total}: 29.08 ± 1.56 s; S_{dec}: 4.1 ± 1.8%	-	-	-
Gantois et al. (2018)	STR	1 × 6	30 m	20 s	P	-	S_{best}: 4.58 ± 0.21 s; S_{avg}: 4.84 ± 0.31; S_{total}: 29.00 ± 1.91 s; S_{dec}: 7.6 ± 5.8%	-	-	-
García-Unanue et al. (2020)	STR	1 × 7	30 m	20 s	P	-	ELT, S_{avg}: 4.37 ± 0.15 s; S_{dec}: 4.2 ± 1.4%; AM, S_{avg}: 4.67 ± 0.18 s; S_{dec}: 6.4 ± 2.2%	-	ELT, △ CMJ ^{AA}: 35.7 ± 6.0 to 34.0 ± 4.3 cm (-4.8%) AM, △ CMJ ^{AA}: 33.8 ± 4.2 to 31.8 ± 3.6 cm (-5.9%)	-
Gatterer et al. (2015b)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	NOR, S_{best}: 7.18 ± 0.24 s; S_{avg}: 7.60 ± 0.19 s; S_{dec}: 5.8 ± 1.9%; HYP, 7.28 ± 0.21 s; S_{avg}: 7.66 ± 0.32 s; S_{dec}: 5.2 ± 2.6%	-	-	-

Study	Exercise protocol						Outcomes			
	RST Mode	Sets × Reps	Distance / Duration	Rest Time	Rest Mode	I-set Rest	Performance	Perceptual	Neuromuscular	Physiological
Gharbi et al. (2014)	SHU	1 × 2	30 m (15 + 15)	30 s	P	-	S_{best}: 6.26 ± 0.24 s; S_{total}: 12.63 ± 0.47 s; S_{dec}: 1.0 ± 0.7%	-	-	B[La]$^{3'}$: 1.8 ± 0.6 to 5.7 ± 1.2 mmol·L^{-1}
	SHU	1 × 3	30 m (15 + 15)	30 s	P	-	S_{best}: 6.18 ± 0.23 s; S_{total}: 18.75 ± 0.61 s; S_{dec}: 1.5 ± 1.0%	-	-	B[La]$^{3'}$: 1.8 ± 0.6 to 9.4 ± 1.7 mmol·L^{-1}
	SHU	1 × 4	30 m (15 + 15)	30 s	P	-	S_{best}: 6.17 ± 0.21 s; S_{total}: 25.05 ± 0.81 s; S_{dec}: 2.0 ± 1.1%	-	-	B[La]$^{3'}$: 1.8 ± 0.6 to 9.6 ± 1.9 mmol·L^{-1}
	SHU	1 × 5	30 m (15 + 15)	30 s	P	-	S_{best}: 6.29 ± 0.20 s; S_{total} 32.36 ± 1.23 s; S_{dec}: 2.6 ± 1.4%	-	-	B[La]$^{3'}$: 1.8 ± 0.6 to 10.5 ± 2.6 mmol·L^{-1};
	SHU	1 × 9	30 m (15 + 15)	30 s	P	-	S_{best}: 6.28 ± 0.23 s; S_{total}: 58.68 ± 2.38 s; S_{dec}: 3.9 ± 1.3%	-	-	B[La]$^{3'}$: 1.8 ± 0.6 to 12.6 ± 2.3 mmol·L^{-1};
	SHU	1 × 10	30 m (15 + 15)	30 s	P	-	S_{best}: 6.23 ± 0.23 s; S_{total}: 64.96 ± 2.57 s; S_{dec}: 4.5 ± 1.4%	-	-	B[La]$^{3'}$: 1.8 ± 0.6 to 12.7 ± 1.0 mmol·L^{-1}
Gharbi et al. (2015)	SHU	1 × 10	30 m (15 + 15)	30 s	P	-	S_{best}: 6.10 ± 0.20 s; S_{total}: 63.20 ± 2.20 s; S_{dec}: 3.5 ± 1.1%	-	-	B[La]$^{3'}$: 15.3 ± 2.1 mmol·L^{-1}
Gibson et al. (2013)	MD^{A}	1 × 6	40 m	25 s	P	-	S_{best}: 7.11 ± 0.25 s; S_{total}: 44.40 ± 1.62 s; S_{dec}: 3.6 ± 1.2%	-	-	-
Girard et al. (2018)	STR	1 × 6	35 m	10 s	P	-	S_{avg}: 5.36 ± 0.29 s; S_{dec}: 8.6 ± 2.8%	-	-	-
Girard, Racinais, et al. (2011)	STR	1 × 6	20 m	20 s	P	-	S_{avg}: 3.23 ± 0.13 s; S_{dec}: 2.8 ± 1.7%	-	Δ*L*: 13.6 ± 2.1 to 15.4 ± 2.7 cm; Δz: 1.7 ± 0.4 to 2.2 ± 0.4 cm; $F_z$max: 2.0 ± 0.28 to 2.1 ± 0.26 N; K_{vert}: 120 ± 9.3 to 97 ± 5.2 kN·m^{-1}; K_{leg}: 15.0 ± 10.0 to 13.7 ± 7.0 kN·m^{-1}	-
González-Frutos et al. (2022)	STR	1 × 6	30 m	30 s	A^{K}		S_{avg}: 4.89 ± 0.07 s	-	-	-
Gonzalo-Skok et al. (2016)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	INT, S_{best}: 7.16 ± 0.23 s; S_{avg}: 7.52 ± 0.23 s; S_{dec}: 5.1 ± 1.8%; CON, S_{best}: 7.17 ± 0.24 s; 7.50 ± 0.24 s; S_{dec}: 4.6 ± 1.8%	-	-	-

Study	Exercise protocol						Outcomes			
	RST Mode	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
	MD^{G}	1 × 5	25 m (5 m per turn)	20 s	P	-	INT, S_{best}: 6.58 ± 0.21 s; S_{avg}: 6.86 ± 0.25 s; S_{dec}: 2.0 ± 0.7; CON, S_{best}: 6.56 ± 0.3; S_{avg}: 6.84 ± 0.22 s; S_{dec}: 2.3 ± 1.5%	-	-	-
Goodall et al. (2015a)	STR	1 × 12	30 m	30 s	P	-	S_{best}: 4.23 ± 0.13 s; S_{avg}: 4.68 ± 0.08 s;	-	-	△ B[La]$^{3'}$: 3.1 ± 1.4 to 12.8 ± 3.0, mmol·L^{-1}; B[La]$_{post}$ sprint 1: 2.7 mmol·L^{-1}; sprint 3: 4.8 mmol·L^{1}; sprint 5: 7.2 mmol·L^{-1}; sprint 7: 9.1 mmol·L^{-1}; sprint 9: 10.4 mmol·L^{-1}; sprint 11: 11.6 mmol·L^{-1}
Hamlin (2007)	STR	1 × 10	40 m	On 30 s (~24 s)	P	-	CWT, S_{avg}: 6.36 ± 0.40 s; ARC: 6.38 ± 0.50 s	-	-	CTWI, B[La]$^{3'}$: 13.6 ± 2.6 mmol·L^{-1}; HR_{avg}: 171 ± 9 b·min^{-1}; AR, B[La]$^{3'}$: 14.2 ± 2.3 mmol·L^{-1}; HR_{avg}: 173 ± 11 b·min^{-1}
Hamlin et al. (2017)	STR	1 × 8	20 m	On 20 s (~17 s)	P	-	NOR, S_{total}: 27.40 ± 3.20; S_{dec}: 3.5 ± 1.2%; HYP, S_{total}: 27.50 ± 3.90 s; S_{dec}: 3.5 ± 1.3%	-	-	-
Hammami et al. (2019)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	INT, S_{best}: 7.13 ± 0.32 s; S_{avg}: 7.39 ± 0.33 s, S_{total}: 44.4 ± 2.0 s; S_{dec}: 3.7 ± 1.4% INT, S_{best}: 7.21 ± 0.13 s; S_{avg}: 7.44 ± 0.15 s, S_{total}: 44.6 ± 0.9 s; S_{dec}: 3.1 ± 1.7%	-	-	-
T. Haugen et al. (2014)	STR	1 × 12	20 m	60 s	P	-	INT, S_{best}: 3.11 ± 0.17 s; S_{avg}: 3.16 ± 0.17 s CON, S_{best}: 3.02 ± 0.17 s; S_{avg}: 3.07 ± 0.17 s	-	-	INT, B[La]$_{post}$: 3.8 ± 1.3 mmol·L^{-1}; HR_{peak} (% HRmax): 85 ± 4% CON, B[La]$_{post}$: 3.5 ± 1.4 mmol·L^{-1}; HR_{peak} (% HRmax): 86 ± 4%
Haugen et al. (2015)	STR	1 × 15	20 m	60 s	P	-	S_{best}: 2.94 ± 0.15; S_{avg}: 2.98 ± 0.15	CR10: 3.8 ± 1.2 au	-	B[La]$_{post}$: 4.4 ± 1.8 mmol·L^{-1}
Hermassi et al. (2018)	STR	1 × 6	30 m	On 20 s (~16 s)	P	-	S_{best}: 4.42 ± 0.14; S_{avg}: 4.57 ± 0.12; S_{total}: 27.40 ± 0.70 s; 3.4 ± 1.6%	-	-	-
	SHU	1 × 6	30 m (15 + 15)	On 20 s (~14 s)	P	-	S_{best}: 5.97 ± 0.36; S_{avg}: 6.23 ± 0.25; S_{total}: 37.40 ± 1.50 s; S_{dec}: 4.5 ± 3.3%	-	-	-

Study	Exercise protocol						Outcomes			
	RST Mode	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
Higham et al. (2013)	STR	1 × 6	30 m	On 20 s (~16 s)	P	-	S_{total}: 24.76 ± 0.62 s	-	-	-
Hollville et al. (2018)	STR	1 × 6	20 m	On 20 s (~17 s)	P	-	S_{best}: 3.14 s± 0.12 s; S_{total}: 19.30 ± 0.60 s; S_{dec}: 2.4 ± 1.3%	CR10: 4.5 ± 1.6 au		HR_{post} (% HRmax): 88 ± 5%
Howatson and Milak (2009)	STR	1 × 15	30 m	60 s	P	-	S_{best}: 4.33 ± 0.21 s; S_{avg}: 4.49 ± 0.09 s; S_{dec}: 4.5 ± 1.5%	-	-	△ CK 24 h: 158 ± 56 to 776 ± 312 u·L^{-1} (385%)
Iaia et al. (2015)	STR	1 × 15	40 m	30 s	P	-	SEP, S_{total}: 86.09 ± 6.30 s; S_{dec}: 5.0 ± 2.3%; SEM, S_{total}: 83.81 ± 2.37 s; S_{dec}: 4.1 ± 1.3%	-	-	-
Iaia et al. (2017)	STR	1 × 6	5 s (~30 m)	15 s	P	-	-	-	-	$B[La]_{post}$: 3.1 ± 0.8 to 9.3 ± 1.6 mmol·L^{-1}
	STR	1 × 6	5 s (~30 m)	30 s	P	-	-	-	-	$B[La]_{post}$: 3.5 ± 1.1 to 6.6 ± 1.8 mmol·L^{-1}
	STR	1 × 15	40 m	30 s	P	-	RS15, S_{total}: 92.91 ± 4.66 s; S_{dec}: 5.9 ± 2.2%; RS30, S_{total}: 91.45 ± 4.35 s; S_{dec}: 5.2 ± 2.1%	-	-	-
Impellizzeri et al. (2008)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	Test, S_{best}: 6.90 ± 0.09 s; S_{avg}: 7.20 ± 0.11; S_{dec}: 4.3 ± 1.2%; Retest, S_{best}: 6.92 ± 0.10 s; S_{avg}: 7.19 ± 0.14 s; S_{dec}: 3.8 ± 1.4%	-	-	-
Impellizzeri et al. (2008)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	PRE, S_{best}: 6.94 ± 0.15 s; S_{avg}: 7.32 ± 0.13 s; S_{dec}: 5.4 ± 2.2%; ELY, S_{best}: 6.87 ± 0.17 s; S_{avg}: 7.16 ± 0.15 s; S_{dec}: 4.3 ± 1.7%; MID, S_{best}: 6.93 ± 0.15 s; S_{avg}: 7.22 ± 0.14 s; S_{dec}: 4.2 ± 1.6%; END, S_{best}: 6.92 ± 0.15 s; S_{avg}: 7.20 ± 0.13 s; S_{dec}: 4.0 ± 1.7%	-	-	-
Impellizzeri et al. (2008)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	PRO, S_{best}: 6.88 ± 0.19 s; S_{avg}: 7.12 ± 0.17 s; S_{dec}: 3.3 ± 1.5%; M-PRO, S_{best}: 6.83 ± 0.18 s; S_{avg}: 7.20 ± 0.19 s; S_{dec}: 5.1 ± 1.8%; AM, S_{best}: 7.08 ± 0.23 s; S_{avg}: 7.55 ± 0.25 s; S_{dec}: 6.1 ± 2.0%	-	-	-
Ingebrigtsen et al. (2014)	STR	1 × 7	35 m	25 s	A	-	S_{avg}: 5.25 ± 0.19 s	-	-	-

Study	Exercise protocol						Outcomes			
	RST Mode	Sets × Reps	Distance / Duration	Rest Time	Rest Mode	I-set Rest	Performance	Perceptual	Neuromuscular	Physiological
Ingebrigtsen et al. (2012)	STR	1 × 7	35 m	25 s	A	-	EL, S_{avg}:.5.24 ± 0.24 s; S_{dec}: 8.3 ± 5.3%; S-EL, S_{avg}: 5.26 ± 0.18 s; S_{dec}: 6.4 ± 3.7%	-	-	EL, HR_{peak}: 179 ± 9; S-EL, HR_{peak}: 188 ± 7
Iacono et al. (2016)	SHU	1 × 6	40 m (20 + 20)	On 20 s (~14 s)	P	-	SSG, S_{best}: 5.30 ± 0.15 s; S_{avg}: 5.48 ± 0.15; S_{dec}: 3.4 ± 0.5% RS, S_{best}: 5.31 ± 0.22 s; S_{avg}: 5.48 ± 0.18; S_{dec}: 3.3 ± 1.0%	-	-	-
Izquierdo et al. (2002a)	STR	1 × 6	15 m	60 s	P	-	PLA, S_{avg}: 2.45 ± 0.06 s; INT, S_{avg}: 2.39 ± 0.06 s	-	-	-
Jiménez-Reyes, Cross, et al. (2019)	STR	1 × 10	40 m	30 s	P	-	-	-	△ sprint 1–10: V_0: ↓ 15.1 ± 1.3%, F_0: ↓ 5.9 ± 4.5%; P_0: ↓ 20.1 ± 3.3%, RF: ↓ 6.8 ± 2.0%, D_{RF}: ↓ 14.0 ± 6.0	-
Johnston and Gabbett (2011)	STR	1 × 12	20 m	On 20 s (~17 s)	A^W	-	S_{best}: 3.09 ± 0.04 s; S_{avg}: 3.49 ± 0.14 s; S_{total}: 41.89 ± 0.20 s; S_{dec}: 11.4 ± 4.5%	6–20: 12.3 ± 1.2 au	-	HR_{peak}: 166 ± 9 b·min^{-1} HR_{avg}: 154 ± 9 b·min^{-1}
Joo (2016)	MD^A	1 × 7	34.2 m	25 s	A	-	S_{total}: 45.7 ± 2.6 s	-	-	-
G. Jorge et al. (2020)	MD^A	1 × 7	34.2 m	25	A^L	-	U20 ELY, S_{avg}: 6.68 ± 0.16 s; S_{dec}: 4.3 ± 1.0%; U20 MID, S_{avg}: 6.20 ± 0.13 s; S_{dec}: 4.1 ± 1.0%; U20 END, S_{avg}: 6.40 ± 0.14 s; S_{dec}: 4.0 ± 1.0%; U17 ELY, S_{avg}: 7.01 ± 0.21 s; S_{dec}: 5.3 ± 2.0%; U17 MID, S_{avg}: 6.25 ± 0.16 s; S_{dec}: 4.5 ± 1.8%; U17 END: S_{avg}: 6.32 ± 0.13 s; S_{dec}: 3.8 ± 1.3%	-	-	-
Kaplan (2010)	MD^A	1 × 7	34.2 m	25	A^L	-	S_{best}: 7.37 ± 0.26 s; S_{avg}: 7.57 ± 0.25 s; S_{dec}: 4.4 ± 1.7%	-	-	-
Keir et al. (2013)	STR	1 × 6	35 m	10 s	P	-	-	-	-	$B[La]_{peak}$: 14.8 ± 2.8 mmol·L^{-1}; VO_{2avg}: 45.6 ± 9.4 ml·min^{-1}·kg^{-1}; HR_{peak}: 182 ± 10 b·min^{-1}
Keogh et al. (2003)	STR	1 × 6	40 m	On 30 s (~25 s)	A^K	-	REP, S_{dec}: 13.1 ± 1.0; Club, S_{dec}: 12.7 ± 1.4	-	-	-

	Exercise protocol						Outcomes			
Study	**RST Mode**	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
Kilduff et al. (2013)	SHU	1 × 6	40 m	20 s	P	-	S_{best}: 6.72 ± 0.16 s; S_{avg}: 7.01 ± 0.16 s; S_{total}: 42.09 ± 0.94 s	-	-	-
Klatt et al. (2021)	SHU	4 × 6	40 m (20 + 20)	30 s	P	5 min P	U20, S_{best}: 6.99 ± 0.17 s; S_{avg}: 7.39 ± 0.26 s SEN, S_{best}: 7.12 ± 0.29 s; S_{avg}: 7.65 ± 0.32 s;	U20, CR10: 8.7 ± 1.2 au SEN, CR10: 8.3 ± 2.0 au	U20, $\triangle$CMJ^{AC}: 37.5 ± 5.1 cm to 39 ± 4.7 cm (4.0%) SEN, $\triangle$CMJ^{AC}: 31.6 ± 3.9 cm to 34.0 ± 3.9 cm (7.6%)	B[La]$_{post}$: 10.2 ± 2.6 mmol·L^{-1} U20, $\triangle$ CK 24 h: 285 ± 155 to 354 ± 134 u·L^{-1} (24%) SEN, $\triangle$ CK 24 h: 214 ± 82 to 443 ± 207 u·L^{-1} (47%)
Krakan et al. (2020)	STR	1 × 6	25 m	25 s	P	-	RS, S_{best}: 3.78 ± 0.08 s; S_{avg}: 3.97 ± 0.10 s; S_{dec}: 5.0 ± 3.2% PLY, S_{best}: 3.74 ± 0.11 s; S_{avg}: 3.96 ± 0.14 s, S_{dec}: 5.8 ± 0.1	RS, CR10: 7.3 ± 1.5 au PLY, CR10: 8 ± 1.1 au	-	RS, B[La]$_{post}$: 13.1 ± 2.5 mmol·L^{-1} PLY, B[La]$_{post}$: 14.8 ± 2.3 mmol·L^{-1}
Krueger et al. (2020)	STR	1 × 6	30 m	On 25 s (~21 s)	P	-	CWI, S_{total}: 26.23 ± 1.06 s; CON, S_{total}: 26.05 ± 0.69 s	-	-	-
Lakomy and Haydon (2004)	STR	1 × 6	40 m	30 s	A^{W}	-	S_{avg}: 5.97 ± 0.40 s; S_{dec}: 4.2 ± 2.4%	-	-	-
	STR	1 × 6	40 m	30 s	P^{R}	-	S_{avg}: 6.03 ± 0.52 s; S_{dec}: 3.9 ± 1.3%	-	-	-
Lapointe et al. (2020)	STR	1 × 12	30 m	20 s	A^{K}	-	CON, S_{best}: 4.83 ± 0.36 s; S_{avg}: 5.18 ± 0.51 s; S_{dec}: 7.1 ± 3.1%; INT, S_{best}: 4.80 ± 0.35 s; S_{avg}: 5.16 ± 0.47 s; S_{dec}: 7.3 ± 3.2%	CON, CR10: 8 ± 1.2 au INT, CR10: 7.5 ± 1.1 au	-	CON, B[La]$^{1'}$: 14.0 ± 2.4 mmol·L^{-1}; INT, B[La]$^{1'}$: 13.5 ± 1.5 mmol·L^{-1}
Le Rossignol et al. (2014)	STR	1 × 6	30 m	On 20 s (~16 s)	P	-	SEL, S_{total}: 25.26 ± 0.55 s; N-SEL, S_{total}: 25.92 ± 0.8 s	-	-	-
Little and Williams (2007)	STR	1 × 15	40 m	1:6^{N} (~34 s)	P	-	S_{avg}: 5.73 ± 0.07 s	6–20: 14.4 ± 1.0 au	-	B[La]$^{2'}$: 9.6 ± 0.6 mmol·L^{-1} ; HR$_{avg}$ (% HR$_{max}$): 85.8 ± 0.8%
	STR	1 × 15	40 m	1:4^{N} (~22 s)	P	-	S_{avg}: 5.93 ± 0.19 s	6–20: 17.1 ± 0.4 au	-	B[La]$^{2'}$: 14.1 ± 1.0 mmol·L^{-1} ; HR$_{avg}$ (% HR$_{max}$): 89.2 ± 1.9%
	STR	1 × 40	15 m	1:6^{N} (~16 s)	P	-	S_{avg}: 2.59 ± 0.05 s	6–20: 17.3 ± 0.5 au	-	B[La]$^{2'}$: 8.8 ± 1.1 mmol·L^{-1} ; HR$_{avg}$ (% HR$_{max}$) : 86.8 ± 1.0%
	STR	1 × 40	15 m	1:4^{N} (~10 s)	P	-	S_{avg}: 2.65 ± 0.10 s	6–20: 18.8 ± 0.4 au	-	B[La]$^{2'}$: 13.0 ± 1.7 mmol·L^{-1} ; HR$_{avg}$ (% HR$_{max}$): 89.3 ± 1.2%

Study	Exercise protocol						Outcomes			
	RST Mode	Sets × Reps	Distance / Duration	Rest Time	Rest Mode	I-set Rest	Performance	Perceptual	Neuromuscular	Physiological
(Robert G. Lockie et al., 2016)	STR	1 × 7	30 m	On 20 s (~16 s)	A^X	-	FSH, S_{avg}: 32.08 ± 1.31 s; EXP, S_{avg}: 31.67 ± 0.76 s	-	-	-
Lockie et al. (2020)	STR	1 × 6	20 m	On 15 s (~11s)	A^X	-	S_{total}: 31.95 ± 1.06 s	-	-	-
Lockie et al. (2019)	STR	1 × 7	20 m	On 20 s (~15s)	A^X	-	S_{total}: 31.95 ± 1.06 s	-	-	-
Lombard et al. (2021)	STR	1 × 6	30 m	On 25 s (~21 s)	A^X	-	S_{total}: 26.77 ± 0.96 s	-	-	-
Madueno et al. (2018)	SHU	1 × 12	20 m (15 + 5)	20 s	P	-	-	CR10: 6.5 ± 0.5 au	-	△ $B[La]_{post}$: 2.0 to 6.8 $mmol \cdot L^{-1}$; △ $B[La]^{5'}$: 4.8 $mmol \cdot L^{-1}$; VO_{2avg}: 33.3 ± 4.0 $mL \cdot kg^{-1} \cdot min^{-1}$; VO_{2avg} (% VO_{2max}): 73.1 ± 9.8%; HR_{avg}: 166 ± 8 $b \cdot min^{-1}$ (% HR_{max}: 83 ± 6%)
	SHU	1 × 12	20 m (15 + 5)	20 s	A^Z	-	-	CR10: 6.0 ± 0.5 au	-	△ $B[La]_{post}$: 2.0 to 8.6 $mmol \cdot L^{-1}$; $B[La]^{5'}$: 6.3 $mmol \cdot L^{-1}$; VO_{2avg}: 37.7 ± 7.1 $mL \cdot kg^{-1} \cdot min^{-1}$ (% VO_{2max}: 82.5 ± 14.9%); HR_{avg}: 173 ± 5 $b \cdot min^{-1}$ (% HR_{max}: 86 ± 2%)
Maggioni et al. (2019)	SHU	3 × 6	40 m (20 + 20)	20 s	P	3 min P	-	CR10: 6.1 ± 2.7 au	-	-
Mancha-Triguero et al. (2021)	STR	1 × 5	14 m	30 s	A	-	M, S_{best}: 2.48 ± 0.18 s; S_{avg}: 2.65 ± 0.16 s; S_{total}: 13.27 ± 0.83 s; F, S_{best}: 2.70 ± 0.16 s; S_{avg}: 2.99 ± 0.15 s; S_{total}: 14.98 ± 0.73 s	-	-	-
Marcelino et al. (2016)	STR	1 × 12	20 m	20 s	A^k	-	SSG 1, S_{best}: 3.20 ± 0.10 s; S_{avg}: 3.36 ± 0.10; S_{dec}: 5.3 ± 3.9%; SSG 2, S_{best}: 3.18 ± 0.07 s; S_{avg}: 3.37 ± 0.07 s; S_{dec}: 6.1 ± 3.3%	-	-	-
Matzenbacher et al. (2016)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	PRE, S_{best}: 7.13 ± 0.26 s; S_{avg}: 7.49 ± 0.34 s; S_{dec}: 4.9 ± 1.7%; END, S_{best}:7.15 ± 0.24 s; S_{avg}: 7.42 ± 0.27 s; S_{dec}: 3.8 ± 1.9%	-	-	-

