COMPARISON OF RESISTANCE TRAINING PROGRESSION MODELS TO DEVELOP MUSCULAR ENDURANCE IN YOUTH ATHLETES: APPLICATIONS FOR ATHLETE MONITORING

SHANKARALINGAM RAMALINGAM

A thesis submitted to

Auckland University of Technology

In fulfilment of the degree

DOCTOR OF PHILOSOPHY

2019

Primary Supervisor: Professor Michael McGuigan

Associate Supervisors: Dr Deborah Dulson and Dr Yeo Wee Kian

Sports Performance Research Institute New Zealand

Auckland University of Technology, Auckland, New Zealand

Abstract

Previous research has documented positive effects of periodised muscular endurance resistance training in untrained men and women. Therefore, the overarching objective of this thesis was to compare the efficacy of two resistance training progression models [linear periodisation (LP) vs. undulating periodisation (UP)], and to elucidate the best method to vary the exercise stimulus to develop muscular endurance in trained youth athletes. With respect to the overarching objective of this thesis, a series of studies were conducted.

The first aim was to identify the reliability and sensitivity of neuromuscular function variables in trained youth athletes. Second, to investigate acute neuromuscular function, endocrine and perceptual wellbeing responses following two different muscular endurance resistance training sessions [3 sets of 25 repetition maximum (RM) and 3 sets of 15RM]. Lastly, to investigate the effects of two distinct resistance training models (LP vs. UP) on selected performance, physiological and psychological variables in trained youth team sports athletes. Also, the different physiological, neuromuscular, perceptual wellbeing responses within this process were described and implications for athlete monitoring discussed.

It was found that the reliability and sensitivity of neuromuscular function variables was unique to the population in question. Specifically, only countermovement jump mean force [CMJMF; smallest worthwhile change (SWC) = 2.7%, coefficient of variation (CV) = 1.0%)], countermovement jump mean power (CMJMP; SWC = 3.2%, CV = 2.7%), countermovement jump peak power (CMJPP; SWC = 3.4%, CV = 3.0%) and plyometric push up mean force (PPMF; SWC = 2.9%, CV = 2.2%) displayed acceptable reliability (CV < 5%) and sensitivity in field hockey youth athletes.

Next, neuromuscular function, endocrine and perceptual wellbeing measures, obtained from trained youth participants, maintained similar acute biological responses irrespective of muscular endurance resistance training protocols. Force and power measures (CMJMF, CMJMP, CMJPP and PPMF) improved ($p \leq 0.05$) 48 hours following both muscular endurance resistance training programmes. At 72 hours, testosterone: cortisol ratio (T:C ratio) showed a moderate increase [effect size (ES) = 0.72] following the 15RM protocol whereas a small decrease (ES = 0.41) was observed after the 25RM session. Overall perceptual wellbeing, fatigue and soreness scores reflected changes in neuromuscular function, while stress, sleep and mood did not show any differences.

Finally, muscular endurance tests demonstrated that UP (back squat ES = 1.62; bench press ES = 1.77) was more efficacious than LP (back squat ES = 0.69; bench press ES = 1.72). Resting salivary testosterone concentration increased in the UP (31.47%) compared to LP (- 8.73%) group, whereas salivary cortisol concentration and T:C ratio remained unchanged. Session rating of perceived exertion (session RPE), mood and stress scores were frequently higher during training phase II and III compared to phase I. No changes were detected in neuromuscular function.

Overall, this thesis offered several practical applications from the findings. First, the reliability and sensitivity of neuromuscular function variables were population specific. As such, practitioners are encouraged to establish the reliability and determine the neuromuscular function variable/s within the group to be trained. Second, as fatigue is multifaceted, practitioners should not rely on a single monitoring approach and incorporate both physiological and psychological aspects to monitor resistance training. Lastly, practitioners working with team sports athletes and intending to develop muscular endurance, can employ UP, performed in conjunction with sport specific training. Most importantly, it is highly advantageous to integrate a suitable monitoring measure, to direct appropriate sequencing of training loads, to result in optimal athletic performance.

Acknowledgements

Proverbs 3:5
“Trust in the LORD with all your heart, and lean not on your own understanding”;

Proverbs 3:6
“In all your ways acknowledge Him, and He shall direct your paths.”

Firstly, I would like to express my sincere gratitude to Professor Michael McGuigan for the continuous support during my PhD journey, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my PhD.

Besides, I would like to thank the rest of my thesis committee: Dr Deborah Dulson and Dr Yeo Wee Kian, for their insightful comments and encouragement.

My sincere thanks also go to the Malaysian Ministry of Education for providing scholarship and National Sports Institute for funding my research.

I thank my fellow colleagues from SPRINZ for the stimulating discussions and for all the fun we had. Specially, many thanks go to Francis, Gustavo, Nico, Tom and Sarah. I am much indebted to them for their valuable advice during discussion, using their precious time to read drafts and gave their critical comments about it. I am grateful in every possible way and hope we can continue working together in the future.

Jad, Prakash, Jusvinder, Lokman, Chua and Moh who were ‘there’ and helping in multitude of ways. Without their precious support it would not be possible to conduct this research.

Last but not the least, I would like to thank my family: my parents, Lussi and to my brother and sister for supporting me spiritually throughout writing this thesis and my life in general.

Table of Contents

List of Figures

List of Tables

List of Common Abbreviations

AMPK	AMP-activated protein kinase
AU	Arbitrary unit
Borg CR-10	Borg 10-point category-ratio scale
BP	Block periodisation
CMJ	Countermovement jump
CMJMF	Countermovement jump mean force
CMJMP	Countermovement jump mean power
CMJPP	Countermovement jump peak power
CV	Coefficient of variation
DALDA	Daily analysis of life demands for athletes
EMG	Electromyography
ES	Effect size
GAS	General adaptation syndrome
ICC	Intraclass correlation coefficient
LP	Linear periodisation
LSD	Long slow distance
MBT	Medicine ball throw

mTOR	Mechanistic target of rapamycin
MVC	Maximum voluntary contraction
PP	Plyometric push up
PPMF	Plyometric push up mean force
POMS	Profile of mood states
PRE	Progressive resistance exercise
RESTQ-Sport	Recovery-stress questionnaire for athletes
RLP	Reverse linear periodisation
RM	Repetition maximum
RPE	Rating of perceived exertion
SLJ	Standing long jump
SWC	Smallest worthwhile change
T:C ratio	Testosterone: cortisol ratio
TQR	Total quality recovery
UP	Undulating periodisation

Attestation of Authorship

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

____

Shankaralingam Ramalingam

Ethics Approval

Ethical approval for the thesis research was granted by the Auckland University of Technology Ethics Committee (AUTEC) on 26 February 2016 for three years:

- AUTEC: 16/13 Comparison of resistance training progression models to develop muscular endurance in youth athletes: Applications for athlete monitoring.

Chapter 1 Introduction

1.1 Rationale of the thesis

Resistance training is fundamental for developing healthy, capable and resilient young athletes (Bergeron et al., 2015). In particular, resistance training plays a vital role in developing muscular strength (Behringer, vom Heede, Yue, & Mester, 2010; Sander, Keiner, Wirth, & Schmidtbleicher, 2013), power (Harries, Lubans, & Callister, 2012; Lesinski, Prieske, & Granacher, 2016), running speed (Mikkola, Rusko, Nummela, Pollari, & Häkkinen, 2007), kicking velocity (Wong, Chamari, & Wisløff, 2010), endurance (Granacher et al., 2016) and general motor performance (Behringer, Heede, Matthews, & Mester, 2011). Also, these improvements have the potential to make youth athletes more resistant to sports related injuries (Faigenbaum, Lloyd, MacDonald, & Myer, 2015; Faigenbaum & Myer, 2010). Importantly, to optimise training adaptations, resistance training programmes are typically structured into different training phases, known as periodisation (Harries, Lubans, Buxton, MacDougall, & Callister, 2018).

Periodisation is a fundamental conceptual framework to prepare athletes and improve performance (DeWeese, Hornsby, Stone, & Stone, 2015a; Issurin, 2016). A key aspect of periodisation is the division of an annual training plan into smaller training phases to ensure the training is more manageable (Bompa, 1990), and creating a dynamic balance between training stimuli and recovery. Consequently, periodisation minimises the potential for overtraining, reduces injury risk and helps to avoid plateaus in performance (Cunanan et al., 2018; Harries, Lubans, & Callister, 2015b; Suchomel, Nimphius, Bellon, & Stone, 2018). A considerable amount of literature has been published on periodisation (Afonso, Nikolaidis, Sousa, & Mesquita, 2017; Conlon et al., 2016; De Souza et al., 2018; Harries et al., 2018; Issurin, 2010; Kiely, 2018). Studies have generally suggested that periodised training effectively improves athletic performance, in contrast to non-periodised training (Fleck, 1999; Williams, Tolusso, Fedewa, & Esco, 2017).

Hartmann et al. (2015) stated that the periodisation models most commonly referred to in the literature are linear periodisation (LP) and undulating periodisation (UP). LP is characterised by initial high training volume and low intensity with progressive increases in training intensity and decreases in volume over time (Rhea, Ball, Phillips, & Burkett, 2002). On the other hand, reverse linear periodisation (RLP) uses a reverse order approach (Prestes, De Lima, Frollini, Donatto, & Conte, 2009a). Instead of gradually lowering training volume and increasing intensity, RLP gradually increases volume and decreases intensity (Rhea et al., 2003). UP is characterised by more regular daily, weekly or bi-weekly variation of intensity and volume (Hoffman, Wendell, Cooper, & Kang, 2003). Studies mainly employ LP and UP in resistance training to improve muscular hypertrophy, strength and/or power (Harries, Lubans, & Callister, 2015a; Moraes, Fleck, Dias, & Simao, 2013; Simao et al., 2012) in untrained adult men and women (Fleck, 1999). Previous research has established that resistance training enhances muscle coordination and motor unit recruitment patterns (Guglielmo, Greco, & Denadai, 2009; Kaikkonen, Yrjämä, Siljander, Byman, & Laukkanen, 2000). In addition, muscular endurance training increases muscle buffer capacity and/or decreases by-product accumulation of anaerobic metabolism, therefore improving locomotor efficiency (Denadai & Greco, 2018; Hoff, Gran, & Helgerud, 2002; Johnston, Quinn, Kertzer, & Vroman, 1997)**.** Despite the importance of periodised resistance training, there is limited information (Moraes et al., 2013) regarding how responses develop muscular endurance, specifically in athlete populations.

To date, one investigation has reported that RLP improves muscular endurance after 15 weeks' training in untrained adult men and women (Rhea et al., 2003). In contrast, another study found that daily UP resulted in greater increases in muscular endurance than LP in untrained women following 12 weeks training (de Lima et al., 2012). However, there is uncertainty regarding the efficacy of LP and UP to develop muscular endurance in youth athletes. Moreover, previous investigations have provided limited details on how to define the optimal periodisation strategy (de Lima et al., 2012; Rhea et al., 2003). Certainly, training monitoring, such as physiological, biochemical and psychological approaches, is important to understand the implications of prolonged training. It is also important to note that excessive accrued fatigue without adequate recovery likely inhibits biological adaptations, which could, in turn, elevate injury risk, illness and overtraining potential (Foster, 1998; Fry & Kraemer, 1997; McGuigan & Foster, 2004). Thus, when determining the optimal periodisation strategy for athlete programming, incorporating a monitoring element is essential.

In addition, there is a paucity of experimental investigation that explores neuromuscular function, endocrine and perceptual wellness responses following a single muscular endurance resistance training session in youth athletes. Gaining insight into the responses after a muscular endurance resistance training in this context may better inform training design to optimise adaptations. Importantly, the magnitude and nature of training stimulus could determine the recovery time required, thus affecting loads of concurrent training modalities such as physical or technical indices (Weakley et al., 2017b). Information regarding the neuromuscular function, endocrine and perceptual wellness after a muscular endurance training session could assist practitioners to make informed decisions in the design of subsequent training sessions to minimise the detrimental effects that may occur because of the accumulated fatigue from various practice sessions.

1.2 Purpose of the research

Training variation is acknowledged as a key aspect in programme design, both for performance and health purposes (Gamble, 2006). Therefore, to systematically vary training, resistance training parameters are managed within a scientific concept of training theory known as periodisation (Issurin, 2008; Naclerio et al., 2013). Numerous terms are used to describe resistance training periodisation models: from traditional, classical and stepwise for LP (Baker, Wilson, & Carlyon, 1994; Rhea et al., 2002) to non-linear and non-traditional for UP (Apel, Lacey, & Kell, 2011; Rhea et al., 2003; Simao et al., 2012). While a variety of descriptors have been suggested, in this thesis the two training progression models will be described as LP and UP.

The primary objective of this thesis was to compare the effects of two training progression models (LP vs. UP) to develop muscular endurance on selected performance, physiological and psychological variables in youth athletes. The secondary objective was to describe the different physiological, neuromuscular and perceptual responses within this process to the training stimulus. This latter information is essential to understanding the internal responses to the two different resistance training models. The findings of the thesis could enable strength and conditioning coaches to monitor and assess the efficiency of a training programme to optimise the stimulus-adaptation process. To this end, four investigations were undertaken to specifically:

1. Investigate the different resistance training progression models and selected monitoring measures (Literature review);

2. Determine the between-day repeatability and sensitivity of commonly utilised neuromuscular function variables in trained youth athletes (Study 1);
3. Examine the acute effects of two distinct muscular endurance resistance training sessions: [3 sets of 25 repetition maximum (RM) and 3 sets of 15RM] on neuromuscular function, endocrine and perceptual wellbeing measures in youth athletes (Study 2);
4. Examine the effects of two different resistance training models (LP vs. UP) to develop muscular endurance on selected performance, physiological and psychological variables in trained youth team-sport athletes (Study 3).

1.3 Significance of the thesis

Despite its pivotal role in coaching practice and previous research with some athlete populations, there were very few published scientific studies that have explored the efficacy of periodisation models to develop muscular endurance in youth athletes. Therefore, this thesis provided insights into the optimal periodisation strategy to improve muscular endurance in trained youth who concurrently perform sports specific training. Additionally, the monitoring approaches incorporated within this thesis highlight the significance of identifying the fatigue/recovery status to facilitate the appropriate sequencing of training loads. As fatigue is multifaceted, it is difficult to comprehensively assess fatigue with a single measure. The physiological and psychological measures applied in this thesis may inform strength and conditioning practitioners regarding the optimal monitoring approach in youth resistance training. While adolescence is a period of increasing competence and resilience, it is also a time of risk and vulnerability (Gunnar, Wewerka, Frenn, Long, & Griggs, 2009). Therefore, youth athletes are at an increased risk of developing emotional and behavioural disorders. An optimal periodisation and monitoring strategy can help to minimise non-functional overreaching and overtraining and thus reduce the possible loss of talent due to early retirement from sport.

1.4 Structure of the thesis

The overall structure of this thesis consists of six chapters (Figure 1.1). Chapter 2 is a comprehensive literature review exploring different resistance training progression models and the selected aspects of resistance training monitoring. The first study (Chapter 3), determined the test-retest reliability and sensitivity of selected neuromuscular function measures in male field hockey youth athletes, and, identified the suitable measures to monitor fatigue following muscular endurance training. The second study (Chapter 4), a randomised cross-over study, examined neuromuscular function, endocrine and perceptual wellness responses to different muscular endurance resistance training sessions in youth athletes. The third study (Chapter 5) examined the effects of a 12-week resistance training progression model to develop muscular endurance on selected performance, physiological and psychological variables in youth team-sport athletes. Chapter 6 provides a thesis summary, practical applications and direction for future research.

Comparison of resistance training progression models to develop muscular endurance in youth athletes: Applications for athlete monitoring

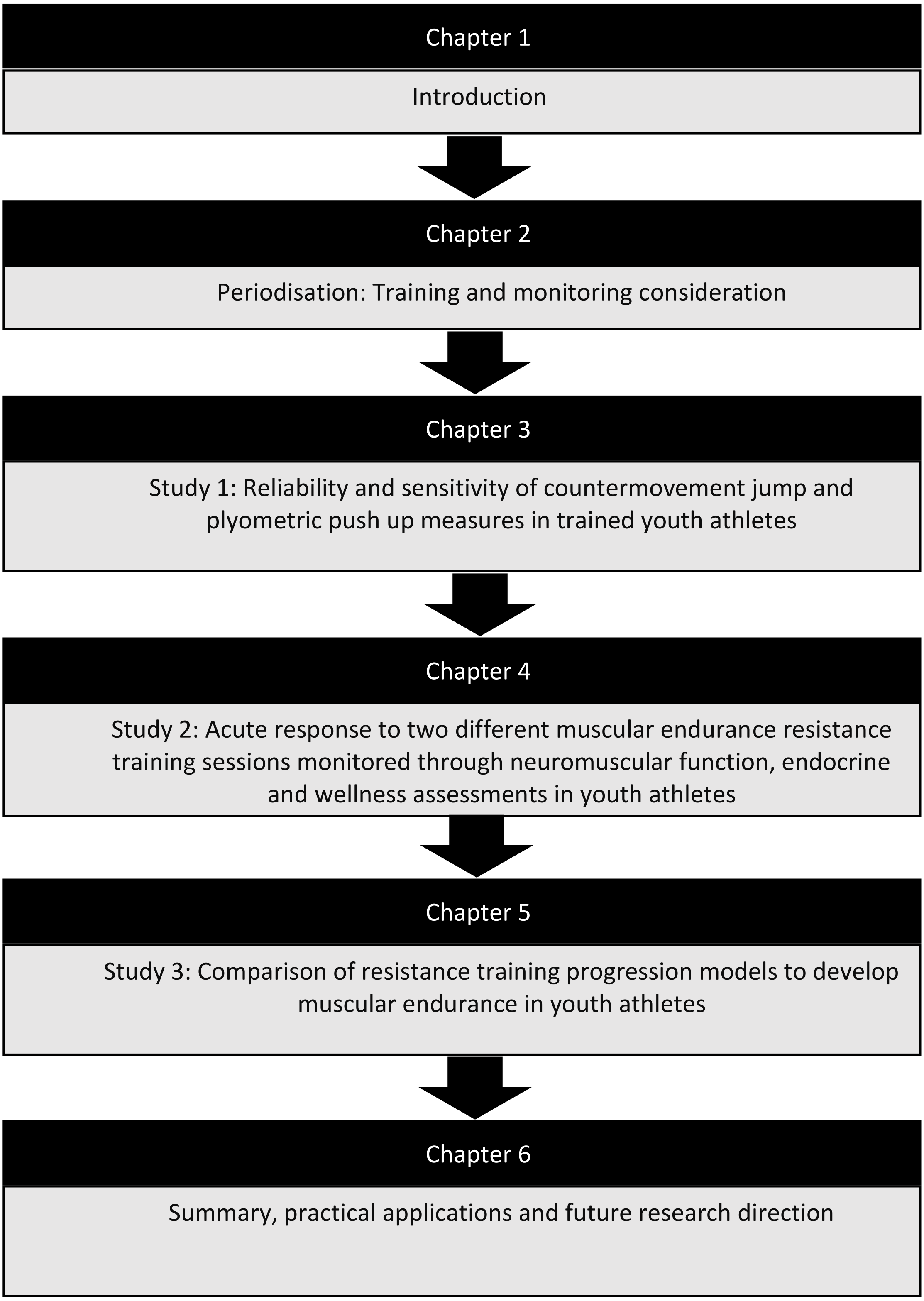

Figure 1.1 Thesis flowchart

Chapter 2 Periodisation: Training and Monitoring Considerations

2.1 Overview

The objective of this chapter was to examine different resistance training progression models and the development of muscular endurance in athletes. Accordingly, this chapter also discussed the selected resistance training monitoring aspects. Firstly, an overview of resistance training for youth is provided. Secondly, the concept of periodisation is reviewed and issues affecting the training studies presented. Next, monitoring aspects are discussed, with the focus on chronic training effects following resistance training. Finally, the chapter conclusion and direction of research is presented.

2.2 Resistance training: Implications for youth

2.2.1 Trainability

In recent years, there has been an increasing interest in youth athlete training and development (Burgess & Naughton, 2010; Cobley, Baker, Wattie, & McKenna, 2009; Ford et al., 2011; Lloyd & Oliver, 2012). This may stem from the introduction of long-term athletic development pathways and early sport specialisation. Moreover, participation at elite level now extends to adolescence. Adolescence is a developmental stage between childhood and adulthood, and is divided into three stages; early (10 to 13 years old), middle (14 to 16 years old) and late youth (17 to 19 years old) (McKay, Broderick, & Steinbeck, 2016). Gamble (2008) stated that this period is divided into distinct stages as individuals attain puberty at different ages, and that it warrants a different approach of planning and implementation of physical preparation. In fact, it is during adolescence that an individual's athletic career is developed for future participation in sport (Gabbett, Whyte, Hartwig, Wescombe, & Naughton, 2014).

There is significant interest and concern from parents, teachers and coaches about the use of resistance training in programmes for children and youth which run counter to the findings within the literature (Faigenbaum & Myer, 2010; Keiner et al., 2013). This concern is primarily due to greater injury risk related to skeletal vulnerability that concurs with the pubertal growth spurt (McKay et al., 2016). An adolescent's anatomical structures are somewhat weaker and less resistant to shear and tensile forces (Miller, Cheatham, & Patel, 2010). Injury to these structures may result in lost time from training, significant discomfort and growth disturbance (Caine, Caine, & Maffulli, 2006). However, it appears that damage to the growth cartilage or bone fracture are rarely caused by resistance training (Faigenbaum & Myer, 2010; Fleck & Kraemer, 2004; Hamill, 1994).

Training under qualified supervision has resulted in significant gains in muscular strength with no training injuries reported following resistance training in youth weightlifters who utilise heavy loads during practice (Faigenbaum & Myer, 2010). Similarly, Palmer-Green et al. (2015) reported that injury rates from resistance training were low compared to rugby specific training activities within academy rugby training. This is understandable given injury incidence during resistance training can be prevented with knowledgeable and qualified coaches making gradual progressions (i.e. technique-driven progressions) in training loads pertinent to learning the technique with developmentally appropriate instruction (Faigenbaum, 2017). Behm et al. (2017) stated that training-induced adaptive processes improve health, fitness and athletic performance in children and youth. Likewise, the current National Strength and

Conditioning Association (NSCA) position statement supports the notion that resistance training is a safe and effective training mode for youth (Lloyd et al., 2016).

Importantly, ligaments and tendons increase in strength by improving their blood supply but there is a time lag before adaptations take place (Hawkins & Metheny, 2001). During puberty, boys will experience rapid increases in body mass and overall strength. However, connective tissues appear to adapt relatively more slowly than muscle tissue (Hawkins & Metheny, 2001). Considering this, youth athletes should create a technical base for the weightlifting exercises during this period (Keiner et al., 2013). Gamble (2008) suggested the use of weight bearing activities and multi-joint resistance exercise variations (i.e. squat, lunge and step up). This increases the forces that the youth can withstand ensuring they are more resistant to soft tissue injury and are able to accommodate the rapid body mass gains acquired during puberty (Adirim & Cheng, 2003).

Furthermore, improved muscle and connective tissue strength will also increase force generation transmission on bone attachment which stimulates bone growth (Frost, 2000). Bone modelling and remodelling processes have also been reported to be enhanced in response to the tensile and compressive forces associated with mechanical loading (Vicente-Rodríguez, 2006). Youth who participate across a variety of activities, particularly resistance training, exhibit increases in bone mass compared to their non-athletic peers (Conroy et al., 1993; Jackowski, Baxter-Jones, Gruodyte-Raciene, Kontulainen, & Erlandson, 2015; Matthews et al., 2006). Resistance training studies in powerlifters and untrained male adults have shown significant increases in bone mineral content and the cross-sectional area of the patella tendon (Granhed, Jonson, & Hansson, 1987; Seynnes et al., 2009). However, these gains are considerably smaller in relation to the pre- and early-puberty periods (Gunter, Almstedt, & Janz, 2012). Thus, pre- and early-puberty provides an "adaptation window" when bone is most responsive to mechanical loading and resistance training may act synergistically with growth-related increases in bone mass (Mountjoy et al., 2011).

2.2.2 Biological maturity

Designing and implementing an appropriate resistance training programme should be specific to the individual's age and maturity level (Gamble, 2008). However, equating and grouping athletes during sports practice according to chronological age is unwise (Bompa, 2000). This may restrict optimal programming (Lloyd, Oliver, Faigenbaum, Myer, & De Ste Croix, 2014b). The biological process has its own timetable (i.e. inter-individual variation in the timing and tempo of the growth spurt). There is an edge (i.e. performance advantage during a systematic training programme) in early maturing boys as high testosterone levels in these males stimulate the neuroendocrine system that develops the secondary sex characteristics as well as muscle and bone growth (Meyers, Oliver, Hughes, Cronin, & Lloyd, 2015).

Determining chronological age is a simple process, whereas biological age is more difficult to assess and predict. However, prediction of physiological maturity is vital to improving biomotor abilities (i.e. strength, endurance, speed, flexibility and balance or coordination). These abilities are complex due to substantial inter-individual differences in timing and tempo of maturity among individuals of the same age (Lloyd & Oliver, 2012). Therefore, advancements in the biomotor abilities are non-linear due to influences of growth, maturation, environment and training (Viru et al., 1999). Several methods are available to evaluate maturation status such as sexual, skeletal and somatic techniques (Tanner, 1990). Unfortunately, these methods are not frequently used to predict maturity level due to assumptions that the prediction of maturation status is inconvenient, expensive and time consuming (Gallahue, 1989). However, assessment of biological maturation is needed to predict and identify the occurrence of rapid growth periods, to serve as a guide to adjust training loads accordingly and to minimise the occurrence of injuries (Gallahue, 1989).

Tanner (1962) described a relatively simple, reliable and valid assessment of development with description of five pubertal stages, referred to as P1-P5. This non-invasive method can easily be administered with youth (Tibana et al., 2012). It involves a self-evaluation of an individual's sexual characteristics with reference to diagrams or photographs (Gastin, Bennett, & Cook, 2013). Assessment of sexual maturation may be utilised during late youth because physical and performance outcomes are minimally confounded by biological maturation (Malina & Bouchard, 1991). This was highlighted by Towlson, Cobley, Parkin, and Lovell (2018) and Gastin et al. (2013) in elite youth male soccer players and junior Australian male football players, with a chronological age between eight to 18 years. The researchers found a high correlation between sprint performance, lower limb power, agility and endurance performance with maturation in youth aged 15 years and below. Therefore, it is imperative to identify the occurrence of peak height velocity within this age group because secondary sex characteristics do not reflect the timing of growth. Thus Mirwald, Baxter-Jones, Bailey, and Beunen (2002) suggested gender specific equations to predict somatic maturity by utilising four anthropometric variables (i.e. chronological age, stature, sitting height and body mass). These gender specific equations could track maturational status and inform any variations in athletic performance as a result of biological maturation (Lloyd et al., 2015).

To this end, it is essential for practitioners and sports scientists working with youth populations to identify the adolescent stage and to organise developmentally appropriate training loads. In fact, developmentally appropriate training will benefit youth throughout the frequent exposure to physical and psychological stresses associated with long-term athletic training (Bergeron et al., 2015). Approaches like periodisation and load monitoring should be integrated with maturity prediction to monitor youth athletic performance (Lloyd et al., 2014b). This could minimise the injury risk factor and optimise the wellbeing of the promising youth athlete; inappropriately balanced training loads, on the other hand, could result in lost opportunity in the development of a young athlete.

2.3 Periodisation

2.3.1 Periodisation in sports

Sports science plays a vital role in the enhancement of athletic performance (Issurin, 2010). Importantly, periodisation is a key conceptual framework of training design, both for athlete preparation and improving performance (DeWeese, Hornsby, Stone, & Stone, 2015b; Issurin, 2016). Furthermore, periodisation plays a fundamental role in minimising the potential for overtraining, reducing injury risk and avoiding plateaus in performance (Cunanan et al., 2018; Harries et al., 2015b; Suchomel et al., 2018). Researchers have shown that periodised training is more effective at improving performance compared to non-periodised training (Fleck, 1999; Kraemer et al., 2000; Williams et al., 2017).

Classical or traditional periodisation was proposed in the 1960s by Leonid P. Matveyev (Bompa & Haff, 2009). The development was underpinned by questionnaires on training practices acquired from Soviet Union athletes while preparing for the 1952 Olympic

Games (Bompa & Haff, 2009). Periodisation is recognised as an annual training plan consisting of different phases, sub-phases and training cycles with one major competition (Figure 2.1). Bompa (1990) further stated that this annual training plan is divided into smaller training phases to make the training more manageable, with the aim of achieving peak performance during the main competition. Peak performance could be attained by developing different physiological mechanisms over time (Baker, 1993). Specifically, biomotor abilities like speed, endurance, strength, skills and coordination are structured into different training phases within a whole training programme, depending upon specific sports requirements. Furthermore, it is important to note that distinction between the first and fourth placing was less than 1.5% in many sports and events during past Olympics (DeWeese et al., 2015a; Painter et al., 2012). Therefore, a systematic approach utilising periodisation is essential in training programme designs to develop these various biomotor abilities.

Yearly Plan					
Phases of training	Preparatory		Competitive		Transition
Sub-phases	General preparation	Specific preparation	Pre-competitive	Competitive	Transition
Mesocycles					
Microcycles					

Figure 2.1 Division of annual training plan
(Bompa & Carrera, 2005)

However, the process to elicit physiological changes systematically over time is complex (Fleck, 1988). It may require fundamental skills to engage the principles of physics, physiology, psychology and other concepts (Stone, Stone, & Sands, 2007; Turner, 2011), to optimise performance by the safest, quickest and most ethical means possible (Yesalis, 1993). More importantly, a continuous increase in training loads could result in overtraining, when physical demands outweigh the body’s ability to recover between training sessions and competitions (Foster, 1998). Recovery from overtraining often requires many weeks or months. In contrast, prolonged decrease in training loads, may result in insufficient training stimulus causing underperformance during competitions. Despite this, overreaching, the accrual of training and non-training stimuli that generates short-term decrement in performance, is a typical training process (Matos & Winsley, 2007). Unlike overtraining, functional overreaching can be resolved with a few days or weeks of recovery, resulting in improved performance. Sports training designs employ functional overreaching to vary the training stimulus (Fry & Kraemer, 1997). However, continuous training and incomplete recovery may lead to non- functional overreaching which, if left undetected, may lead to overtraining. Overreaching and overtraining are just two ends of the same continuum (Matos, Winsley, & Williams, 2011).

It is imperative to achieve a dynamic balance between training stimuli and recovery. In fact, Matveyev and Zdornyj (1981) stated that physical performance fluctuates in a cyclic manner throughout the year and therefore the classical periodisation approach is the appropriate one. It is unrealistic for an athlete to achieve peak performance in every race or competition within an annual plan. Within a periodised training programme, light and heavy training days are altered to avoid overtraining by allowing time for physical and mental recovery (Fleck, 1999). In other words, periodisation offers a framework to plan systematic variations in training stimuli and allows practitioners to utilise the residual effects from the preceding training cycles to develop the genetic abilities of their athletes to meet their sporting demands (Brown & Greenword, 2005; Williams et al., 2017).

2.3.2 Annual training plan

The macrocycle or season is the largest phase and is often referred to as the yearly plan. However, the macrocycle may follow an Olympic cycle, or quadrennial cycle, where an athlete is to peak for the Olympic Games or other pinnacle event. Next is the mesocycle, a medium-sized training period consisting of many weeks to months and including notable phases of preparatory training, competition and transition. Each mesocycle comprises a number of microcycles, which are generally periods of one week, to focus on or segregate sport-specific training (Brown & Greenword, 2005). It is within these microcycles that the training stimulus is changed progressively and systematically (Robertson, 2004). These training cycles are regulated by the number of competitions, the amount of time available between competitions within a specific cycle and the athlete's progress in competition performances and physical fitness (Issurin, 2010).

The macrocycle begins with the preparatory phase and is divided into two parts: general and specific preparation phases (Bompa, 1999). The main objective during the general preparation phase is physical conditioning with limited sport-specific skill practices or tactical sessions. General physical abilities are developed with various exercises at relatively low intensity and high volume, depending on training status and demands of the sport (Bompa & Haff, 2009). Training methods such as long slow distance (LSD), low-intensity plyometric and resistance training with high repetitions are typical in this phase (Issurin, 2009). The specific preparation phase integrates greater sport-specific activities with a notable increase in training volume. Technical and tactical aspects are incorporated to increase the athlete's performance capabilities before transitioning into competition phase (Haff, 2014). Generally, the preparatory phase is three to six months of a macrocycle, however this duration will depend on the competition schedule and the training status of the athletes (Bompa & Haff, 2009).

The competition phase commences with transference to low volume and high intensity training. This period is separated into pre-competition and main competition phases (Haff & Haff, 2012). Competitive success is not the objective during pre-competition phase. Rather it functions to monitor progress towards the main competition phase which allows the coach to evaluate any shortcomings discovered from the previous training cycle (Matveyev, 1992). Sports specific skill practices or tactical sessions become the focus during this period to progress the athlete towards peak performance (Issurin, 2010). During the main competition phase, the priority is to achieve the optimal fitness level and performance during the most important competition. Transition phase, after a season of competition, is an active rest period of one to four weeks with recreational activities. This assists the athletes to recover from competition stresses and to prepare for the new season. Reductions in training volume and intensity could allow athletes to engage in light, non-specific resistance training and play games in a leisurely manner to maintain fitness while regenerating mentally and physically (Charniga et al., 1986). In addition, the transition period can also be included between the preparatory and competition periods with a shorter duration than at the end of the season.

At this point, classical periodisation is suggested as fundamental to manage a dynamic balance between: (1) variation and novelty in training stimuli to minimise overtraining syndrome and (2) the specific adaptation needed to improve already well-developed fitness attributes (DeWeese et al., 2015a; Plisk & Stone, 2003). Increased training monotony shows a lack of training variation (Foster, 1998), that may elevate the incidence of overtraining syndrome (Smith, 2003), decreased performance and increased frequency of infections (Kellmann & Günther, 2000). On the other hand, a low training monotony index had been linked with improved performances and is utilised as a monitoring tool in elite rowing (Suzuki, Sato, & Takahasi, 2003) and sprinting (Suzuki, Sato, Maeda, & Takahashi, 2006). Therefore, a classical periodisation approach facilitates both focus and variation within and between training.

However, two arguments have emerged within the literature that highlight the limitations in the classical periodisation approach (Issurin, 2010; Verhoshansky, 1999). First, if training stimuli are varied excessively, elite athletes may attain plateau or slow performance growth due to a wide distribution of adaptive energy. Second, it has commonly been assumed that periodic reductions in training variations could facilitate rapid improvements in a limited range of training objectives, however, prolonged exposure may lead to negative consequences such as monotony.

2.3.3 Block periodisation

Matveyev proposed the foundation of classical periodisation theory in the 1960s with workload levels, competition frequency and results that were much lower than present day (Kiely, 2012). Therefore, the main weakness in the classical periodisation approach was the inability to address multi peak performances in elite athletes across a season. Of note, the classical periodisation approach was recommended with one, two or three annual peaks. However, since the 1980s, multi peak performances have been the trend within annual training plans in high performance sports. For example, Sergey Bubka from the Soviet Union attained seven peak performances in pole vault during the 1991 season, with 23 – 43 days of intervals between the peaks (Issurin, 2008). Hence, block periodisation (BP) was proposed to overcome the shortcomings in traditional periodisation in which short training periods are utilised to develop a few selected abilities through highly concentrated specialised workloads (Breil, Weber, Koller, Hoppeler, & Vogt, 2010; Ronnestad, Hansen, & Ellefsen, 2014; Ronnestad, Hansen, Thyli, Bakken, & Sandbakk, 2016).

In particular, traditional periodisation may lead to suboptimal stimulus and adaptations in elite athletes due to the multi-faceted approach of developing multiple abilities simultaneously (Kiely, 2010). Also, simultaneous development of multiple physical capacities through intensive and exhaustive efforts that persist between three to four weeks could induce negative stress responses, thereby inhibiting adaptive processes (Steinacker, Lormes, Kellmann, & Liu, 2000; Steinacker, Lormes, Lehmann, & Altenburg, 1998), which, in turn, may elevate the risk of overtraining (Lehmann et al., 1997; Lindsay et al., 1996). Moreover, negative interactions of non-compatible workloads are likely to induce conflicting training responses (Issurin, 2008; Wilson et al., 2012). This was illustrated in research with elite skiers (Koutedakis, Boreham, Kabitsis, & Sharp, 1992), elite fencers (Koutedakis, Ridgeon, Sharp, & Boreham, 1993), elite rowers (Hagerman & Staron, 1983) and elite basketball players (Hoffman, Fry, Howard, Maresh, & Kraemer, 1991) in which intense mixed training attenuates maximal strength.

BP concentrates on developing a few selected abilities in each mesocycle to ensure sufficient stimuli and adaptations while maintaining other essential abilities for performance concurrently (Issurin, 2010; Ronnestad, Ofsteng, & Ellefsen, 2018). More specifically, BP comprises a number of stages, with each stage incorporating three blocks: accumulation, transmutation and realisation (DeWeese et al., 2015b). First, during accumulation, high volume with less specific training is designed to focus on changes in features, such as body composition, work capacity and basic strength. Next, transmutation shifts into specific exercises with low volume and high training intensity that could substantially improve maximum strength in specific areas. Finally, realisation, usually planned with power oriented task-specific exercises, is typically followed by a taper to prepare the athlete for a competition and a period of active recovery before the next intensive training cycle (Painter et al., 2018). Generally, every block lasts for between three to four weeks. BP has been utilised in high performance sports because it allows multiple peak training design which facilitates participation in many competitions throughout a season (Issurin & Yessis, 2008). Furthermore, elite athletes are nearer to their non-functional overreaching or overtraining limits than novices. For this reason, they require greater variation and better fatigue management. Additionally, elite athletes may be close to their genetic potential, thus there is a need for greater variation and unique training design to interrupt homeostasis and induce adaptations (DeWeese et al., 2015b).

It should be noted that as sharp changes in training intensity can be hazardous for less experienced athletes, BP is only recommended for elite athletes (Baker, 2007). Traditional periodisation uses a relatively long duration of time to develop various biomotor abilities (Garcıa-Pallares, Garcia-Fernandez, Sanchez-Medina, & Izquierdo, 2010). A gradual progression of training volume and intensity is essential when training male youth athletes because during puberty boys will experience a rapid increase in body mass and strength but with connective tissue adapting more slowly. These youth athletes are therefore more susceptible to overuse injury (Hawkins & Metheny, 2001). As well, more time is required to increase the forces which they can withstand and stimulate bone growth (Adirim & Cheng, 2003).