	Exercise protocol						**Outcomes**			
Study	**RST Mode**	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
McGawley and Andersson (2013)	STR	1 × 6	30 m	On 20 s (~16 s)	P	-	Condition 1, S_{best}: 27.70 ± 0.50 s; S_{dec}: 4.7 ± 1.6%; Condition 2, S_{best}: 26.70 ± 0.90 s; S_{dec}: 5.2 ± 1.1%	-	-	-
Meckel et al. (2018)	STR	1 × 6	30 m	30 s	P	-	PRE, S_{total}: 22.50 ± 0.60 s; S_{dec}: 2.9 ± 0.3%; MID, S_{total}: 23.70 ± 0.63 s; S_{dec}: 2.3 ± 0.2%; END, S_{total}: 23.51 ± 0.62 s; S_{dec}: 2.2 ± 0.2%	-	-	-
Meckel, Gottlieb, et al. (2009)	STR	1 × 12	20 m	On 20 s (~17 s)	P	-	S_{total}: 39.70 ± 0.60 s; S_{dec}: 5.0 ± 0.5%	CR10: 6.9 ± 0.4 au	-	△ $B[La]^{2'}$: 2.0 ± 0.1 to 8.8 ± 0.7 $mmol \cdot L^{-1}$; HR_{peak}: 182 ± 2 $b \cdot min^{-1}$
Meckel, Machnai, et al. (2009)	STR	1 × 6	40 m	On 30 s (~24 s)	P	-	S_{best}: 5.60 ± 0.26 s; S_{total}: 35.10 ± 1.50 s; S_{dec}: 4.8 ± 1.9%	CR10: 4.9 ± 1.4 au	-	$B[La]^{2'}$: 11.3 ± 2.5 $mmol \cdot L^{-1}$; HR_{peak}: 179 ± 8 $b \cdot min^{-1}$
	STR	1 × 12	20 m	On 20 s (~17 s)	P	-	S_{best}: 3.10 ± 0.10 s; S_{total}: 38.80 ± 1.20 s; S_{dec}: 5.0 ± 2.0%	CR10: 4.0 ± 1.3 au	-	$B[La]^{2'}$: 10.5 ± 1.8 $mmol \cdot L^{-1}$; HR_{peak}: 184 ± 8 $b \cdot min^{-1}$
Meckel et al. (2015)	STR	1 × 6	30 m	30 s	P	-	S_{total}: 27.71 ± 1.40 s; S_{dec}: 1.6 ± 0.7%	CR10: 5.4 ± 1.5 au	-	$B[La]^{2'}$: 10.1 ± 2.1 $mmol \cdot L^{-1}$; HR_{peak}: 171 ± 7 $b \cdot min^{-1}$
Meckel et al. (2014)	STR	1 × 12	20 m	On 20 s (~17 s)	P	-	S_{total}: 37.80 ± 1.40 s; S_{dec}: 4.4 ± 1.5%	CR10: 5.2 ± 1.3 au	-	$B[La]^{2'}$: 6.7 ± 1.1 $mmol \cdot L^{-1}$; HR_{peak}: 174 ± 9 $b \cdot min^{-1}$
Michalsik et al. (2015)	STR	1 × 7	30 m	25 s	A^{Q}	-	S_{best}: 4.09 ± 0.12 s; S_{avg}: 4.30 ± 0.13 s	-	-	-
Mohr et al. (2016)	STR	1 × 5	30 m	25 s	A^{K}	-	S_{avg}: 4.58 ± 0.15 s	-	-	-
Mohr and Krustrup (2016)	STR	1 × 5	30 m	25 s	A^{K}	-	SEP, S_{best}: 4.34 ± 0.05 s; S_{avg}: 4.45 ± 0.05 s; SEM, S_{best}: 4.32 ± 0.06 s; S_{avg}: 4.41 ± 0.07 s	-	-	-
Mohr et al. (2012)	STR	1 × 3	30 m	25 s	A^{K}	-	S_{total}: 13.36 ± 0.11 s	-	-	-
Moncef et al. (2012)	SHU	1 × 6	40 m (20 + 20)	On 20 s (~14 s)	P	-	S_{avg}: 6.38 ± 0.86 s	-	-	-
Morcillo et al. (2015)	STR	1 × 12	30 m	30 s	P	-	S_{best}: 4.09 ± 0.05 s; S_{dec}: 3.7 ± 1.5%	-	-	$B[La]_{peak}$: 9.5 ± 2.3 $mmol \cdot L^{-1}$
Moreira et al. (2015)	STR	1 × 5	30 m	25 s	A^{Q}	-	S_{total}: 4.65 ± 0.68 s	-	-	-

	Exercise protocol						**Outcomes**			
Study	**RST Mode**	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
Mujika et al. (2009)	STR	1 × 6	30 m	On 30 s (~26 s)	A^{L}	-	U17, S_{avg}: 4.43 ± 0.11 s; S_{total}: 26.61 ± 0.53 s; S_{dec}: 4.1 ± 1.1%; U18, S_{avg}: 4.39 ± 0.12 s; S_{total}: 26.34 ± 0.94 s; S_{dec}: 4.6 ± 1.1%	-	-	U17, $B[La]_{peak}$: 10.9 ± 1.7 mmol·L^{-1}; U18, $B[La]_{peak}$: 12.3 ± 1.5 mmol·L^{-1}
Müller et al. (2021)	STR	1 × 6	35 m	10 s	P	-	-	-	△ CMJ ^{AC}: 36.1 ± 5.7 to 34.4 ± 4.9 cm (-4.8%)	$B[La]_{post}$: 11.2 ± 4.4 mmol·L^{-1}; $B[La]^{5'}$: 15.0 ± 3.9 HR_{peak}: 174 ± 20 b·min^{-1}
Nakamura et al. (2009)	SHU	1 × 6	30 m (15 + 15)	On 20 s (~15 s)	P	-	S_{best}: 5.62 ± 0.16 s; S_{avg}: 6.03 ± 0.18 s; S_{dec}: 7.4 ± 2.5%	-	-	$B[La]^{3'}$: 10.6 ± 2.1 mmol·L^{-1}; HR_{peak}: 180 ± 6 b·min^{-1}
Nascimento et al. (2015)	SHU	1 × 8	40 m (10 + 20 + 10)	20 s (~14 s)	P	-	CON, S_{best}: 8.53 ± 0.34 s; S_{avg}: 9.09 ± 0.39 s; S_{dec}: 6.5 ± 1.1%; INT, S_{best}: 8.14 ± 0.18 s; S_{avg}: 8.53 ± 0.15 s; S_{dec}: 4.8 ± 0.8%	-	-	CON, $B[La]_{peak}$: 13.2 ± 2.7 mmol·L^{-1} INT, $B[La]_{peak}$: 16.2 ± 2.8 mmol·L^{-1}
Nedrehagen and Saeterbakken (2015)	SHU	1 × 6	40 m (20 + 20)	30 s	P	-	INT, S_{avg}: 7.79 ± 0.37 s CON, S_{avg}: 7.79 ± 0.5	-	-	-
Nikolaidis et al. (2015)	STR	1 × 10	20 m	On 30 s (~27 s)	A^{Q}	-	S_{best}: 3.14 ± 0.11 s; S_{avg}: 3.24 ± 0.11 s; S_{dec}: 3.4 ± 1.6%	-	-	-
Okuno et al. (2013)	SHU	1 × 6	30 m (15 + 15)	On 20 s (~14 s)	P	-	S_{best}: 5.82 ± 0.15 s; S_{avg}: 6.06 ± 0.18; S_{dec}: 4.2 ± 1.1%	-	-	-
Padulo et al. (2016)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	Test, S_{best}: 7.09 ± 0.18 s; S_{total}: 44.84 ± 1.09 s; S_{dec}: 5.5 ± 1.6%; Retest, S_{best}: 7.06 ± 0.15 s; S_{total}: 44.76 ± 1.09 s; S_{dec}: 5.7 ± 1.7%	Test, CR10: 7.2 ± 0.9 au; Retest, CR10: 7.2 ± 0.4 au	-	Test, $B[La]^{3'}$: 11.3 ± 2.0 mmol·L^{-1}; Retest, $B[La]^{3'}$: 11.7 ± 1.7 mmol·L^{-1}
Padulo et al. (2014)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	Test, S_{best}: 6.97 ± 0.12 s; S_{total}: 43.76 ± 0.90 s; S_{dec}: 4.6 ± 1.5%; Retest, S_{best}: 7.03 ± 0.15 s; S_{total}: 44.08 ± 0.75 s; S_{dec}: 4.5 ± 1.1%	-	-	Test, $B[La]^{3'}$: 11.6 ± 2.2 mmol·L^{-1}; Retest, $B[La]^{3'}$: 11.6 ± 2.1 mmol·L^{-1}
Johnny Padulo et al. (2015)	SHU	1 × 10	30 m (15 + 15)	30 s	P	-	Test, S_{best}: 5.81 ± 0.32 s; S_{total}: 60.19 ± 3.57 s; S_{dec}: 3.5 ± 1.7%; Retest, S_{best}: 5.82 ± 0.31 s; S_{total}: 60.50 ± 3.56 s; S_{dec}: 3.8 ± 1.6%;	Test, CR10: 7.8 ± 1.3 au; Retest, CR10: 8.0 ± 1.2 au	-	Test, $B[La]^{3'}$: 11.9 ± 2.5 mmol·L^{-1}; Retest, $B[La]^{3'}$: 11.9 ± 2.1 mmol·L^{-1}

Study	Exercise protocol						Outcomes			
	RST Mode	Sets × Reps	Distance / Duration	Rest Time	Rest Mode	I-set Rest	Performance	Perceptual	Neuromuscular	Physiological
	SHU	1 × 10	30 m (10 + 10 + 10)	30 s	P	-	Test, S_{best}: 7.02 ± 0.44 s; S_{total}: 72.49 ± 4.82 s; S_{dec}: 3.3 ± 1.3%; Retest, S_{best} 7.01 ± 0.44 s; S_{total}: 72.51 ± 4.77 s; S_{dec}: 3.4 ± 1.4%	Test, CR10: 7.8 ± 1.6 au Retest, CR10: 8.1 ± 1.5 au	-	Test, $B[La]^{3'}$: 11.3 ± 2.8 mmol·L^{-1} Retest, $B[La]^{3'}$: 11.4 ± 2.5 mmol·L^{-1}
J Padulo, M Tabben, G Attene, et al. (2015)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	Test, S_{best}: 7.10 ± 0.20 s; S_{total}: 44.89 ± 1.14 s; S_{dec}: 5.5 ± 1.9%; Retest, S_{best}: 7.09 ± 0.20; S_{total}: 44.79 ± 1.13 s; S_{dec}: 5.3 ± 1.7%	Test, CR10: 7.0 ± 1.2 au; Retest, CR10: 7.2 ± 0.7 au	-	Test, $B[La]^{3'}$: 11.2 ± 2.1 mmol·L^{-1} Retest, $B[La]^{3'}$: 11.3 ± 2.0 mmol·L^{-1}
	SHU	1 × 6	40 m (20 + 20)	20 s	A^{P}	-	S_{best}: 7.16 ± 0.23; S_{total}: 45.77 ± 1.34 s; S_{dec}: 6.6 ± 1.6%	CR10: 7.9 ± 1.2 au	-	$B[La]^{3'}$: 13.1 ± 2.1 mmol·L^{-1}
J Padulo, M Tabben, LP Ardigò, et al. (2015)	SHU	1 × 6	40 m (20 + 20)	15 s	P		S_{best}: 7.36 ± 0.10 s; S_{total}: 46.12 ± 0.85 s; S_{dec}: 4.5 ± 1.2%	-	△ CMJ ^{AA}: 39.2 cm to 35.6 ± 0.9 cm (-9.0%)	$B[La]^{3'}$: 14.5 ± 0.4 mmol·L^{-1}
	SHU	1 × 6	40 m (20 + 20)	20 s	P		S_{best}: 7.35 ± 0.16 s; S_{total}: 45.41 ± 0.94 s; S_{dec}: 3.0 ± 0.9%	-	△ CMJ ^{AA}: 39.2 cm to 37.5 ± 2.7 cm (-4.3%)	$B[La]^{3'}$: 12.7 ± 1.2 mmol·L^{-1}
	SHU	1 × 6	40 m (20 + 20)	25 s	P		S_{best}: 7.33 ± 0.13 s; S_{total}: 44.82 ± 0.90 s; S_{dec}: 1.9 ± 0.7%	-	△ CMJ ^{AA}: 39.2 cm to 38.3 ± 3.7 cm (-2.3%)	$B[La]^{3'}$: 8.0 ± 1.5 mmol·L^{-1}
Paulauskas et al. (2020)	SHU	3 × 10	30 m (15 + 15)	30 s	P	5 min P	S_{best}: set 1, 58.45 ± 1.63 s; set 2, 59.25 ± 2.03 s; set 3, 60.02 ± 2.41 s;	-	-	$B[La]^{3'}$: 13.02 ± 2.28 mmol·L^{-1}; HR_{peak}: set 1, 175 ± 8 b·min^{-1}; set 2, 178 ± 5 b·min^{-1}; set 3, 182 ± 10 b·min^{-1}; HR_{avg}: set 1, 163 ± 9.1 b·min^{-1}; set 2, 169 ± 7 b·min^{-1}; set 3, 169 ± 6 b·min^{-1}
	SHU	3 × 20	15 m (7.5 + 7.5)	15 s	P	5 min P	S_{best}: set 1, 53.37 ± 1.64 s; set 2, 53.58 ± 1.48 s; set 3, 54.04 s	-	-	$B[La]^{3'}$: 8.5 ± 3.4 mmol·$L^{-1;}$ HR_{peak}: set 1, 174 ± 9 b·min^{-1}; set 2, 178 ± 8 b·min^{-1}; set 3, 179 ± 7 b·min^{-1}; HR_{avg}: set 1, 161 ± 10 b·min^{-1}; set 2, 170 ± 9 b·min^{-1}; 171 ± 8 b·min^{-1}
Perroni et al. (2013)	MD^{A}	1 × 7	30 m	25 s	A^{K}	-	S_{avg}: 6.12 ± 0.04 s; S_{total}: 42.84 ± 1.96 s; S_{dec}: 3.7 ± 1.2%	-	-	-
Petisco et al. (2019)	SHU	1 × 6	30 m (15 + 15)	20 s	P	-	S_{best}: 5.77 ± 0.15 s; S_{total}: 35.70 ± 0.65 s	-	-	-

Study	Exercise protocol						Outcomes			
	RST Mode	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
Purkhús et al. (2016)	STR	1 × 5	30 m	25 s	A^K	-	CON, S_{avg}: 5.46 ± 0.38 s INT, S_{avg}: 5.64 ± 0.29 s	-	-	-
Pyne et al. (2008)	STR	1 × 6	30 m	On 20 s (~16 s)	P	-	S_{total}: 25.83 ± 0.60 s; S_{dec}: 3.8 ± 1.1%	-	-	-
Ramírez-Campillo et al. (2016)	STR	1 × 6	35 m	10 s	P	-	CON, S_{avg}: 7.35 ± 0.50 s; PLA, S_{avg}: 7.08 ± 0.60 s; INT, S_{avg}: 7.48 ± 1.00 s	-	-	-
Ermanno Rampinini et al. (2007)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	S_{best}: 7.00 ± 0.19 s; S_{avg}: 7.25 ± 0.17 s; S_{dec}: 3.3 ± 1.6%	-	-	-
Rampinini et al. (2009)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	PRO, S_{best}: 6.86 ± 0.13 s; S_{avg}: 7.17 ± 0.09 s; S_{dec}: 4.5 ± 1.9%; AM, S_{best}: 6.97 ± 0.15 s; S_{avg}: 7.41 ± 0.19 s; S_{dec}: 6.0 ± 1.9%	-	-	-
Rodríguez-Fernández et al. (2018)	STR	1 × 8	30 m	25 s	A	-	YTH, S_{best}: 4.03 ± 0.15 s; S_{avg}: 4.19 ± 0.12 s; S_{total}: 33.52 ± 0.97 s; S_{dec}: 3.9 ± 1.6% PRO, S_{best}: 3.92 ± 0.11 s; S_{avg}: 4.12 ± 0.12 s; S_{total}: 32.91 ± 0.91 s; S_{dec}: 5.2 ± 1.9%	-	-	-
Rodríguez-Fernández et al. (2016)	STR	1 × 8	30 m	25 s	A^K	-	S_{best}: 3.87 ± 0.04 s; S_{avg}: 4.03 ± 0.04 s; S_{total}: 32.26 ± 0.31 s; S_{dec}: 4.3 ± 0.3%	-	-	-
Rey et al. (2017)	STR	1 × 6	25 m	25 s	A^K	-	INT, S_{best}: 3.21 ± 0.08 s; S_{avg}: 3.29 ± 0.07 s; S_{total}: 19.77 ± 0.46 s; S_{dec}: 2.4 ± 1.5% CON, S_{best}: 3.15 ± 0.12 s; S_{avg}: 3.25 ± 0.15 s; S_{total}: 19.53 ± 0.95 s; S_{dec}: 3.1 ± 1.9%	-	-	-
Røksund et al. (2017)	STR	1 × 8	30 m	On 30 s (~27 s)	P	-	S_{avg}: 3.14 ± 0.10 s	-	-	-
Ruscello et al. (2017)	STR	1 × 7	30 m	$1{:}5^N$ (~26 s)	P	-	S_{avg}: 5.24 ± 0.33 s	-	-	$B[La]^{3'}$: 10.9 ± 1.8 $mmol{\cdot}L^{-1}$
	SHU	1 × 7	30 m (15 + 15)	$1{:}3^N$ (~21 s)	P	-	S_{avg}: 6.84 ± 0.44 s	-	-	$B[La]^{3'}$: 7.9 ± 2.4 $mmol{\cdot}L^{-1}$

Study	Exercise protocol						Outcomes			
	RST Mode	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
Ruscello et al. (2013)	STR	1 × 7	30 m	1:5^{N} (~22 s)	P	-	S_{avg}: 4.53 ± 0.28 s; S_{dec}: 4.8%	-	△ CMJ ^{AD}: 46.8 ± 4.5 to 43.3 ± 5.0 cm (-7.5%)	-
	SHU	1 × 7	30 m (15 + 15)	1:5^{N} (~30 s)	P	-	S_{avg}: 5.89 ± 0.35 s; S_{dec}: 3.4%	-	△ CMJ ^{AD}: 46.9 ± 4.5 to 43.0 ± 5.1 cm (-8.3%)	-
	MD^{C}	1 × 7	30 m (5 m per turn)	1:5^{N} (~42 s)	P	-	S_{avg}: 8.51 ± 0.41 s; S_{dec}: 2.5%	-	△ CMJ ^{AD}: 46.9 ± 4.4 to 43.5 ± 5.0 cm (-7.1%)	-
Russell et al. (2017b)	STR	1 × 15	30 m	60 s	P	-	CON, S_{avg}: 4.34 ± 0.17 s; S_{total}: 65.08 ± 2.56 s; INT, S_{avg}: 4.37 ± 0.23 s; S_{total}: 65.56 ± 3.38 s	-	-	CON, △ CK 24 h: 232 ± 44 u·L^{-1} to 785 ± 129 u·L^{-1} (238%); INT △ CK 24 h: 232 ± 49 u·L^{-1} to 799 ± 141 u·L^{-1} (244%)
Salleh et al. (2017)	MD^{C}	1 × 5	40 m	60 s	A^{U}	-	S_{avg}: 7.54 ± 0.65 s; S_{dec}: 1.9 ± 1.6%	-	-	-
Sánchez-Sánchez et al. (2014)	SHU	1 × 6	40 m (20 + 20)	20 s	A	-	Sys1, S_{best}: 7.38 ± 0.25 s; S_{avg}: 7.93 ± 0.30 s; S_{total}: 47.55 ± 1.74 s; Sys2, S_{best}: 7.5 ± 0.26 s; S_{avg}: 7.97 ± 0.26 s; S_{total}: 47.85 ± 1.59 s; Sys3, S_{best}: 7.74 ± 0.29 s; S_{avg}: 8.24 ± 0.29 s; S_{total}: 49.46 ± 1.75 s; Sys4, S_{best}: 7.51 ± 0.32 s; S_{avg}: 8.02 ± 0.25 s; S_{total}: 48.14 ± 1.48 s	-	Sys1, △ CMJ^{AA}: 36.5 ± 4.4 to 28.3 ± 4.5cm (-22.5%); Sys2, △ CMJ^{AA}: 35.5 ± 5.4 to 26.0 ± 4.9 cm (-26.1%); Sys3, △ CMJ^{AA}: 36.4 ± 5.7 to 26.5 ± 5.2 cm (-27.1%); Sys4, △ CMJ^{AA}: 36.9 ± 5.1 to 30.1 ± 5.9 cm (-18.5%)	Sys1, B[La]$^{1'}$: 12.9 ± 2.3 mmol·L^{-1}; B[La]$^{3'}$: 13.0 ± 2.5 mmol·L^{-1}; HR_{peak} 184 ± 13 b·min^{-1}; Sys2, B[La]$^{1'}$: 12.4 ± 2.4 mmol·L^{-1}; B[La]$^{3'}$: 13.0 ± 3.0 mmol·L^{-1}; HR_{peak} 185 ± 12 b·min^{-1}; Sys3, B[La]$^{1'}$: 11.0 ± 2.3 mmol·L^{-1}; B[La]$^{3'}$: 11.0 ± 1.9 mmol·L^{-1}; HR_{peak} 183 ± 13 b·min^{-1}; Sys4, B[La]$^{1'}$: 11.8 ± 2.5 mmol·L^{-1}; B[La]$^{3'}$: 11.1 ± 2.5 mmol·L^{-1}; HR_{peak} 185 ± 12 b·min^{-1}
Sánchez-Sánchez et al. (2019)	STR	1 × 7	30 m	20 s	A	-	S_{avg}: 4.46 ± 0.17 s; S_{dec}: 4.7 ± 2.0%	-	-	-

Study	Exercise protocol						Outcomes			
	RST Mode	Sets × Reps	Distance / Duration	Rest Time	Rest Mode	I-set Rest	Performance	Perceptual	Neuromuscular	Physiological
Sanchez-Sanchez et al. (2018)	STR	1 × 6	20 m	20 s	P	-	S_{best}: 3.19 ± 0.11 s; S_{avg}: 3.29 ± 0.08 s	-	-	-
Sanders et al. (2017)	STR	1 × 10	30 m	25 s	P	-	-	-	-	HR_{post} (% HR_{max}): 93%
Scanlan and Madueno (2016)	STR	1 × 10	20 m	30 s	P	-	S_{total}: 35.02 ± 2.1 s; S_{dec}: 2.7 ± 1.2%	6–20: 15.2 ± 2.1	-	$B[La]_{post}$: 4.6 ± 0.8 to 11.0 ± 1.6 mmol·L^{-1}; HR_{peak}: 169 ± 12 b·min^{-1}
	STR	1 × 10	20 m	30 s	A^{AG}	-	S_{total}: 37.73 ± 2.5 s; S_{dec}: 9.4 ± 5.2%	6–20: 18.4 ± 1.3 au	-	$B[La]_{post}$: 5.0 ± 1.1 to 16.5 ± 4.5 mmol·L^{-1}; HR_{peak}: 187 ± 9 b·min^{-1}
Scanlan et al. (2021)	SHU	1 × 12	20 m ^{AE}	20 s	P	-	S_{dec}: 2.8 ± 0.8%	-	-	-
Selmi et al. 2016	STR	2 × 5	20 m	15 s	A^{J}	1 min P	S_{best}: set 1, 3.31 ± 0.14 s; set 2, 3.38 ± 0.12 s; S_{total}: set 1, 16.97 ± 0.69 s; set 2, 17.69 ± 0.58 s; S_{dec}: Set 1, 2.9 ± 1.6%; Set 2, 5.1 ± 2.8%	CR10: 6.3 ± 1.4 au	-	△ $B[La]^{3'}$: 1.8 ± 0.6 to 8.1 ± 2.2 mmol·L^{-1} HR_{peak}: 186 ± 14 b·min^{-1} HR_{avg}: 137 ± 12 b·min^{-1}
	STR	2 × 5	20 m	15 s	A^{J}	2 min P	S_{best}: set 1, 3.28 ± 0.10 s; set 2, 3.33 ± 0.11 s; S_{total}: set 1, 16.90 ± 0.57 s; set 2, 17.11 ± 0.47 s; S_{dec}: Set 1, 3.2 ± 1.6%; Set 2, 2.8 ± 1.6%	CR10: 3.2 ± 1.5 au	-	△ $B[La]^{3'}$: 1.5 ± 0.2 to 8.2 ± 1.0 mmol·L^{-1} HR_{peak}: 182 ± 9 b·min^{-1} HR_{avg}: 125 ± 11 b·min^{-1}
	STR	2 × 5	20 m	15 s	A^{J}	4 min P	S_{best}: set 1, 3.31 ± 0.11 s; set 2, 3.31 ± 0.11 s; S_{total}: set 1, 16.97 ± 0.64 s; set 2, 17.06 ± 0.55 s; S_{dec}: Set 1, 2.7 ± 1.3%; Set 2, 3.1 ± 1.4%	CR10: 3.4 ± 1.2 au	-	△ $B[La]^{3'}$: 1.6 ± 0.3 to 8.5 ± 1.8 mmol·L^{-1} HR_{peak}: 180 ± 10 b·min^{-1} HR_{avg}: 114 ± 5 b·min^{-1}
Selmi et al. (2018)	SHU	1 × 20	40 m (20 + 20)	20 s	P	-	INT, S_{best}: 7.53 ± 0.48 s; S_{total}: 47.86 ± 2.81 s; S_{dec}: 6.0 ± 1.9% CON, S_{best}: 7.69 ± 0.31 s; S_{total}: 49.05 ± 1.52 s; S_{dec}: 6.3 ± 2.0%	-	-	-
Shalfawi et al. (2014)	STR	1 × 7	30 m	30 s	P	-	S_{best}: 4.93 ± 0.20 s; S_{avg}: 5.04 ± 0.20 s; S_{total}: 35.35 ± 1.40 s; S_{dec}: 2.2 ± 1.0%	-	-	-
Shalfawi et al. (2012)	STR	1 × 10	40 m	60 s	P	-	INT, S_{avg}: 5.92 ± 0.26 s CON, S_{avg}: 5.84 ± 0.27 s	-	-	-
Shalfawi et al. (2013)	STR	1 × 10	40 m	60 s	P	-	ATG, S_{avg}: 6.15 ± 0.4 s RS, S_{avg}: 6.19 ± 0.25 s	-	-	-