2.3.4 Physiological basis of periodisation

Periodisation is underpinned by renowned Canadian endocrinologist, Dr. Hans Seyle's General Adaptation Syndrome (GAS) (Selye, 1936). It outlines the rhythmical generic responses and adaptations of an organism to stress (Figure 2.2). Stone, O'Bryant, Garhammer, McMillan, and Rozenek (1982) incorporated this theory and defined its application to resistance training. Subsequently, GAS is often referred to in the literature as the tenet in the programming of resistance training to optimise performance and recovery (Kraemer & Ratamess, 2004; Prestes et al., 2009b; Turner, 2011).

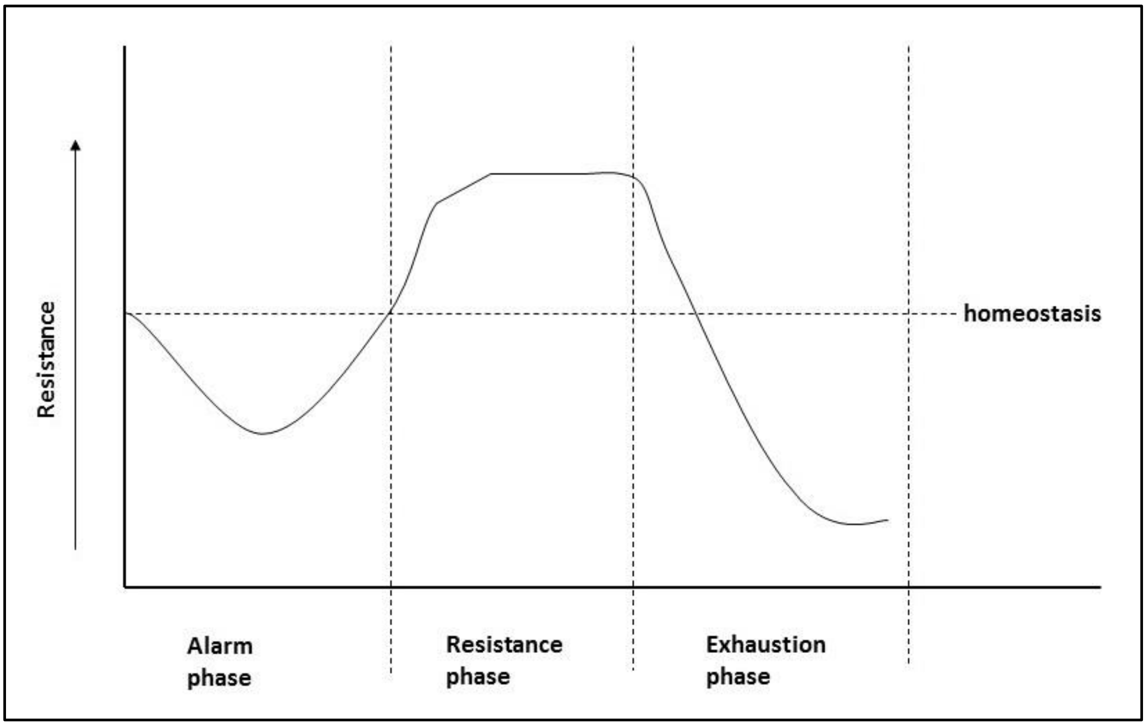

Figure 2.2 General adaptation syndrome
(Haff, 2016)

Recently, Buckner et al. (2017) criticised the classical extrapolation of Selye's conclusions to resistance training, arguing that GAS focused on the stress responses of rodents exposed to toxic levels of pharmacological agents and stimuli. The three phases of responses were developed based on muscle tissue reactions to sub-lethal doses of various drugs and stimuli (e.g. temperature and exercise) (Selye, 1938). Buckner et al therefore maintain that Selye's findings on the effects of various drugs and exercise on rodents was unlikely to have any application to human training models (Buckner et al., 2017). The authors argued that the findings may be further confounded by the involuntary nature of forced exercise during the stress experimentation process. Thus, it was unclear if the stress was induced by exercise or psychological stress. It remains uncertain within the scientific community whether the GAS hypothesis can be applied to regular, non-toxic, voluntary exercise in human training models.

However, Cunanan et al. (2018) challenged the claims by Buckner et al. (2017) on the ground that the authors failed to acknowledge the significance of GAS as a conceptual framework for the training process. Selye (1938) had stated that the disturbance to the homeostasis was essential for biological adaptation, which is the primary objective of the GAS model. This concurs with musculoskeletal, neuromuscular and metabolic adaptations in relation to exercise in humans (Egan & Zierath, 2013; Meerson, 1965; Viru, 1984). For instance, acute and chronic stimuli from resistance training induces mechanical tension, muscle damage and metabolic responses (Chen, Nosaka, & Chen, 2012; Taipale et al., 2014). As a consequence, these change the intracellular milieu with various known reactive adjustments such as mechanistic target of rapamycin (mTOR) pathway and AMP-activated protein kinase (AMPK) activations (Laplante & Sabatini, 2009). Collectively, these reactive adjustments were thought to improve connective tissue, muscle cross-sectional area, architectural changes, and neural input and output alterations (Sale, 1988; Tanimoto et al., 2008). Accordingly, these changes were likely to result in improved strength, hypertrophy and power (Hartmann, Bob, Wirth, & Schmidtbleicher, 2009; Schoenfeld et al., 2016). Therefore, the observed changes following resistance training correspond to the initial GAS concept that biological modification to a stimulus could only happen after a period of habituation (Selye, 1938). As a result, GAS has been adapted as a framework in other models such as the stimulus-fatigue-recovery-adaptation (Figure 2.3) to understand the mechanistic process of providing a training stimulus to induce specific adaptations that result in functional enhancements (Cunanan et al., 2018).

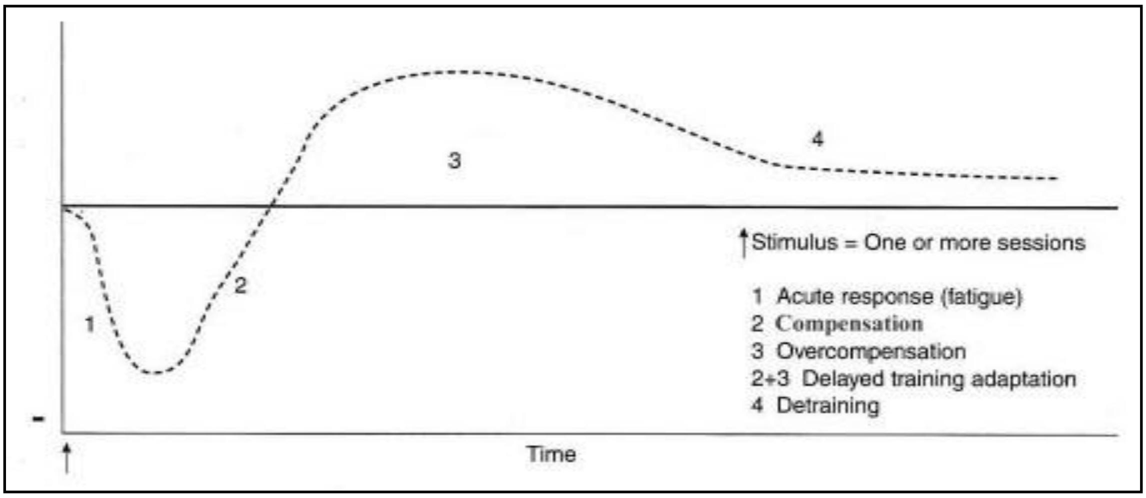

Figure 2.3 Stimulus-fatigue-recovery-adaptation model
(Stone et al., 2007)

As shown in Figure 2.3, the human body stressed with a training load or stimulus may create catabolic responses (*stage 1*). This is accompanied by fatigue, muscle soreness and acute reduction in work capabilities, especially during the first few days of a new training programme (Stone et al., 1982). Next is the resistance phase, which is observed as a marked process of recovery that eventually increases working capabilities in tandem with rises in physiological and psychological adaptations in the body (*stage 2*). During the resistance phase the human body reaches the baseline fitness level (compensation). Since the human body can adapt to changes, with sufficient recovery provided, it will adjust itself to a higher fitness level in anticipation of another training load, which will exceed the baseline fitness level, achieving a condition/phase known as overcompensation (*stage 3*). If the next training load is applied during the overcompensation phase, the body will advance to a higher fitness level (Stone et al., 1982). If no training load is applied, then the body will slowly return to the baseline fitness level which is known as detraining (*stage 4*). If the training load is applied during the compensation phase, the human body will enter the exhaustion phase, because of fatigue accumulation. Training into the exhaustion phase should be avoided. This is likely to attenuate adaptation processes and subsequently performance decline, that may lead to overtraining (Meeusen et al., 2013). As a result, negative physiological and psychological states may occur which affects performance outcomes due to imbalances between training stimuli and recovery (van Borselen, Vos, Fry, & Kraemer, 1992).

Therefore, a cyclical approach to the training programme design is essential to optimise training progress. Importantly, the stimulus-fatigue-recovery-adaptation model underscores the importance of planning the appropriate ratio between training stimuli and recovery to avoid overtraining (Haff, 2014; Rhea et al., 2002). Variations in training specificity, intensity and volume within a whole programme would help to manage fatigue, eliminate monotony in training routines, optimise recovery and avoid plateaus in fitness levels. These would culminate in a composite aggregation of all training stimuli from the sports practice, in which an optimal performance at a specific point in time would be obtained (Haff, 2004; Kraemer, 1997).

2.3.5 Quantifying training volume and intensity

The ability to manage training stressors dictates an optimal periodised training plan (Bompa & Haff, 2009). As a result, an optimal periodised training plan could augment the adaptation recovery mechanism, improve preparedness and attain peak performance at predetermined time points (Haff, 2010). In fact, safe and effective periodised resistance training programmes involve variation in training variables between training sessions to achieve intended neuromuscular adaptations (Feigenbaum & Pollock, 1999). This is accomplished by varying the training volume and intensity at regular intervals to elicit optimal gains in different neuromuscular qualities such as hypertrophy, maximal strength, power or muscular endurance (Fleck, 1999). Typically, high-volume/low-intensity (i.e. hypertrophic adaptation) training during the preparation phase prepares the athletes for high intensity (i.e. neural adaptation) training during the competition phase (Stone et al., 1982). The high-intensity/low-volume training is planned during the competition phase to avoid overtraining and achieve an optimal fitness level (O'Bryant, Byrd, & Stone, 1988).

The training volume and related load utilised during resistance training is known as a stimulus for muscle adaptations (Peterson, Rhea, & Alvar, 2004). Training volume is defined as the sum of work accomplished, or total work performed, in a session, a day, a microcycle or a mesocycle (Bompa, 1999; Haff, 2010). Rhea et al. (2002) and Rhea et al. (2003) suggested that training volume is calculated as total repetitions completed for each load, also known as the repetition method. Training volume could also be calculated as load x repetitions x sets, commonly known as volume load (Peterson, Pistilli, Haff, Hoffman, & Gordon, 2011). The former is the most basic method to quantify the total training volume in resistance training. Such an approach, however, may not reflect the actual load performed by athletes (McCaulley et al., 2009). The physiological stress encountered may vary between individuals (Dankel et al., 2016). Thus, relying on the total amount of repetitions performed in a training session, day or training cycles may provide a poor estimate of the total training volume completed (Stone et al., 1999a). Hence, McBride et al. (2009) proposed the calculation of mechanical work performed during resistance training. This entails the evaluation of the dynamics of the lifting task (i.e. force and displacement) for each exercise. However, it may be impractical to monitor each repetition of every exercise performed during training, especially when working with large groups of athletes (Haff, 2010). Moreover, financial limitations, time constrains and the manpower required to collect, analyse and report findings may restrict the application in practical settings (Bourdon et al., 2017). It has been suggested that total volume load is calculated by multiplying the number of repetitions completed by the actual resistance encountered, which expands the repetition method (Haff, 2010). The estimation of total volume load has been utilised to match dosages in experimental investigations (Lian-Yee, Hamer, & Bishop, 2009; Tran, Docherty, & Behm, 2006) and to monitor athlete progress (Haff et al., 2008). More importantly, it may benefit periodisation studies, to compare similar training protocols with equated frequencies and training intensities (Williams et al., 2017).

Evidence suggests that improvement in maximal strength is significantly greater following periodised resistance training with multiple sets compared to single set training (Kramer et al., 1997; Marx et al., 2001). However, such experimental designs have failed to equalise the training volume between groups. As such, the accumulated work performed could have influenced the alterations in strength within the periodised groups. Therefore, studies have attempted to equalise the training volume to investigate the efficacy of other programme variables (Potteiger, Judge, Cerny, & Potteiger, 1995; Willoughby, 1991). However, the volume calculation method has varied between studies. Several investigations utilised the repetition method (DeBeliso, Harris, Spitzer-Gibson, & Adams, 2005; Kraemer et al., 2003; Stone et al., 2000), while others utilised relative training volume (Schiotz, Potteiger, Huntsinger, & Denmark, 1998) and volume load (Herrick & Stone, 1996; Souza et al., 2014). As previously mentioned, volume load is recommended to quantify total work performed over the repetition method (Haff, 2010). This may overcome the limitation of substantial differences in the amount of work being performed between groups. For example, Stone et al. (2000) compared non-periodised, LP and overreaching periodisation groups. Despite that the non-periodised and LP groups matched in terms of repetitions, the non-periodised group trained with 23% higher volume load. Also, the LP group executed 19% additional repetitions compared to the overreaching periodisation group. Importantly, the overreaching periodisation group accrued 6% more volume load than LP and obtained larger strength gains.

Optimally quantified training volume is also important to monitor the impact on performance measures. Several training studies have investigated the effects of increased training volume while maintaining intensity in elite male weight lifters (Fry et al., 1994; Fry et al., 1993; Häkkinen, Pakarinen, Alen, Kauhanen, & Komi, 1987b). Findings revealed that a deliberate increase in training volume reduced strength measures. Interestingly, Fry et al. (1994) detected significant performance increases following a return to normal training volume. A cautiously deliberate increase in training volume may not always negatively affect performance. Following a reduction in training volume, performance usually improves (Storey, Birch, Fan, & Smith, 2016). These inconsistencies may be explained by the fact that there needs to be a training volume before performance can be significantly affected (Fry & Kraemer, 1997). Thus, deliberate progressive increases in training volume may not lead to signs of overtraining. Practitioners must identify the threshold of training volume that likely affects performance and thereby minimise the possibility of overtraining.

Another essential variable in designing resistance training is the training intensity. It is reflected by the load or resistance used (Bosco, Colli, Bonomi, von Duvillard, & Viru, 2000). Training intensity is positively related to the load lifted, with fewer repetitions performed with heavy loads (Haff, 2016). In resistance training, training intensity is usually calculated in relation to concentric or isometric maximal strength (Fleck &

Kraemer, 2004; Steinhofer, 1997). For example, an individual may perform an exercise at 60% of one repetition maximum (1RM) for 15 repetitions. This requires frequent evaluation of maximal strength in different types of exercises (upper- vs. lower-body; single vs. multi-joint) in tandem with increases in physical strength (Paul & Nassis, 2015). Furthermore, if the assessment is not conducted periodically, the current strength level would be unknown which would eventually affect the training intensity. Chapman, Whitehead, and Binkert (1998) suggested that the relative training intensity may not be useful to prescribe training because it is not practical to use a percentage of 1RM of one exercise to assess other exercises.

There is an alternate method of identifying the training intensity or load by RM target zones (Kraemer, Deschenes, & Fleck, 1988; Tan, 1999; Zatsiorsky, 1992). This is defined as the maximal number of repetitions performed at a given weight through the full range of motion (Haff, 2016). RM target zones allow an athlete to adjust the resistance as the strength level changes for each lift in order to stay within the prescribed training intensity (Kraemer et al., 2000). When training is prescribed based on RM, this may also reduce the risk of unintentional under or overtraining in a training session (Hoeger, Hopkins, Barette, & Hale, 1990). In addition, to induce the required training effects, absolute loads need to be increased by 2 - 10% for the next set or training session where an individual exceeds the prescribed workload for one to two repetitions (Feigenbaum & Pollock, 1999; Velez, Golem, & Arent, 2010).

Fisher, Steele, Bruce-Low, and Smith (2011) proposed that training intensity should be defined as the level of effort employed to a specific load. The authors argued that training intensity should be quantified as how hard an individual is working during an exercise as opposed to expressing training intensity as a percentage of 1RM. Hoeger, Barette, Hale, and Hopkins (1987), Hoeger et al. (1990) and Shimano et al. (2006) noted large differences in the number of repetitions possible for a similar percentage of 1RM in male, female, trained and untrained participants. It is also important to highlight that individuals with a high proportion of type II muscle fibres completed less repetitions at 70% of 1RM than those with a lower proportion of type II muscle fibres (Douris, White, Cullen, & Keltz, 2006). It has been advocated that exertion should be considered in relation to set endpoints (i.e. muscular failure) to regulate the training intensity (Willardson, 2007).

2.3.6 Linear periodisation

In sports, an appropriate periodisation model is essential for athletes to attain the highest physical performance at a precise time by minimising injuries, avoiding plateaus and overtraining syndrome (Stone, O'Bryant, & Garhammer, 1981). The influence of a periodised resistance training programme to elicit strength gains has been examined (Faigenbaum et al., 2007; Fleck, 1999; Kraemer et al., 2000; Moraes et al., 2013). These studies have noted that to achieve optimal adaptations, manipulation of the training intensity and volume is important. In contrast, with non-periodised training the RM load is consistent (Kraemer, 1997; O'Bryant et al., 1988; Willoughby, 1991). Specifically, a non-periodised resistance training may maintain the stimuli in a constant manner, which diminishes its efficacy to induce physiological changes (Williams et al., 2017). Therefore, periodised resistance training provides a framework to arrange training variables such as number of sets and repetitions, exercise order, load and rest at regular time intervals to accomplish specific gains in hypertrophy, strength, power and/or muscular endurance (Fleck, 1999). It emphasizes both the hypertrophic and neural mechanisms responsible for improving strength in different mesocycles and microcycles (Stone et al., 1982). Traditional, classical, stepwise or LP is a model that increases training intensity gradually between successive mesocycles with simultaneous reductions in the training volume as the training progresses towards the main competition (Baker et al., 1994; Rhea et al., 2002). However, there remains much confusion in the literature about the nonlinear variations in the training variables in LP (Stone & Wathen, 2001; Stone & O'Bryant, 1995). Although, at the macrocycle and mesocycle levels, linear increases in training intensity and decreases in volume seem evident, frequent alterations in intensity and volume prevail at the microcycle level (Stone et al., 1999a; Stone et al., 1999b) in the same way as UP. For example, strength qualities such as endurance, strength and power are modified between phases (Lian-Yee et al., 2009) or repetition patterns are altered between weeks (de Lima et al., 2012) in LP. It should be noted that holistically, periodisation is the management of fitness phases into time periods whereas programming manages the manipulation of acute training variables (Cunanan et al., 2018). Therefore, research comparing periodisation models establishes differentiation at the programming level (Williams et al., 2017). Despite the uncertainty in the term, within this thesis, the gradual increase in training intensity and decrease in volume will be defined as LP.

Originally, Stone et al. (1981) developed a LP model for strength and power sports. This model starts with hypertrophy training, with an emphasis on morphological adaptations and body composition alterations during the preparation phase (Figure 2.4).

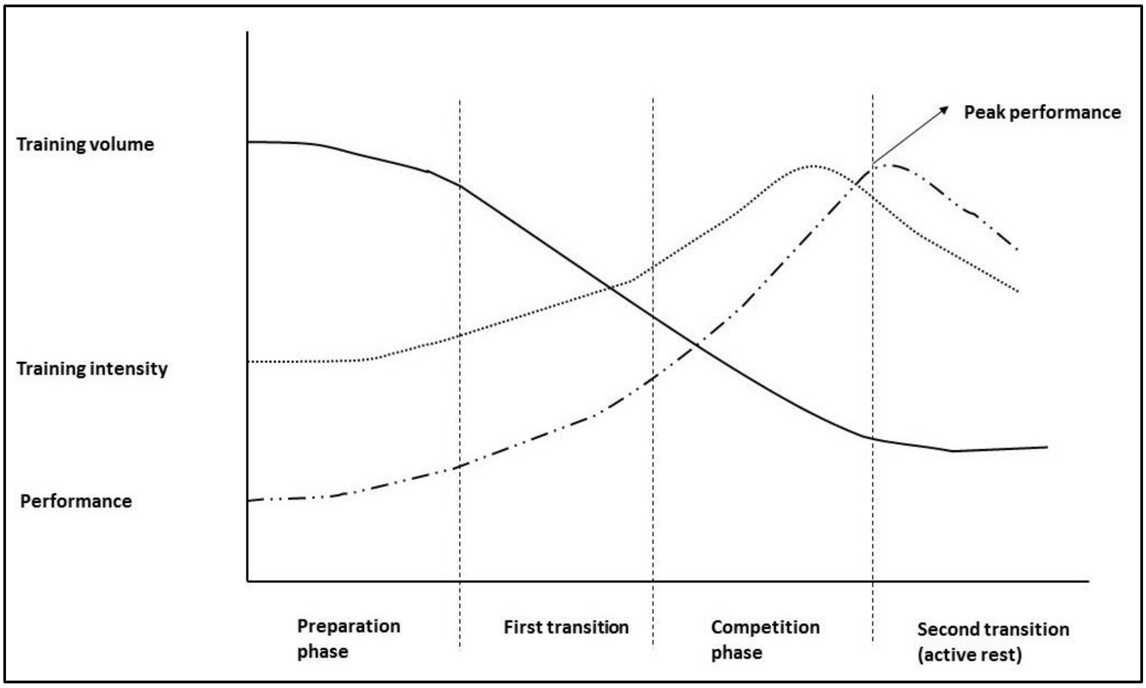

Figure 2.4 Hypothetical model for resistance training
(Stone et al., 1981)

This builds a stable foundation that prepares the athletes to tolerate the programmed workload increase in subsequent mesocycles (Simao et al., 2012). Next, is the first transition phase in which strength development is the priority with planned high workload intensities. This is followed by the competition phase that extends upon the first transition phase with exercises performed at low training volume to stabilise or improve techniques while improving performance variables specific to the sport (Bompa & Haff, 2009). To maintain maximum strength and power, a decrease in training volume is essential to offset the increase in training intensity. The second transition is characterised by low training workloads and intensities to regenerate which may involve recreational activities. The LP training model allows progressive improvements in general fitness components and therefore is ideal for young or novice individuals (Gamble, 2013). For example, the initial high training volume emphasizes hypertrophic adaptations observed as significant increases in lean body mass (Stone et al., 1981), whereas the high training intensity period stresses neural responses and provides an efficient training structure for strength gains (Stone et al., 1982). This model is recommended for sports that require peak physical performances at a specific point in time, such as major competitions (Buford, Rossi, Smith, & Warren, 2007).

2.3.7 Issues in linear periodisation training studies

The basic tenet of LP has been examined in several studies that are summarised in Table 2.1. These investigations have generally compared two protocols, LP and Progressive Resistance Exercise (PRE), in which the RM is constant. However, each study varied in durations to develop hypertrophy, maximal strength and power. Likewise, differences in training volume and intensity existed, making a comparison of the studies challenging. Stone et al. (1981) demonstrated significant differences in the 1RM squat and vertical jump test in the LP group. Stowers et al. (1983) reported that the periodised group improved 27% in the 1RM squat. This was significantly different to the 1 x 10RM group (14%) and 3 x 10RM group at 20%. Similarly, O'Bryant et al. (1988) obtained significant results in LP group for 1RM squat (38%) and cycle power performance (17%) compared to the PRE group. In line with previous studies, the LP programme elicited greater 1RM bench press (28% increase) and squat (48% increase) compared to non-periodised training with improvements of 23% and 34% respectively in college aged males with previous resistance training experience (Willoughby, 1993). These results indicated that LP obtained significant gains in strength and power compared with a PRE programme. Recently, Mattocks et al. (2016) have taken issue with the contention that the improvements in strength within LP may be defined by the principle of specificity. For instance, the predominance of LP compared to PRE was attributed to the greater training intensity (i.e. high % 1RM) executed during the final mesocycle that likely resembles the 1RM test utilised to evaluate strength. Hence, a participant who trained at higher load (e.g. 3RM) could possibly outperform someone who trained with lower load (e.g. 10RM) during the strength test, because the training was performed at a higher intensity during the final phase of the experimental period.

Table 2.1 Training studies comparing linear periodisation with non-periodised training model

Investigators	Participants (training status)	Study period (weeks)	Sessions per week	Periodised training protocol	Non-periodised training protocol	Tests
Stone et al., (1981)	20 male adults (college resistance – training class)	6	3	Wk 1-3: 5 x 10RM Wk 4 : 5 x 5RM Wk 5 : 3 x 3RM Wk 6 : 3 x 2RM	Wk 1-6: 3 x 6RM	1RM squat†#§, vertical jump†#, vertical jump power†§, body composition†
Stowers et al., (1983)	84 male adults males (untrained college students)	7	3	Wk 1-2: 5 x 10RM Wk 3-5: 3 x 5RM Wk 6-7: 3 x 3RM	Wk 1-7: 1 x 10RM (NP1) : 3 x 10RM (NP2)	1RM bench press†#, 1RM squat†§, vertical jump†, vertical jump power†
O'Bryant et al., (1988)	90 male adults males (untrained college students)	11	3	Wk 1-4: 5 x 10RM Wk 4-8: 3 x 5RM 1 x 10RM Wk 9-11: 3 x 2RM 1 x 10RM	Wk 1-11: 3 x 6RM	1RM squat†§, cycle power test†§

McGee et al., (1992)	27 male adults (college resistance – training class)	7	3	Wk 1-2: 3 x 10RM Wk 3-5: 3 x 5RM Wk 6-7: 3 x 3RM	Wk 1-7: 1 x 12RM (NP1) 3 x 10RM (NP2)	Cycle endurance test[†#], squat repetition to exhaustion[†#]
Willoughby et al., (1993)	92 male adults (resistance-trained)	16	3	Wk 1-4: 5 x 10 (79%1RM) Wk 5-8: 6 x 8 (83%1RM) Wk 9-12: 3 x 6 (88%1RM) Wk 13-16: 3 x 4 (92%1RM)	Wk 1-16: 5 x 10RM(79%1RM) (NP1) 6 x 8RM (83%1RM) (NP2) Control group – no training	1RM bench press[§^], 1RM squat[§^]
Schiotz et al., (1998)	14 male Reserve Officers Training Corps (ROTC) (trained)	10	4	Wk 1-2: 5x10RM Wk 3: 3x10RM, 1x8RM, 1x6RM Wk 4: 2x8RM, 3x5RM Hypertrophy	Wk 1-10: 4 x 6RM	1RM bench press[†#], 1RM squat[†#], body composition[†], Army Physical Fitness Test[†#]

Wk 5: 1x8RM, 1x6RM, 3x5RM	Strength
Wk 6: 1x8RM, 4x5RM	
Wk 7: 1x8RM, 2x5RM 1x3RM, 1x1RM	
Wk 8: 2x5RM, 1x3RM 1x2RM, 1x1RM	Power
Wk 9-10: 2x3RM, 4x1RM	

† indicates significant (p ≤ 0.05) change for periodised group(s) from baseline to post-test; # indicates significant (p ≤ 0.05) change for non-periodised group from baseline to post-test; § indicates significantly (p ≤ 0.05) higher than non-periodised group; ^ indicates significant (p ≤ 0.05) different from control group; Wk indicates week; RM indicates repetition maximum; NP1 indicates non-periodised group 1; NP2 indicates non-periodised group 2

Furthermore, a closer examination revealed that the training volume or workload between the comparative groups was not equated. Baker et al. (1994) estimated that the significant results obtained by Stone et al. (1981) and O'Bryant et al. (1988) were attributed to the PRE group performing 56% lower training volume than the LP group. Also, Stowers et al. (1983) and McGee, Jessee, Stone, and Blessing (1992) may have observed similar findings with programmes that were not matched in training volume and intensity. High training volume likely provides an opportunity for participants to experience greater learning and coordination which, in turn, influences strength gains in novices (Rutherford & Jones, 1986). In addition, Schlumberger, Stec, and Schmidtbleicher (2001) indicated that high training volume may impose greater overload to the musculature, thus improving strength over time. Therefore, it is unclear if the effectiveness was due to the structure of the training programmes or the increased volume and intensity.

To address this issue, Willoughby (1993) attempted to equate training volume and intensity in resistance trained men. This study matched four different training groups; one group trained with an LP model while the others utilised constant, but different set and repetition ranges for 16 weeks. It is important to note that the training volume was partially matched during the first eight weeks of training, but the repetitions were not. Furthermore, training intensity was not regulated. The periodised group trained with a low training volume during the second eight weeks and obtained significant improvements in the bench press and back squat compared to other groups. The strength gains may have been achieved because of the decreased training volume with a concomitant increase in intensity towards the end of the training period as demonstrated by Stone et al. (1981), O'Bryant et al. (1988), McGee et al. (1992) and

Stowers et al. (1983). Likewise, Potteiger et al. (1995) utilised an LP model with male and female collegiate track and field athletes during a six month competition period. Significant improvements in power (i.e. overhead shot-put throw and kneeling shot-put throw) and lean body mass were detected following the LP programme with no significant changes in fat percentage. However, the findings would have been more meaningful if a control group was included. Nevertheless, Potteiger et al. (1995) attempted to regulate the training volume and proposed that LP was suitable for athletes to improve performance and body composition in both genders.

Schiotz et al. (1998) examined the effects of equated training volume between LP and a non-periodised training protocol in male Reserve Officers' Training Corps (ROTC) over a ten-week experimental period. Significant decreases in fat percentage, estimated from skinfold measurements, were detected in the LP group (1.5%), while no significant decrease (0.6%) was detected in the non-periodised training group. This was in contrast to the results of Potteiger et al. (1995) after studying highly trained athletes for 24 weeks. The contradictory results may, in part be due to the four cardiovascular endurance training sessions performed each week in addition to the resistance training sessions. Therefore, these findings must be interpreted with caution.

Many previous investigations utilised either trained (Bartolomei, Hoffman, Merni, & Stout, 2014; Monteiro et al., 2009; Prestes et al., 2009b) or untrained (Apel et al., 2011; De Souza et al., 2018; Souza et al., 2014) men. Untrained participants almost certainly exhibit greater improvements following a short-term training period because of neural factors. Findings from this research may not indicate the true efficacy of a training programme (Hakkinen & Komi, 1985). Furthermore, regardless of the amount and method, untrained participants are more likely to benefit from a periodised training because of a broader adaptation window (Hartmann et al., 2015; Rhea & Alderman, 2004). In contrast, trained participants exhibit improvements at a slower rate (Fleck, 1999). This was observed in elite male weight lifters who exhibited a 3.5% non-significant increase in maximal isometric strength of the leg extensors following one year of training (Häkkinen, Komi, Alén, & Kauhanen, 1987a). Hence, there needs to be a different manipulation of training volume and intensity for resistance trained and untrained participants (Fleck & Kraemer, 1997). The classic structure of beginning the training with high volume and low intensity, followed by low volume and high intensity may not be optimal for trained participants (Kraemer & Ratamess, 2004). Trained participants have greater capacity to tolerate and recover from high training volume and intensity and may require greater variations in volume and intensity to induce significant gains (Kraemer & Ratamess, 2004; Wernbom, Augustsson, & Thomee, 2007). Therefore, more research is warranted to determine the appropriate structure of periodisation for trained and untrained participants to optimise the training effects. One model may not be generalised to other populations (Buford et al., 2007).

Variations in training frequency and exercises also seem to contribute to differences in training volume and workloads which again complicates comparability (Fleck, 1999). For example, most studies utilised three days per week training frequency whereas Schiotz et al. (1998) used four days per week. To further complicate the issue, Kraemer (1997) made comparisons between two groups with one group trained three times while the other trained four times per week. Therefore, the ability to generalise these results is limited to the factors mentioned previously. Almost all of the investigations examined the efficacy of periodised training focusing on maximal strength, hypertrophy or power gains (Fleck, 1999). Thus, the conclusions from these studies are applicable to strength or power-oriented sports and not to endurance-based sports.

2.3.8 Undulating periodisation

The non-linear or non-traditional model, UP, is another model that develops various strength qualities of the neuromuscular system within the same period. UP features changes in training volume and intensity on a daily, weekly or bi-weekly basis across a time period (Apel et al., 2011; Rhea et al., 2003; Simao et al., 2012). The frequent changes between training stimuli of high intensity (i.e. neural adaptation) and high volume (i.e. hypertrophic adaptation) yields positive gains in comparison to LP (Peterson, Dodd, Alvar, Rhea, & Favre, 2008; Rhea & Alderman, 2004). It is thought that this alteration between training stimuli could provide variations to optimise physiological strain (Monteiro et al., 2009). In particular, prolonged periods of low volume, high intensity training inherent in LP may induce neural fatigue because of the increased level of stress with minimal time for regeneration (Komi, 1986).

Proponents of UP suggest that the morphological adaptations gained during the early phase of training in the LP model are not maintained during periods of high intensity/low volume training in which optimal muscle mass is essential (Baker et al., 1994; Buford et al., 2007; Moraes et al., 2013). In fact, it has previously been observed, in college male students, that a LP programme improved lean body mass after the first three weeks of resistance training while the subsequent three week period showed a decrease (Stone et al., 1981). This finding may be attributed to the shift from high volume/low intensity to the low volume/high intensity training phase, in which muscle adaptations could not be sustained across distinct phases (Mattocks et al., 2016). Conversely, Baker et al. (1994) and Stone et al. (1982) reported unaltered lean body mass (measured via skin folds) in weight trained participants when training shifted from high volume/low intensity to the low volume/high intensity training phase. Conversely, Simao et al. (2012) found significant increases in lean body mass, evaluated with ultrasound, in men, following 12 weeks of resistance training with an UP model compared to the LP model. Findings from subsequent studies comparing periodisation models to observe changes in lean body mass were rather equivocal (Monteiro et al., 2009; Rhea et al., 2002; Schiotz et al., 1998). In view of the relationship between lean body mass and strength, investigations should employ a more direct estimate, such as magnetic resonance imaging or ultrasound, to gain better insights between training models.

Monteiro et al. (2009) preferred an UP model for trained athletes to improve strength, rather than a LP or non-periodised programme, because greater training variation is experienced within and between training cycles. The authors argued that LP did not include sufficient training load variability to enhance adaptations. It should be noted, however, that the non-periodised programme was likely to sustain the same absolute load throughout the 12 weeks' experimental period (Mattocks et al., 2016). Therefore, the investigators may have failed to acknowledge the principle of progressive overload, hence the participants in the non-periodised programme may have trained with a different level of fatigue (i.e. perceived effort) compared to the UP and LP groups (Dankel et al., 2016). This could possibly explain the inconsistencies in the findings to discover the optimal periodised programme for trained individuals (Peterson et al., 2008; Prestes et al., 2009b; Rhea et al., 2002; Stone et al., 2000).

Regardless, Simao et al. (2012) proposed that variations occurring from one training session to another might lessen the monotony of performing repetitive training sessions and improve adherence. The current trend requires team and individual sports play matches over a long season and sometimes involves two games in a week (Fleck & Kraemer, 1997). Therefore, adjustments can be made to suit an individual's physiological and psychological preparedness for a particular workout following an intense travel timetable (McNamara & Stearne, 2010). This would help athletes stay close to their peak performance for multiple competitions and over an extended period because multiple training goals could be addressed simultaneously (Zatsiorsky & Kraemer, 2006). Table 2.2 shows a summary of training studies that compared LP, non-periodised and UP models to specifically develop muscular endurance or integrate muscular endurance training sessions within a whole training programme.

Table 2.2 Training studies comparing linear periodisation, undulating periodisation and non-periodised programme

Investigators	Participants (training status)	Study period (weeks)	Sessions per week	Comparative training programme(s)		Tests
Kraemer et al., (2000)	24 adult women (trained)	36	2-3	Nonlinear periodised multi-set group	Wk 1-36: Day 1 2- 4 x 4 – 6 RM Day 2 2- 4 x 8 - 10 RM Day 3 2- 4 x 12 – 15 RM	Body fat percentage†, anaerobic power†, counter movement jump†, 1RM bench press†, 1RM shoulder press†, 1RM leg press†, serve velocity†
				Single-set group	Wk 1-36: 1 x 8-10RM	
				Control		
Marx et al., (2001)	34 adult women (untrained)	24	3 (Single set group) 4 (Nonlinear periodised multi-set group)	Nonlinear periodised multi-set group	Wk 1-24: Monday/Thursday 2- 4 x 3 – 5 RM* Monday/Thursday 2- 4 x 8 - 10 RM* Monday/Thursday 2- 4 x 12 – 15 RM* Tuesday/Friday 2- 4 x 8 - 10 RM	Body fat percentage# † ^, Fat-free mass†, 1RM bench press†#, 1RM leg press†#, bench press repetition to exhaustion†#, leg press repetition to exhaustion†#, anaerobic power†, vertical jump†#, 40-yard dash†, resting serum testosterone†, resting serum cortisol†, resting serum insulin-like growth factor†, serum growth hormone
				Single-set group	Wk 1-24: 1 x 8-12RM	
				Control		
Rhea et al., (2003)	30 men and 30 women (untrained)	15	2	Linear Periodisation	Wk 1-5: 3 x 25 RM Wk 6-10: 3 x 20 RM Wk 11-15: 3 x 15 RM	Leg extension repetition to exhaustion§ ∞ *, 1 RM leg extension§ ∞ *. Mid-thigh circumference§∞*.
				Reverse Linear Periodisation	Wk 1-5: 3 x 15 RM Wk 6-10: 3 x 20 RM Wk 11-15: 3 x 25 RM	
				Daily Undulating Periodisation	Workout 1; 3 x 25 RM Workout 2; 3 x 20 RM Workout 3; 3 x 15 RM Workout 4; 3 x 25 RM Workout 5; 3 x 20 RM Workout 6; 3 x 15 RM	

De Lima et al., (2012)	28 adult women (untrained)	12	4	Linear Periodisation	Wk 1 3 x 30RM Wk 2 3 x 25RM Wk 3 3 x 20RM Wk 4 3 x 15RM Wk 5 3 x 30RM Wk 6 3 x 25RM Wk 7 3 x 20RM Wk 8 3 x 15RM Wk 9 3 x 30RM Wk 10 3 x 25RM Wk 11 3 x 20RM Wk 12 3 x 15RM	Fat percentage[§∞β], fat mass[§∞], fat free mass[§ ∞ ^], 1RM bench press[§ ∞ ^], 1RM leg press[§ ∞ ^], 1RM arm curl[§ ∞ ^], bench press repetition to exhaustion[§∞^ β], leg press repetition to exhaustion[§∞^], arm curl repetition to exhaustion[§∞^], cardiorespiratory fitness
				Daily Undulating Periodisation	Wk 1-3-5-7-9-11 Day 1 and 2; 3 x 30RM Day 3 and 4; 3 x 25RM Wk 2-4-6-8-10-12 Day 1 and 2; 3 x 20RM Day 3 and 4; 3 x15RM	