Study	Exercise protocol						Outcomes			
	RST Mode	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
Silva et al. (2019)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	S_{best}: 6.44 ± 0.14 s; S_{avg}: 6.57 ± 0.26 s; S_{total}: 44.20 ± 0.40 s; S_{dec}: 9.8 ± 1.4%	-	-	-
Soares-Caldeira et al. (2014)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	INT, S_{best}: 7.17 ± 0.37 s; S_{avg}: 7.62 ± 0.35 s; S_{dec}: 6.3 ± 2.0%; CON, S_{best}: 6.95 ± 0.16 s; S_{avg}: 7.49 ± 0.20 s; S_{dec}: 7.8 ± 4.3%	-	-	-
Spineti et al. (2015)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	CCT, S_{best}: 6.93 ± 0.15 s; S_{avg}: 7.43 ± 0.10; S_{dec}: 7.2 ± 2.2% TST, S_{best}: 7.11 ± 0.19 s; S_{avg}: 7.54 ± 0.23; S_{dec}: 6.1 ± 1.9%	-	-	-
Suarez-Arrones et al. (2014)	MD^{AF}	1 × 6	40 m (20 + 20)	20 s	P	-	RS, S_{best}: 7.60 ± 0.20 s; S_{avg}: 8.00 ± 0.20 s; S_{dec}: 5.3 ± 1.3%; SQ, S_{best}: 7.50 ± 0.30 s; S_{avg}: 7.90 ± 0.30 s: S_{dec}: 5.0 ± 2.0%	-	-	-
	SHU	3 × 6	40 m (20 + 20)	20 s	P	4 min P	-	6–20: 13.9 ± 0.4 au	-	-
Stojanovic et al. (2012)	SHU	1 × 10	30 m (15 + 15)	30 s	P	-	S_{avg}: 5.77 ± 0.18 s; S_{dec}: 3.5 ± 1.1%	-	-	-
Taylor et al. (2016)	STR	3–4 × 7	30 m	20 s	P	4 min P	-	-	-	HR_{peak} (% HRmax): 92 ± 5%
	SHU	3–4 × 7	30 m	20 s	P	4 min P	-	-	-	HR_{peak} (% HRmax): 89 ± 11%
Teixeira et al. (2019)	STR	1 × 8	40 m	20 s	P	-	$IT_{7.5}$, S_{best}: 8.86 ± 0.25 s; S_{avg}: 9.39 ± 0.26 s; S_{dec}: 6.5 ± 1.4%; IT_{15}, S_{best}: 8.83 ± 0.36 s; S_{avg}: 9.33 ± 0.36 s; S_{dec}: 5.7 ± 3.2%	-	-	-
Thomassen et al. (2010)	STR	1 × 10	20 m	15 s	A^{K}	-	INT, S_{avg}: 3.35 ± 0.07 s; S_{total}: 33.44 ± 0.44 s; S_{dec}: 5.8 ± 1.0% NT, S_{avg}: 3.34 ± 0.09 s; S_{total}: 33.41 ± 0.32 s; S_{dec}: 5.9 ± 0.8%	-	-	-
Tønnessen et al. (2011)	STR	1 × 10	40 m	60 s	-	P	INT, Savg: 5.42 ± 0.18 s; CON, S_{avg}: 5.41 ± 0.19 s	-	-	-

	Exercise protocol						**Outcomes**			
Study	**RST Mode**	**Sets × Reps**	**Distance / Duration**	**Rest Time**	**Rest Mode**	**I-set Rest**	**Performance**	**Perceptual**	**Neuromuscular**	**Physiological**
Torreblanca-Martinez et al. (2020)	STR	1 × 12	30 m	30 s	P	-	S$_{dec}$: 6.5 ± 3.0%	6–20: 15.2 ± 2.5 au	-	HR$_{post}$: 179 ± 12 b·min^{-1}
Tounsi et al. (2019)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	M, S$_{best}$: 7.09 ± 0.24 s; S$_{avg}$: 7.32 ± 0.28; S$_{dec}$: 3.2 ± 1.2% F, S$_{best}$: 8.42 ± 0.47 s; S$_{avg}$: 8.85 ± 0.45; S$_{dec}$: 5.1 ± 2.5%	-	-	-
Trecroci et al. (2020)	STR	1 × 5	30 m	25 s	P	-	SST, S$_{best}$: 4.26 ± 0.11 s; S$_{total}$: 21.94 ± 0.67 s; ARC, S$_{best}$: 4.25 ± 0.07 s; S$_{total}$: 21.91 ± 0.58 s	-	-	-
Turki et al. (2020)	MD^{X}	1 × 6	20 m (4 m per turn)	25 s	A^{K}	-	PRO, S$_{best}$: 5.39 ± 0.18 s; S$_{avg}$: 5.52 ± 0.17 s; S$_{total}$: 33.09 ± 1.00 s; S$_{dec}$: 2.4 ± 1.0%; COL, S$_{best}$: 5.49 ± 0.26 s; S$_{avg}$: 5.62 ± 0.27 s; S$_{total}$: 33.70 ± 1.60 s; S$_{dec}$: 2.4 ± 0.6%	-	-	-
Ulupınar, Özbay, et al. (2021)	STR	1 × 10	40 m	30 s	P	-	S$_{best}$: 5.43 ± 0.03 s; S$_{total}$: 56.7 ± 1.6 s; S$_{dec}$: 4.8 ± 1.7%	6–20: 17 ± 1 au	-	B[La]$_{peak}$: 18.6 ± 1.7 mmol·L^{-1}; HR$_{peak}$: 184 ± 8 b·min^{-1} HR$_{avg}$: 164 ± 7 b·min^{-1}
	STR	1 × 20	20 m	15 s	P	-	S$_{best}$: 3.18 ± 0.03 s; S$_{total}$: 67.3 ± 3.0 s; S$_{dec}$: 6.9 ± 2.8%	6–20: 19 ± 1 au	-	B[La]$_{peak}$: 16.6 ± 2.2 mmol·L^{-1}: HR$_{peak}$: 188 ± 8 b·min^{-1} HR$_{avg}$: 168 ± 9 b·min^{-1}
Ulupınar, Hazır, et al. (2021)	STR	1 × 20	15 m	30 s	P	-	S$_{total}$: 49.9 ± 1.2; S$_{dec}$: 3.6 ± 1.8%	6–20: 11.5 ± 2.9 au	-	B[La]$_{peak}$: 9.1 ± 3.0 mmol·L^{-1}: HR$_{peak}$: 186 ± 9 b·min^{-1} HR$_{avg}$: 168 ± 9 b·min^{-1}
	STR	1 × 20	15 m	1:5^{N} (~12 s)	P	-	S$_{total}$: 52.7 ± 1.3; S$_{dec}$: 8.7 ± 2.8%	6–20: 16.3 ± 1.9 au	-	B[La]$_{peak}$: 14.9 ± 3.7 mmol·L^{-1}: HR$_{peak}$: 190 ± 11 b·min^{-1} HR$_{avg}$: 178 ± 11 b·min^{-1}
	STR	1 × 10	30 m	30 s	P	-	S$_{total}$: 44.9 ± 1.2; S$_{dec}$: 7.1 ± 3.8%	6–20: 13.9 ± 2.4 au	-	B[La]$_{peak}$: 15.0 ± 4.1 mmol·L^{-1}: HR$_{peak}$: 191 ± 13 b·min^{-1} HR$_{avg}$: 172 ± 10 b·min^{-1}
	STR	1 × 10	30 m	1:5^{N} (~22 s)	P	-	S$_{total}$: 45.8 ± 1.1; S$_{dec}$: 9.3 ± 2.3%	6–20: 15.8 ± 2.9 au	-	B[La]$_{peak}$: 16.9 ± 3.5 mmol·L^{-1}: HR$_{peak}$: 190 ± 12 b·min^{-1} HR$_{avg}$: 177 ± 8 b·min^{-1}
van den Tillaar (2018)	STR	1 × 7	30 m	On 30 s (~25 s)	A^{K}	-	S$_{avg}$: 5.46 ± 0.33 s	-	-	-

Study	Exercise protocol						Outcomes			
	RST Mode	Sets × Reps	Distance / Duration	Rest Time	Rest Mode	I-set Rest	Performance	Perceptual	Neuromuscular	Physiological
Vasquez-Bonilla et al. (2021)	STR	1 × 8	20 m	20 s	A^K	-	S_{best}: 3.81 ± 0.17 s; S_{avg}: 4.08 ± 0.21 s; S_{total}: 32.64 ± 1.75 s; S_{dec}: 7 ± 3%	-	-	-
Wadley and Le Rossignol (1998)	STR	1 × 12	20 m	20 s	P	-	S_{total}: 39.31 ± 0.12 s; S_{dec}: 5.5 ± 3.3%	-	-	-
West et al. (2016)	SHU	1 × 6	40 m (20 + 20)	20 s	P	-	S_{best}: 6.60 ± 0.16 s; S_{avg}: 6.87 ± 0.15 s; S_{total}: 41.23 ± 0.92 s	-	-	-
Woolley et al. (2014)	STR	1 × 40	15m	30s	P^R	-	-	6–20: 16.7 ± 1.8 au	-	△ CK 24 h: 279 ± 322 to 1121 ± 1362 $u\cdot L^{-1}$ (302%)
Yanci et al. (2017)	STR	1 × 6	30 m	25 s	A	-	CON, S_{avg}: 4.57 ± 0.20 s PLY1: S_{avg}: 4.47 ± 0.22 s PLY2: S_{avg}: 4.45 ± 0.23 s	-	-	-
Zagatto et al. (2017)	SHU	1 × 10	30m	30 s	P	-	S_{best}: 6.56 ± 0.30 s; S_{avg}: 6.84 ± 0.30 s; S_{total}: 68.40 ± 2.91 s; S_{dec}: 4.2 ± 1.8%	-	-	$B[La]_{peak}$: 9.8 ± 2.5 $mmol\cdot L^{-1}$; VO_{2avg}: 37.0 ± 2.9 $ml\cdot min^{-1}\cdot kg^{-1}$; HR_{peak}: 185 ± 9 $b\cdot min^{-1}$
	MD^C	1 × 10	30 m (5 m per turn)	30 s	P	-	S_{best}: 8.14 ± 0.36 s; S_{avg}: 8.39 ± 0.36 s; S_{total}: 83.99 ± 3.60 s; S_{dec}: 3.0 ± 1.1%	-	-	$B[La]_{peak}$: 8.2 ± 1.9 $mmol\cdot L^{-1}$; VO_{2avg}: 36.1 ± 3.2 $ml\cdot min^{-1}\cdot kg^{-1}$; HR_{peak}: 186 ± 9 $b\cdot min^{-1}$
Zagatto et al. (2021)	SHU	2 × 10	30 m (10 + 10 + 10)	30 s	P	P 5.50 min	Set 1, S_{best}: 6.85 ± 0.35 s; S_{avg}: 7.01 ± 0.31 s; S_{total}: 70.15 ± 3.07 s; S_{dec}: 2.4 ± 1.5% Set 2, S_{best}: 6.88 ± 0.32 s; S_{avg}: 7.13 ± 0.36 s; S_{total}: 71.31 ± 3.59 s; S_{dec}: 3.6 ± 1.58%	-	△ CMJ^{AB}: 43.2 ± 9.7 to 37.6 ± 4.0 cm (-9.4 ± 18.0%)	-
Zagatto et al. (2022)	MD^C	1 × 10	30 m	30 s	P	-	S_{best}: 7.09 ± 0.57 s; S_{avg}: 7.30 ± 0.63 s; S_{total}: 72.84 ± 6.42 s	-	-	-

Data are presented as mean ± SD.

Abbreviations: I-set = inter-set; RST = repeated-sprint training; sRPE = session ratings of perceived exertion; au = arbitrary units; CR10 = category ration 0–10 rating of perceived exertion scale; 6–20 = 6–20 rating of perceived exertion scale; SHU = shuttle repeated-sprint; STR = straight-line repeated-sprint; MD = multi-directional repeated-sprint; A = active recovery; P = passive recovery; M = male; F = female; $B[La]_{post}$ = blood lactate measured immediately post-exercise; $B[La]_{peak}$ = highest blood lactate value measured from two or more time-points between 0–10 min post-exercise; $B[La]^{1'}$ = blood lactate measured 1 minutes post-exercise; $B[La]^{2'}$ = blood lactate measured 2 minutes post-exercise; $B[La]^{3'}$ = blood lactate measured 3 minutes post-exercise; $B[La]^{4'}$ = blood lactate measured 4 minutes post exercise; $B[La]^{5'}$ = blood lactate measured 5 minutes post-exercise; CK 24 h = serum creatine kinase measured 24 hours post-exercise S_{dec} = percentage sprint decrement; S_{avg} = average sprint time; S_{best} = best sprint time; S_{total} = total sprint time; CMJ = counter movement jump height; HR_{avg} = average heart rate; HR_{peak} = peak heart rate; HR_{post} = end-set heart rate recorded immediately post-exercise; % HRmax = percentage of maximal heart rate; VO_{2avg} = average oxygen consumption; % VO_{2max} = percentage of maximal oxygen consumption; V_0 = theoretical maximal velocity F_0 = theoretical maximal force; P_0 = theoretical maximal power; RF_{peak} = maximal ratio of force; D_{RF} = slope/rate of decrease in ratio of force with increasing velocity; K_{vert} vertical stiffness;; K_{leg} = leg stiffness; ΔL = leg compression; Δz = centre of mass vertical displacement; $F_z max$ = maximal vertical force; PLA = placebo group = CON = control group; STR-G = straight-line repeated-sprints groups; SHU-G = shuttle repeated-sprints group; High = high VO_2 max group; Med = medium VO_2 max group; Low = low VO_2 max group; INT = intervention group; U17 = under 17 players; U18 = under 18 players; U19 = under 19 players;

U20 = under 20 players; PRE = pre-season; ELY = early/start of season; MID = mid-season; END = end/post of season; YTH = youth players; SEN = senior players; PRO = professional players; SEMI = semi-proffessional players; COL = college players; REP = representative players; Club = club players; AM = amateur players; EL = elite players; S-EL = sub-elite players; M-PRO = mid-proffessional players; EXP = experienced players; FSH = freshman players; FUT = futsal players; SOC = soccer players; SAN = sand training group; GRA = grass training group; NOR = normoxia group; HYP = hypoxia group; MG = Melaneysian group; N-MG = non-Meleynesian group; ARC = active recovery condition; SSG = small sided games group; SEM = speed endurance maintenance group; SEP = speed endurance production group; RS15 = repeated-sprint group with 15 s rest; RS30 = repeated-sprint group with 30 s rest; Sys1 = turf system 1; Sys2 = turf system 2; Sys3 = turf system 3; Sys4 = turf system 4; $IT_{7.5}$ = interval training 7.5 seconds group; IT_{15} = interval training 15 seconds group; RS = repeated sprint group; ATG = agility training group; 1TR = under 17 group born 1st tertile; 2TR = under 17 group born 2nd tertile; 3TR = under 17 group born 3rd tertile; Sham = sham group; RES = resisted sprint training group; PLY = plyometric group; PLY1 = plyometrics one day per week group; PLY2 plyometrics two days per week group; LLTL = live low-train low group; IT_{100} = interval training at 100% group; IT_{86} = interval training at 86% group; SQ = squat group; TG = take-off group; PAS = passive recovery group; COL = cold water recovery group; CWT = contrast water therapy group; NT = Non-training group; ST = starting players; N-ST = non-starting players; N-SEL = non-selected players; SST = soccer specific training condition; △ = change from baseline; - = not applicable.

[A] 3 × multi-angle turns

[B] 4 × multi-angle turns

[C] 5 × multi-angle turns

[D] 2 × 45° turns

[E] 2 × 90° turns

[F] 2 × 135° turns

[G] 4 × 45° turns

[H] Run at 8 $km·h^{-1}$ back to one way start line

[I] Light stretching

[J] 10 m deceleration zone + 10m run zone at either end

[K] Jog back to one way start line

[L] Jogging at 2–2.1 $m·s^{-1}$

[M] Single counter-movement jump following each sprint

[N] Exercise to rest ratio

[O] Walking or running to maintain 60-65% of HR maximum

[P] 3 × counter-movement jumps following each sprint

[Q] Self-paced jogging

[R] Short enforced deceleration zone (<10m)

[S] Run at 6 $km·h^{-1}$

[T] 4 × 90° turns (quadrangle)

[U] Walk for 40 s, stationary rest for 20 s

[V] 4 × 100° turns

[W] 10m zone at both ends to decelerate, then jog back to two-way start line.

[X] Run at 20% maximal aerobic speed

[Y] Run at 35% maximal aerobic speed

[Z] Run at 50% maximal aerobic speed

[AA] Measured via an Optojump

[AB] Measured via force-platforms

[AC] Measured via a contact mat

[AD] Measured via FreePower Jump

[AE] Repeated 5-0-5 Agility test: total rep distance = 20 m, timed distance = 10 m

[AF] Change of direction performed around a cone

[AG] Run at 50% maximal speed

APPENDIX 4. Influence of programming variables on the variance of meta-analysed acute physiological, perceptual and performance demands of repeated-sprint training in team sport athletes. Evidence from Study 1.

		Total Variance (σ^2)		**Variance Explained by Moderators (R_{2META})**
		Observed (no moderators)	**With Moderators**	
HR_{avg}	$b \cdot min^{-1}$	335	-	-
	% HR_{max}	19	-	-
HR_{peak}	$b \cdot min^{-1}$	59	55	0.07
VO_{2avg}	$ml \cdot kg^{-1} \cdot min^{-1}$	89.6	-	-
B[La]	$mmol \cdot L^{-1}$	9.3	6.3	0.32
sRPE	au (deciMax)	3.1	3.0	0.03
S_{best}	s	2.71	1.10	0.60
S_{avg}	s	2.68	0.69	0.74
S_{dec}	%	4.8	3.5	0.27

Dashed lines indicate outcome measure where moderator analysis could not be performed.

APPENDIX 5. Study 2 search strategy for Pubmed.

Search number	Search phrase	Items found
1	"Repeated sprint training" OR "repeated sprint" OR "repeated-sprint exercise" OR "intermittent sprint training"	1103
2	("Repeated sprint training" OR "repeated sprint" OR "repeated-sprint exercise" OR "intermittent sprint training") AND ("physical performance" OR "physical fitness" OR "physiological adaptation" OR "aerobic endurance" OR "aerobic fitness" OR "aerobic capacity" OR "VO2 max" OR "maximal oxygen uptake" OR "maximal oxygen consumption" OR "repeated-sprint ability" OR "speed" OR "sprint performance" OR "agility" OR "change of direction" OR "counter-movement jump" OR "vertical jump" OR "lower body power" OR “leg power” OR "acceleration" OR "intermittent running performance")	895
3	("Repeated sprint training" OR "repeated sprint" OR "repeated-sprint exercise" OR "intermittent sprint training") AND ("physical performance" OR "physical fitness" OR "physiological adaptation" OR "aerobic endurance" OR "aerobic fitness" OR "aerobic capacity" OR "VO2 max" OR "maximal oxygen uptake" OR "maximal oxygen consumption" OR "repeated-sprint ability" OR "speed" OR "sprint performance" OR "agility" OR "change of direction" OR "counter-movement jump" OR "vertical jump" OR "lower body power" OR “leg power” OR "acceleration" OR "intermittent running performance") NOT ("cycling" OR "swimming")	780

APPENDIX 6. Study 2 search strategy for Scopus.

Search number	Search phrase	Items found
1	"Repeated sprint training" OR "repeated sprint" OR "repeated-sprint exercise" OR "intermittent sprint training"	1512
2	("Repeated sprint training" OR "repeated sprint" OR "repeated-sprint exercise" OR "intermittent sprint training") AND ("physical performance" OR "physical fitness" OR "physiological adaptation" OR "aerobic endurance" OR "aerobic fitness" OR "aerobic capacity" OR "VO2 max" OR "maximal oxygen uptake" OR "maximal oxygen consumption" OR "repeated-sprint ability" OR "speed" OR "sprint performance" OR "agility" OR "change of direction" OR "counter-movement jump" OR "vertical jump" OR "lower body power" OR “leg power” OR "acceleration" OR "intermittent running performance")	1232
3	("Repeated sprint training" OR "repeated sprint" OR "repeated-sprint exercise" OR "intermittent sprint training") AND ("physical performance" OR "physical fitness" OR "physiological adaptation" OR "aerobic endurance" OR "aerobic fitness" OR "aerobic capacity" OR "VO2 max" OR "maximal oxygen uptake" OR "maximal oxygen consumption" OR "repeated-sprint ability" OR "speed" OR "sprint performance" OR "agility" OR "change of direction" OR "counter-movement jump" OR "vertical jump" OR "lower body power" OR “leg power” OR "acceleration" OR "intermittent running performance") NOT ("cycling" OR "swimming")	1068
4	Filter: article only	987

APPENDIX 7. Study 2 search strategy for SPORTDiscus.

Search number	Search phrase	Items found
1	"Repeated sprint training" OR "repeated sprint" OR "repeated-sprint exercise" OR "intermittent sprint training"	1099
2	("Repeated sprint training" OR "repeated sprint" OR "repeated-sprint exercise" OR "intermittent sprint training") AND ("physical performance" OR "physical fitness" OR "physiological adaptation" OR "aerobic endurance" OR "aerobic fitness" OR "aerobic capacity" OR "VO2 max" OR "maximal oxygen uptake" OR "maximal oxygen consumption" OR "repeated-sprint ability" OR "speed" OR "sprint performance" OR "agility" OR "change of direction" OR "counter-movement jump" OR "vertical jump" OR "lower body power" OR “leg power” OR "acceleration" OR "intermittent running performance")	923
3	("Repeated sprint training" OR "repeated sprint" OR "repeated-sprint exercise" OR "intermittent sprint training") AND ("physical performance" OR "physical fitness" OR "physiological adaptation" OR "aerobic endurance" OR "aerobic fitness" OR "aerobic capacity" OR "VO2 max" OR "maximal oxygen uptake" OR "maximal oxygen consumption" OR "repeated-sprint ability" OR "speed" OR "sprint performance" OR "agility" OR "change of direction" OR "counter-movement jump" OR "vertical jump" OR "lower body power" OR “leg power” OR "acceleration" OR "intermittent running performance") NOT ("cycling" OR "swimming")	786
4	Filter: academic journals	756

Appendix 8. Modified Downs and Black scale outcomes for the assessment of reporting quality and risk of bias in Study 2.

Study	Item number														Total score (out of 14)
	1	2	3	6	7	10	12	15	16	18	20	22	23	25	
Attene et al. (2016)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Attene et al. (2014)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Arede et al. (2022)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Beato et al. (2019)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	10
Beato et al. (2022)	1	1	1	1	1	0	0	0	1	1	1	0	1	0	9
Boer and Van Aswegen (2016)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Bravo et al. (2008)	1	1	1	1	1	1	0	1	1	1	1	0	1	0	11
Seifeddine Brini, Nejmeddine Ouerghi, et al. (2020)	1	1	1	1	1	0	0	0	1	1	1	0	1	1	10
Brini et al. (2018)	1	1	1	1	1	0	0	0	1	1	1	0	1	0	9
Seifeddine Brini, Abderraouf Ben Abderrahman, et al. (2020)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Buchheit et al. (2008)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
M. Buchheit, A. Mendez-Villanueva, et al. (2010)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Chtara et al. (2017)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Eniseler et al. (2017a)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Fernandez-Fernandez et al. (2012)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Gantois et al. (2019)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Gantois et al. (2022b)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	12
Gatterer et al. (2014)	1	1	1	1	1	1	0	1	1	1	1	0	1	1	12
Gatterer et al. (2015a)	1	1	1	1	1	1	0	1	1	1	1	0	1	1	12
Haugen et al. (2015)	1	1	1	1	1	0	0	0	1	1	1	0	1	1	10
Iaia et al. (2017)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Asín Izquierdo et al. (2021)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10
Kaynak et al. (2017a)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10
Krakan et al. (2020)	1	1	0	1	1	1	0	0	1	1	1	0	0	0	8
Lapointe et al. (2020)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Maggioni et al. (2019)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10
Le Scouarnec et al. (2022)	1	1	1	1	1	1	0	0	1	1	1	0	0	0	9
Markovic et al. (2007)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Michailidis et al. (2022)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	12
Nascimento et al. (2015)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10
Nedrehagen and Saeterbakken (2015)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10
Negra et al. (2022b)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	12
Ouergui et al. (2020)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10
Rey et al. (2019)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Sanchez-Sanchez et al. (2019)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Selmi et al. (2018)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Soares-Caldeira et al. (2014)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10
Suarez-Arrones et al. (2014)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	11
Taylor et al. (2016)	1	1	1	1	1	1	0	0	1	1	1	0	0	1	10
Taylor and Jakeman (2021)	1	1	1	1	1	1	0	0	1	1	1	0	1	0	10

Notes: 0 = no; 1 = yes; U = unable to determine. Item 1: clear aim/hypothesis; Item 2: outcome measures clearly described; Item 3: patient characteristics clearly described; Item 6: main findings clearly described; Item 7: measures of random variability provided; Item 10: actual probability values reported; Item 12: participants prepared to participate representative of the entire population; Item 15: blinding of outcome measures; Item 16: analysis completed was planned; Item 18: appropriate statistics; Item 20: valid and reliable outcome measures; Item 22: participants recruited over the same period; Item 23: randomised; Item 25: adjustment made for confounding variables.

Appendix 9. Recommendation, Assessment, Development and Evaluation tool for the assessment of certainty of evidence in Study 2.

Outcome	**Study design (# studies)**		**Grade assessment**					
	RT	NRT	Inconsistency	Risk of bias	Imprecision	Indirectness	Publication bias	Certainty of evidence
10 m sprint	10	5	Not serious	Serious	Serious	Not serious	Not serious	Moderate
20 m sprint	7	2	Not serious	Not serious	Not serious	Not serious	Not serious	Moderate
VO_{2max}	7	1	Not serious	Not serious	Not serious	Not serious	Not serious	Moderate
YYIR1 distance	16	2	Not serious	Not serious	Not serious	Not serious	Not serious	High
RSA average time	21	2	Not serious	Not serious	Serious	Not serious	Not serious	Moderate
RSA decrement	16	2	Not serious	Not serious	Not serious	Not serious	Not serious	Moderate
CMJ height	17	3	Not serious	Not serious	Serious	Not serious	Not serious	Moderate
COD ability	10	4	Not serious	Serious	Serious	Not serious	Not serious	Moderate

Abbreviations: RT = randomised trials; NRT = non-randomised trials; # = number; VO_{2max} = maximal oxygen consumption; YYIR1 = Yo-Yo Intermittent Recovery Test level 1; RSA = repeated-sprint ability; CMH = counter-movement jump; COD = change of direction ability.

Appendix 10. Summary of participant and study characteristics in Study 2.

Study	Participants						Experimental Approach		
	N#	**Sport**	**Level**	**Age (yrs)**	**Stature (cm)**	**Body mass (kg)**	**Design**	**Type**	**Details**
Attene et al. (2016)	36 (39%)	BB	NAT	M: 16 ± 1; F: 16 ± 1	M: 178 ± 1 F: 165 ± 1	M: 66 ± 6 F: 56 ± 7	NC	PAG (r)	2 RSG's. RST performed in addition to regular practice during the competitive season.
Attene et al. (2014)	16 100%	BB	TRA	14.9 ± 0.4	167 ± 0.1	55.3 ± 3.2	NC	PAG (r)	1 RSG. RST performed in addition to regular practice during the competitive season.
Arede et al. (2022)	29	BB	NAT	G3: 17 ± 1	G3: 179 ± 9	G3: 74 ±15	NC	PAG	1 RST group met the inclusion criteria, with athletes selected according to peak-height velocity. RST performed within normal training during the competitive season.
Beato et al. (2019)	36	SOC	TRA	21 ± 2	179 ± 7	74 ± 7	NC	PAG (r)	2 RSG's. RST performed during the pre-season.
Beato et al. (2022)	20	SOC	NAT	18–21	177 ± 6	71 ± 7	NC	PAG (r)	2 RSG's. RST performed in addition to regular practice during the competitive season.
Boer and Van Aswegen (2016)	46	SOC	TRA	22 ± 2	173 ± 10	66 ± 8	C	PAG	1 RSG. RST performed in addition to regular practice during the pre-season and conducted under single-blind conditions.
Bravo et al. (2008)	26	SOC	TRA	21 ± 5	179 ± 5	71 ± 6	NC	PAG (r)	1 RSG. RST substituted in-part for regular practice during the competitive season.
Seifeddine Brini, Nejmeddine Ouerghi, et al. (2020)	16	BB	TRA	23 ± 2	186 ± 9	78 ± 11	C*	PAG (r)	1 RSG. RST performed following 15 days recovery from a month of Ramadan.
Brini et al. (2018)	16	BB	TRA	23 ± 2	186 ± 9	78 ± 11	C*	PAG (r)	1 RSG. RST performed following 15 days recovery from a month of Ramadan.
Seifeddine Brini, Abderraouf Ben Abderrahman, et al. (2020)	16	BB	NAT	22 ± 3	186 ± 10	78 ± 8	C	PAG (r)	1 RSG. RST substituted in-part for regular practice during the competitive season.
Buchheit et al. (2008)	17	HB	TRA	16 ± 1	178 ± 9	76 ± 7	NC	PAG (r)	1 RSG with groups matched for maturation. RST performed in addition to regular practice.
M. Buchheit, A. Mendez-Villanueva, et al. (2010)	20	SOC	NAT	15 ± 1	174 ± 10	64 ± 8	NC	PAG (r)	1 RSG. RST performed in addition to regular practice during the competitive season.

Study	Participants						Experimental Approach		
	N$^{\#}$	Sport	Level	Age (yrs)	Stature (cm)	Body mass (kg)	Design	Type	Details
Chtara et al. (2017)	42	SOC	NAT	14 ± 0	165 ± 7	54 ± 7	C	PAG (r)	1 RSG. RST substituted in-part for regular practice, during the competitive season.
Eniseler et al. (2017a)	19	SOC	NAT	17 ± 1	174 ± 5	66 ± 6	C	PAG (r)	1 RSG. RST performed in addition to regular practice during the competitive season.
Fernandez-Fernandez et al. (2012)	31	TEN	NAT	RSG: 21 ± 5 CON: 22 ± 3	RSG 178 ± 6 CON: 180 ± 5	RSG: 74 ± 8 CON: 77 ± 7	C	PAG (r)	1 RSG. RST performed in addition to regular practice.
Gantois et al. (2019)	20	BB	NAT	21 ± 2	181 ± 8	74 ± 9	C	PAG (r)	1 RSG. RST performed in addition to regular practice during the pre-season.
Gantois et al. (2022b)	19	VB	NAT	RSG: 22 ± 3 CON: 21 ± 3	RSG: 181 ± 7 CON: 181 ± 8	RSG: 82 ± 16 CON: 80 ± 15	C	PAG (r)	1 RSG. RST performed in addition to regular practice during the pre-season.
Gatterer et al. (2014)	10	SOC	TRA	15 ± 1	173 ± 7	63 ± 7	C	PAG (r)	2-group, in addition to regular training, pre-season, normobaric hypoxic room under nromoxia, single blind
Gatterer et al. (2015a)	14	SOC	TRA	24 ± 2	178 ± 7	77 ± 7	C*	PAG	1 RSG. RST performed in an altitude room under normoxia under double-blind conditions, in addition to regular practice.
Haugen et al. (2015)	42	SOC	TRA	17 ± 1	178 ± 6	66 ± 9	C	PAG (r)	1 RSG. RST performed in addition to regular training during the pre-season
Iaia et al. (2017)	29	SOC	NAT	17 ± 1	178 ± 10	69 ± 8	C	PAG (r)	2 RSG's matched for distance. RST performed during the competitive season.
Asín Izquierdo et al. (2021)	27	SOC	TRA	18 ± 1	177 ± 6	70 ± 9	C	PAG (r)	1 RSG. RST performed in replacement of some football training, during the competitive season.
Kaynak et al. (2017a)	18	VB	NAT	RSG: 21 ± 1 CON: 21 ± 2	RSG: 183 ± 5 CON: 184 ± 4	RSG: 71 ± 7 CON: 76 ± 9	C	PAG (r)	1 RSG. RST performed in addition to regular practice during the pre-season.
Krakan et al. (2020)	41	MIX	TRA	19 ± 1	181 ± 7	RS-G, 81 ± 8	NC	PAG	1 RSG. RST performed in total replacement of other exercise.
Lapointe et al. (2020)	17 (71%)	BB	NAT	22	186 ± 12	89 ± 17	C	PAG (r)	1 RSG. RST performed during pre-season.
Maggioni et al. (2019)	15	SOC	NAT	17 ± 0	176 ± 4	66 ± 5	C	PAG	RSG that acts as a control. RST performed in addition to regular practice during the competitive season.

Study	Participants						Experimental Approach		
	$N^{\#}$	Sport	Level	Age (yrs)	Stature (cm)	Body mass (kg)	Design	Type	Details
Le Scouarnec et al. (2022)	36	BB	NAT	19 ± 1	182 ± 7	74 ± 10	C	PAG (r)	1 RSG. RST performed during the competitive season.
Markovic et al. (2007)	93	MIX	TRA	20 ± 1	181 ± 7	77 ± 9	C	PAG (r)	1 RSG. RST substituted in total replacement of other exercise.
Michailidis et al. (2022)	29	SOC	TRA	RSG: 16 ± 0 CON: 16 ± 0	RSG: 176 ± 6 CON: 177 ± 6	RSG: 66 ± 11 CON: 66 ± 9	C	PAG (r)	1 RSG. RST performed in addition to regular training during the competitive season.
Nascimento et al. (2015)	18	FUT	TRA	17 ± 1	177 ± 5	69 ± 7	C	PAG (r)	1 RSG. RST substituted in-part for regular practise during the competitive season.
Nedrehagen and Saeterbakken (2015)	22 (41%)	SOC	TRA	INT: 20 ± 3 CON: 22 ± 3	INT: 20 ± 3 CON: 22 ± 3	69 ± 10	C	PAG (r)	1 RSG. RST substituted in-part for regular practise during the competitive season.
Negra et al. (2022b)	20	SOC	TRA	16 ± 0	170 ± 10	60 ± 5	NC	PAG (r)	2 RSG's. RST performed in addition to regular practice during the competitive season.
Ouergui et al. (2020)	36	TKD	NAT	RSG: 16 ± 1 CON: 16 ± 1	RSG: 166 ± 7 CON: 162 ± 10	RSG: 57 ± 7 CON: 57 ± 13	C	PAG (r)	1 RSG. RST performed in addition to regular practice.
Rey et al. (2019)	27	SOC	TRA	RS1: 15 ± 1 RS2: 14 ± 0	RS1: 178 ± 13 RS2: 177 ± 8	RS1: 64 ± 7 RS2: 63 ± 6	NC	PAG (r)	2 RSG, volume-matched. RST performed in addition to regular practice during the competitive season.
Sanchez-Sanchez et al. (2019)	29	SOC	TRA	High: 15 ± 1 Low: 14 ± 1 CON: 15 ± 0	High: 170 ± 8 Low: 169 ± 6 CON: 169 ± 07	High: 63 ± 9 Low: 58 ± 7 CON: 63 ± 7	C	PAG (r)	2 RSG's with participants split into low and high VO_2max groups. RST performed in addition to regular practice.
Selmi et al. (2018)	30	SOC	NAT	18 ± 1	178 ± 5	70 ± 7	C	PAG (r)	1 RSG. RST substituted into regular practice during the pre-season.
Soares-Caldeira et al. (2014)	14	FUT	NAT	INT: 25 ± 8 CON: 21 ± 5	172 ± 6	72 ± 9	C	PAG (r)	1 RSG. RST performed in addition to regular practice during the pre-season.
Suarez-Arrones et al. (2014)	16	RUG	TRA	27 ± 5	180 ± 7	91 ± 16	C	PAG (r)	1 RSG. RST substituted in-part for regular practice during the competitive season.
Taylor et al. (2016)	15	SOC	TRA	24 ± 4	179 ± 6	77 ± 8	NC	PAG	2 RSG's. RST substituted in total replacement of other practice.
Taylor and Jakeman (2021)	18	HOC	NAT	20 ± 1	179 ± 7	75 ± 8	NC	PAG	1 RSG. RST substituted into regular practice.

Study	Participants						Experimental Approach		
	N#	Sport	Level	Age (yrs)	Stature (cm)	Body mass (kg)	Design	Type	Details

Data are presented as mean ± standard deviation.

Abbreviations: N# = number of participants (unless stated, the proportion of males was 100%). M = male; F = female; NR = not reported; PAG = parallel groups design; r = random assignment of participants to experimental groups; C = controlled study; NC = non-controlled study; SOC = soccer, FUT = futsal; RUG = rugby; HOC = field hockey; BB = basketball; VB = volleyball; HB = handball; TEN = tennis; MIX = mixture of sports; TKD = taekwondo; REC = recreationally active; TRA = trained/developmental athletes; INT = international/elite athletes; NAT = national/highly trained athletes; CON = control group; RSG = repeated-sprint group; RST = repeated-sprint training; LST = linear sprint training; CODT = change of direction sprint training; U17 = under 17; U19 = under 19; G1 = pre-peak height velocity group; G2: mid-peak height velocity group; G3 = post-peak height velocity group; RS1 = repeated-sprint training 1-day per week group; RS2 = repeated-sprint training 2-days per week group; VO$_2$max = maximal oxygen consumption; High = high V0$_2$max group; Low = low VO$_2$max group; yrs = years cm = centimetre; kg = kilogram; * = controlled study where RST performed under normal conditions acts as the control.

Appendix 11. Summary of the training protocols and outcomes in Study 2

Study	Group	Training Protocol									Outcomes				Change	
		Dur. (wks)	Freq. (p/w)	Vol. (p/w)	RST mode	Sets	Reps	Rep distance/ duration	Inter-rep rest	Inter-set rest	Test	Measure	Pre training (mean ± SD)	Post training (mean ± SD)	Raw	%
Attene et al. (2016)	RST	4	2	1260 m	SHU^D	3	6–8	30 m	20 s, P	4 min, P	RSA^B	Sdec (%)	11.4 ± 4.8	7.0 ± 2.4	-4.4	-38.6
											RSA^C	Sdec (%)	10.4 ± 4.0	8.3 ± 2.1	-2.1	-20.2
											CMJ^H	JH (cm)	29.6 ± 8.5	31.3 ± 7.8	1.7	5.7
	RST	4	2	1260 m	MD^R	3	6–8	30 m	20 s, P	4 min, P	RSA^B	S$_{dec}$ (%)	10.3 ± 3.7	7.3 ± 3.8	-3.0	-29.1
											RSA^C	S$_{dec}$ (%)	9.9 ± 4.7	8.0 ± 3.6	-1.9	-19.2
											CMJ^H	JH (cm)	29.2 ± 8.8	31.0 ± 8.4	1.8	6.2
Attene et al. (2014)	RST	6	2	1260 m	SHU	3	6–8	30 m	20 s, P	4 min, P	RSA^B	Sdec (%)	3.8 ± 1.6	2.7 ± 0.6	1.1	-29.0
											IRT	YYIR1 (m)	605 ± 233	775 ± 242	170	28.1
Arede et al. (2022)	RST	9	2	800 m	STR	2	10	20 m	30 s, P	3 min, P	10 m	Time (s)	1.88 ± 0.21	1.81 ± 0.17	-0.07	-3.5
											CMJ^k	JH (cm)	34.7 ± 10.0	35.5 ± 8.6	0.8	2.2
											COD	Mod 5-0-5	2.78 ± 0.32	2.72 ± 0.22	-0.06	-2.2
Beato et al. (2019)	RST	3	2	1890 m	STR	3	7	30 m	20 s, P	4 min, P	10 m	Time (s)	1.75 ± 0.11	1.74 ± 0.11	-0.01	-0.6
											20 m	Time (s)	2.94 ± 0.11	2.92 ± 0.11	-0.02	-0.7
											RSA^B	Savg (s)	7.46 ± 0.19	7.40 ± 0.20	-0.06	-0.8
											IRT	YYIR1 (m)	1642 ± 365	1822 ± 461	180	11.0
											COD	5-0-5 (s)	4.77 ± 0.22	4.76 ± 0.19	-0.01	-0.2
	RST	3	2	2520 m	SHU^D	3	7	40 m	20 s, P	4 min, P	10 m	(s)	1.78 ± 0.11	1.70 ± 0.12	-0.08	-4.5
											20 m	(s)	2.96 ± 0.12	2.90 ± 0.10	-0.06	-2.0
											RSA^B	Savg (s)	7.50 ± 0.21	7.48 ± 0.21	-0.02	-0.3
											IRT	YYIR1 (m)	1686 ± 359	1811 ± 260	125	7.4
											COD	5-0-5 (s)	4.70 ± 0.21	4.73 ± 0.16	0.03	0.6

Study	Group	Training Protocol									Outcomes				Change	
		Dur. (wks)	Freq. (p/w)	Vol. (p/w)	RST mode	Sets	Reps	Rep distance/ duration	Inter-rep rest	Inter-set rest	Test	Measure	Pre training (mean ± SD)	Post training (mean ± SD)	Raw	%
Beato et al. (2022)	RST	8	1	630 m	STR	3	7	30 m	20 s, P	4 min, P	10 m	(s)	1.86 ± 0.13	1.82 ± 0.09	-0.01	-2.2
											RSA[B]	Savg (s)	7.56 ± 0.20	7.52 ± 0.19	-0.04	-0.5
											IRT	YYIR1 (m)	2472 ± 223	2604 ± 362	132	5.3
											COD	5-0-5 (s)	4.91 ± 0.15	4.79 ± 0.16	-0.12	-2.4
	RST	8	1	840 m	SHU[D]	3	7	40 m	20 s, P	4 min, P	10 m	(s)	1.80 ± 0.08	1.79 ± 0.09	-0.01	-0.6
											RSA[B]	Savg (s)	7.46 ± 0.31	7.40 ± 0.31	-0.06	-0.8
											IRT	YYIR1 (m)	2500 ± 246	2696 ± 344	196	7.8
											COD	5-0-5 (s)	4.75 ± 0.17	4.65 ± 0.15	-0.10	-2.1
Boer and Van Aswegen (2016)	RST	6	3	2160 m	SHU[D]	3	6	40 m	10 s, P	4 min, P	IRT	YYIR2 (m)	435 ± 175	788 ± 200	353	81.1
											COD	T-test (s)	9.3 ± 0.5	9.1 ± 0.4	-0.2	-2.2
											CMJ[I]	JH (cm)	53.2 ± 7	57.3 ± 8	4.1	7.7
											GXT	VO_2max (ml·min^{-1}·kg^{-1})	51.5 ± 6.7	53.6 ± 6.6	2.1	4.1
	CON	6	3	-	-	-	-	-	-	-	IRT	YYIR2 (m)	415 ± 160	508 ± 196	93	22.4
											COD	T-test (s)	9.3 ± 0.4	9.4 ± 0.6	0.1	1.1
											CMJ[I]	JH (cm)	53.1 ± 5.8	54.2 ± 7.8	1.1	2.1
											GXT	VO_2max (ml·min^{-1}·kg^{-1})	51.6 ± 5.7	49.4 ± 4.7	-2.2	-4.3
Bravo et al. (2008)	RST	7	2	1440 m	SHU[F]	3	6	40 m	20 s, P	4 min, P	10 m	(s)	1.77 ± 0.06	1.76 ± 0.06	-0.1	-0.6
											RSA[B]	Savg (s)	7.53 ± 0.21	7.37 ± 0.16	-0.16	-2.1
											IRT	YYIR1 (m)	1917 ± 440	2455 ± 493	538	28.1
											CMJ[J]	JH (cm)	46.1 ± 3.5	46.1 ± 3.0	0	0
											GXT	VO_2max (ml·min^{-1}·kg^{-1})	55.7 ± 2.0	58.5 ± 4.1	2.8	5.0
Seifeddine Brini, Nejmeddine Ouerghi, et al. (2020)	RST	4	2	1260 m	SHU[D]	3	6–8	30 m	20 s, P	4 min, P	COD	T-test (s)	10.08 ± 0.91	9.98 ± 0.92	-0.10	-1.0
											CMJ[K]	JH (cm)	35.8 ± 5.3	37.4 ± 5.3	1.6	4.5
Brini et al. (2018)	RST	4	2	1260 m	SHU[D]	3	6–8	30 m	20 s, P	4 min, P	IRT	YYIR1 (m)	1667 ± 441	1852 ± 499	185	11.1
Seifeddine Brini, Abderraouf Ben Abderrahman, et al. (2020)	RST	12	2	1440 m	MD[R]	3	8	30 m	20 s, P	4 min, P	IRT	YYIR1 (m)	1792 ± 209	2065 ± 331	273	15.2
											COD	T-test (s)	10.21 ± 0.90	9.86 ± 0.91	-0.35	-3.4
											CMJ	JH (cm)	43.9 ± 6.9	39 ± 7.8	-4.9	-11.2
	CON	12	2	-	-	-	-	-	-	-	IRT	YYIR1 (m)	1627 ± 413	1805 ± 530	178	10.9
											COD	T-test (s)	10.18 ± 0.98	10.01 ± 0.87	-0.17	-1.7
											CMJ[K]	JH (cm)	40.3 ± 7.0	42.1 ± 6.9	1.8	4.5

Study	Group	Training Protocol									Outcomes					
		Dur. (wks)	Freq. (p/w)	Vol. (p/w)	RST mode	Sets	Reps	Rep distance/ duration	Inter-rep rest	Inter-set rest	Test	Measure	Pre training (mean ± SD)	Post training (mean ± SD)	Change	
															Raw	%
Buchheit et al. (2008)	RST	8	1–2	828 m	SHU^{D}	2–3	5–6	30–40 m	14 s, P; 23 s, A	2 min, P	10 m RSA^{B} RSA^{B} CMJ^{K} COD	Time (s) Savg (s) Sdec (%) JH (cm) 4×5 m shuttle (s)	1.88 ± 0.10 5.93 ± 0.2 3.7 ± 2.2 47.1 ± 4.4 5.44 ± 0.4	1.86 ± 0.10 5.87 ± 1.70 3.0 ± 0.8 49.3 ± 2.6 5.26 ± 0.1	-0.02 -0.06 -0.7 2.2 -0.18	-1.1 -1.0 18.9 4.7 -3.3
M. Buchheit, A. Mendez-Villanueva, et al. (2010)	RST	10	1	424 m	SHU^{D}	2–3	5–6	30–40 m	14 s, P; 23 s, A	2 min, P	10 m RSA^{B} CMJ^{K}	Time (s) Savg (s) JH (cm)	1.96 ± 0.05 6.35 ± 0.2 35.5 ± 5.8	1.93 ± 0.08 6.18 ± 1.14 38.0 ± 7.0	-0.03 -0.17 2.5	-1.5 -2.7 7.0
Chtara et al. (2017)	RST	6	2	817 m	SHU^{D}	2–4	5–6	20–30 m	20 s, P	4 min, P	10 m RSA^{B} COD	Time (s) Savg (s) Zig-zag 20m (s)	1.90 ± 0.07 6.53 ± 0.13 7.15 ± 0.20	1.82 ± 0.06 6.42 ± 0.14 6.88 ± 0.14	-0.08 -0.09 -0.27	-4.2 -1.7 -3.8
	CON	6	2	-	-	-	-	-	-	-	10 m RSA^{B} COD	Time (s) Savg (s) Zig-zag 20m (s)	1.90 ± 0.06 6.56 ± 0.22 7.12 ± 0.22	1.89 ± 0.06 6.57 ± 0.23 7.07 ± 0.21	-0.01 0.01 -0.05	-0.5 0.2 -0.7
Eniseler et al. (2017a)	RST	6	2	1440 m	STR / MD ^{M}	3	6	40 m	20 s, P	4 min, P	RSA^{B} RSA^{B} IRT	Savg (s) Sdec (%) YYIR1 (m)	7.13 ± 0.17 5.5 ± 0.8 2307 ± 252	7.13 ± 0.21 4.8 ± 0.5 2480 ± 159	0 -0.7 173	0 -12.7 7.5
Fernandez-Fernandez et al. (2012)	RST	6	3	1980 m	SHU^{E}	3	10	22 m	15 s, P	8 min, A^{N}	20 m RSA^{B} CMJ^{L} GXT	Time (s) Savg JH (cm) VO_2max ($ml \cdot min^{-1} \cdot kg^{-1}$)	3.2 ± 0.1 5.3 ± 0.2 38.4 ± 4.0 55.6 ± 5.0	3.2 ± 0.1 5.1 ± 0.2 38.4 ± 3.3 58.6 ± 2.9	0 -0.2 0 3.0	0 -3.8 0 5.4
	CON	6	3	-	-	-	-	-	-	-	20 m RSA^{B} CMJ^{L} GXT	Time (s) Savg JH (cm) VO_2max ($ml \cdot min^{-1} \cdot kg^{-1}$)	3.2 ± 0.1 5.3 ± 0.3 42.5 ± 4.7 57.3 ± 4.0	3.2 ± 0.1 5.3 ± 0.3 40.5 ± 4.5 57.4 ± 3.8	0 0 -2.0 0.1	0 0 -4.7 0.2
Gantois et al. (2019)	RST	6	2	960 m	STR	2–3	6	30 m	20 s P	3 min A^{P}	RSA^{A} RSA^{A} CMJ^{J} GXT	Savg (s) Sdec (%) JH (cm) V O_2max ($ml \cdot min^{-1} \cdot kg^{-1}$)	4.83 ± 0.38 6.4 ± 3.5 34.5 ± 4.7 49.2 ± 5.5	4.67 ± 0.21 3.0 ± 1.7 37.9 ± 3.3 50.2 ± 4.6	-0.16 -3.4 3.4 1.0	-3.3 -53.3 9.9 2.0

Study	Group	Training Protocol									Outcomes				Change	
		Dur. (wks)	Freq. (p/w)	Vol. (p/w)	RST mode	Sets	Reps	Rep distance/ duration	Inter-rep rest	Inter-set rest	Test	Measure	Pre training (mean ± SD)	Post training (mean ± SD)	Raw	%
	CON	6	2	-	-	-	-	-	-	-	RSA^{A} RSA^{A} CMJ^{J} GXT	Savg (s) Sdec (%) JH (cm) VO$_2$max (ml·min^{-1}·kg^{-1})	4.84 ± 0.26 4.1 ± 1.8 35.0 ± 6.4 48.4 ± 4.3	4.87 ± 0.21 4.4 ± 1.5 35.3 ± 5.0 46.4 ± 2.6	0.03 0.30 0.03 -1.8	0.6 7.3 0.9 -4.1
Gantois et al. (2022a)	RST	6	2	960 m	STR	2–3	6	30 m	20 s, P	5 min, A^{W}	CMJ^{L} GXT	JH (cm) VO$_2$max (ml·min^{-1}·kg^{-1})	36.3 ± 5.7 50.4 ± 4.3	38.3 ± 5.9 52.3 ± 4.9	2.0 1.9	5.5 3.8
	CON	6	2	-	-	-	-	-	-	-	CMJ^{L} GXT	JH (cm) VO$_2$max (ml·min^{-1}·kg^{-1})	37.3 ± 7.1 48.8 ± 5.9	37.6 ± 7.3 47.9 ± 5.1	0.3 -0.9	0.8 -1.8
Gatterer et al. (2014)	RST	5	1–2	840 m	SHU^{Q}	3	5	10 s	20 s, P	5 min, P	RSA^{B} RSA^{B} IRT	Savg (s) Sdec (%) YYIR1 (m)	7.6 ± 0.3 5.2 ± 1.5 1832 ± 310	7.6 ± 0.2 4.6 ± 1.5 2216 ± 395	0 -0.6 384	0 -11.5 21.0
Gatterer et al. (2015a)	RST	2	4	2100 m	SHU^{Q}	3	5	10 s	20 s, P	5 min, P	RSA^{B} RSA^{B} IRT	Savg (s) Sdec (%) YYIR1 (m)	7.60 ± 0.19 5.8 ± 1.9 1029 ± 273	7.63 ± 0.18 4.2 ± 0.9 1303 ± 211	0.03 -1.6 274	0.4 -27.6 26.6
Haugen et al. (2015)	RST	7	1	300 m	STR	1	15	20 m	60 s, P	-	RSA^{A} IRT CMJ	Savg (s) YYIR1 (m) JH (cm)	2.98 ± 0.15 1515 ± 275 34.9 ± 4.6	2.98 ± 0.15 1612 ± 290 35.4 ± 4.1	0 97 0.5	0 6.4 1.4
	CON	7	1	-	-	-	-	-	-	-	RSA^{A} IRT CMJ^{J}	Savg (s) YYIR1 (m) JH (cm)	2.97 ± 0.13 1547 ± 352 37.3 ± 3.3	3.00 ± 0.13 1693 ± 333 36.6 ± 3.0	0.03 146 -0.7	1.0 9.4 -1.9
Iaia et al. (2017)	RST	5	1–2	576 m	STR	1–3	6	30 m	15 s, P	2 min, P	20 m RSA^{A}	(s) Sdec (%)	3.30 ± 0.09 5.9 ± 2.2	3.25 ± 0.06 4.1 ± 1.6	-0.05 1.8	-1.5 -30.5
	RST	5	1–2	576 m	STR	1–3	6	30 m	30 s, P	2 min, P	20 m RSA^{A}	(s) Sdec (%)	3.29 ± 0.08 5.2 ± 2.1	3.21 ± 0.08 3.7 ± 1.7	-0.08 1.5	-2.4 -28.8
	CON	5	1–2	-	-	-	-	-	-	-	20 m RSA^{A}	Time (s) Sdec (%)	3.11 ± 0.09 5.5 ± 2.8	3.05 ± 0.13 5.5 ± 2.6	-0.06 0	-1.9 0
Asín Izquierdo et al. (2021)	RST	4	3	960 m	STR	2	8	10–30 m	8–20 s, P	10-15 min, A	CMJ^{x} RSA^{A} RSA^{A}	JH (cm) Savg (s) Sdec (%)	30.9 ± 4.3 4.84 ± 0.30 4.8 ± 2.2	33.8 ± 4.2 4.79 ± 0.25 4.5 ± 1.5	2.9 -0.05 -0.3	9.4 -1.0 -6.3