Moraes et al., (2013)	38 male adolescents (untrained)	12	3	Non-periodised	Wk 1-12: 3 x 10 – 12 RM	1RM bench press[#^†], 1RM leg press[#^†], sit and reach test[†^], countermovement vertical jump, standing long jump
				Daily Undulating Periodisation	Wk 1-12: Session 1 3 x 18–20RM Session 2 3 x 8–10RM Session 3 3 x 13–15RM Session 4 3 x 3–5RM Session 5 3 x 10–12RM Session 6 3 x 13–15RM Session 7 3 x 5–7RM Session 8 3 x 10–12RM Session 9 3 x 18–20RM Session 10 3 x 3–5RM Session 11 3 x 13–15RM Session 12 3 x 8–10RM	
				Control		

† indicates significant (p ≤ 0.05) change for nonlinear periodised group from baseline to post-test; # indicates significant (p ≤ 0.05) change for non-periodised group from baseline to post-test; § indicates significant (p ≤ 0.05) change for Linear Periodisation group from baseline to post-test; ∞ indicates significant (p ≤ 0.05) change for Undulating Periodisation group from baseline to post-test; * indicates significant (p ≤ 0.05) change for Reverse Linear Periodisation group from baseline to post-test; β indicates significant (p ≤ 0.05) different between periodised groups; ^ indicates significant (p ≤ 0.05) different from control group; Wk indicates week; RM indicates repetition maximum

2.3.9 Issues affecting training studies

Kraemer et al. (2000) compared integrated muscular endurance sessions within a non-linear periodised multi-set resistance training and single-set circuit resistance training, in adult women tennis players for a period of nine months. Training sessions were conducted two to three times per week, depending on the participants' match schedules. Within the non-linear periodised multi-set group training schemes were altered during each session. Significant improvements were obtained in body composition, power, strength, and serve velocity, compared to baseline scores. This suggests the periodised multi-set resistance training was superior to the single-set protocol. Similarly, Marx et al. (2001) showed that a non-linear periodised multi-set resistance training was superior to a single-set resistance training in untrained women. The periodised group incorporated muscular endurance training sessions within the whole training programme. Participants trained with three to 15 repetitions for two to four sets whereas the other group performed only one set of eight to 12 repetitions for 24 weeks. The non-linear periodised multi-set resistance training improved 12 out of 13 test measures significantly compared to the single-set resistance training. Hence, Kraemer et al. (2000) and Marx et al. (2001) corroborate the advantages of training with non-linear periodised multi-set resistance training programmes which induce homeostatic disruptions and improve physiological capacity in women. It should be noted however, that experimental groups in both studies trained with unequal training volume and intensity, and likely those in the periodised groups trained with higher training volumes. Resistance training with high training volumes yields better responses in comparison to low training volumes (Kramer et al., 1997). This reinforces the significance of training volume as a factor to improve muscular performance (Schiotz et al., 1998).

Rhea et al. (2003) attempted to match training volume and intensity to compare LP, RLP and daily UP to develop muscular endurance in adult men and women. There were no significant differences between the training models after a 15 weeks intervention period. The participants trained two days per week performing only the leg extension exercise in every training session. RLP (72.8%) was more effective than LP (55.9%) and daily UP (54.5%) in developing muscular endurance. Furthermore, training with high volume and light resistance resulted in significant strength gains in RLP, LP and daily UP with 5.6%, 9.1% and 9.8% increases respectively. However, of note, in this research, the resistance used for the muscular endurance test was calculated as 50% of each participant's body mass. This may have provided an advantage to those with light body mass to perform more repetitions in the muscular endurance test (American College of Sports Medicine, 2010). It is also important to highlight that a large variance was observed within the training groups. This may be due to the inclusion of both men and women in the training groups. Additionally, training was performed with only the leg extension exercise during each training session. It is therefore difficult to generalise the findings to recreational or sports performance training in which variations of single- and multi-joint exercises are essential (Kell, 2011).

de Lima et al. (2012) compared LP and daily UP in 28 untrained women to develop muscular endurance over 12 weeks. Findings suggested that both training models improved body composition and strength performance variables with no statistically significant differences observed between experimental groups. LP was more effective for reducing percentage of body fat (12.73%) compared to daily UP (9.93%). Similarly, significant improvements in fat free mass were observed in LP and daily UP, with 4.64% and 3.45% respectively. With respect to maximal strength, LP revealed significant increases in bench press, leg press and arm curl (1.77%, 2.99%, 1.30%) in contrast to daily UP (0.95%, 1.73%, 1.19%) from baseline scores. It should be noted that the initial strength gains obtained (one to eight weeks) may have been due to neural adaptations and thereafter were influenced by increases in muscle mass (Kraemer et al., 2004b; Rhea et al., 2002). Effect size (ES) demonstrated that the daily UP training group yielded significantly higher gains in muscular endurance performance (bench press = 4.48; leg press = 5.16; arm curl = 7.77) as opposed to LP (bench press = 2.19; leg press = 2.67; arm curl = 3.87). Moreover, cardiorespiratory fitness did not exhibit significant improvements in either of the training groups after 12 weeks of training.

Moraes et al. (2013) investigated the effects of two resistance training programmes (non-periodised vs. daily UP) on strength, power and flexibility by integrating muscular endurance training sessions within the whole programme, in untrained adolescents for 12 weeks. ES in bench press (3.4 vs. 1.2) and leg press (6.3 vs. 5.1), were larger following daily UP compared to the non-periodised training programme. The counter movement jump (CMJ) and standing long jump (SLJ) test results showed no change after 12 weeks training within both experimental groups. For these measures, percent change and ES were trivial in both training models. In fact, the performance of these tasks depends on power, and the training did not include any training specific to power development, such as plyometrics, which may, in part, explain why performances were not significantly changed in these tasks (Stone et al., 1999a). Likewise, Millet et al. (2002) stated that minimal changes could be observed within the muscles and metabolic pathways that are not directly recruited during training. Hence, the essence of training specificity was not adhered to and it seems logical that no progress was observed in this strength quality.

In summary, it has been shown that periodisation in resistance training is beneficial to develop strength, hypertrophy, power and muscle endurance in untrained and trained individuals. However, the periodisation strategy should also involve a proper monitoring instrument to guide the designed training plan. Informed decisions about the quality of the periodised plan could be made if physiological, biochemical and psychological elements are incorporated. Of note, excessive accrued fatigue without adequate recovery likely inhibits biological adaptations without which injury risk, illness and overtraining potential are elevated (Foster, 1998; Fry & Kraemer, 1997; McGuigan & Foster, 2004). Therefore, to determine the suitable periodisation structure, monitoring elements should be integrated to regulate and optimise long-term adaptations.

2.4 Monitoring training load: Implications for practice

Multidisciplinary approaches are utilised during training sessions to induce adaptations in the physiological system to obtain positive changes in sports performance (Borresen & Lambert, 2009). As such, the management of training load has a pivotal role in increasing the chances of a prolonged sporting career. Importantly, young athletes need to focus on their prospective psychophysiological development in order to achieve competitive success in their professional careers (Leite & Sampaio, 2012; Murray, 2017). Accordingly, this entails an understanding of how to implement a progressive training load that minimises the possibilities of non-functional overreaching or injury and avoids overtraining (Bourdon et al., 2017). The term training load is defined as the accrued stress from multiple training sessions following a timeframe. This definition includes external training load (e.g. total mileage or poundage) performed, or the internal physiological responses to the training sessions (Gabbett et al., 2014).

Training load is modified to establish functional overreaching at various time points within a periodised training programme. Fatigue may impair physical, technical, decision-making and psychological abilities during different periods of the training mesocycle (Brito, Hertzog, & Nassis, 2016; Knicker, Renshaw, Oldham, & Cairns, 2011). Fatigue monitoring can assist to identify the regeneration capability and can help practitioners to regulate training loads (Fowles, 2006; Scott, Duthie, Thornton, & Dascombe, 2016). Importantly, proper fatigue monitoring could provide an objective justification to positive/negative changes in performance. Thereafter, the obtained data may facilitate prospective training load and readiness for competitions. Of note, acute increases in training load beyond the tolerable training limit may increase the risk of overuse injury, illness and non-functional overreaching (Hulin et al., 2014; Scott et al., 2016). Jayanthi, LaBella, Fischer, Pasulka, and Dugas (2015) stated that practitioners are alert to these risks. They realise it is essential to determine the period when an athlete might be vulnerable to such harmful effects if they are to reduce the loss of training days. Systematic training load monitoring could guide practitioners to identify periods at which an athlete could be experiencing suboptimal training stimulus and/or reduced recovery ability (Claudino et al., 2016b).

In their systematic review, Gabbett et al. (2014) established a relationship between training load and the occurrence of injury and illness in athletes. Likewise, Dennis, Finch, and Farhart (2005) reported that a high bowling workload with less than 3.5 days rest between bowling sessions increased injury risk in fast bowlers aged 14.7 ± 1.4 years, monitored prospectively over the 2002-2003 season. Similarly, Brink et al. (2010b) suggested that soccer players aged 16.5 ± 1.2 years were susceptible to traumatic injury and high risk of illness following high physical (odds ratio 1.01 – 2.59) and psychosocial stress (odds ratio 0.56 – 2.27) in a prospective longitudinal cohort design study over two competitive seasons. Visnes and Bahr (2013) likewise identified training volume as a risk factor for overuse injury. They reported that every additional hour trained in a week (odds ratio 1.18 – 2.53) and every extra set played in competition per week (odds ratio 1.80 – 8.40) were likely to develop jumper's knee in volleyball athletes age 16 to 18 years.

In contrast, Brink, Nederhof, Visscher, Schmikli, and Lemmink (2010a) demonstrated that training load was positively related with field test performance in elite adolescent soccer players with every additional hour of training resulting in enhanced submaximal interval shuttle run test. Similarly, Lovell, Galloway, Hopkins, and Harvey (2006) demonstrated that high training volume may have a protective effect on groin injury in male junior soccer players aged 15 to 17 years. More importantly, Lyman et al. (2001) reported that 300 – 600 baseball pitches a season reduced the risk factor for elbow pain in youth pitchers. Therefore, evidence suggests that training monitoring is of great importance to practitioners. It could help identify the minimal threshold of training load necessary to induce increases in physical performance. A better understanding of the acute and chronic training load patterns will likely improve the management of training load to avoid injury.

Youth athletes may exhibit negative training responses as a consequence of inadequate recovery, which could affect growth, physical development and participation in sport and physical activity (Hartwig, Naughton, & Searl, 2009). It has been postulated that the training load for youth athletes may sometimes rival that of elite adult athletes (Brooks, Fuller, Kemp, & Reddin, 2008). This is due to the fact that some youth athletes participate in a single or several sports with different teams and in different levels of competition (DiFiori et al., 2014). There is a concern that these athletes may be forced to retire, because of overuse injury, before 18 years of age. Huxley, O'Connor, and Healey (2014) indicated that these early retired athletes trained at a higher intensity at 13 – 14 years, completed more high-intensity training sessions at 13 – 14 years and 15 – 16 years and had a higher yearly training load at 13 – 14 years old.

It is also important to highlight that adolescents who switch trainers can be more susceptible to injury risk; individual coaches have different coaching philosophies, experience, planning, and perceptions about the need for high workloads (Murray, 2017). Hence, an adult training prescription might be implemented simply because there is a dearth of longitudinal research associated with youth athlete training load within the literature. It is therefore imperative to monitor training loads routinely to reflect the prescription in training dose. Commonly, youth athletes who desire to achieve elite status often engage in tight training schedules involving several hours of training per day with limited time for recovery (Kentta & Hassmen, 1998). Thus, practitioners should understand the adolescent growth and maturation process to better regulate training load and recovery. However, the adaptation process is often imperfect (i.e. athletes often train fatigued). Therefore, it remains a huge challenge to achieve balance between training load and recovery that would likely induce positive training responses and curtail maladaptation in youth athletes (Kellmann & Günther, 2000).

Muscle fatigue has been defined as an inability to generate maximal force output, decreased efficiency or the inability to attain a performance that was achieved within a recent time frame (Bigland-Ritchie & Woods, 1984; Pyne & Martin, 2011). Fatigue can also be defined as an increased sense of effort (i.e. perception) to sustain work output and it may precede any decrement in performance (Noakes, 2012). Sahlin (1992) suggested that fatigue is influenced by the type of stimulus, type of muscle contraction (e.g. isotonic, isometric), duration, frequency, intensity of exercise and type of muscle involved (large or small muscle group). It is also influenced by the training status of the athlete as well as environmental conditions. Indeed, fatigue is a complex phenomenon that involves a variety of mechanisms (Cairns, Knicker, Thompson, & Sjøgaard, 2005). Given its multifaceted nature, it is difficult to quantify and monitor fatigue in athletes.

The most ecologically valid test of fatigue appears to be the maximal performance test replicating the athlete's event or competition (Halson, 2014). However, it would be impractical to administer such tests regularly in the normal training environment (Thorpe, Atkinson, Drust, & Gregson, 2017a; Wallace, Slattery, & Coutts, 2014). Athletes in a fatigued state may lack motivation to perform maximal effort for non-competitive purposes (Halson, 2014). In addition, it is challenging in many sports, especially team sports, to replicate or define maximal performance (Taylor, Chapman, Cronin, Newton, & Gill, 2012). If only maximal performances are evaluated, it is likely that minimal information would be obtained, possibly excluding the mechanism of fatigue.

For these reasons, various performance and functional capacity monitoring strategies should be implemented during training to get a complete view of the workload of the particular activity (Hendricks et al., 2018; Hoffman & Kaminsky, 2000). It is important to both athletes and coaches that these strategies are simple, non-exhaustive and can provide timely information regarding fatigue status (Thorpe et al., 2017a). The monitoring data could then be reviewed to identify any significant changes prior to making any decision to adjust future training loads. This is critical, as without a systematic approach to training load monitoring in young athletes, practitioners may continue to prescribe adult programmes.

This section has provided a summary of the literature relating to the importance of monitoring training load in young athletes. The following sections will discuss the selected monitoring approaches that can be applied to monitor such training.

2.4.1 Endocrine responses to resistance training

Resistance training induces significant acute hormonal responses and chronic adaptations which are essential to improve muscular strength, hypertrophy, power and muscle endurance (Loebel & Kraemer, 1998). Monitoring these blood hormonal responses could reflect the skeletal muscle growth and remodelling processes within the human physiological system (Viru, Viru, & Bosco, 2003). Kraemer and Ratamess (2005) stated that acute alterations in circulating hormone concentrations as a result of increased secretion, reduced hepatic clearance, plasma volume reductions or reduced degradation rates may indicate interactions with the target tissue cell membrane or with nucleus/cytoplasmic receptors within the target tissue. These interaction processes trigger a plethora of biological events that could initiate a specific response such as elevations in muscle protein and neurotransmitter synthesis (Kraemer et al., 1999). It has been suggested that the micromanagement of the resistance training variables such as training volume, intensity, rest intervals, frequency, type and sequence of exercises plays a vital role in acute responses and subsequent adaptations to ensure optimal neuroendocrine responses (Crewther, Cronin, Keogh, & Cook, 2008). For example, high training volume, moderate to high training intensity coupled with short rest intervals, focusing on large muscle mass, appears to elevate hormonal (e.g. testosterone, growth hormone and cortisol) levels compared to low volume, high intensity protocols with long rest intervals (Kraemer & Ratamess, 2005). Therefore, to improve hypertrophy, strength or power, a programme design must include three principles of training: progressive overload, variation and specificity (Kraemer & Ratamess, 2004). For example, with progressive overload, motor unit recruitment likely increases as a result of intense neuromuscular activity (Sale, 1988). Subsequently, greater muscle fibre recruitment could elevate hormone tissue interactions. As a result, tissue activation could lead to skeletal muscle anabolism (Passelergue & Lac, 2012).

Evidence suggests that monitoring endocrine profiles could provide valuable information regarding the training plan. Fry et al. (2000) reported a noticeable relationship between percentage changes in weightlifting performance and testosterone: cortisol ratio (T:C ratio) in junior weightlifters aged 17 to 18 years, after one week of high volume and three weeks of normal training phases. Changes in baseline T:C ratio for the non-elite group (r = - 0.70) were inversely related to changes in weightlifting performances whereas the elite group (r = 0.00) exhibited no relationship between these variables during high-volume training. In contrast, the non-elite group exhibited positive correlation coefficients (r = 0.51) while the elite group yielded a significant positive relationship during the normal training phase (r = 0.92). This could signify that the elite group tolerated the high training volume while the non-elite group improved, resulting from decreased training volume during the normal training phase. Similar findings had been reported in endocrine profiles of elite male junior weightlifters and Naval Special Warfare Operators (Fry et al., 1994; Oliver et al., 2015b) highlighting the likely advantage of a periodised training plan. This neuroendocrine response following training is also known as the "rebound effect" (Storey et al., 2016).

Several studies have revealed that monitoring endocrine profiles could also be utilised to monitor fatigue in young team sport athletes (Arruda et al., 2015; Maso, Lac, Filaire, Michaux, & Robert, 2004). For instance, McNamara, Gabbett, Naughton, Farhart, and

Chapman (2013) demonstrated that saliva cortisol concentration was high with no significant changes in saliva testosterone following a seven week physical preparation phase. However, testosterone concentration was low with increased cortisol level during the intensified competition period in elite junior cricket players. It may be that these results were due to high workloads and training intensities (batting and fielding drills during the physical preparation phase) and low speed activity with high speed runs during the competition period. Similar results were reported by Alix-Sy, Le Scanff, and Filaire (2008) in football players during a pre-competition period, suggesting that increased cortisol concentrations were due to increases in emotional stress. Taken together, these findings do suggest that monitoring the endocrine profiles of athletes could mirror the physiological milieu of skeletal muscles. However, there is a need to be cautious when making comparisons between experimental studies where training strategies differ between sports (Vingren et al., 2010).

Resistance training monitoring adopting endocrine markers in youth has received limited attention from researchers (Falk & Eliakim, 2014). The restricted number of investigations within this population perhaps stems from ethical and practical issues concerning procedures such as invasive blood sampling. Advancements in non-invasive methods such as saliva analysis to monitor biological variables between and within individuals in sports has attenuated this concern (Urhausen, Gabriel, & Kindermann, 1995). Saliva is an alternative to serum, plasma and urine and enables multiple sampling during training or competition, is stress free and requires minimal medical experience (Papacosta & Nassis, 2011). The use of saliva measures has become attractive in sports and exercise science to monitor hormonal markers (Papacosta & Nassis, 2011). Importantly, saliva hormone levels generally mirror the bioactive component from blood sampling (Rilling, Worthman, Campbell, Stallings, & Mbizva, 1996). For instance, a strong correlation between salivary and serum testosterone concentration has been demonstrated (r = 0.97), reflecting gonadal function (Vittek, L'Hommedieu, Gordon, Rappaport, & Southren, 1985). Several investigators have suggested that salivary cortisol is a superior measure for clinical assessment of adrenocortical function than serum cortisol (Gozansky, Lynn, Laudenslager, & Kohrt, 2005; Neary, Malbon, & McKenzie, 2002). This is, in large part, because saliva sampling, unlike blood sampling, is non-invasive which minimises confounding elements such as additional stress (Passelergue & Lac, 2012).