Study	Group	Training Protocol									Outcomes				Change	
		Dur. (wks)	Freq. (p/w)	Vol. (p/w)	RST mode	Sets	Reps	Rep distance/ duration	Inter-rep rest	Inter-set rest	Test	Measure	Pre training (mean ± SD)	Post training (mean ± SD)	Raw	%
	CON	4	3	-	-	-	-	-	-	-	CMJ^{x} RSA^{A} RSA^{A}	JH (cm) Savg (s) Sdec (%)	32.3 ± 4.3 4.82 ± 0.28 5.9 ± 1.9	32.8 ± 4.9 4.75 ± 0.31 6.0 ± 2.2	0.5 -0.07 0.1	1.5 -1.5 1.7
Kaynak et al. (2017a)	RST	6	3	630 m	STR	1–3	5	20 m	20 s, A^{o}	4 min P	RSA^{A} RSA^{A} GXT	Savg (s) Sdec (%) VO$_2$max (ml·min^{-1}·kg^{-1})	3.21 ± 0.14 9.5 ± 3.0 50.0 ± 3.6	3.03 ± 0.11 6.1 ± 3.0 53.4 ± 1.8	-0.18 -3.4 3.4	-5.6 -35.8 6.8
	CON	6	3	-	-	-	-	-	-	-	RSA^{A} RSA^{A} GXT	Savg (s) Sdec (%) VO$_2$max (ml·min^{-1}·kg^{-1})	3.23 ± 0.10 6.9 ± 2.1 50.4 ± 4.0	3.15 ± 0.14 6.2 ± 2.9 50.6 ± 4.0	-0.18 0.7 0.2	-2.5 -10.1 0.4
Krakan et al. (2020)	RST	6	3	1200 m	STR	2–3	6–10	20 m	25 s, P	2 min, P	10 m RSA^{A} RSA^{A} CMJ^{K} COD GXT	Time (s) Savg (s) Sdec (%) JH (cm) 20m shuttle (s) VO$_2$max (ml·min^{-1}·kg^{-1})	1.88 ± 0.07 3.96 ± 0.14 5.8 ± 0.10 40.0 ± 5.1 4.73 ± 0.17 55.2 ± 6.3	1.86 ± 0.06 3.99 ± 0.15 4.5 ± 2.2 40.9 ± 5.2 4.75 ± 0.22 55.8 ± 5.3	0.01 0.03 -1.3 0.9 0.02 0.6	-1.1 0.8 -22.4 2.3 0.4 1.1
Lapointe et al. (2020)	RST	4	2	1470 m	STR / SHU^{E}	3	6–8	6 s (30–40 m)	24, P	3 min, P	RSA^{A} RSA^{A}	Savg (s) Sdec (%)	5.18 ± 0.51 7.1 ± 3.1	5.01 ± 0.55 6.5 ± 2.5	-0.17 -0.6	-3.3 -8.5
Le Scouarnec et al. (2022)	RST	7	1–2	666 m	STR	1–2	12–14	~30 m	26 s, P	3 min, P	10 m 20 m	Time (s) Time (s)	2.12 ± 0.06 3.43 ± 0.11	2.12 ± 0.05 3.44 ± 0.08	0.00 0.01	0.0 0.3
Maggioni et al. (2019)	RST	8	3	2160 m	SHU^{D}	3	6	40 m	20 s, P	3 min, P	10 m 20 m IRT CMJ^{J} COD GXT	Time (s) Time (s) YYIR1 (m) JH (cm) T-test (s) VO$_2$max (ml·min^{-1}·kg^{-1})	1.87 ± 0.10 3.20 ± 0.25 1350 ± 450 31.1 ± 5.3 10.0 ± 0.3 55.7 ± 7.2	1.82 ± 0.14 3.22 ± 0.22 1725 ± 479 31.1 ± 5.9 9.7 ± 0.6 57.5 ± 5.8	-0.05 0.02 375 0 -0.3 1.8	-2.7 0.6 27.8 0 -3 3.2

Study	Group	Training Protocol									Outcomes				Change	
		Dur. (wks)	**Freq. (p/w)**	**Vol. (p/w)**	**RST mode**	**Sets**	**Reps**	**Rep distance/ duration**	**Inter-rep rest**	**Inter-set rest**	**Test**	**Measure**	**Pre training (mean ± SD)**	**Post training (mean ± SD)**	**Raw**	**%**
	CON	8	3	-	-	-	-	-	-	-	10 m	Time (s)	1.77 ± 0.04	1.78 ± 0.04	0.01	0.6
											20 m	Time (s)	3.10 ± 0.12	3.12 ± 0.30	0.02	0.6
											IRT	YYIR1 (m)	1445 ± 420	1505 ± 486	60	4.2
											CMJ^{J}	JH (cm)	33.5 ± 3.7	32.0 ± 4.9	-1.5	-4.5
											COD	T-test (s)	9.8 ± 0.2	9.6 ± 0.3	-0.2	-2.0
											GXT	VO$_2$max (ml·min^{-1}·kg^{-1})	56.7 ± 2.8	54.2 ± 4.1	-2.5	-4.4
Markovic et al. (2007)	RST	10	3	945 m	STR	3–4	3	10–50 m	60 s, P	3 min, P	20 m	(s)	3.23 ± 0.14	3.13 ± 0.10	-0.10	-3.1
											CMJ^{J}	JH (cm)	47.9 ± 4.4	51.4 ± 5.1	3.5	7.3
											COD	20 yd shuttle (s)	5.13 ± 0.2	4.93 ± 0.19	-0.20	-3.9
	CON	10	3	-	-	-	-	-	-	-	20 m	Time (s)	3.18 ± 0.14	3.21 ± 0.12	0.03	0.9
											CMJ^{J}	JH (cm)	47.7 ± 4.8	48.8 ± 4.1	1.1	2.3
											COD	20 yd shuttle (s)	5.08 ± 0.2	5.10 ± 0.22	0.02	0.4
Michailidis et al. (2022)	RST	4	2	780 m	STR	2–4	6	40 m	20, P	4 min, P	10 m	Time (s)	1.96 ± 0.12	1.90 ± 0.07	-0.06	-3.1
											RSA^{B}	Savg (s)	8.08 ± 0.18	7.70 ± 0.19	-0.38	-4.7
											CMJ^{L}	JH (cm)	31.1 ± 5.1	34.3 ± 4.7	3.2	10.3
											COD	IAT	16.36 ± 0.41	16.24 ± 0.34	-0.12	-0.7
	CON	4	2	-	-	-	-	-	-	-	10 m	Time (s)	1.95 ± 0.05	1.94 ± 0.14	-0.01	-0.5
											RSA^{B}	Savg (s)	7.86 ± 0.21	7.83 ± 0.26	-0.03	-0.4
											CMJ^{L}	JH (cm)	31.8 ± 4.4	31.9 ± 4.7	0.1	0.3
											COD	IAT	16.38 ± 0.50	16.17 ± 0.48	-0.21	-1.3
Nascimento et al. (2015)	RST	4	2	1440 m	SHU^{G}	3	6	40 m	20 s, P	4 min, P	RSA^{B}	Savg (s)	8.53 ± 0.15	8.56 ± 0.22	0.03	0.4
											RSA^{B}	Sdec (%)	4.8 ± 0.8	3.5 ± 0.7	-1.3	-27.1
											CMJ^{J}	JH (cm)	45.1 ± 6.6	45.5 ± 5.7	0.4	0.9
	CON	4	2	-	-	-	-	-	-	-	RSA^{B}	Savg (s)	9.09 ± 0.39	9.00 ± 0.28	-0.09	-1.0
											RSA^{B}	Sdec (%)	6.5 ± 1.1	4.3 ± 1.5	-2.2	-33.8
											CMJ^{J}	JH (cm)	40.3 ± 3.9	41.3 ± 4.4	1.0	2.5
Nedrehagen and Saeterbakken (2015)	RST	8	1	518 m	SHU^{D}	3–4	4–6	30 m	30 s, P	5 min, P	RSA^{B}	Savg (s)	7.79 ± 0.37	7.68 ± 0.31	-0.11	-1.4
											IRT	YYIR1 (m)	1455 ± 188	1677 ± 308	222	15.3
	CON	8	1	-	-	-	-	-	-	-	RSA^{B}	Savg (s)	7.79 ± 0.50	7.83 ± 0.49	0.04	0.5
											IRT	YYIR1 (m)	1409 ± 336	1291 ± 365	222	-8.4

Study	Group	Training Protocol									Outcomes				Change	
		Dur. (wks)	Freq. (p/w)	Vol. (p/w)	RST mode	Sets	Reps	Rep distance/ duration	Inter-rep rest	Inter-set rest	Test	Measure	Pre training (mean ± SD)	Post training (mean ± SD)	Raw	%
Negra et al. (2022b)	RST	9	2	450 m	STR	2–4	7	20 m	20 s, P	4 min P	10 m	Time (s)	1.90 ± 0.14	1.82 ± 0.11	-0.08	-4.2
											20 m	Time (s)	3.37 ± 0.27	3.20 ± 0.16	-0.17	-5.0
											IRT	Yo-Yo (m)	1104 ± 448	1404 ± 314	300	27.2
											COD	Mod 5-0-5 (s)	2.47 ± 0.15	2.36 ± 0.15	-0.11	-4.5
	RST	9	2	450 m	SHU[D]	2–4	7	20 m	20 s, P	4 min P	10 m	Time (s)	1.85 ± 0.14	1.76 ± 0.11	-0.09	-4.9
											20 m	Time (s)	3.28 ± 0.25	3.14 ± 0.22	-0.14	-4.3
											IRT	Yo-Yo (m)	860 ± 454	1076 ± 405	216	25.1
											COD	Mod 5-0-5 (s)	2.48 ± 0.20	2.33 ± 0.15	-0.15	-6.0
Ouergui et al. (2020)	RST	4	2	3150 m	STR	3–6	10	35 m	10 s, P	3 min, P	CMJ[K]	JH (cm)	29.4 ± 6.4	30.5 ± 6.8	1.1	3.7
											COD	Mod. T-test (s)	6.8 ± 0.6	6.3 ± 0.6	-0.5	-7.4
	CON	4	2	-	-	-	-	-	-	-	CMJ[K]	JH (cm)	25.1 ± 4.7	25.3 ± 4.7	0.2	0.8
											COD	Mod. T-test (s)	7.2 ± 0.7	6.8 ± 0.6	-0.4	-5.6
Rey et al. (2019)	RST	6	1	477 m	STR	4–6	4–6	15–30 m	20 s, P	4 min, P	10 m	Time (s)	1.87 ± 0.09	1.85 ± 0.11	-0.02	-1.1
											20 m	Time (s)	3.31 ± 0.15	3.23 ± 0.21	-0.08	-2.4
											RSA[A]	Savg (s)	4.20 ± 0.17	4.12 ± 0.20	-0.08	-1.9
											RSA[A]	Sdec (%)	3.0 ± 1.9	2.5 ± 1.2	-0.5	-16.7
	RST	6	2	477 m	STR	4–6	4–6	15–30 m	20 s, P	4 min, P	10 m	Time (s)	1.84 ± 0.09	1.81 ± 0.11	-0.03	-1.6
											20 m	Time (s)	3.28 ± 0.15	3.23 ± 0.22	-0.05	-1.5
											RSA[A]	Savg (s)	4.20 ± 0.20	4.08 ± 0.19	-0.12	-2.9
											RSA[A]	Sdec (%)	3.5 ± 1.8	2.7 ± 1.1	-0.8	-22.9
Sanchez-Sanchez et al. (2019)	RST[U]	8	2	1080 m	MD[S]	3	10	18 m	16 s, A[T]	4 min, P	RSA[A]	Savg (s)	4.40 ± 0.33	4.26 ± 0.33	-0.14	-3.2
											RSA[A]	Sdec (%)	2.6 ± 2.3	3.0 ± 2.1	0.4	15.4
											IRT	YYIR1 (m)	1764 ± 334	1798 ± 335	34	1.9
	RST[V]	8	2	1080 m	MD[S]	3	10	18 m	16 s, A[T]	4 min, P	RSA[A]	Savg (s)	4.77 ± 0.41	4.76 ± 0.40	-0.01	-0.2
											RSA[A]	Sdec (%)	4.1 ± 2.7	3.9 ± 2.6	-0.2	-4.9
											IRT	YYIR1 (m)	914 ± 330	985 ± 337	69	7.8
	CON	8	2	-	-	-	-	-	-	-	RSA[A]	Savg (s)	4.65 ± 0.18	4.70 ± 0.24	0.05	1.1
											RSA[A]	Sdec (%)	5.2 ± 2.4	3.9 ± 2.6	-1.3	-25.0
											IRT	YYIR1 (m)	1269 ± 371	1556 ± 308	287	22.6
Selmi et al. (2018)	RST	6	3	1417 m	SHU[D]	2–3	5–6	30–40 m	20 s, P	4 min, P	RSA[B]	Sdec (%)	6.0 ± 1.9	4.8 ± 1.7	-1.2	-20.0
	CON	6	3	-	-	-	-	-	-	-	RSA[B]	Sdec (%)	6.3 ± 2.0	6.6 ± 1.9	0.3	4.8

Study	Group	Training Protocol									Outcomes					
		Dur. (wks)	Freq. (p/w)	Vol. (p/w)	RST mode	Sets	Reps	Rep distance/ duration	Inter-rep rest	Inter-set rest	Test	Measure	Pre training (mean ± SD)	Post training (mean ± SD)	Change Raw	Change %
Soares-Caldeira et al. (2014)	RST	4	3	1095 m	STR	2	6–8	30 m	20 s, P	5 min, P	RSA[B]	Savg (s)	7.62 ± 0.35	7.43 ± 0.33	-0.19	-2.5
											RSA[B]	Sdec (%)	6.3 ± 2.0	5.2 ± 1.9	-1.1	-17.5
											CMJ[L]	JH (cm)	38.8 ± 6.4	38 ± 6.9	-0.8	-2.1
	CON	4	3	-	-	-	-	-	-	-	RSA[B]	Savg (s)	7.49 ± 0.20	7.28 ± 0.19	-0.21	-2.8
											RSA[B]	Sdec (%)	7.8 ± 4.4	4.8 ± 1.3	-3.0	-38.5
											CMJ[L]	JH (cm)	42.8 ± 2.8	42.5 ± 3.7	-0.3	-0.7
Suarez-Arrones et al. (2014)	RST	6	2	1440 m	SHU[D]	3	6	40 m	20 s, P	4 min, P	RSA[B]	Savg (s)	8.0 ± 0.2	7.8 ± 0.2	-0.2	-2.5
											RSA[B]	Sdec (%)	5.3 ± 1.3	3.7 ± 17	-1.6	-30.2
Taylor et al. (2016)	RST	2	3	2205 m	STR	3–4	7	30 m	20 s, P	4 min, P	10 m	Time (s)	1.73 ± 0.07	1.62 ± 0.09	-0.09	-6.4
											20 m	Time (s)	2.96 ± 0.10	2.85 ± 0.13	-0.11	-3.7
											IRT	YYIR1 (m)	1830 ± 274	2270 ± 294	440	24.0
											CMJ[K]	JH (cm)	41.9 ± 3.8	42.5 ± 3.6	0.6	1.4
											COD	IAT (s)	15.20 ± 0.52	15.23 ± 0.69	0.03	0.2
	RST	2	3	2205 m	SHU[D]	3–4	7	20 m	20 s, P	4 min, P	10 m	Time (s)	1.75 ± 0.05	1.64 ± 0.07	-0.11	-6.3
											20 m	Time (s)	3.03 ± 0.07	2.91 ± 0.11	-0.12	-4.0
											IRT	YYIR1 (m)	1691 ± 600	2183 ± 645	492	29.1
											CMJ[K]	JH (cm)	36.6 ± 4.4	37.3 ± 5.4	0.7	1.9
											COD	IAT (s)	15.55 ± 0.48	15.3 ± 0.4	-0.25	-1.6
Taylor and Jakeman (2021)	RST	8	2	563 m	STR	1	6–12	30 m	30 s, P	-	10 m	Time (s)	1.70 ± 0.05	1.68 ± 0.10	-0.02	-1.2

Abbreviations: SD = standard deviation; Dur. = duration; Freq. = frequency; Vol. = average weekly repeated-sprint training volume; wks = weeks; p/w = per week; RST = repeated-sprint training; Reps = repetitions; inter-rep = inter-repetition; CON = control; STR = straight-line repeated sprints; SHU = shuttle repeated sprints; MD = multi-directional repeated sprints; COD = change of direction; Savg = average sprint time; Sdec = percentage sprint decrement; CMJ = counter movement jump; JH = jump height; RSA = repeated-sprint ability; IRT = intermittent running test; IAT = Illinois agility test; YYIR1 = yo-yo intermittent recovery test level 1; GXT = graded exercise test on a treadmill with gas analyses; P = passive rest; A = active rest; mod. = modified; s = seconds; m = metres; cm = centimetres; min = minutes; yd = yard

[A] RSA straight-line test
[B] RSA shuttle test
[C] RSA muti-directional test
[D] 1 × 180° COD
[E] 2 × 180° COD
[F] 2 × 180° COD in weeks 1–3, 3 × 180° COD in weeks 4–7
[G] 3 × 180° COD
[H] Measured via an accelerometer
[I] Measured via the jump and reach test

[V] Low VO_2max group (<48 ml·kg^{-1}·min^{-1})
[W] Active recovery defined as a self-selected low-intensity
[X] Measured via the MyJump application

[J] Measured via force plates
[K] Measured via the Optojump
[L] Measured via a contact mat
[M] 1st set performed as straight-line sprints, 2nd and 3rd sets performed as multi-directional sprints with 45° and 90° COD
[N] 2 vs 1 tennis game played between sets, at 75–85 heart rate max
[O] Participants jogged back to a one-way start line
[P] Active recovery defined as “easy” on the Borg rating of perceived exertion scale
[Q] Shuttle distance of 4.5m per turn
[R] 5 × multi-directional COD
[S] 2 × 90° COD
[T] Active recovery performed as a slow jog
[U] High VO_2max group (≥ 48 $ml \cdot kg^{-1} \cdot min^{-1}$)

Appendix 12. Comparing multilevel meta-regression models for the moderating effects of programming variables on 10 m sprint time in Study 2.

Variable	Univariate Models		Naïve Multivariate Model		Unconditional model-averaged multivariate model		
	b	**90% CI**	**b**	**90% CI**	**b**	**90% CI**	**Importance (rank)**
Session frequency	-0.091	-0.271, 0.088	0.694	0.087, 1.302	-0.011	-0.094, 0.072	0.21 (3)
Program duration	0.026	-0.029, 0.081	-0.04	-0.146, 0.065	0.001	-0.016, 0.018	0.182 (6)
Mode: Shuttle [a]	-0.151	-0.36, 0.058	-0.051	-0.374, 0.272	-0.009	-0.05, 0.032	0.054 (7)
Sets per session	-0.095	-0.253, 0.062	0.366	-0.005, 0.736	-0.035	-0.162, 0.091	0.274 (2)
Reps per set	0.039	-0.029, 0.108	0.137	-0.020, 0.295	0.006	-0.022, 0.034	0.195 (4)
Weekly volume	< .01	< .01, < .01	-0.001	-0.002, < .01	< .01	< .01, < .01	0.362 (1)
Sprint distance	-0.001	-0.016, 0.014	0.052	0.015, 0.089	0.001	-0.005, 0.008	0.183 (5)

[a] reference = Straight-line

Appendix 13. Comparing multilevel meta-regression models for the moderating effects of programming variables on 10 m sprint time in Study 2.

Variable	Univariate Models		Naïve Multivariate Model		Unconditional model-averaged multivariate model		
	b	**90% CI**	**b**	**90% CI**	**b**	**90% CI**	**Importance (rank)**
Session frequency	-0.119	-0.418, 0.181	0.147	-0.978, 1.271	-0.022	-0.115, 0.070	0.125 (3)
Program duration	-0.037	-0.125, 0.051	-0.047	-0.207, 0.113	-0.004	-0.023, 0.015	0.114 (4)
Mode: Shuttle [a]	0.030	-0.303, 0.364	0.092	-0.534, 0.719	< .01	-0.004, 0.004	0.009 (7)
Sets per session	-0.231	-0.468, 0.006	0.016	-0.627, 0.66	-0.048	-0.219, 0.123	0.204 (2)
Reps per set	0.108	0.034, 0.181	0.219	-0.103, 0.542	0.047	-0.065, 0.159	0.474 (1)
Weekly volume	< .01	< .01, < .01	-0.001	-0.002, 0.001	< .01	< .01, < .01	0.09 (5)
Sprint distance	-0.009	-0.037, 0.019	0.027	-0.042, 0.096	< .01	-0.003, 0.003	0.077 (6)

[a] reference = Straight-line

Appendix 14 Comparing multilevel meta-regression models for the moderating effects of programming variables on maximal oxygen consumption in Study 2.

Variable	Univariate Models		Naïve Multivariate Model		Unconditional model-averaged multivariate model		
	b	90% CI	b	90% CI	b	90% CI	Importance (rank)
Session frequency	-0.01	-0.616, 0.597	2.569	-2.644, 7.782	-0.001	-0.008, 0.006	0.009 (4)
Program duration	0.082	-0.357, 0.521	0.045	-0.468, 0.558	0.001	-0.006, 0.008	0.010 (3)
Sets per session	0.164	-0.936, 1.263	11.571	-0.53, 23.672	0.005	-0.019, 0.029	0.010 (3)
Reps per set	-0.124	-0.310, 0.061	-0.971	-1.665, -0.278	-0.003	-0.015, 0.009	0.019 (1)
Weekly volume	< .01	-0.001, 0.001	-0.003	-0.011, 0.004	< .01	< .01, < .01	0.009 (4)
Sprint distance	0.01	-0.021, 0.041	-0.193	-0.401, 0.015	< .01	-0.001, 0.001	0.013 (2)

Appendix 15. Comparing multilevel meta-regression models for the moderating effects of programming variables on the Yo-Yo Intermittent Recovery Test Level 1 in Study 2.

	Univariate Models		Naïve Multivariate Model		Unconditional model-averaged multivariate model		
Variable	b	90% CI	b	90% CI	b	90% CI	Importance
Session frequency	0.127	-0.115, 0.369	-0.104	-0.822, 0.614	< .01	-0.047, 0.046	0.142 (5)
Program duration	-0.038	-0.105, 0.029	-0.025	-0.115, 0.065	-0.004	-0.025, 0.016	0.165 (4)
Mode: multi-directional [a]	0.082	-0.326, 0.490	0.05	-0.401, 0.502	-0.001	-0.014, 0.012	0.021 (6)
Mode: shuttle [a]	0.012	-0.234, 0.257	-0.167	-0.466, 0.131	-0.002	-0.014, 0.011	0.021 (6)
Sets per session	0.378	0.013, 0.743	-0.379	-1.569, 0.810	-0.094	-0.513, 0.325	0.276 (2)
Reps per set	-0.146	-0.224, -0.067	-0.212	-0.521, 0.098	-0.156	-0.317, 0.005	0.866 (1)
Weekly volume	< .01	< .01, < .01	< .01	-0.001, 0.001	< .01	< .01, < .01	0.142 (5)
Sprint distance	0.026	0.007, 0.045	0.012	-0.038, 0.062	0.003	-0.010, 0.016	0.209 (3)

[a] reference = Straight-line

Appendix 16. Comparing multilevel meta-regression models for the moderating effects of programming variables on repeated-sprint ability average time in Study 2.

	Univariate Models		Naïve Multivariate Model		Unconditional model-averaged multivariate model		
Variable	**b**	**90% CI**	**b**	**90% CI**	**b**	**90% CI**	**Importance**
Session frequency	0.133	-0.041, 0.306	0.505	-0.228, 1.239	0.058	-0.120, 0.235	0.358 (1)
Program duration	-0.062	-0.140, 0.017	-0.119	-0.292, 0.055	-0.015	-0.069, 0.040	0.289 (2)
Mode: multi-directional [a]	0.238	-0.355, 0.832	0.451	-0.282, 1.185	0.001	-0.007, 0.010	0.009 (7)
Mode: shuttle [a]	0.054	-0.192, 0.300	0.197	-0.259, 0.652	< .01	-0.003, 0.003	0.009 (7)
Sets per session	-0.005	-0.188, 0.177	0.274	-0.221, 0.768	-0.014	-0.094, 0.065	0.196 (5)
Reps per set	0.026	-0.05, 0.103	0.134	-0.043, 0.311	0.007	-0.024, 0.038	0.215 (3)
Weekly volume	< .01	< .01, < .01	-0.001	-0.002, 0.000	< .01	< .01, < .01	0.205 (4)
Sprint distance	0.001	-0.017, 0.018	0.03	-0.026, 0.087	< .01	-0.005, 0.004	0.18 (6)

[a] reference = Straight-line

Appendix 17. Comparing multilevel meta-regression models for the moderating effects of programming variables on repeated-sprint ability decrement in Study 2.

	Univariate Models		Naïve Multivariate Model		Unconditional model-averaged multivariate model		
variable	**b**	**90% CI**	**b**	**90% CI**	**b**	**90% CI**	**Importance**
Session frequency	0.12	-0.303, 0.543	1.83	0.266, 3.395	0.01	-0.081, 0.101	0.146 (5)
Program duration	-0.011	-0.210, 0.187	-0.13	-0.461, 0.2	0.001	-0.028, 0.029	0.138 (6)
Mode: multi-directional [a]	0.298	-0.299, 0.895	0.44	-0.508, 1.387	0.004	-0.017, 0.024	0.018 (7)
Mode: shuttle [a]	-0.453	-1.000, 0.094	-0.376	-1.305, 0.553	-0.007	-0.037, 0.023	0.018 (7)
Sets per session	0.024	-0.306, 0.354	1.038	0.206, 1.87	0.012	-0.065, 0.088	0.149 (4)
Reps per set	0.178	0.013, 0.344	0.648	0.067, 1.229	0.101	-0.126, 0.328	0.527 (1)
Weekly volume	< .01	-0.001, 0.001	-0.003	-0.006, 0	< .01	< .01, < .01	0.23 (3)
Sprint distance	-0.027	-0.059, 0.005	0.137	0.001, 0.273	-0.006	-0.029, 0.016	0.259 (2)

[a] reference = Straight-line

Appendix 18. Comparing multilevel meta-regression models for the moderating effects of programming variables on counter-movement jump height in Study 2.

	Univariate Models		**Naïve Multivariate Model**		**Unconditional model-averaged multivariate model**		
variable	**b**	**90% CI**	**b**	**90% CI**	**b**	**90% CI**	**Importance**
Session frequency	0.044	-0.164, 0.252	0.051	-0.463, 0.566	0.012	-0.06, 0.083	0.188 (5)
Program duration	-0.012	-0.060, 0.035	-0.033	-0.089, 0.024	< .01	-0.011, 0.011	0.171 (6)
Mode: multi-directional [a]	-0.253	-0.617, 0.112	-0.271	-0.672, 0.129	-0.003	-0.017, 0.011	0.012 (7)
Mode: shuttle [a]	-0.051	-0.295, 0.194	-0.087	-0.405, 0.23	-0.001	-0.007, 0.005	0.012 (7)
Sets per session	0.007	-0.184, 0.198	0.128	-0.479, 0.734	< .01	-0.060, 0.061	0.191 (4)
Reps per set	-0.044	-0.099, 0.011	-0.019	-0.206, 0.168	-0.014	-0.062, 0.034	0.317 (1)
Weekly volume	< .01	< .01, < .01	< .01	-0.001, 0.001	< .01	< .01, < .01	0.242 (2)
Sprint distance	0.005	-0.012, 0.022	0.008	-0.032, 0.048	0.001	-0.005, 0.007	0.194 (3)

[a] reference = Straight-line

Appendix 19. Comparing multilevel meta-regression models for the moderating effects of programming variables on change of direction ability in Study 2.

Variable	**Univariate Models**		**Naïve Multivariate Model**		**Unconditional model-averaged multivariate model**		
	b	**90% CI**	**b**	**90% CI**	**b**	**90% CI**	**Importance (rank)**
Session frequency	0.347	0.107, 0.587	0.736	-0.020, 1.492	0.15	-0.216, 0.516	0.458 (2)
Program duration	-0.056	-0.112, 0.001	-0.068	-0.160, 0.024	-0.024	-0.094, 0.047	0.338 (3)
Mode: Multi-directional [a]	-0.169	-0.961, 0.623	0.257	-0.800, 1.314	0.009	-0.074, 0.092	0.056 (7)
Mode: Shuttle [a]	-0.171	-0.420, 0.079	-0.095	-0.404, 0.215	-0.017	-0.087, 0.052	0.056 (7)
Sets per session	0.105	-0.291, 0.500	0.366	-0.453, 1.186	-0.05	-0.256, 0.156	0.214 (5)
Reps per set	0.115	-0.036, 0.266	0.337	0.054, 0.620	0.077	-0.096, 0.250	0.526 (1)
Weekly volume	< .001	< .001, 0.001	-0.001	-0.002, < .001	< .001	< .001, < .001	0.328 (4)
Sprint distance	0.014	-0.006, 0.034	0.052	0.005, 0.098	0.003	-0.009, 0.014	0.204 (6)

[a] reference = Straight-line

Appendix 20. Top five models (conditional model-averaged) for predicting change in 10 m sprint time in Study 2.

	AICC	Weighting	Model
1	22.24	0.20	10 m sprint$_{\Delta}$ = -0.14 + 0.0001(Volume)
2	23.48	0.11	10 m sprint$_{\Delta}$ = 0.037 -0.143(Sets)
3	25.46	0.04	10 m sprint$_{\Delta}$ = -0.126 -0.106(Frequency)
4	25.61	0.036	10 m sprint$_{\Delta}$ = -0.628 + 0.038(Reps)
5	25.62	0.036	10 m sprint$_{\Delta}$ = -0.525 + 0.028(Duration)

Appendix 21. Top five models (conditional model-averaged) for predicting change in 20 m sprint time in Study 2.

	AICC	Weighting	Model
1	21.348	0.305	20 m sprint$_{\Delta}$ = -1.153 + 0.102(Reps)
2	23.48	0.11	20 m sprint$_{\Delta}$ = 0.327 -0.264(Sets)
3	25.46	0.04	20 m sprint$_{\Delta}$ = -0.1 -0.155(Frequency)
4	25.61	0.04	20 m sprint$_{\Delta}$ = -0.265 -0.036(Duration)
5	25.62	0.04	20 m sprint$_{\Delta}$ = -0.607 -0.136(Sets) + 0.082(Reps)

Appendix 22. Top five models (conditional model-averaged) for predicting change in maximal oxygen consumption (VO_{2max}) in Study 2.

	AICC	Weighting	Model
1	22.24	0.20	$VO_{2max\Delta}$ = 1.573 -0.148(Reps)
2	23.479	0.105	$VO_{2max\ \Delta}$ = 0.381 + 0.365(Mode)
3	25.457	0.039	$VO_{2max\ \Delta}$ = 0.027 + 0.018(Distance)
4	25.609	0.036	$VO_{2max\ \Delta}$ = -0.738 + 0.473(Sets)
5	25.622	0.036	$VO_{2max\ \Delta}$ = -0.111 + 0.113(Duration)

Appendix 23. Top five models (conditional model-averaged) for predicting change in distance covered during the Yo-Yo Intermittent Recovery Test Level 1 (YYIR1) in Study 2.

	AICC	Weighting	Model
1	21.35	0.31	$\mathrm{YYIR1}_{\Delta}$ = 1.731 -0.159(Reps)
2	22.24	0.20	$\mathrm{YYIR1}_{\Delta}$ = 3.749 -0.469(Sets) -0.245(Reps)
3	23.479	0.105	$\mathrm{YYIR1}_{\Delta}$ = 1.326 -0.14(Reps) + 0.009(Distance)
4	25.457	0.039	$\mathrm{YYIR1}_{\Delta}$ = 1.8 -0.02(Duration) -0.153(Reps)
5	25.609	0.036	$\mathrm{YYIR1}_{\Delta}$ = 1.77 -0.013(Frequency) -0.16(Reps)

Appendix 24. Top five models (conditional model-averaged) for predicting change in repeated-sprint ability average time ($\mathrm{RSA}_{\mathrm{avg}}$) in Study 2.

	AICC	Weighting	Model
1	22.24	0.20	$\mathrm{RSA}_{\mathrm{avg}\Delta}$ = -0.646 + 0.155(Frequency)
2	23.479	0.105	$\mathrm{RSA}_{\mathrm{avg}\Delta}$ = -0.016 -0.054(Duration)
3	25.457	0.039	$\mathrm{RSA}_{\mathrm{avg}\Delta}$ = -0.514 + 0.028(Reps)
4	25.609	0.036	$\mathrm{RSA}_{\mathrm{avg}\Delta}$ = -0.434 + 0.0001(Volume)
5	25.622	0.036	$\mathrm{RSA}_{\mathrm{avg}\Delta}$ = -0.123 -0.072(Sets)

Appendix 25. Top five models (conditional model-averaged) for predicting change in repeated-sprint ability decrement ($\mathrm{S}_{\mathrm{dec}}$) in Study 2.

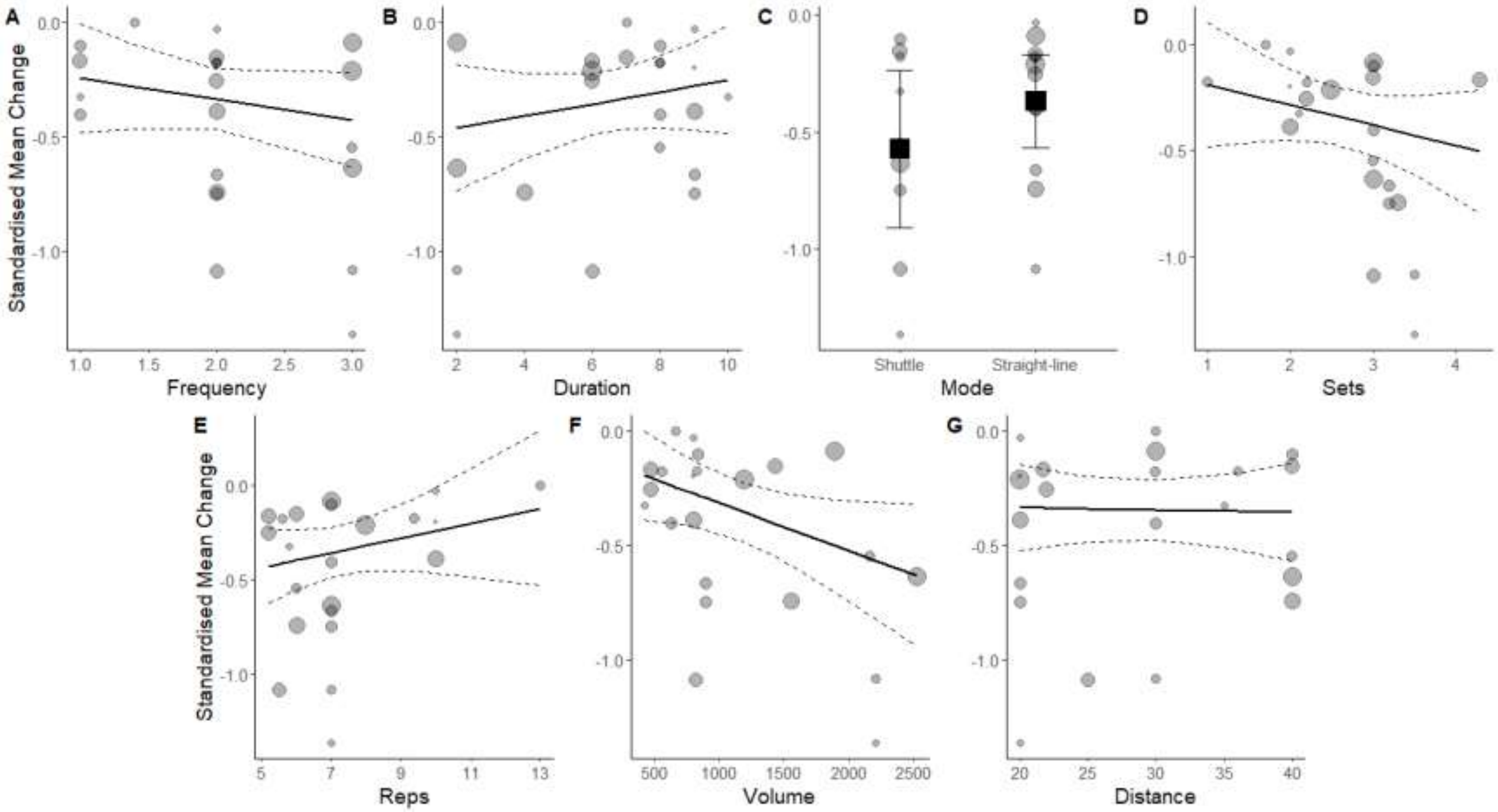
	AICC	Weighting	Model
1	21.35	0.31	RSA $\mathrm{S}_{\mathrm{dec}\Delta}$ = -1.84 + 0.184(Reps)
2	23.479	0.105	RSA $\mathrm{S}_{\mathrm{dec}\Delta}$ = -1.557 + 0.228(Reps) -0.001(Volume)
3	25.457	0.039	RSA $\mathrm{S}_{\mathrm{dec}\Delta}$ = 0.221 -0.029(Distance)
4	25.609	0.036	RSA $\mathrm{S}_{\mathrm{dec}\Delta}$ = -1.063 + 0.144(Reps) -0.018(Distance)
5	25.622	0.036	RSA $\mathrm{S}_{\mathrm{dec}\Delta}$ = -2 + 0.06(Sets) + 0.184(Reps)

Appendix 26. Top five models (conditional model-averaged) for predicting change in counter-movement jump height (CMJ) in Study 2.

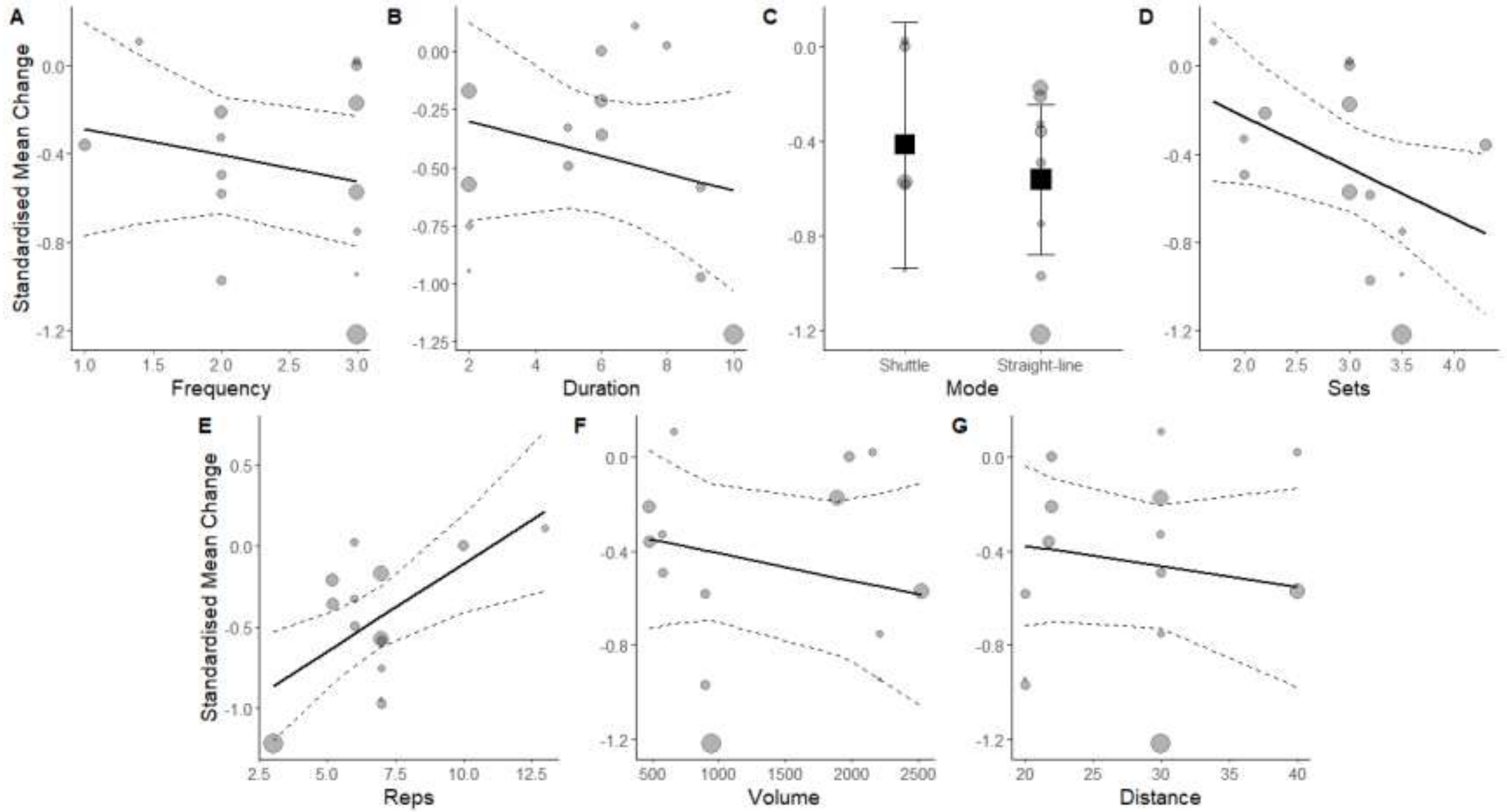
	AICC	**Weighting**	**Model**
1	22.235	0.195	$CMJ_{\Delta} = 0.546 - 0.041(Reps)$
2	23.479	0.105	$CMJ_{\Delta} = 0.364 + 0.0001(Volume)$
3	25.457	0.039	$CMJ_{\Delta} = 0.079 + 0.006(Distance)$
4	25.609	0.036	$CMJ_{\Delta} = 0.118 + 0.054(Frequency)$
5	25.622	0.036	$CMJ_{\Delta} = 0.236 + 0.001(Duration)$

Appendix 27. Top five models (conditional model-averaged) for predicting change in change of direction ability in Study 2.

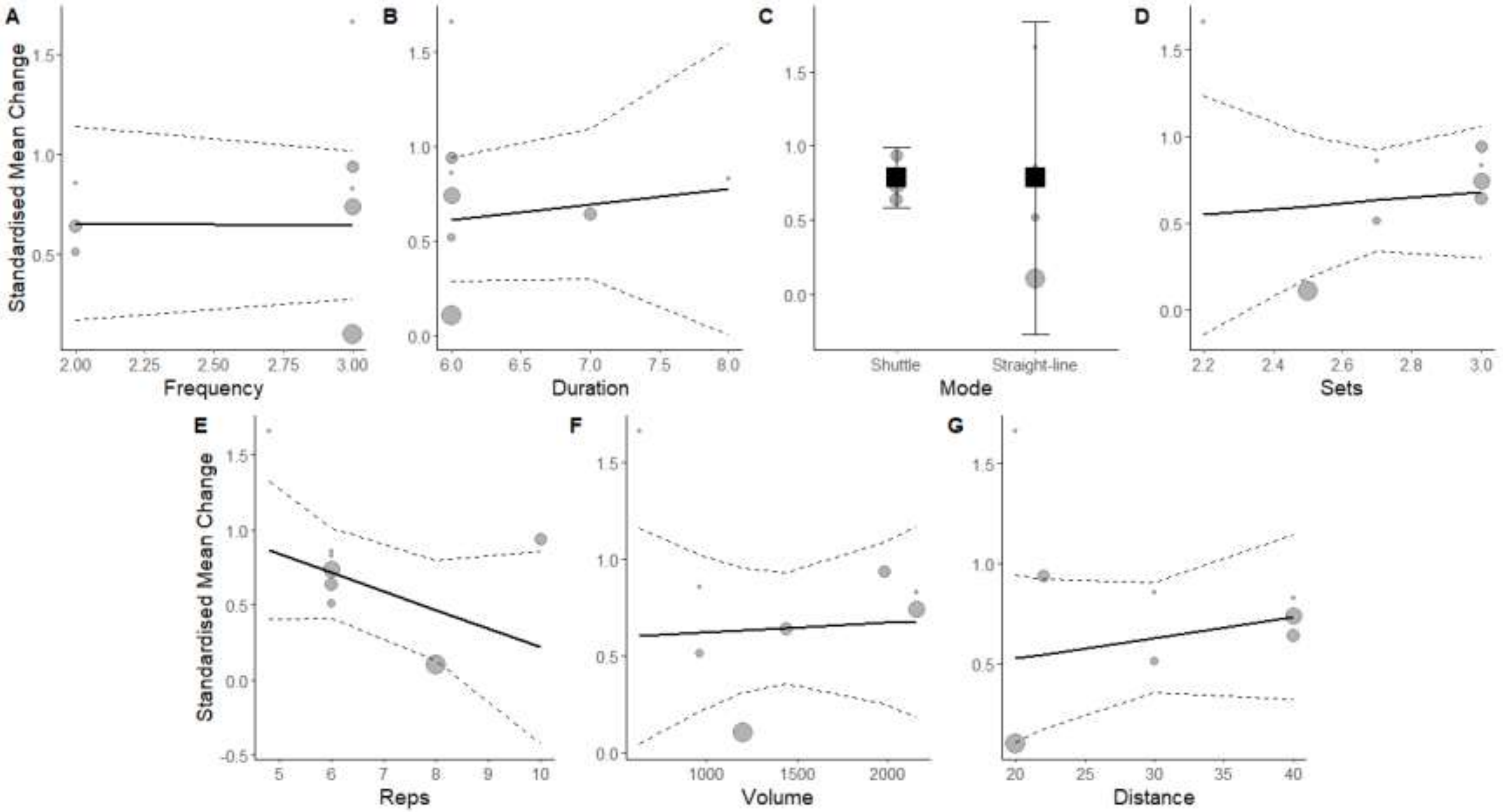
	AICC	**Weighting**	**Model**
1	21.35	0.31	$COD_{\Delta} = -0.923 - 0.091(Duration) + 0.158(Reps)$
2	22.235	0.195	$COD_{\Delta} = -1.053 + 0.336(Frequency)$
3	23.479	0.105	$COD_{\Delta} = -1.989 + 0.376(Frequency) + 0.111(Reps)$
4	25.457	0.039	$COD_{\Delta} = -3.273 + 0.398(Frequency) + 0.19(Reps) + 0.022(Distance)$
5	25.609	0.036	$COD_{\Delta} = 0.214 - 0.41(Sets) + 0.0001(Volume)$



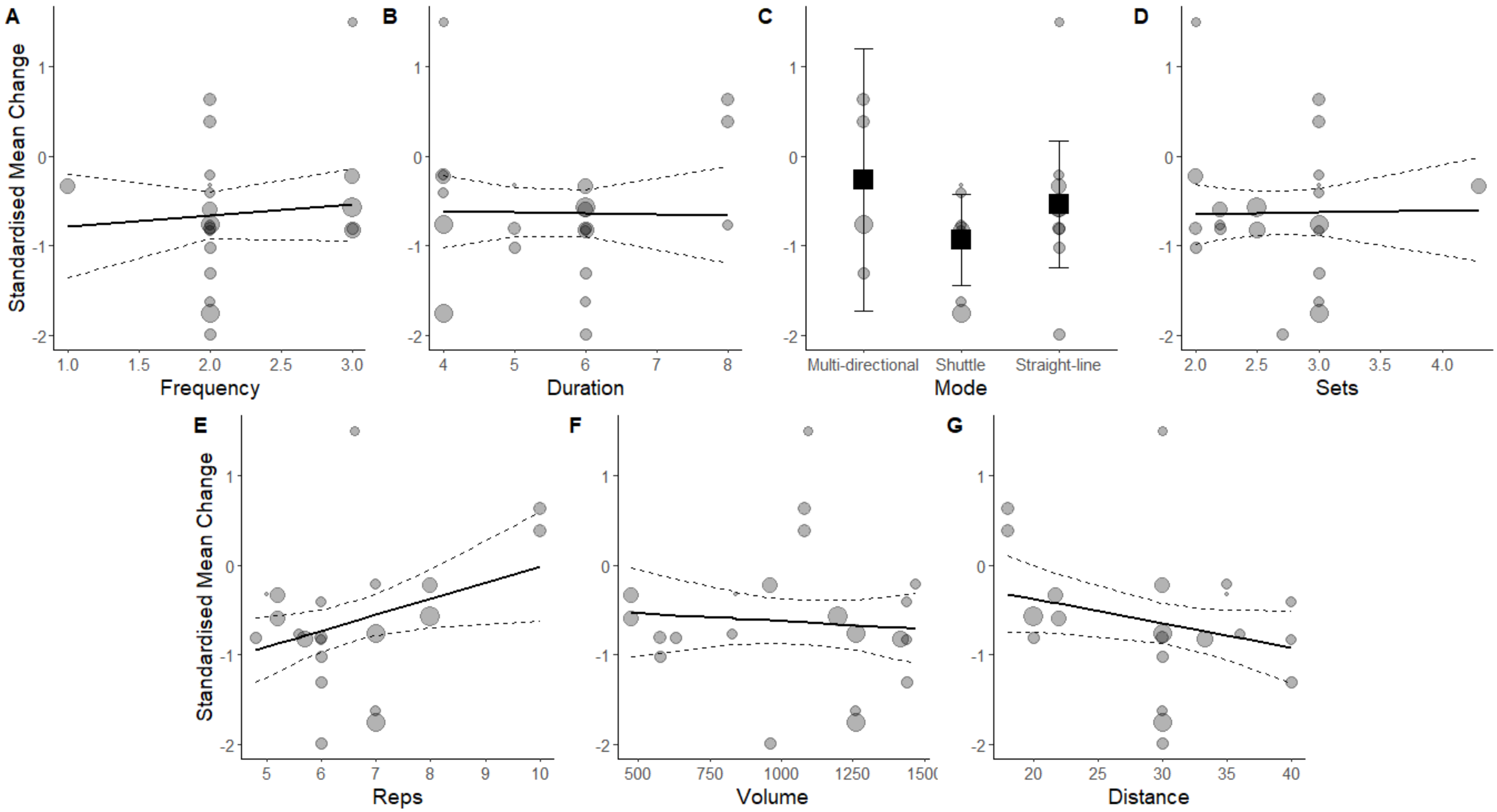
Appendix 28. Univariate meta-regression displaying the moderating effects of (A) training frequency, (B) program duration, (C) sprint modality, (D) sets per session, (E) repetitions per set, (F) weekly volume, and (G) repetition distance on 10 m sprint time, following repeated-sprint training. Evidence from Study 2. Larger circles = greater study size; black line = effect estimate; dotted line = confidence interval.