Testosterone

Testosterone is responsible for many functions in the body, with its secretion controlled by the hypothalamic-pituitary-gonadal-axis (Loebel & Kraemer, 1998). It is a cholesterol-derived hormone that is anabolic in nature (Crewther, Keogh, Cronin, & Cook, 2006). Approximately 44 – 60% of total testosterone are bound to sex hormone binding globulin while the remaining testosterone is either bound to albumin and other binding proteins, or bioavailable. The most biologically active fraction of testosterone (i.e. free testosterone) only accounts about 0.2 - 2% of circulating testosterone (Vingren et al., 2010). It has been suggested that testosterone plays a vital role in the preservation of muscle mass and function in males (Schoenfeld, 2010). There is an indication that an elevation in androgen levels could establish optimal physiological milieu for training and possibly increase strength parameters in athletes (Hakkinen, Pakarinen, Alen, Kauhanen, & Komi, 1988). Likewise, some propose that testosterone affects neural adaptations (Fargo & Sengelaub, 2004). For instance, several studies demonstrated that testosterone levels were positively correlated with a range of performance linked parameters such as muscle mass, lean body mass, maximum strength, rate of force development and power output (Crewther, Cook, Cardinale, Weatherby, & Lowe, 2011a; Crewther, Lowe, Weatherby, Gill, & Keogh, 2009; Häkkinen et al., 1987b). Cook and Beaven (2013) reported that testosterone could predict training motivation and proposed that it may be utilised as a marker to monitor readiness to train and compete. Likewise, elevated testosterone values have also been associated with aggression (Hermans, Ramsey, & van Honk, 2008) and risk-taking (Ronay & Hippel, 2010). Importantly, salivary testosterone concentration seems to negatively correlate to indicators of overtraining, suggesting that it is a reliable marker to monitor training (Maso et al., 2004).

Despite this, research investigating resting testosterone modification following resistance training has produced conflicting findings. Tsolakis, Messinis, Stergioulas, and Dessypris (2000) reported significant testosterone increase following eight weeks of training and which remained unaltered after eight weeks of detraining period. This study recruited 11 to 16-year-old untrained males who trained three sessions per week with seven upper-body machine weight exercises using 3 x 10RM. This finding may inform future resistance training programme designers, especially with respect to recovery phases between resistance training sessions within similar populations. Similarly, Izquierdo et al. (2006) and Staron et al. (1994) observed significant resting testosterone increases in trained men and sedentary males, respectively subsequent to eight to 11 weeks training with different modes (e.g. free weight, machine weight, single- or multi-joint) of resistance training exercises.

In contrast, Gorostiaga, Izquierdo, Iturralde, Ruesta, and Ibáñez (1999) demonstrated no significant differences in resting testosterone after six weeks of combined handball and resistance training in elite junior players. The players trained two resistance training sessions per week with a combination of machine and free weight exercises. Also, Kraemer et al. (1992) demonstrated no significant changes in resting testosterone levels between experienced (>2 years) and less experienced (<2 years) 17-year-old male weight lifters. Similar resting testosterone levels were also reported in adult male weight lifters following four months (Guezennec, Leger, Lhoste, Aymonod, & Pesquies, 1986) and two years (Hakkinen et al., 1988) of training. In their detailed examination of elite junior weight lifters, Kraemer et al. (1992) proposed that chronic intense resistance training could induce significant changes in resting baseline testosterone within trained individuals. It is likely that hormonal alteration in young, trained individuals is linked to the neuroendocrine stimulation process in the hypothalamus pituitary gonadal axis that may elevate testosterone secretion. Other possible known physiological mechanisms that may differentiate responses between trained and untrained individuals would be decreased degradation, modification in clearance rates from tissues, alterations in protein transport and binding and differential cell receptor alterations as a result of training adaptations at the cellular level (Kraemer et al., 1992).

A significant decline in resting testosterone concentration along with reduction in vertical jump height has been observed in elite junior weight lifters aged 17 years old after one week of high volume training (Fry et al., 1993). These responses might be a planned strategy to induce overreaching as the cortisol concentration did not change. However, Gorostiaga et al. (1999) argued that prolonged high load training (i.e. > 80% of 1RM) may likely overstrain the nervous and endocrine systems. Therefore, training frequency (two or three sessions/day) and volume of training (~30000 kg/day to 90000 kg/day) might have elicited an enormous endocrine demand in those elite junior weight lifters, subsequently leading to overtraining. Another point to consider is that youth may have low circulating testosterone, luteinizing hormone and follicle stimulating hormone compared to adults (Martha et al., 1989; Minuto et al., 1988). Thus, high training loads could elicit high endocrine demands, which theoretically, may affect growth processes. This does not mean that training will advance linear growth, but it may affect the mechanism of muscle growth (Falk & Eliakim, 2014). Also, decrements in testosterone levels may have been induced by various concurrent training modalities such as speed, agility and endurance performed by these young athletes to improve sports performance (Gomes et al., 2013; Gorostiaga et al., 2004; McNamara et al., 2013). Painter et al. (2018) stated that these discrepancies in findings were likely influenced by regulatory factors such as environment (e.g. training age, biological age) and training programme design (e.g. rest period duration, volume and intensity). In addition, the modification of resting testosterone levels is suggested to be affected by numerous mechanisms like psychological (Cook & Beaven, 2013), social (Archer, 1991) and physiological (Urhausen et al., 1995) factors.

Recently, Hooper et al. (2017) suggested that resistance training may positively impact performance in youth. For example, Pullinen, Mero, Huttunen, Pakarinen, and Komi (2002) and Pullinen, Mero, Huttunen, Pakarinen, and Komi (2011) observed concurrent increase in testosterone concentrations and strength following resistance training in male youths even though the basal testosterone concentrations were lower than men. Of note, testosterone concentrations have been associated with improved neurotransmitters, regeneration of neurons, increase in neural cell body size and dendrite length (Crewther et al., 2011a; Fargo & Sengelaub, 2004). These neural factors could impact trainability and performance following resistance training. Overall, there seems to be some evidence to indicate that resting testosterone concentrations reflect the present condition of muscle tissue in which the increase or decrease could happen at various time points, depending on substantial changes in training volume and intensity (Hakkinen et al., 1988). Accordingly, it is also important to highlight that tissue remodelling involves two processes: (1) catabolism initiates the process following stimulus and (2) anabolism prevails in the recovery period leading to growth and repair (Kraemer & Ratamess, 2005).

Cortisol

Cortisol is a glucocorticoid, regulated via the hypothalamic-pituitary-adrenal axis. Numerous physical and emotional stressors could generate afferent signals that subsequently induce the secretion of cortisol (Gozansky et al., 2005). Cortisol accounts for relatively 95% of all glucocorticoid activity. It is a widely held view that elevated cortisol levels enhance lipolysis in adipose cells and elevate protein degradation and reduce protein synthesis in muscle cells, thus mobilising fuels for recovery and regeneration after exercise (Crewther et al., 2006; Kraemer & Ratamess, 2005; Nindl et al., 2001). Similarly, the catabolic characteristics of cortisol are suggested to attenuate anabolic hormones like testosterone and growth hormone (Crewther et al., 2006). Approximately 15% of circulating cortisol is bound to albumin and 75% is bound to corticosteroid-binding globulin. The 10% that circulates freely represents the biologically active component (Crewther, Heke, & Keogh, 2011b).

Changes to cortisol concentration is believed to occur as a result of alterations in metabolism, immunity and intense physical exercise (Papacosta & Nassis, 2011). Experiencing a new training programme or substantial elevation in training volume might increase resting cortisol concentrations (Fry et al., 1994; Fry et al., 2000; Painter et al., 2018). Accordingly, as adaptation occurs, cortisol normally returns to baseline levels or lower (Maresh et al., 1994). In contrast, when training volume and/or intensity are reduced, cortisol decreases, likely improving the recovery adaptation mechanism and readiness (Bompa & Haff, 2009; Viru & Viru, 2004). This phenomenon of increase/decrease in cortisol concentrations was observed during training involving elite weight lifters (Tsai et al., 2012). Tsai and colleagues (2012) observed significantly higher cortisol concentrations during training, partly attributed to the high training volume, compared to the recovery phase. Theoretically, greater training stress matched with external stressors such as academic commitments (Lewis, Nikolova, Chang, & Weekes, 2008; Weekes et al., 2006), anxiety and depression (Gold et al., 1986; O'Connor & Corrigan, 1987; Sapolsky, Romero, & Munck, 2000) may elevate cortisol concentrations.

Typically, cortisol is associated to catabolic processes and may impact performance (Leite et al., 2011). For example, an inverse relationship (r = - 0.58) has been detected between cortisol concentrations and explosive strength following 15 weeks of concurrent aerobic and resistance training involving elite junior wrestlers (Passelergue & Lac, 2012). This indicates that following a prolonged period of hard training, the catabolic effects of glucocorticoids could hinder the development of explosive performance. This is due to a higher catabolic condition that may decrease force production because of losses in contractile proteins or neural transmitters normally triggered by testosterone interactions (Kraemer et al., 2004a).

Fry et al. (1994) reported increased cortisol concentration after one year of weightlifting training without attenuating performance. Therefore, other factors may have mediated the improved performance associated with elevated cortisol concentrations. The causal role of cortisol in regulating or controlling energy metabolism (Viru & Viru, 2004), motor cortex function (Sale, Ridding, & Nordstrom, 2008), intracellular signals (Passaquin, Lhote, & Rüegg, 1998), brain neural activity (Papir-Kricheli & Feldman, 1983) and cognitive function (Putman, Antypa, Crysovergi, & van der Does, 2010) has been proposed to affect performance. However, more investigations are required to clarify the likely instrumental mechanism associated with increased cortisol without affecting sports performance (Crewther et al., 2011b).

It has been suggested that resting cortisol levels provide an indication of the chronic effects of training stress (Kraemer & Ratamess, 2005). However, like testosterone, training studies monitoring resting cortisol responses to chronic resistance training do not appear to yield consistent findings. Junior weight lifters and tennis players exhibited no cortisol alterations after training between six weeks to one year (Fry et al., 1994; Fry et al., 1993; Sarabia et al., 2015) whereas reductions were observed by Gorostiaga et al. (2004) in young soccer players following 11 weeks of explosive resistance and soccer training. On the other hand, Passelergue and Lac (2012) reported significant elevation in cortisol concentrations after 15 weeks of mixed aerobic and resistance training in elite junior wrestlers. Considering all the evidence incorporating testosterone and cortisol measures, it seems that the hormonal responses to physical exertion following training yield inconsistent findings. Therefore, there is an obvious need to utilise other available monitoring indexes such as T:C ratio.

Testosterone: cortisol ratio

Evidence suggests that cortisol and testosterone are instrumental in neuromuscular development (Crewther et al., 2006; Crewther et al., 2011a). These endocrine markers have responded after or during stressful conditions to maintain homeostasis (Thorpe & Sunderland, 2012). Since testosterone and cortisol shift in opposite directions following exercise, scientists have advocated the calculation of unbound T:C ratio to estimate the "anabolic milieu" and monitor training and tapering induced performance alterations (Leite et al., 2011; Maso et al., 2004; Urhausen et al., 1995). Either an elevation in testosterone, a reduction in cortisol concentration, or both may indirectly mirror the tissue remodelling of the skeletal muscle, compared to testosterone and cortisol alone (Handziski et al., 2006). Typically, hormonal responses display dual effects: acute and chronic. An acute increase in T:C ratio likely exhibits strength/power characteristics while a chronic increase indicates the possibility of improving strength and power (Crewther et al., 2011a). Previous investigations have established that extended high volume training may negatively impact the neuroendocrine system and magnitude of the T:C ratio (Nemet et al., 2012). Consequently, a consistent prolonged low T:C ratio may impair muscular adaptation, diminish readiness and increase overtraining potential (Painter et al., 2018). A 30% or more decrease in T:C ratio may indicate incomplete recovery and the onset of non-functional overreaching which may develop into overtraining (Urhausen et al., 1995). On the other hand, a tapering, T:C ratio typically returns to baseline or surpasses baseline value resulting from supercompensation (Nelson, Winchester, Stewart, & Stone, 2009). Regardless, a brief deliberate increase in training volume, such as planned overreaching, which almost certainly reduces the T:C ratio was suggested to induce tissue growth and consequently improve performance capabilities after returning to normal training (Storey et al., 2016).

In recent years, there has been an increasing amount of research utilising circulating anabolic: catabolic hormonal balance to manage and optimise training (Antualpa, Aoki, & Moreira, 2017; Miranda et al., 2018; Scudese et al., 2016; West et al., 2014b). In fact, several studies have suggested that athletic readiness was positively correlated to T:C ratio (Fry et al., 1994; Fry et al., 1993; Haff et al., 2008; Nelson et al., 2009). Despite this, it should be noted that correlations do not imply causality (Kraemer & Ratamess, 2005). Nevertheless, T:C ratio still seems to be a beneficial index for monitoring training (Kraemer et al., 2004a; Wu, Hung, Wang, & Chang, 2008). Gorostiaga et al. (1999) demonstrated the significance of T:C ratio after six weeks of heavy resistance training (80 – 90% of 1RM), involving youth handball players. Findings revealed that strength development plateaued simultaneously with T:C ratio in participants who concurrently performed handball and resistance training while a significant increase in T:C ratio was observed in the control group. Also, an increase approaching statistical significance (p = 0.08) was noted in the handball only training group. Prior studies have noted decreases (Fry et al., 1993) and increases (Zakas, Mandroukas, Karamouzis, & Panagiotopoulou, 1994) in T:C ratio, suggesting as overreaching/overtraining or an enhanced milieu for improvement, respectively, following a heavy resistance training period in youth. The catabolic state in participants who concurrently performed handball and resistance training may highlight the overreaching or overtraining condition which requires recovery strategies to restore homeostasis (Nédélec et al., 2013). Likewise, researchers have studied T:C ratio to monitor hormonal alterations in soccer, track and field and basketball athletes (Andre et al., 2018; Kraemer et al., 2004a; Nelson et al., 2009). Thus, the T:C ratio may be utilised to better understand the balance between anabolic and catabolic activity following training (Twist & Highton, 2013).

Indeed, hormonal measures are important indicators of internal load that provides mechanistic insights regarding fatigue (West et al., 2014c). The obtained data would inform researchers and practitioners on the athlete's health status, and from there influence training prescription and recovery strategies (Thorpe & Sunderland, 2012). However, Fry, Kraemer, and Ramsey (1998) have noted overtraining syndrome without alterations to T:C ratio following two weeks of high intensity training in resistance trained individuals. It seems that only monitoring T:C ratio would not detect overtraining symptoms. That said, monitoring T:C ratio is likely essential as it may reflect recovery, preparedness and the physiological status of athletes (Andre et al., 2018). These measures could be expensive, time consuming and practically challenging in the applied environment. Moreover, the multifaceted components of fatigue could not be ascertained on hormonal measures alone (Halson, 2014). Thus, endocrine responses should be examined concurrently with other measures such as neuromuscular and perceptual responses to interpret and provide meaningful feedback to athletes and practitioners.

2.4.2 Rating of perceived exertion

Several investigations have highlighted the significance of monitoring training load to improve performance by varying periods of hard and easy training sessions/days (Antualpa et al., 2017; Aoki et al., 2017; Foster, 1998). Training load may be defined as the total stress imposed on an athlete from multiple training sessions over a period of time, consisting of two elements: (1) external workloads performed, and (2) internal response to the workload (Gabbett et al., 2014). While the external load in periodised training programmes is easy to collect and quantify, it provides limited information about the effects of the training dose. Therefore, sport scientists have attempted to identify a suitable single indicator or measure to monitor the internal training load across all training modalities (Foster et al., 2001; Hendricks et al., 2018).

Monitoring intensity during resistance training had traditionally been a dilemma for athletes, practitioners and researchers. Measures like percentage of maximal heart rate or aerobic capacity and lactate concentration may be utilised to monitor intensity in endurance sports (Halson, 2014). However, there is no commonly accepted means to monitor exertion during resistance training (McGuigan & Foster, 2004; Scott et al., 2016). Exertion is usually associated with intense effort and pain experienced while performing physical or mental work (Hollander et al., 2003). Hence, to achieve optimal results, monitoring exertion during exercise is critical to managing training variations in a periodised programme (Foster et al., 2001). In this regard, training programmes with minimal variation over a prolonged period may affect motivation and might be ineffective, leading to decrement in performance, increased injury risk and illness (Painter et al., 2018). Therefore it is important to adjust the training stimulus at regular time intervals to prevent overtraining (Gamble, 2006). Overtraining could exhibit as a decrease or stagnation in performance which prolongs for weeks or months. However, early stages of overtraining may not be observed as a decline in performance, rather they could initiate as subjective feelings of fatigue and staleness (Hoffman & Kaminsky, 2000).

In order to quantify internal training load, rating of perceived exertion (RPE) was developed and validated by Gunnar Borg in the 1960s (Borg, 1998). A considerable amount of research has investigated RPE across sports, physiological, clinical and psychological settings (Grisbrook, Gittings, Wood, & Edgar, 2017; Haddad, Stylianides, Djaoui, Dellal, & Chamari, 2017; Randall et al., 2002; Turner et al., 2017). RPE is a psychophysiological indicator of stress which acts as a barometer defining the magnitude of discomfort or fatigue felt at a particular moment (Foster et al., 1995; Hollander et al., 2003). It allows a practitioner or researcher to assess trends in training, injury and illness (Foster, 1998; Wing, 2018). RPE is positively correlated to various objective measures of resistance training intensity such as blood lactate concentration

(Hollander et al., 2003; Kraemer, Noble, Clark, & Culver, 1987; Suminski et al., 1997), total weight lifted (Robertson et al., 2003) and muscle activity (Lagally, Robertson, Gallagher, Gearhart, & Goss, 2002a). As a result, RPE has been utilised to quantify internal resistance training intensity (Lagally & Robertson, 2006; Lagally et al., 2002b; McGuigan, Egan, & Foster, 2004; Weakley et al., 2017b). It is also important to highlight that RPE can be used across various training modalities. Therefore, monitoring internal training load is simplified across different training means (Scott et al., 2016).

Resistance training and rating of perceived exertion

Investigations have evaluated resistance training intensity with Borg's 15 category scale (Gearhart et al., 2002; Lagally et al., 2002b) and Borg's 10-point category-ratio scale (CR-10) (Sweet, Foster, McGuigan, & Brice, 2004). Also, experiments have employed the *omnibus* (OMNI) resistance exercise scale that incorporates verbal and pictorial descriptors to evaluate the internal training load (Lagally & Robertson, 2006; Robertson et al., 2003). Gearhart et al. (2002) suggested that RPE is influenced by the relative intensity of the training load in men and women. The participants in their study performed two conditions: a) high load (5 x 90% 1RM) and b) low load (15 x 30% 1RM), in seven resistance exercises. RPE ratings were obtained following every repetition in the high load condition and after every third repetition in the low load protocol. Even though both conditions were identical for total relative volume, findings showed that low load is perceived as easier than high load in resistance exercise. Similarly, much of the research to date, has only investigated RPE responses following different relative intensities but not different loads after individual training sets (Scott et al., 2016). Thus, it is uncertain if the higher perceived ratings were influenced by the high volume of work performed or the high force exerted during each repetition.

Also, RPE ratings could be utilised to distinguish perceived exertion to certain body segments, also known as differential ratings (Gearhart et al., 2002; Lagally et al., 2002b; McLaren, Smith, Spears, & Weston, 2017). Lagally et al. (2002b) and Colado et al. (2014) investigated differentiated RPE ratings and suggested that active muscles rating was always higher compared to whole body rating (i.e. overall RPE) through various range of loads. This demonstrates that high exertion feelings are more dominant in contracting muscles compared to ratings of whole-body exertion. More importantly, differential ratings could provide detailed quantification of internal load to better understand training dose response as it isolates the specific perceptual demands of training (McLaren, Graham, Spears, & Weston, 2016; Weston, Siegler, Bahnert, McBrien, & Lovell, 2015). As a result, individualised recovery strategies could be implemented to individuals who consistently report high RPE values, in order to accelerate the regeneration process. Alternatively, if an athlete reports low values an increase in training load might be required to prevent impairments in fitness profiles (Gil-Rey, Lezaun, & Los Arcos, 2015). Despite providing detailed quantification of internal load, obtaining RPE during resistance training is time consuming, which limits its practical application (Scott et al., 2016). Practitioners dealing with team sports may encounter difficulties obtaining RPE ratings for each set performed by each athlete. Hence, sports scientists have proposed a single index known as session RPE approach to evaluate the global intensity of a whole training session whereas differential ratings utilised as supplementary data (Foster, 1998).

Session RPE

Session RPE offers a convenient strategy to assess internal training load. An athlete needs to state a single RPE index after a training session, compared to providing multiple ratings during the session after each set (McGuigan & Foster, 2004). It is believed that session RPE incorporates the overall sense of effort from the actual loads being lifted in tandem with the number of repetitions, inter-set rest periods, and velocity of repetitions during training (Scott et al., 2016). Egan, Winchester, Foster, and McGuigan (2006) reported no significant difference comparing set RPE and session RPE. Thus, session RPE could signify how intense the training session was perceived to be, in relation to an athlete's current physical and psychological condition (Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004; Lupo, Tessitore, Gasperi, & Gomez, 2017).

Session RPE could minimise the possibility of illness, overtraining and injuries by improving awareness of an athlete's responses to training (Haddad et al., 2017). Importantly, session RPE may enable practitioners to objectively identify excessive training load and subsequently design a training plan that not only improves physical resilience but decreases the likelihood of negative outcomes such as prolonged impaired wellness in young athletes (Lathlean, Gastin, Newstead, & Finch, 2018a). Previously, for consistency of data collection, session RPE was recorded 30 minutes after the training session (Foster, 1998; McGuigan & Foster, 2004; Turner, Bishop, Marshall, & Read, 2015). However, Singh, Foster, Tod, and McGuigan (2007) demonstrated that 15 minutes would also yield a reliable value after resistance training and would permit the athlete to reflect the session as a whole. Singh and colleagues (2007) also proposed that average session RPE at five- or ten-minutes post exercise were significantly higher compared to 30 minutes, because of the influence of the last set of exercises. These lesser time intervals should not be utilised to obtain session RPE despite Uchida et al. (2014) suggesting that session RPE may be obtained ten minutes after a boxing training session. Recently, Scantlebury, Till, Sawczuk, Phibbs, and Jones (2018) proposed that session RPE could be obtained 24 hours after a school training session in youth from three different sports (hockey, rugby and football). It is to be noted that the differences in responses from distinct training modalities might contribute to the different timeframes between studies. Hence, in this thesis, session RPE was obtained 15 minutes after resistance training.

Session RPE allows the calculation of training load, by multiplying the RPE and duration of the session to quantify internal training load (Aoki et al., 2017; Freitas et al., 2014a). Daily and weekly training load can be calculated from this score and depicted graphically to allow practitioners to view and retrospectively examine the training plan. Also, other derivatives like training monotony and strain can be calculated (Foster, 1998). Training monotony is the weekly variation in training load (i.e. mean daily session RPE/standard deviation of the training load over a one-week period). The product of training load and training monotony could be utilised to yield training strain, or the overall stress imposed on the athlete (Foster, 1998).

This strategy seems to be most appropriate for team sports in which the athletes often train together in group exercises such as technical, tactical and conditioning drills (Aoki et al., 2017; Impellizzeri et al., 2004; Lathlean et al., 2018a; Lupo et al., 2017). For instance, if internal training load is computed for resistance training, this could be added to the load calculated from other training modes and, as a result, cumulative internal load for a microcycle from all training sessions can be determined.

Validity of session RPE was assessed in male youth basketball players aged 16.5 ± 0.5 years, for five weeks during an in season (Lupo et al., 2017). Results suggested that practitioners could utilise session RPE to track the internal training load, irrespective of session durations and workout. The general [r = 0.85, intraclass correlation coefficient (ICC) = 0.74] and individual (r range = 0.80 - 0.95, ICC range = 0.62 - 0.82) correlations found from the study of youth basketball players corroborates the findings of a previous work involving senior basketball (Manzi et al., 2010) and other team sports such as water polo (Lupo, Capranica, & Tessitore, 2014) and Australian Football (Scott, Black, Quinn, & Coutts, 2013). Session RPE is a useful strategy to regularly monitor training and is less expensive than measuring heart rate, hormonal levels and lactate (Haddad et al., 2017). Likewise session RPE was demonstrated as a reliable index of global internal training load to monitor soccer training in youth during the first seven weeks of a competitive season in which both anaerobic and aerobic energy systems were trained (Impellizzeri et al., 2004).

Using this approach, researchers have been able to detect changes in internal training load during different phases of training. For instance, Aoki et al. (2017) noted high internal training load during the preparation phase compared to competition phase for both under 16 and under 19 volleyball players. However, the under 19 players reported a higher internal training load during the preparation phase than the under 16. A comparison of these findings with those of other studies confirms the sensitivity of session RPE to monitor external training load (Antualpa et al., 2017; Miloski et al., 2015). Thus, session RPE is widely adopted in team sports to quantify different types of training sessions (Impellizzeri et al., 2004). This may enable practitioners to attain a suitable training load periodisation, consequently minimising overtraining, injury and illness, and optimising physical development (Chamari, Haddad, Wong, Dellal, & Chaouachi, 2012; de Freitas Cruz et al., 2018).

Despite the fact that session RPE is a valuable tool to monitor internal training load, there is still no conclusive agreement about the influencing element of the perceptual effort in resistance training. Genner and Weston (2014) suggested that session RPE is influenced by total training volume performed. A study of physically active men, who trained with three sets of 85, 70 and 55% of 1RM, with two-minute recovery between sets involving five multi-joint exercises, in a randomized, crossover design, separated by seven days reported the following results. The session RPE showed that training with 55% of 1RM was significantly higher [8.0 ± 1.6 arbitrary unit (AU)] than training with 70% of 1RM (6.9 ± 1.4 AU) or training with 85% of 1RM (6.2 ± 2.2 AU). Likewise, Pritchett, Green, Wickwire, and Kovacs (2009) compared resistance training protocols performed to failure (i.e. 3 sets x 60% 1RM vs. 3 sets x 90% 1RM) in leg press, bench press, latissimus pull down, shoulder press, triceps press and biceps curl with 2 minutes rest between sets and exercises in untrained males. Findings revealed that session RPE and total work in 3 sets x 60% 1RM protocol were high (8.8 ± 0.8 AU and 17461 ± 4419 kg) compared to 3 sets x 90% 1RM (6.3 ± 1.2 AU and 8659 ± 2256 kg). In line with previous studies, sport scientists believed that session RPE may be more closely correlated with training volume (Lodo et al., 2012).

Several studies have demonstrated that session RPE is mainly influenced by exercise intensity (Morishita, Tsubaki, Takabayashi, & Fu, 2018; Singh et al., 2007; Sweet et al., 2004). These studies employed resistance-training protocols at sub-maximal intensities (i.e. level of effort) and terminated the training protocol before failure. For example, Day, McGuigan, Brice, and Foster (2004) compared high (4-5 repetitions at 90% 1RM), moderate (10 repetitions at 70% 1RM) and low (15 repetitions at 50% 1RM) intensity training performed with only one set in trained college students. The findings suggest that session RPE was high after the high protocol (6.9 ± 1.4 AU), in which participants attempted to complete a maximum of five repetitions. However, some participants attained failure upon reaching the fourth repetition, but the participants in the moderate and low protocol did not perform the respective trainings to failure. Differences in the perception of effort may have occurred. As a result, it was likely that the participants were instantly able to detect the heavy resistance variation between trials compared to physiological changes and the related sensation of fatigue (Gearhart et al., 2002). Furthermore, it has been noted that various physiological elements could contribute to an individual's RPE (Eston, 2012). Acid-base balance (Stamford & Noble, 1974), greater motor unit recruitment and firing frequency (Gearhart et al., 2002) and neuromotor activity (Lagally et al., 2002b) have also been found to influence elements to RPE ratings. Nonetheless, more research is needed to elucidate the causative link to RPE.

2.4.3 Neuromuscular function measures

There are two general categories of neuromuscular function measures: a) voluntary and b) involuntary. Voluntary assessments consist of isometric, isokinetic dynamometry and isoinertial testing whereas involuntary tests involve twitch or tetanus-interpolation technique. In addition, electromyography (EMG) could be incorporated into both measures to study the motor drive to the muscles (Enoka, 1995). Difficulties arise when comparing muscle force loss between voluntary and involuntary neuromuscular function measures. Repeated and high (e.g. >30Hz) electrical stimulation can decrease peak tetanic force by more than 60% in fast or slow twitch fibres (Cairns, Taberner, & Loiselle, 2009). In comparison, rate coding in volitional contraction is suggested to be slower, and the rate declines as a form of protection or "muscle wisdom" (Enoka & Stuart, 1992; Gandevia, 2001). Therefore, it is thought that fatigue during dynamic exercise could induce smaller force reductions compared to stimulation. For instance, fatigue following repeated-sprint running exercise evoked a 5 – 15% reduction of peak maximal voluntary contraction in physically active males (Perrey, Racinais, Saimouaa, &

Girard, 2010). Likewise, Millet and Lepers (2004) indicated that peak maximal voluntary contraction decreased up to 30% after prolonged cycling. Hence, involuntary neuromuscular function measures may not be appropriate to examine fatigue before/after training as they only investigate mechanisms underlying fatigue instead of the fatigue influence on performance (Cairns et al., 2005; Knicker et al., 2011). Generally, voluntary strategies are favoured over involuntary neuromuscular tests due to the invasive methodology of the latter that may hinder their application to monitor the training processes.

Abernethy, Wilson, and Logan (1995) outlined three classifications of voluntary assessments, which are: a) isometric, b) isokinetic dynamometry and c) isoinertial testing. During isometric assessment, neuromuscular function is evaluated by applying force against an unyielding resistance (Wilson & Murphy, 1996). Isokinetic assessment evaluates force/torque and/or power with constant angular velocity (Cronin & Hansen, 2005) whereas isoinertial testing investigates neuromuscular function, performed with a constant gravitational load that affects muscle tension, length and velocity (Abernethy et al., 1995). Isometric assessment is well-established as a neuromuscular function measure, likely due to its high reliability and experimenter control (Abernethy et al., 1995; Blazevich, Gill, & Newton, 2002). Isometric assessment has consistently been demonstrated to be reliable with high (> 0.80) ICC (Requena et al., 2009; Sawczuk et al., 2017; Thomas, Dos'Santos, Comfort, & Jones, 2017; Till et al., 2018) and coefficient of variation (CV) ≤ 5% or less for maximum voluntary contraction (MVC) force (Howatson & Milak, 2009; Place, Maffiuletti, Martin, & Lepers, 2007). However, several investigators have questioned the usefulness of such an approach due to muscle contraction differences between isometric tests and dynamic performance (Abernethy et al., 1995; Harris, Cronin, & Keogh, 2007; Twist & Highton, 2013). Harris et al. (2007) argued that mechanical profiles and motor unit recruitment patterns of isometric contractions were notably different from dynamic motions. For instance, Cairns et al. (2005) suggested that dynamic motions normally activate less than 50% of muscles while quadriceps MVC activates 95% (Babault, Pousson, Ballay, & Van Hoecke, 2001). Also, power has been exhibited to be reduced significantly due to fatigue compared to force only (Knicker et al., 2011). Therefore, by evaluating force in isolation, isometric testing may miss other important variables related to functional deterioration induced by fatigue (Cairns et al., 2005).

It has been suggested that the isometric mid-thigh pull is a simple measure to monitor skeletal muscle function (Brownlee et al., 2018; Mcguigan, Newton, Winchester, & Nelson, 2010). This test was significantly related to various dynamic performances such as 1RM squat, sprint and agility tests (Wang et al., 2016). Similarly, the isometric mid-thigh pull measure has been positively related to bench press, squat and vertical jump performances (McGuigan & Winchester, 2008). Cronin and Hansen (2005) explained that similar measures/constructs could produce high correlations even though different movement patterns were involved between tests. Specifically, if the investigated constructs are similar such as peak force or rate of force development, then the isometric test likely produces a valid outcome to monitor training. However, since fatigue is multifaceted, tests involving dynamic movement may be more practical to monitor training.

Isokinetic assessment has been reported to have high reliability and experimenter control (Abernethy et al., 1995). However, it may have minimal validity to test dynamic performance, because of the variations in movement patterns (Cairns et al., 2005;

Cronin & Hansen, 2005). In addition, the expensive equipment required and lengthy testing time could hinder the use of this mode in a normal training environment (Falvo, Schilling, & Weiss, 2006). Several investigations had reported a wide range of CVs (3.6 – 16.4%) following isokinetic knee extension/flexion assessment (Brown, Whitehurst, & Findley, 2005; Pua, Koh, & Teo, 2006; Wilson, Walshe, & Fisher, 1997), due to variations in contraction velocity, the test equipment and software used.

Dynamic performances involve isoinertial movements that constitutes eccentric, isometric and concentric contractions (Komi, 2000). Isoinertial tests are likely a more valid mode to evaluate neuromuscular function following dynamic performances (Abernethy et al., 1995). To this end, the vertical jump is often utilised to examine lower-body neuromuscular function. This test is simple and demands minimal familiarisation (Moir, Button, Glaister, & Stone, 2004; Moir, Sanders, Button, & Glaister, 2005). Furthermore, the vertical jump has been utilised to map the recovery process and determine the minimum time required to repeat maximal performance following training and/or competition (Chiodo et al., 2012; Malone et al., 2015; Oliver, Armstrong, & Williams, 2008).

Generally, there are two vertical jump strategies to examine neuromuscular function, CMJ and squat jump (Byrne & Eston, 2002; Cronin, Hing, & McNair, 2004; McLellan, Lovell, & Gass, 2011b). The squat jump specifically evaluates concentric muscle performance. Several studies (Cronin et al., 2004; McGuigan et al., 2006; Moir et al., 2004) have demonstrated high reliability (CV < 5%) in numerous force, power and jump height associated variables in squat jump. However, low reliability (CV > 11%) was reported in rate-based and time derivatives such as rate of force development and time to peak force (Cronin et al., 2004; McLellan et al., 2011b). This inconsistency may be due to the differing sampling frequencies utilised, as rate-based derivatives require higher sampling frequencies (McMaster, Gill, Cronin, & McGuigan, 2014).

Despite comprising concentric movement only, the squat jump measure has been reported to provide more information related to neuromuscular fatigue than CMJ following back squat exercise (Byrne & Eston, 2002) and 90 km ultramarathon (Chambers, Noakes, Lambert, & Lambert, 1998). The CMJ might be less affected due to the potentiating effect of the stretch shortening cycle; the eccentric jump phase might restrict fatigue-induced decreases in neuromuscular function (Byrne & Eston, 2002). However, significant decrements have been observed in CMJ height (-3.0 ± 2.9 cm) compared to squat jump height (-1.4 ± 1.6 cm) after a soccer-specific intermittent exercise test (Oliver et al., 2008). These discrepancies could be attributed to the specificity of the fatigue protocol (Oliver et al., 2008). Byrne and Eston (2002) utilised the barbell parallel squat (10 sets x 10 repetitions at 70% body mass load) while Chambers et al. (1998) described the time course of recovery following an ultramarathon. Oliver et al. (2008) used a procedure that represents the functional characteristics of the exercise bout performed. The findings suggest that the stretch shortening cycle likely detects neuromuscular fatigue following sports specific activities (Girard & Millet, 2009; Nicol, Avela, & Komi, 2006). Therefore, the use of the squat jump for neuromuscular fatigue detection warrants further investigation.

The CMJ, utilising the stretch shortening cycle, may potentially provide a more practical athlete-monitoring tool to assess lower-body neuromuscular fatigue (Oliver, Lloyd, & Whitney, 2015a; Roe et al., 2016b). Ross, Leveritt, and Riek (2001) noted that central and peripheral neuromuscular components could negatively affect stretch shortening cycle activity. Likewise Fowles (2006) and Skurvydas et al. (2007) proposed impaired excitation-contraction coupling would likely reduce stretch shortening cycle activity. As a result, diminished excitation-contraction activity would possibly have adverse effects on CMJ performance and the associated force-time variables. Importantly, Markovic, Dizdar, Jukic, and Cardinale (2004) demonstrated high reliability (CV = 2.8%) for CMJ compared to squat jump (CV = 3.3%).

Thus, the CMJ has been adopted to examine seasonal variations in neuromuscular function and fatigue from training and competition workloads in youth athletes (Malone et al., 2015; Nemet et al., 2012; Oliver et al., 2015a; Sawczuk, Jones, Scantlebury, & Till, 2018; Wehbe, Gabbett, Dwyer, McLellan, & Coad, 2015). For instance, a significant reduction (> 7.5%) in CMJ height was detected after a seven week in-season training and competition mesocycle in academy soccer players (Oliver et al., 2015a). However, Freitas, Nakamura, Miloski, Samulski, and Bara-Filho (2014b) did not observe any significant improvements in CMJ height following a mesocycle (25 days) of normal training in young volleyballers. Aoki et al. (2017) reported that CMJ height significantly improved in elite youth volleyball players after five and four weeks of preparation and competition periods, respectively. Hence, difficulties arise, to ascertain the recovery status of the neuromuscular function from training and competition load, if only CMJ height is utilised.

Markovic et al. (2004) and Gathercole, Sporer, Stellingwerff, and Sleivert (2015a) believed that trained participants might be able to demonstrate altered movement strategies to maintain performance, which aligns with the concept of dynamic systems theory (Davids, Glazier, Araújo, & Bartlett, 2003; Seifert, Button, & Davids, 2013). Legg, Pyne, Semple, and Ball (2017) observed an increase in dip magnitude suggesting that basketball players were attempting a deeper squat before the jump phase, to maintain jump height, following increased training load from pre- to mid-season. Also, evidence supports the assumption that trained athletes exhibit high intra limb joint coordination variability to sustain performance outcome (Gathercole, Stellingwerff, & Sporer, 2015b). In fact, Mudie, Gupta, Green, and Clothier (2016) and Pupo, Dias, Gheller, Detanico, and Santos (2013) detected significant variability of the knee-ankle and hip-knee couplings in the flexion/extension axis during loading and take-off phases in a unilateral hop and bilateral jump protocol, respectively. Hence, these results are in line with those of Thorpe et al. (2017b) who maintain that CMJ height has limitations as a variable to identify fatigue.