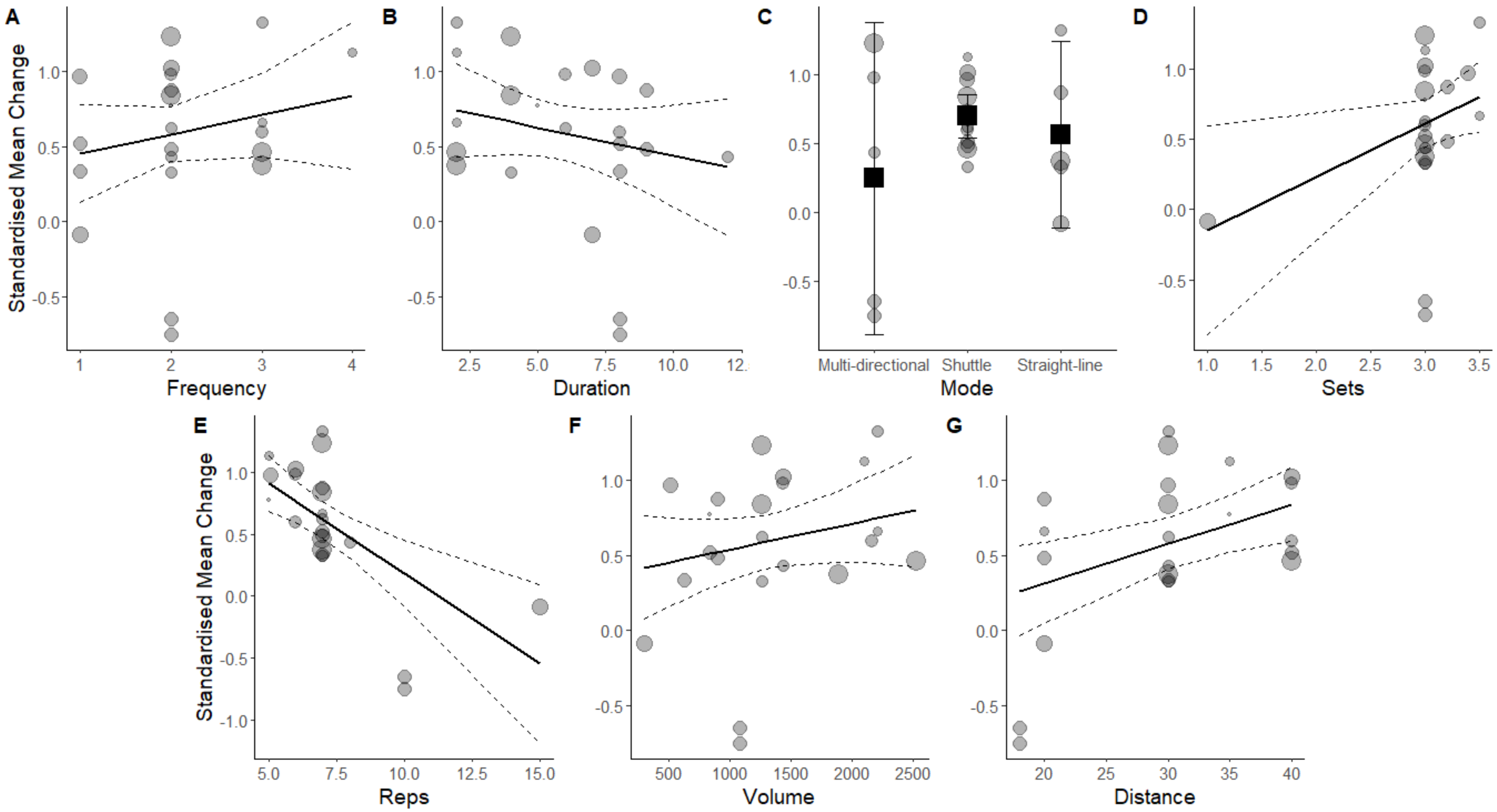
Appendix 29. Univariate meta-regression displaying the moderating effects of (A) training frequency, (B) program duration, (C) sprint modality, (D) sets per session, (E) repetitions per set, (F) weekly volume, and (G) repetition distance on 20 m sprint time, following repeated-sprint training. Evidence from Study 2. Larger circles = greater study size; black line = effect estimate; dotted line = confidence interval.



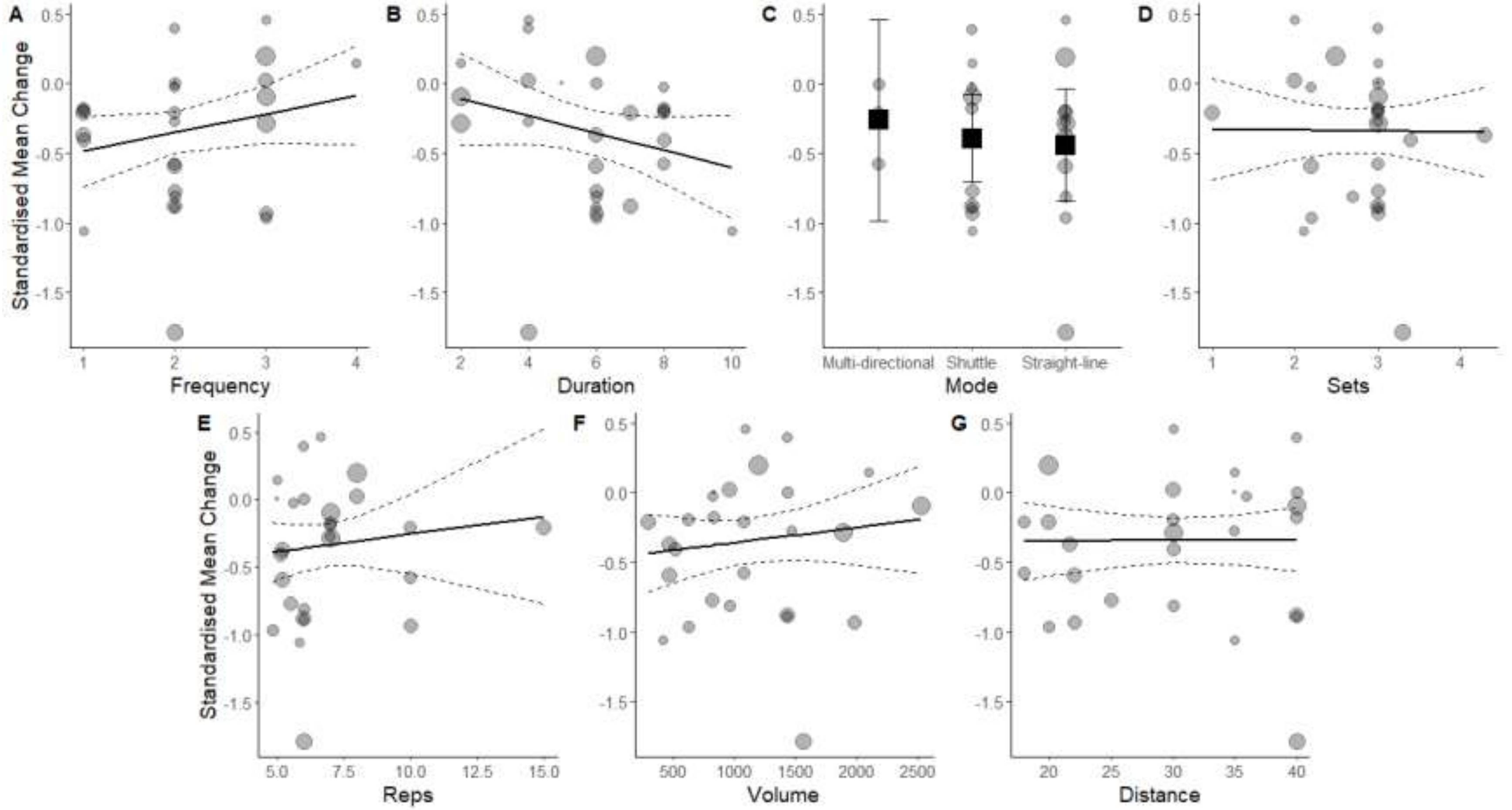
Appendix 30. Univariate meta-regression displaying the moderating effects of (A) training frequency, (B) program duration, (C) sprint modality, (D) sets per session, (E) repetitions per set, (F) weekly volume, and (G) repetition distance on VO_{2max}, following repeated-sprint training. Evidence from Study 2. Larger circles = greater study size; black line = effect estimate; dotted line = confidence interval.



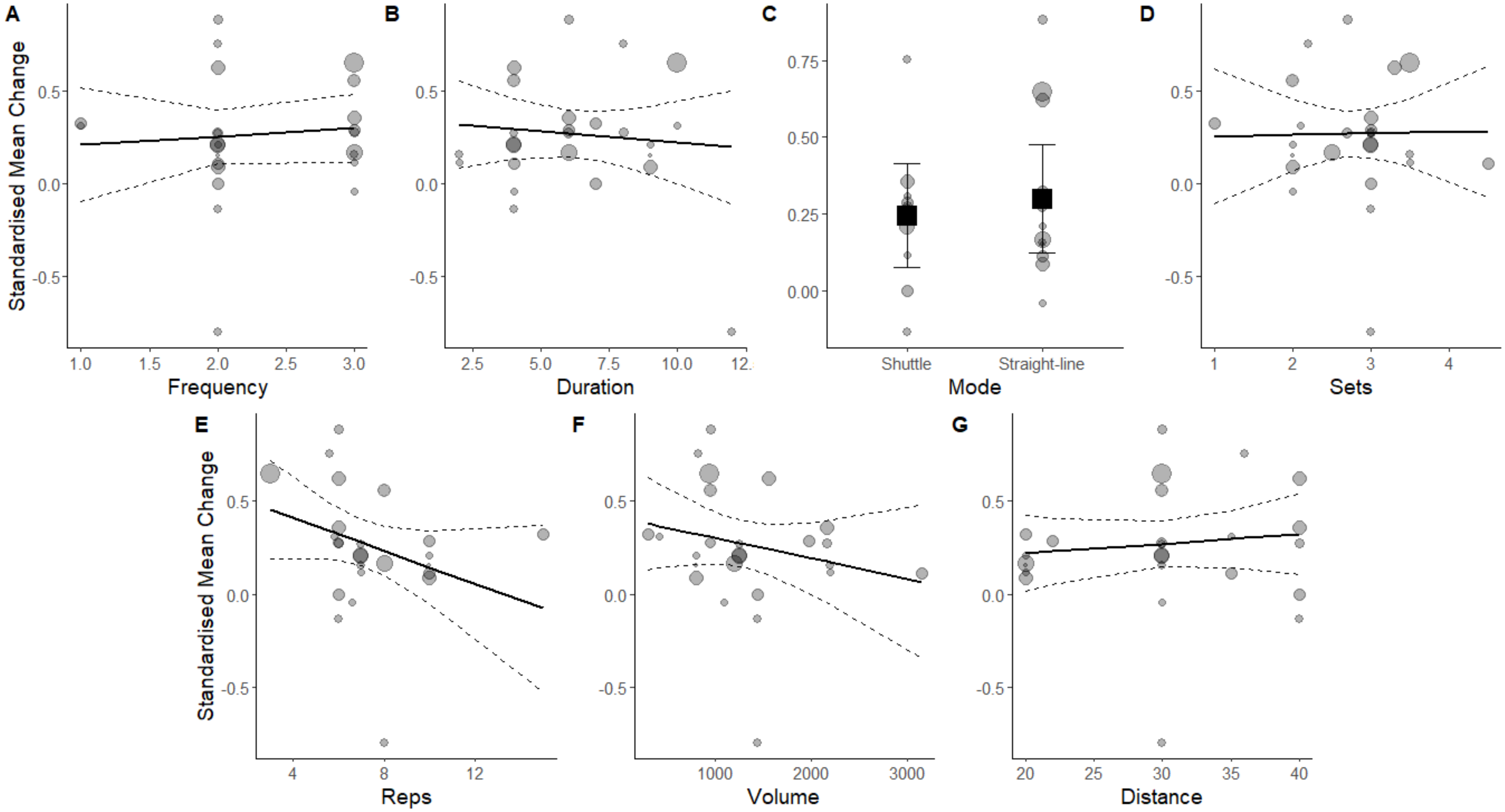
Appendix 31. Univariate meta-regression displaying the moderating effects of (A) training frequency, (B) program duration, (C) sprint modality, (D) sets per session, (E) repetitions per set, (F) weekly volume, and (G) repetition distance on the Yo-Yo Intermittent Recovery Test Level 1, following repeated-sprint training. Evidence from Study 2. Larger circles = greater study size; black line = effect estimate; dotted line = confidence interval.



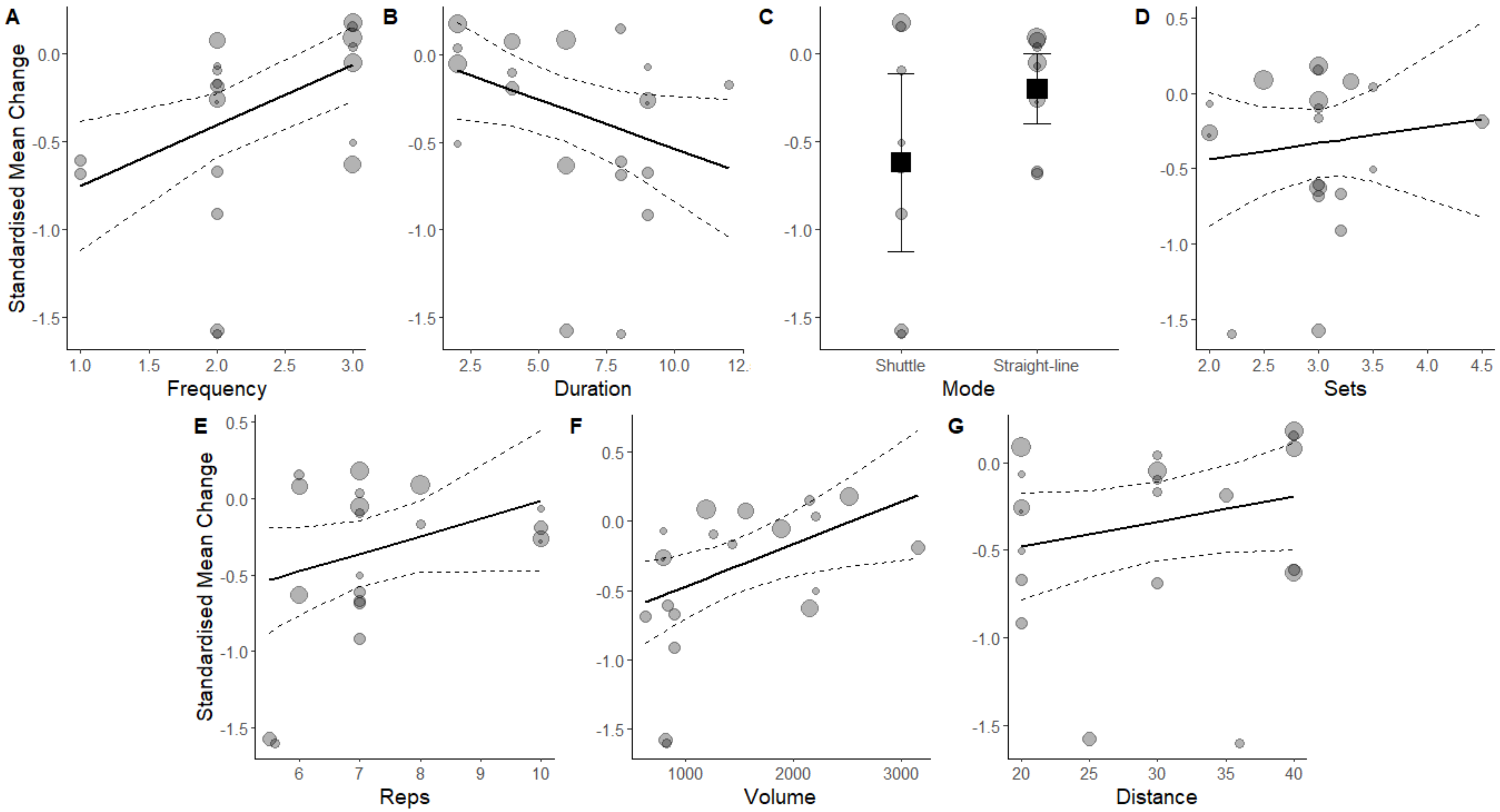
Appendix 32. meta-regression displaying the moderating effects of (A) training frequency, (B) program duration, (C) sprint modality, (D) sets per session, (E) repetitions per set, (F) weekly volume, and (G) repetition distance on repeated-sprint ability average time, following repeated-sprint training. Evidence from Study 2. Larger circles = greater study size; black line = effect estimate; dotted line = confidence interval.



Appendix 33. Univariate meta-regression displaying the moderating effects of (A) training frequency, (B) program duration, (C) sprint modality, (D) sets per session, (E) repetitions per set, (F) weekly volume, and (G) repetition distance on repeated-sprint ability decrement, following repeated-sprint training. Evidence from Study 2. Larger circles = greater study size; black line = effect estimate; dotted line = confidence interval.



Appendix 34. Univariate meta-regression displaying the moderating effects of (A) training frequency, (B) program duration, (C) sprint modality, (D) sets per session, (E) repetitions per set, (F) weekly volume, and (G) repetition distance on counter-movement jump height, following repeated-sprint training. Evidence from Study 2. Larger circles = greater study size; black line = effect estimate; dotted line = confidence interval.



Appendix 35. Univariate meta-regression displaying the moderating effects of (A) training frequency, (B) program duration, (C) sprint modality, (D) sets per session, (E) repetitions per set, (F) weekly volume, and (G) repetition distance on change of direction ability, following repeated-sprint training. Evidence from Study 2. Larger circles = greater study size; black line = effect estimate; dotted line = confidence interval.

APPENDIX 36. Physiological demands of the repeated-sprint training sessions in Study 3.

Outcome		**Protocol**							
		10×40		**5×40**		**10×20**		**5×20**	
		Raw	% Max	Raw	% Max	Raw	% Max	Raw	% Max
HR$_{avg}$ (b·min^{-1})	**Set 1**	171 ± 7	88 ± 4	164 ± 14	85 ± 7	161 ± 14	83 ± 7	153 ± 13	79 ± 6
	Set 2	175 ± 9	90 ± 4	169 ± 15	87 ± 7	168 ± 14	87 ± 7	160 ± 10	82 ± 5
	Session	173 ± 6	89 ± 3	166 ± 14	86 ± 7	165 ± 14	85 ± 7	157 ± 11	81 ± 5
HR$_{peak}$ (b·min^{-1})	**Session**	188 ± 7	96 ± 2	180 ± 18	93 ± 8	177 ± 18	91 ± 8	171 ± 16	88 ± 7
VO$_{2avg}$ (L·min^{-1})	**Set 1**	2.96 ± 0.74	72 ± 9	2.79 ± 0.62	68 ± 7	2.67 ± 0.61	65 ± 9	2.58 ± 0.63	62 ± 6
	Set 2	2.97 ± 0.82	72 ± 9	2.90 ± 0.64	70 ± 6	2.76 ± 0.68	67 ± 8	2.75 ± 0.67	66 ± 6
	Session	2.97 ± 0.78	72 ± 9	2.85 ± 0.63	69 ± 6	2.72 ± 0.64	66 ± 8	2.72 ± 0.60	64 ± 6
T > 90% VO$_{2max}$ (s)	**Set 1**	29 ± 26	-	12 ± 10	-	18 ± 16	-	6 ± 3	-
	Set 2	37 ± 34	-	11 ± 8	-	19 ± 14	-	10 ± 5	-
	Session	66 ± 59	-	23 ± 17	-	37 ± 28	-	16 ± 7	-

Abbreviations: HR$_{avg}$ = average heart rate; HR$_{peak}$ = peak heart rate; VO$_{2avg}$ = average oxygen consumption; T > 90% HR$_{max}$ = time (seconds) above 90% of maximal heart rate; T > 90% VO$_{2max}$ = time (seconds) above 90% of maximal oxygen consumption.

APPENDIX 37. Performance and perceptual demands of the repeated-sprint training sessions in Study 3.

Outcome measure		**Protocol**			
		10×40	**5×40**	**10×20**	**5×20**
S_{dec} (%)	**Set 1**	6.3 ± 3.6	3.4 ± 1.9	3.4 ± 1.7	2.4 ± 1.0
	Set 2	7.3 ± 5.1	3.6 ± 1.9	3.6 ± 1.6	2.6 ± 1.2
	Session	6.8 ± 4.2	3.5 ± 1.7	3.5 ± 1.5	2.5 ± 0.9
Distance > 90% MSS (m)	**Set 1**	78 ± 52	63 ± 18	33 ± 34	17 ± 15
	Set 2	52 ± 57	42 ± 36	33 ± 33	19 ± 13
	Session	130 ± 105	105 ± 53	67 ± 64	36 ± 27
Acceleration load (au)	**Set 1**	4.72 ± 3.09	2.53 ± 1.37	6.25 ± 2.64	3.36 ± 1.67
	Set 2	4.91 ± 2.66	2.21 ± 1.20	6.86 ± 3.61	3.46 ± 1.44
	Session	9.62 ± 5.63	4.75 ± 2.53	13.11 ± 6.10	6.82 ± 2.87
RPE-L (au)	**Set 1**	47 ± 26	42 ± 21	34 ± 20	19 ± 12
	Set 2	52 ± 24	45 ± 21	41 ± 21	24 ± 17
	Session	49 ± 25	43 ± 21	38 ± 20	22 ± 14
RPE-B (au)	**Set 1**	63 ± 22	48 ± 20	34 ± 16	27 ± 14
	Set 2	73 ± 22	58 ± 18	41 ± 22	28 ± 14
	Session	68 ± 22	53 ± 19	37 ± 19	28 ± 14
sRPE-TL (au)	**Session**	109 ± 35	46 ± 18	60 ± 26	24 ± 12

Abbreviations: S_{best} = best sprint time; S_{avg} = average sprint time; S_{dec} = percentage sprint decrement; MSS = maximal sprinting speed; avg = average; RPE-L = rating of perceived exertion for the leg muscles; RPE-B = rating of perceived exertion for breathlessness; sRPE-TL = session rating of perceived exertion-training load.

APPENDIX 38. Between protocol comparisons for physiological measures in Study 3.

Outcome	**Comparison**	**Standardised difference ±90% CL**	p_{MET}
HR_{avg}	10×40 vs 5×40	0.58; -0.07 to 1.23	0.165
	10×40 vs 10×20	0.69; 0.05 to 1.34	0.103
	10×40 vs 5×20	1.38; 0.74 to 2.03	0.002
	5×40 vs 10×20	0.11; -0.52 to 0.75	0.589
	5×40 vs 5×20	0.80; 0.17 to 1.44	0.059
	10×20 vs 5×20	0.69; 0.05 to 1.33	0.101
HR_{peak}	10×40 vs 5×40	0.52; -0.17 to 1.52	0.206
	10×40 vs 10×20	0.72; 0.09 to 1.78	0.093
	10×40 vs 5×20	1.10; 0.60 to 2.26	0.011
	5×40 vs 10×20	0.20; -0.57 to 1.09	0.502
	5×40 vs 5×20	0.58; -0.06 to 1.22	0.160
	10×20 vs 5×20	0.38; -0.26 to 1.02	0.316
VO_{2avg}	10×40 vs 5×40	0.18; -0.46 to 0.81	0.524
	10×40 vs 10×20	0.36; -0.27 to 1.00	0.333
	10×40 vs 5×20	0.38; -0.26 to 1.01	0.321
	5×40 vs 10×20	0.19; -0.45 to 0.82	0.514
	5×40 vs 5×20	0.20; -0.43 to 0.83	0.501
	10×20 vs 5×20	0.01; -0.61 to 0.64	0.691
T > 90% VO_{2max}	10×40 vs 5×40	1.29; 0.67 to 1.91	0.002
	10×40 vs 10×20	0.88; -0.36 to 2.12	0.181
	10×40 vs 5×20	1.47; 0.84 to 2.11	<0.001
	5×40 vs 10×20	-0.41; -1.04 to 0.22	0.291
	5×40 vs 5×20	0.18; -0.45 to 0.82	0.516
	10×20 vs 5×20	0.59; -0.04 to 1.23	0.151

Abbreviations: HR_{avg} = average heart rate; HR_{peak} = peak heart rate; VO_{2avg} = average oxygen consumption; T > 90% VO_{2max} = time above 90% of VO_{2max}; CL = confidence limit

APPENDIX 39. Between protocol comparisons for perceptual measures in Study 3.

Outcome	**Comparison**	**Standardised difference ±90% CL**	p_{MET}
RPE-L	10×40 vs 5×40	0.31; -0.32 to 0.94	0.384
	10×40 vs 10×20	0.59; -0.04 to 1.22	0.153
	10×40 vs 5×20	1.37; 0.74 to 2.00	0.001
	5×40 vs 10×20	0.28; -0.35 to 0.91	0.420
	5×40 vs 5×20	1.06; 0.43 to 1.69	0.013
	10×20 vs 5×20	0.78; 0.15 to 1.41	0.063
RPE-B	10×40 vs 5×40	0.79; 0.15 to 1.42	0.064
	10×40 vs 10×20	1.64; 1.01 to 2.28	<0.001
	10×40 vs 5×20	2.19; 1.56 to 2.83	<0.001
	5×40 vs 10×20	0.85; 0.22 to 1.49	0.046
	5×40 vs 5×20	1.41; 0.77 to 2.04	0.001
	10×20 vs 5×20	0.55; -0.09 to 1.19	0.181
sRPE-TL	10×40 vs 5×40	2.59; 1.96 to 3.23	<0.001
	10×40 vs 10×20	2.00; 1.37 to 2.63	<0.001
	10×40 vs 5×20	3.47; 2.84 to 4.11	<0.001
	5×40 vs 10×20	-0.59; -1.23 to 0.04	0.152
	5×40 vs 5×20	0.88; 0.25 to 1.51	0.039
	10×20 vs 5×20	1.47; 0.84 to 2.11	<0.001

Abbreviations: RPE-L = differential rating of perceived exertion for the leg muscles; RPE-B = differential rating of perceived exertion for breathlessness; sRPE-TL = session rating of perceived exertion-training load; CI = confidence limit

APPENDIX 40. Between protocol comparisons for performance measures in Study 3.

Outcome	**Comparison**	**Standardised difference ±90% CL**	***p_{MET}***
S_{dec}	10×40 vs 5×40	1.37; 0.74 to 2.01	0.002
	10×40 vs 10×20	1.39; 0.75 to 2.03	0.001
	10×40 vs 5×20	1.79; 1.16 to 2.43	<0.001
	5×40 vs 10×20	0.02; -0.62 to 0.66	0.682
	5×40 vs 5×20	0.42; -0.22 to 1.06	0.282
	10×20 vs 5×20	0.40; -0.23 to 1.04	0.297
Distance > 90% MSS	10×40 vs 5×40	0.37; -0.26 to 1.01	0.323
	10×40 vs 10×20	0.94; 0.30 to 1.57	0.029
	10×40 vs 5×20	1.38; 0.75 to 2.02	0.001
	5×40 vs 10×20	0.56; -0.07 to 1.20	0.172
	5×40 vs 5×20	1.01; 0.38 to 1.64	0.018
	10×20 vs 5×20	0.45; -0.19 to 1.08	0.258
Acceleration load	10×40 vs 5×40	1.07; 0.43 to 1.70	0.013
	10×40 vs 10×20	-0.76; -1.40 to -0.13	0.071
	10×40 vs 5×20	0.61; -0.02 to 1.25	0.140
	5×40 vs 10×20	-1.83; -2.46 to -1.20	<0.001
	5×40 vs 5×20	-0.45; -1.09 to 0.18	0.252
	10×20 vs 5×20	1.38; 0.74 to 2.01	0.002

Abbreviations: S_{dec} = percentage sprint decrement; MSS = maximal sprint speed; CL = confidence limit

APPENDIX 41. The time course of recovery of neuromuscular performance within each repeated-sprint training protocol in Study 3.

		Pre-post			**Pre-24 hr**			**Pre-48 hr**		
	Pre (mean ±SD)	**Change ±90% CI**	**Standardised difference ±90 CI**	p_{MET}	**Change ±90% CI**	**Standardised difference ±90 CI**	p_{MET}	**Change ±90% CI**	**Standardised difference ±90 CI**	p_{MET}
Hamstring PF90° (N)										
10×40	235 ±54	-10 ±34	-0.18 ±0.63	0.52	-8 ±34	-0.16 ±0.63	0.55	-4 ± 34	-0.08 ±0.63	0.62
5×40	227 ±58	-8 ±32	-0.16 ±0.63	0.54	-2 ±32	-0.04 ±0.63	0.66	-5 ±32	-0.11 ±0.63	0.60
10×20	226 ±48	-2 ±32	-0.03 ±0.64	0.67	8 ±32	0.16 ±0.63	0.54	11 ±32	0.22 ±0.65	0.48
5×20	224 ±50	-2 ±32	-0.04 ±0.53	0.70	-6 ±33	-0.11 ±0.63	0.59	5 ±32	-0.03 ±0.64	0.61
Hamstring PF30° (N)										
10×40	227 ±61	-4 ±36	-0.07 ±0.66	0.63	-4 ±36	-0.07 ±0.66	0.63	-3 ±36	-0.05 ±0.66	0.64
5×40	220 ±54	-8 ±31	-0.15 ±0.62	0.56	-1 ±31	-0.02 ±0.61	0.69	-2 ±31	-0.03 ±0.62	0.67
10×20	223 ±50	4 ±30	0.08 ±0.60	0.63	5 ±30	0.09 ±0.60	0.62	0 ±67	0.00 ± 1.32	0.60
5×20	221 ±50	0 ±32	0.00 ±0.63	0.70	2 ±34	0.03 ±0.67	0.66	6 ±33	0.11 ±0.64	0.59
CMJ height (cm)										
10×40	35.9 ±7.1	-1.1 ±4.5	-0.15 ±0.63	0.55	-1.4 ±4.5	-0.20 ±0.63	0.50	0.0 ±4.4	-0.01 ±0.61	0.70
5×40	35.7 ±7.7	0.4 ±4.8	0.05 ±0.63	0.65	-0.3 ±4.8	-0.04 ±0.64	0.66	0.0 ±4.7	0.00 ±0.62	0.70
10×20	35.9 ±7.4	-0.2 ±4.7	-0.03 ±0.64	0.67	-0.7 ±4.7	-0.09 ±0.64	0.61	0.4 ±4.8	0.05 ±0.65	0.65
5×20	36.1 ±7.7	-0.6 ±4.9	-0.08 ±0.63	0.62	-1.3 ±5.0	-0.17 ±0.64	0.53	0.3 ±4.9	0.04 ±0.63	0.66
CMJ mean power (W.kg)										
10×40	25.8 ±4.3	-0.6 ±2.8	-0.13 ±0.63	0.57	-0.9 ±2.8	-0.20 ±0.63	0.50	0.4 ±2.8	0.08 ±0.63	0.62
5×40	26.0 ±4.2	0.5 ±2.7	0.12 ±0.63	0.58	-0.4 ±2.7	-0.10 ±0.63	0.61	-0.3 ±2.7	-0.06 ±0.63	0.64
10×20	25.8 ±4.6	0.6 ±2.9	0.12 ±0.63	0.58	-0.1 ±2.9	-0.03 ±0.64	0.67	0.2 ±3.0	0.05 ±0.65	0.65
5×20	25.6 ±4.6	0.4 ±3.0	0.09 ±0.63	0.61	-0.6 ±2.9	-0.12 ±0.88	0.59	0.6 ±4.2	0.12 ±0.88	0.56

Continued next page

		Pre-post			Pre-24 hr			Pre-48 hr		
	Pre (mean ±SD)	**Change ±90% CI**	**Standardised difference ±90 CI**	p_{MET}	**Change ±90% CI**	**Standardised difference ±90 CI**	p_{MET}	**Change ±90% CI**	**Standardised difference ±90 CI**	p_{MET}
CMJ FT:CT										
10×40	0.58 ±0.13	0.00 ±0.09	-0.02 ±0.66	0.67	-0.01 ±0.08	-0.08 ±0.63	0.63	0.03 ±0.08	0.19 ±0.63	0.51
5×40	0.59 ±0.10	0.03 ±0.07	0.29 ±0.64	0.40	-0.01 ±0.08	-0.09 ±0.63	0.62	0.01 ±0.07	0.11 ±0.62	0.60
10×20	0.58 ±0.14	0.04 ±0.09	0.27 ±0.64	0.43	0.00 ±0.08	0.03 ±0.60	0.68	0.01 ±0.09	0.06 ±0.62	0.64
5×20	0.57 ±0.15	0.03 ±0.08	0.22 ±0.63	0.48	0.00 ±0.08	-0.03 ±0.63	0.67	0.01 ±0.09	0.10 ±0.64	0.61
CMJ EccDur										
10×40	667 ±199	-15 ±99	-0.10 ±0.63	0.61	-11 ±100	-0.07 ±0.64	0.63	55 ±99	-0.35 ±0.63	0.35
5×40	642 ±120	-36 ±111	-0.20 ±0.63	0.44	7 ±112	0.04 ±0.63	0.61	-8 ±113	-0.04 ±0.64	0.61
10×20	660 ±164	-70 ±102	-0.53 ±0.78	0.25	-24 ±102	-0.18 ±0.78	0.53	-20 ±104	-0.15 ±0.79	0.55
5×20	672 ±196	-47 ±90	-0.34 ±0.64	0.20	-32 ±92	-0.23 ±0.65	0.29	29 ±90	-0.20 ±0.64	0.31
Leg stiffness										
10×40	43.9 ±7.4	-2.0 ±5.1	-0.25 ±0.63	0.45	-2.0 ±5.1	-0.25 ±0.63	0.45	-0.3 ±5.1	-0.04 ±0.63	0.67
5×40	43.0 ±8.2	-1.2 ±5.1	-0.15 ±0.63	0.55	-0.8 ±5.1	-0.09 ±0.63	0.61	0.2 ±5.1	0.02 ±0.63	0.68
10×20	42.9 ±8.8	-0.3 ±5.3	-0.04 ±0.63	0.66	1.6 ±5.3	0.20 ±0.63	0.50	0.7 ±5.4	0.09 ±0.64	0.62
5×20	42.6 ±8.5	0.1 ±5.6	0.01 ±0.62	0.69	0.5 ±5.8	0.05 ±0.64	0.65	1.5 ±5.7	0.16 ±0.63	0.54

Abbreviations: PF90° = peak force at 90° of knee flexion; PF30° = peak force at 30° of knee flexion; CMJ = countermovement jump; FT:CT = flight-time to contraction-time ratio; EccDur = eccentric duration; SD = standard deviation; CI = confidence interval; hr = hour.

APPENDIX 42. Author contributions.

Study 1: Thurlow, F., Weakley, J., Townshend, A. D., Timmins, R. G., Morrison, M., & McLaren, S. J. (2023). The Acute Demands of Repeated-Sprint Training on Physiological, Neuromuscular, Perceptual and Performance Outcomes in Team Sport Athletes: A Systematic Review and Meta-analysis. Sports Medicine, 1-32.

I acknowledge that my contribution to the above paper is 60% percent

Fraser Thurlow __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 5% percent

Jonathon Weakley __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 5% percent

Andrew Townshend __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 3% percent

Ryan Timmins __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 2% percent

Matthew Morrison __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 25% percent

Shaun McLaren __________________ 01/01/2024

Study 2: Thurlow, F., Huynh, M., Townshend, A., McLaren, S. J., James, L. P., Taylor, J. M., ... & Weakley, J. (2023). The Effects of Repeated-Sprint Training on Physical Fitness and Physiological Adaptation in Athletes: A Systematic Review and Meta-Analysis. *Sports Medicine*, 1-22.

I acknowledge that my contribution to the above paper is 60% percent

Fraser Thurlow __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 15% percent

Minh Huynh __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 5% percent

Andrew Townshend __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 5% percent

Shaun McLaren __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 2% percent

Lachlan James __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 3% percent

Jonathon Taylor __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 3% percent

Matthew Weston __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 7% percent

Jonathon Weakley ____________________ 01/01/2024

Study 3: The Effects of Session Volume on Acute Demands During Repeated-Sprint Training, and the Recovery Time-course of Neuromuscular Performance

I acknowledge that my contribution to the above paper is 70% percent

Fraser Thurlow __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 10% percent

Shaun McLaren __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 5% percent

Andrew Townshend __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 2% percent

Matthew Morrison __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 3% percent

Nicholas Cowley __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 10% percent

Jonathon Weakley __________________ 01/01/2024

Study 4: The Effects of Repeated Sprint vs Short Interval Training on Hamstring Muscle Architecture and Physical Fitness in Rugby League Players

I acknowledge that my contribution to the above paper is 65% percent

Fraser Thurlow __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 10% percent

Ryan Timmins __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 10% percent

Shaun McLaren __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 5% percent

Bradley Lawton __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 2% percent

Nicholas Cowley __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 3% percent

Andrew Townshend __________________ 01/01/2024

I acknowledge that my contribution to the above paper is 5% percent

Jonathon Weakley __________________ 01/01/2024

APPENDIX 43. Information letters and consent forms for Studies 3 and 4.

PARTICIPANT INFORMATION LETTER

PROJECT TITLE: THE ACUTE RESPONSES AND RECOVERY TIME-COURSE TO REPEATED-SPRINT TRAINING
APPLICATION NUMBER: 2222
PRINCIPAL INVESTIGATOR: Dr Jonathon Weakley
CO-INVESTIGATOR: Dr Andrew Townshend
STUDENT RESEARCHER: Mr Fraser Thurlow
STUDENT'S DEGREE: PhD

Dear Participant,

You are invited to participate in the research project described below, which is beginning in March 2022.

What is the project about?

Repeated-sprint training is a highly effective training method used to develop fitness and athletic performance. The aim of our research is to determine the acute responses and the recovery time-course to RST. This project will be split into two parts: Part 1 (beginning March) will investigate the effect of session volume and Part 2 (beginning around July) will investigate the effects of rest duration. You are welcome to participate in one or/ both parts of this project.

Who is undertaking the project?

This project is being conducted by Fraser Thurlow and will form part of his PhD thesis at the Australian Catholic University under the supervision of Dr Jonathon Weakley and Dr Andrew Townshend. Jonathon has a BAppSci in Sports Nutrition, a MSc in Nutrition, GCert in Strength and Conditioning, and a PhD in Strength and Conditioning. He has over 50 peer-reviewed publications on this topic. Andrew has a BAppSci and a PhD in Exercise Science with numerous publications on running performance. Fraser has a BEXSc (Hon) and Msc in Strength and conditioning. Fraser is also a strength and conditioning coach at Southport Sharks in the Victorian Football League.

Are there any risks associated with participating in this project?

While the risks in this project are low, as this project involves exercise it is possible injury or cardiopulmonary events can occur. To mitigate this risk, you are required to be well-trained (exercising at a moderate to high-intensity at least 3x per week), be between the ages of 18-35, and free of any current injuries or health concerns that would prevent you from sprinting with maximal effort. You will be taken through a thorough warm up prior to completing the procedures. Person to person contact will be minimal, testers will be wearing face masks at all times and ACU COVID guidelines will be thoroughly followed to minimise the risk of disease transmission.

What will I be asked to do?

For each part of this project, across a four-week period, you will be required to attend 12 exercise sessions and one familiarisation session. The fimilirisation session will be held one week before the commencement of the training sessions and will involve a maximal running test on a treadmill to determine VO_2max, as well as a full-explanation of the up-coming sessions. On day one of each week, you will perform a repeated-sprint training session with a series of tests performed immediately before and following the training session. In the following two days (after 24 and 48 hours) you will return and repeat the tests to determine how well you have recovered from the repeated-sprint training session. This process will be repeated over four consecutive weeks with four different repeated-sprint training sessions. Each training session will consist of between 10-20 repetitions of 20–40 m sprints interspersed with brief recovery times of between 15–60 s. The main testing measures are jumping performance, short sprint performance, maximal hamstring strength and oxygen uptake. All sessions will take place at ACU, Brisbane campus. You will be made aware of the exact dates, location and times of these sessions once you have provided your interest.

In the day preceding each repeated-sprint training session, as well as between each session and the follow-up testing sessions, you will be instructed to refrain from performing intense exercise involving the leg muscles (e.g., running, sport training, resistance training) and consuming alcohol. Therefore, please be aware that this will give you four full days per week (Thursday to Sunday) and Wednesday evenings to engage in exercise of your own choice (e.g., other training commitments). You will be asked to refrain from consuming caffeine in the six hours before testing, abstain from the consumption of food and beverage other than water within two hours of each session and to otherwise maintain your usual nutritional habits during the intervention period (four weeks).

How much time will the project take?
For each part of this project, you will be required to attend 12 exercise sessions over a four-week period and one familiarisation session. Each session will take approximately 60 minutes.

What are the benefits of the research project?
You will gain a great understanding of your sprint performance and your ability to recover from high-intensity training, as well as your jumping ability, hamstring strength and aerobic fitness. If you complete all 13 sessions will go in the draw to win a cash prize of $750, which will be separately offered for each part of the project (i.e., one prize for part 1 and one prize for part 2). The wider community will gain a greater understanding of repeated-sprint training, which will help practitioners prescribe exercise.

Can I withdraw from the study?
Participation in this study is completely voluntary. You are not under any obligation to participate. If you agree to participate, you can withdraw from the study at any time without adverse consequences, except you will not be eligible to win the cash reward. If you chose to withdraw during the study, data collected during sessions up until that point in time may be kept and utilised for research purposes.

Will anyone else know the results of the project?
The results of this study will be published within a peer-reviewed sport science journal or may be provided to other researchers in a form that does not identify you in any way. All data will be anonymised immediately during the project. In accordance with ACU’s data retention policy, all data will be destroyed after 15 years.

Will I be able to find out the results of the project?
When you exercise, we will inform you of your running times and discuss your performance with you at the end of each session. Furthermore, once the project is published, you will be able to read the final manuscript.

Who do I contact if I have questions about the project?

Please feel free to contact Fraser Thurlow at fraser.thurlow@myacu.edu.au or Jonathon Weakley at jonathon.weakley@acu.edu.au.

What if I have a complaint or any concerns?

The study has been reviewed by the Human Research Ethics Committee at Australian Catholic University (review number 2222). If you have any complaints or concerns about the conduct of the project, you may write to the Manager of the Human Research Ethics and Integrity Committee care of the Office of the Deputy Vice Chancellor (Research).

Manager, Ethics and Integrity
c/o Office of the Deputy Vice Chancellor (Research)
Australian Catholic University
North Sydney Campus
PO Box 968
NORTH SYDNEY, NSW 2059
Ph.: 02 9739 2519
Fax: 02 9739 2870
Email: resethics.manager@acu.edu.au

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

I want to participate! How do I sign up?

If you are interested in participating, please contact Fraser Thurlow at fraser.thurlow@myacu.edu.au or Dr Jonathon Weakley at jonathon.weakley@acu.edu.au. We will then provide you with further information regarding the exact date and time of the first session that you will be required. At the beginning of this session, we will get you to sign a consent form.

Yours sincerely,

Fraser Thurlow

CONSENT FORM

THE EFFECT OF SESSION VOLUME AND REST DURATION ON ACUTE RESPONSES AND THE RECOVERY TIME-COURSE TO REPEATED-SPRINT TRAINING

ACU Ethics Approval 2222

PRINCIPAL INVESTIGATORS: Dr Jonathon Weakley, Dr Andrew Townshend
STUDENT INVESTIGATOR: Mr Fraser Thurlow

I .... *(the participant)* have read (*or, where appropriate, have had read to me)* and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. Please acknowledge the following conditions by marking an '**X**' within the corresponding box:

☐ I am between the ages of 18-35 years and am a well-trained athlete with prior experience performing repeated-sprint efforts.

☐ I do not have any known medical condition or injury that may impact my ability to participate in this project, including but not limited to diabetes, cardiovascular or respiratory disease or musculoskeletal injuries.

☐ If I chose to participate in Part 1 of this project, I understand that I will be required to attend 17 sessions over a four-week period and that each session will last approximately 60-90 mins.

☐ If I chose to participate in Part 2 of this project, I understand that I will be required to attend 17 sessions over a four-week period and that each session will last approximately 60-90 mins.

☐ I understand that this project includes repeated-sprint training and that there is a risk for musculoskeletal injury and/or cardiovascular events, albeit slight.

☐ I understand that I can withdraw my consent at any time and under any circumstances.

☐ I understand that if I chose to withdraw during the project, data collected during sessions up until that point in time may be kept and utilised for research purposes.

☐ I understand that If I withdraw during the project, I will not be in the draw to win the cash reward.

☐ I agree that research data collected for the project may be published or may be provided to other researchers in a form that does not identify the participants in any way.

NAME OF PARTICIPANT: ....

SIGNATURE: .... DATE: ....

SIGNATURE OF PRINCIPAL INVESTIGATOR (or SUPERVISOR): ....
DATE: ....

(and, if applicable)
SIGNATURE OF STUDENT RESEARCHER: .... DATE: ....

PARTICIPANT INFORMATION LETTER

PROJECT TITLE: THE EFFECTS OF REPEATED-SPRINT VS SHORT INTERVAL TRAINING
APPLICATION NUMBER: 2773
PRINCIPAL INVESTIGATOR: Dr Jonathon Weakley
CO-INVESTIGATOR: Dr Andrew Townshend, Dr Ryan Timmins
STUDENT INVESTIGATOR: Mr Fraser Thurlow
STUDENT'S DEGREE: PhD

Dear Participant,

You are invited to participate in the research project described below, which is beginning in January 2023.

What is the project about?

High-intensity interval training is an effective training method used to develop fitness and athletic performance. However, there are several different types of interval training which require further investigation and comparison. Additionally, knowledge is required regarding the effects of high-intensity interval training on physiological (e.g., aerobic fitness), neuromuscular (e.g., speed and power) and morphological (e.g., muscle size and strength) adaptations. The aim of our research is to determine the physical adaptations to repeated-sprint training and short interval training.

Who is undertaking the project?

This project is being conducted by Fraser Thurlow and will form part of his PhD thesis at the Australian Catholic University under the supervision of Dr Jonathon Weakley and Dr Andrew Townshend. Jonathon has a BAppSci in Sports Nutrition, a MSc in Nutrition, GCert in Strength and Conditioning, and a PhD in Strength and Conditioning. He has over 50 peer-reviewed publications on this topic. Andrew has a BAppSci and a PhD in Exercise Science with numerous publications on running performance. Fraser has a BEXSc (Hon) and Msc in Strength and conditioning. Fraser is also a strength and conditioning coach at Southport Sharks in the Victorian Football League. Additionally, Dr Ryan Timmins will be assisting with this project. Dr Timmins is a researcher at ACU having completed his PhD in 2015 focusing on hamstring muscle architecture and its role in injury and response to training interventions.

Are there any risks associated with participating in this project?

While the risks in this project are low, as this project involves exercise it is possible injury or cardiopulmonary events can occur. To mitigate this risk, you are required to be well-trained (exercising at a moderate to high-intensity at least 3x per week), and free of any current injuries or health concerns that would prevent you from performing the training with maximal effort. You will be taken through a thorough warm up prior to completing any training or testing Person to person contact will be minimal and ACU COVID guidelines will be thoroughly followed to minimise the risk of any disease transmission.

What will I be asked to do?

To begin, you will be required to attend two testing sessions to assess your initial fitness. Tests will involve short sprints, jumping, the yo-yo intermittent recovery test level 2, a VO_2max test on a treadmill, the Nordic hamstring strength test and ultrasonography of your lower limb muscles. Following baseline testing, you will be randomly grouped into a repeated-sprint training or short interval training group, where you will perform 8–20 mins of this training, twice per week for 8 weeks, within your normal sports training sessions. The repeated-sprint training will involve 2–3 sets of 6–10 repetitions of 20–40m maximal sprints. The short intervals will involve 2–3 sets of 6–10 repetitions of 15 second sub-maximal runs. During this period, you will perform all other training at your sports club as per normal. Following the training period, you will repeat the same baseline fitness tests as described above. All sessions will take place at your sports club. You will be made aware of the exact dates, location and times of these sessions once you have confirmed your participation.

In the day preceding each testing session, you will be instructed to refrain from performing strenuous exercise involving the leg muscles (e.g., running, sport training, resistance training) and consuming alcohol. You will be also asked to refrain from consuming caffeine in the six hours before testing, abstain from the consumption of food and beverage other than water within two hours of each session and to otherwise maintain your usual nutritional habits during the intervention period (10 weeks).

How much time will the project take?
For each part of this project, you will be required to attend 16 exercise sessions over an eight-week period, which are included within your normal sports training sessions, as well four testing sessions. Each testing session will take approximately 60 minutes.

What are the benefits of the research project?
You and your coaches will gain a great understanding of your fitness and athletic performance. The results will be used to improve your training practices. The wider community will gain a greater understanding of high-intensity interval training, which will help practitioners prescribe exercise.

Can I withdraw from the study?
Participation in this study is completely voluntary. You are not under any obligation to participate. If you agree to participate, you can withdraw from the study at any time without adverse consequences. If you chose to withdraw during the study, data collected during sessions up until that point in time may be kept and utilised for research purposes.

Will anyone else know the results of the project?
The results of this study will be published within a peer-reviewed sport science journal or may be provided to other researchers in a form that does not identify you in any way. The results will be provided to your sports coaches. In accordance with ACU's data retention policy, all data will be destroyed after 15 years.

Will I be able to find out the results of the project?
We will provide you with a detailed written report describing your results across all areas. Once the project is published, you will be able to read the final manuscript.

Who do I contact if I have questions about the project?
Please feel free to contact Fraser Thurlow at fraser.thurlow@myacu.edu.au or Jonathon Weakley at jonathon.weakley@acu.edu.au.

What if I have a complaint or any concerns?
The study has been reviewed by the Human Research Ethics Committee at Australian Catholic University (review number 2222). If you have any complaints or concerns about the conduct of the project, you may write to the Manager of the Human Research Ethics and Integrity Committee care of the Office of the Deputy Vice Chancellor (Research).

Manager, Ethics and Integrity
c/o Office of the Deputy Vice Chancellor (Research)
Australian Catholic University
North Sydney Campus
PO Box 968
NORTH SYDNEY, NSW 2059
Ph.: 02 9739 2519
Fax: 02 9739 2870
Email: resethics.manager@acu.edu.au

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

I want to participate! How do I sign up?

If you are interested in participating, please contact Fraser Thurlow at fraser.thurlow@myacu.edu.au. We will then provide you with further information regarding the exact date and time of the first session that you will be required. At the beginning of this session, we will get you to sign a consent form.

Yours sincerely,

Fraser Thurlow

CONSENT FORM

THE EFFECTS OF REPEATED-SPRINT TRAINING VS SHORT INTERVAL TRAINING

ACU Ethics Approval 2773

PRINCIPAL INVESTIGATOR: Dr Jonathon Weakley
CO-INVESTIGATOR: Dr Andrew Townshend, Dr Ryan Timmins
STUDENT INVESTIGATOR: Mr Fraser Thurlow

I .... *(the participant)* have read (*or, where appropriate, have had read to me)* and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. Please acknowledge the following conditions by marking an '**X**' within the corresponding box:

☐ I am a well-trained athlete participating in vigorous activity at least three times per week

☐ I do not have any known medical condition or injury that may impact my ability to participate in this project, including but not limited to diabetes, cardiovascular or respiratory disease or musculoskeletal injuries.

☐ If I chose to participate in this project, I understand that I will be required to attend 12 exercise sessions over an 8-week period, as part of my usual team sports training.

☐ If I chose to participate in this project, I understand that I will be required to attend two testing sessions and that each session will take approximately 60 mins.

☐ I understand that this project includes sprint and high-intensity interval training and that there is a risk of musculoskeletal injury and/or cardiovascular events, albeit slight.

☐ I understand that my results will be shared with coaches at my sports club.

☐ I understand that I can withdraw my consent at any time and under any circumstances, without any adverse consequences.

☐ I understand that if I chose to withdraw during the project, data collected during sessions up until that point in time may be kept and utilised for research purposes

☐ I agree that research data collected for the project may be published or may be provided to other researchers in a form that does not identify the participants in any way.

NAME OF PARTICIPANT: ....

SIGNATURE: .... DATE: ....

SIGNATURE OF PRINCIPAL INVESTIGATOR (or SUPERVISOR):................................DATE:...............................

SIGNATURE OF STUDENT INVESTIGATOR:... DATE: ....