Researchers investigating neuromuscular responses to fatigue have utilised several parameters (i.e. eccentric, concentric, and total duration, time to peak force/power, flight time: contraction time ratio) obtained from CMJ (Claudino et al., 2016a; Kennedy & Drake, 2017; Twist & Highton, 2013). Gathercole et al. (2015a) reported a decrement in 18 different neuromuscular variables following a high intensity fatiguing protocol in college team sports athletes. Johnston et al. (2013b) observed significant reduction in CMJ peak power (CMJPP), while no changes were noted in CMJ peak force during five days of male amateur rugby league competition. In contrast, young male soccer players showed decreased contractile rate of force development while no changes in CMJPP and CMJ mean power (CMJMP) immediately after and three to five days post competition (Thorlund, Aagaard, & Madsen, 2009).

Recent meta-analysis supports the use of CMJ as a neuromuscular fatigue measure (Claudino et al., 2016a). However, investigated CMJ variables are not consistent between populations. For example, Roe et al. (2016a) reported flight-time, peak and mean force were within acceptable reliability in youth rugby players, while Cormack, Newton, McGuigan, and Doyle (2008b) reported flight-time, peak and mean force, peak power and jump height were reliable in elite Australian rules players. This contradictory finding emphasizes the need for population focused reliability data to account for differences in anthropometry, physical characteristics and level of athletes between populations. This could be easily accomplished if the data for a specific variable is readily available for the intended population (Buchheit, Lefebvre, Laursen, & Ahmaidi, 2011; Pyne, 2003).

Specifically, researchers must understand when a meaningful change in performance has happened, or, if the degree of change lies between the acceptable reliability of the outcome variable, known as typical error or CV (Hopkins, 2000). Importantly, trained individuals likely have acquired expertise to sustain performance, which in turn could affect reliability (Seifert et al., 2013). Therefore, it is vital for researchers investigating neuromuscular function in trained athletes to report the between day reliability of a variable to permit researchers and practitioners to confidently interpret their findings (Roe et al., 2016a). A large volume of published studies refer to the reliability of tests conducted in different populations (Johnston, Gabbett, Jenkins, & Hulin, 2015; McLean, Coutts, Kelly, McGuigan, & Cormack, 2010). There are also studies that report reliability data, however, these studies do not report how the reliability data was derived (within or between day) (Johnston et al., 2015; Johnston et al., 2013b; Twist, Waldron, Highton, Burt, & Daniels, 2012) and a considerable amount of research does not report reliability data (Johnston, Gabbett, & Jenkins, 2013a; McLellan, Lovell, & Gass, 2011a; West et al., 2014a; West et al., 2014c).

Along with CMJ, the plyometric push up (PP) had been examined to monitor upper-body neuromuscular fatigue (Johnston et al., 2013b). In fact, previous investigations have involved post-match analysis, whereas limited experiments have been conducted with CMJ and PP as evaluators of fatigue and readiness prior to resistance training. Importantly, Watkins et al. (2017) suggest differences may exist between post-match team sport competition and resistance training performance, specifically in movement patterns and central nervous system activity such as decision making. It seems that a neuromuscular function measure could provide information pertaining to the recovery status of an individual following sports specific training or competition. Surprisingly, there is limited research regarding the utility of CMJ and PP to investigate the long-term responses following a periodised resistance training.

2.4.4 Subjective self-report measures

Subjective self-report measures to monitor overall well-being of athletes have become increasingly prominent in high performance sports (McLean, Petrucelli, & Coyle, 2012; Saw, Main, & Gastin, 2015a; Taylor et al., 2012). A plethora of subjective self-report measures is currently available to understand an athlete's readiness to train. These include: Profile of Mood States (POMS) (Chennaoui et al., 2016), Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) (Kellmann, Altfeld, & Mallett, 2016), Daily Analysis of Life Demands for Athletes (DALDA) (Rushall, 1990) and Total Quality Recovery (TQR) scale (Kentta & Hassmen, 1998). It has been suggested that an increase in global mood disturbance appears to be positively related to increased risk of overtraining (Halson & Jeukendrup, 2004). Whereas optimal exercise load may augment mood state of trained athletes, very high training loads could negatively affect wellness measures (Morgan, Costill, Flynn, Raglin, & O'connor, 1988), suggesting a link between exercise load and mood state. In fact, changes in perceived fatigue and muscle soreness have persisted up to four days following competition (Fullagar, Govus, Hanisch, &

Murray, 2017) compared to recovery period for neuromuscular performance and biochemical markers (Twist et al., 2012).

These subjective self-report measures can be lengthy, time consuming and not sports specific (Fuller et al., 2017; Halson, 2014). These drawbacks could influence athlete compliance, and elevate the difficulty of data analysis and reporting (Twist & Highton, 2013). Even though 84% of respondents reported using self-report tools to evaluate fatigue in high-performance sports, in practice, the application is often limited (Taylor et al., 2012). Taylor et al. (2012) noted that psychometric questionnaires like RESTQ-Sport, DALDA and POMS were only used by practitioners 13%, 2% and 2%, respectively. Therefore, Thorpe et al. (2017a) recommended customised wellness questionnaires to obtain subjective information. Customised wellness questionnaires may be sensitive to acute and chronic training loads compared to generally utilised objective methods (Saw, Main, & Gastin, 2015b). Likewise, data from several studies suggested that customized questionnaires detected changes in training load, with a reduction in wellness scores associated with an increment in training load (Bouaziz et al., 2016; Buchheit et al., 2013; Elloumi et al., 2012). Also, decreased training load improved wellness scores during a tapering phase (Bouaziz et al., 2016). As a result, 80% of practitioners applied customised Likert scale questionnaires consisting of 4–12 items encompassing scores from one to five or one to 10 (Bouaziz et al., 2016; Taylor et al., 2012). These customized questionnaires are commonly used to evaluate perceived muscle soreness, sleep quality, sleep duration and perceived fatigue and wellness.

McLean et al. (2010) established a customised wellness questionnaire to evaluate global well-being of athletes. This five-point scale instrument evaluates five items: fatigue, sleep quality, general muscle soreness, stress level and mood. Hence, the global well-being of athletes can be monitored by adding the five ratings, in addition to an individual examination of each characteristic. In recent years, in parallel with increased professionalisation of sport at younger ages, investigators have established that customised wellness questionnaires are sensitive to daily, within-weekly and seasonal changes in training load within youth (Antualpa et al., 2017; Noon, James, Clarke, Akubat, & Thake, 2015) and collegiate/high school sport athletes (Fullagar et al., 2017). The five item customised wellness questionnaire likely identifies players with reduced wellbeing scores as this may impact players training output and match performance (Lathlean, Gastin, Newstead, & Finch, 2018b). Taken together, these results suggest that a customised wellness questionnaire is likely beneficial in youth sport settings. The context in which youth are required to operate, academic, social and maturational, and the impact these may have on their well-being alongside their sporting careers warrants the use of such a tool (Mountjoy et al., 2008).

Accordingly, to monitor training cycles, strength and conditioning practitioners may incorporate subjective tools to track athletes' wellbeing. Wellness questionnaires may not reflect resistance training stresses per se, however, they may indicate cumulative training stress from various training strategies that likely affects trained athletes. Therefore, it is recommended that practitioners who incorporate resistance training as part of the overall training process include wellness questionnaires to monitor training (Saw et al., 2015b). Antualpa et al. (2017) investigated the responses to a four-week intensified training phase, followed by two weeks of reduced training load in youth gymnasts aged 14.9 ± 2.5 years. Importantly, the investigators managed to identify periods (i.e. intensified training phase) in which the gymnasts reported low global well-being scores, suggesting coaches should be cognizant of these lows and incorporate supportive measures during the long-term training process. Furthermore, youth athletes are vulnerable to non-training stressors like academic stress that could require the attention of practitioners or sport scientists as this may affect an athlete's sleep, mood and fatigue, consequently increasing fatigue levels (Hamlin, Wilkes, Elliot, Lizamore, & Kathiravel, 2019).

Evidence suggests that it might be beneficial to quantify wellness data (Lathlean et al., 2018b). For example, if an athlete reports excessive muscle soreness of the lower-body for three consecutive days after high load squat training, the practitioner could adjust the subsequent training loads or propose appropriate recovery strategies. Therefore, soreness ratings might be utilised to improve decision making about the subsequent training plan. However, it is important to highlight that interrelations between training, competition and resistance training may exist that could have implication on wellness ratings (Scott et al., 2016). Wellness ratings should be compared with other objective monitoring modes before an informed decision is made. There is still limited use of this wellness questionnaire specifically to monitor a periodised resistance training (Scott et al., 2016). Even though the evidence is encouraging, more research is required to elucidate the application of a wellness questionnaire to monitor resistance training.

2.5 Direction of research

Resistance training has been utilised as part of a total strength and conditioning programme for many years by sports scientists and practitioners to improve performance. To optimise further the benefits of resistance training, periodisation has been implemented to achieve the desired training goals. The literature reviewed suggests that even though more youth are becoming involved in sports and include resistance training as part of their training programmes, research utilising them as participants in a periodised resistance training remains scarce. The research that is available is indirect and speculative since the participants were typically untrained or trained men or women. Most studies examined the development of neuromuscular qualities such as hypertrophy, maximum strength and power. Thus, it is difficult to generalise the findings of these studies to youth populations. Specifically, direct comparison of LP and UP to develop muscular endurance in youth athletes is limited. With this mind, this thesis seeks to further clarify the efficacy of periodisation and elucidate the best method to vary the exercise stimulus to develop muscular endurance in youth athletes. In addition, the effects of muscular endurance training on other neuromuscular qualities such as strength, hypertrophy and power were also examined. Accordingly, the thesis describes the responses within this process (i.e. physiological, neuromuscular and perceptual) to the training stimulus. Indeed, a concurrent monitoring approach to resistance training is critical. Specifically, internal and external training loads should be evaluated together to obtain greater insight into training stressors. Evaluating internal and external training loads together may provide the fatigue/recovery status which could allow the implementation of appropriate sequence of training loads to ensure optimal physical performance. Importantly, adolescence is a challenging period due to lifestyle factors (i.e. family and academic commitments). As such, adapting a holistic approach to monitor how young athletes adapt with training may not just benefit the regulation process but optimise the stimulus-adaptation process.

Chapter 3 Reliability and Sensitivity of Countermovement Jump and Plyometric Push Up Measures in Trained Youth Athletes

3.1 Overview

Chapter 2 underscored the significance of consistency in neuromuscular function measures. Specifically, the reliability and sensitivity of neuromuscular function measures varied between populations within the literature. As limited information was available regarding the consistency of neuromuscular function measures in field hockey athletes, the primary objective of this study was to determine the between-day reliability and sensitivity of the commonly utilised CMJ and PP measures in youth field hockey athletes.

3.2 Introduction

Strength and conditioning practitioners have regularly utilised performance assessments to monitor an athlete's readiness for competition, to support player selection and monitor training (Bangsbo, Mohr, Poulsen, Perez-Gomez, & Krustrup, 2006). Performance assessments provide an objective justification to observed changes, thereby minimising the degree of uncertainty in decision making (McGuigan, Cormack, & Gill, 2013). Importantly, assessments should be reliable with minimal measurement error (Atkinson & Nevill, 1998). Test-retest reliability is defined as consistency of measurements (i.e. degree of precision) or consistency of an individual's performance excluding measurement error (Hopkins, 2000). However, practically there will be a minimal amount of error (i.e. systematic and non-systematic) that contributes to the difference between observed and true value with repeated assessments (Hopkins, 2000). Hence, test-retest reliability is considered as the amount of acceptable measurement error of an assessment or performance which has essential implication towards the analysis of the observed data.

The CMJ is a popular assessment tool used to measure lower-body neuromuscular function in athletes (Sawczuk et al., 2017; Taylor et al., 2012). It is simple to execute with low physiological strain and allows multiple individual assessments over a short period of time. Research has suggested that it is beneficial to explore a range of variables that characterise an athlete's jump performance (Gathercole et al., 2015a; Markovic et al., 2004). This has led sport scientists and practitioners to investigate other kinetic and kinematic performance variables in an attempt to understand the underlying factors contributing to the maximal jump performance, reflecting movement efficiency of the athlete (Newton & Dugan, 2002). Likewise the obtained data (i.e. kinetic and kinematic variables) can potentially provide information to practitioners for monitoring training programmes (i.e. examine lower-body explosive qualities), optimising programme design or determining the neuromuscular status of their athletes in response to training and competition (Cormack, Newton, & McGuigan, 2008a; McGuigan, Cormack, & Newton, 2009). The PP has been proposed as a test to evaluate various force and power related measures (Lyttle, Wilson, & Ostrowski, 1996; Wilson, Murphy, & Giorgi, 1996). The PP has also been utilised to investigate and monitor upper-body neuromuscular function in players following rugby league match-play (Johnston et al., 2015; Johnston, Gabbett, Jenkins, & Speranza, 2016) and in military personnel (Dhahbi et al., 2016).

Studies investigating changes in neuromuscular function in team sport athletes should establish the reliability of the CMJ and PP tests as the reliability of these tests is population specific (Roe et al., 2016a; Weakley et al., 2017a). Importantly, trained individuals have likely acquired expertise to sustain performance which, in turn, could affect reliability (Seifert et al., 2013). Improvement in physical performance may have been related to training and/or to maturation and growth (Quatman, Ford, Myer, & Hewett, 2006). Biological age, increases (i.e. body height and weight) and maturation of the nervous, endocrine, muscular and cardiovascular systems lead to gains in neuromuscular performance (Naughton, Farpour-Lambert, Carlson, Bradney, & Praagh, 2000). Thus, it is essential to report the reliability of specific tests to assist other investigators to confidently interpret the presented data.

There is a plethora of investigations on the reliability of CMJ (Cormack et al., 2008b; Hori et al., 2009) and PP (Hrysomallis & Kidgell, 2001) in trained adults. However, limited data exists on the reliability of CMJ and PP in trained youth athletes (Roe et al., 2016a; Thomas et al., 2017). Youth athletes are susceptible to injury due to maturation (Hewett, Myer, Ford, & Slauterbeck, 2006). Thus, additional information will provide accurate neuromuscular measures to assess their responses to training programmes or preparedness for training and competition. Common measures of reliability are the CV and ICC. The CV refers to 'the typical percent error', the standard deviation of an individual's repeated measures expressed as a percent of the individual's mean test score and is the within participant random variation from one trial to the next (Hopkins, Schabort, & Hawley, 2001). The ICC, measures how well the values from one trial relate to the values from another trial when moving from participant to participant, as well as the reproducibility of the rank order of the participants with retesting (Hopkins, 2000; Hopkins et al., 2001).

Reliability statistics are imperative to practitioners and sport scientists. Constraints associated with the field of strength and conditioning, such as time limitation, player access and logistics may prevent the development of retest reliability statistics specific to the cohort under training. Whilst several studies have utilised CMJ and PP in non-athletic (Quatman et al., 2006) and athletic youth (Al Haddad, Simpson, & Buchheit, 2015; Haines, Bourdon, & Deakin, 2016; Roe et al., 2016a), it is important to note that currently no study has attempted to determine the between-day reliability of neuromuscular function in youth field hockey players. Therefore, the purpose of this study was to establish the between-day repeatability and sensitivity of each variable of interest in CMJ and PP in well-trained youth field hockey athletes.

3.3 Methods

3.3.1 Experimental approach to the problem

To establish the between day reliability and sensitivity of both CMJ and PP, well-trained youth athletes underwent two testing sessions separated by a minimum of seven days (i.e. test-retest approach). The testing sessions were conducted during the pre-season phase as part of their normal training. Each participant performed nine training sessions a week including both physical preparation and sports specific training. The participants continued their normal schedule and did not perform any strenuous lower- or upper-body exercise 48 hours prior to any testing session to minimise the influence of fatigue. Three habituation sessions were administered prior to the first test. Maturity status was self-reported (Tanner stage) by the participants.

3.3.2 Participants

Sixteen male trained youth field hockey athletes (mean ± SD age = 16.4 ± 0.5 years, height = 1.66 ± 0.06 m, body mass = 60.7 ± 8.4 kg, Tanner scale = 4.75 ± 0.40) volunteered for the study. All participants were from the national sports school (i.e. academy). Inclusion criteria required volunteers to have a minimum of two years of resistance training. The sample size for the current investigation was consistent with previous reliability investigations in trained athletes (Cormack et al., 2008b; Markwick, Bird, Tufano, Seitz, & Haff, 2015). Participants were fully informed about the procedures, possible risks and purpose of the study and signed informed consent along with parental consent before commencing. Ethics approval was granted by the University's ethics committee.

3.3.3 Procedures

Test sessions were conducted indoors at the same time of the day (± 1 hour across all trials) to minimise potential variation of results due to diurnal fluctuations (Souissi et al., 2012). Prior to administration of the tests, a standardised warm-up was conducted as previously described (Roe et al., 2016a). Briefly, following a five-minute self-paced jogging, dynamic stretching consisting of walking lunges, squats, heel flicks, high knees, skipping, legs swings and three practice submaximal CMJ and PP was performed. Subsequently, CMJ and PP were assessed using a portable force plate (400 Series Performance Plate, Fitness Technology, Adelaide, Australia) interfaced to a computer using software (Ballistic Measurement System, Fitness Technology, Adelaide, Australia) with a sampling rate of 600 Hz. For CMJ, the participants kept their hands akimbo during the entire jump. When instructed, they dipped to a self-selected depth before rapidly jumping as high as possible. A self-selected depth during a countermovement has been suggested to minimise error. The minimal technique adjustments involved (i.e. skill) maximises the potential application where time constraints might exist (Cormack et al., 2008b; Theodorou & Cooke, 1998). The PP commenced in a push-up position with the volunteers' hands on the force platform in a self-selected width and arms extended. When instructed, they lowered their body by flexing their elbows before extending as fast as possible, so the hands leave the force platform simultaneously. No instruction was provided regarding the depth performed before the concentric phase of the push up. Participants performed two practice trials before performing three maximum test trials for both CMJ and PP assessments. One-minute recovery was given between efforts.

The following measures were calculated to investigate suitable metrics of interest in youth field hockey athletes. These were selected based on the commonly examined metrics in team sports within the literature (Johnston et al., 2013b; Roe et al., 2016a).

Jump/push up height in metres: peak height

Flight time in seconds: difference between take-off and landing time

Flight time: contraction time: ratio of flight time to contraction time (eccentric + concentric time)

Peak force in Newtons: highest force recorded during the concentric phase

Mean force in Newtons: mean force during the concentric phase of the jump/push up

Peak power in Watts: highest power generated during the concentric phase

Mean power in Watts: mean power generated during the concentric phase of the jump/push up

3.3.4 Statistical analysis

Data were presented with 90% confidence limits (CL). All data were first log-transformed to reduce non-uniformity of error. The between-day reliability of the examined metrics of interest was calculated to determine typical error (TE) and was transformed to a CV expressed as a percentage. A CV of 5% was set as the standard to confirm if a variable was reliable (Roe et al., 2016a). ICC was interpreted as follows; > .20 - < .49 = low, > .50 - < .74 = moderate, > .75 - < .89 = high, > .90 - < .98 = very high or > .99 - 1.0 = extremely high (Hopkins, 2015b). CV, together with ICC, was calculated from the best of three trials using a Microsoft Excel spreadsheet (Hopkins, 2015a). In order to determine the sensitivity of each metric, the smallest worthwhile change (SWC) was calculated as 0.2 x between subject standard deviation and determined as a percentage of the mean in order to match with the CV (Roe et al., 2016a). Sensitivity of each metric was classified as follows; good (CV < SWC), OK (CV = SWC) or poor (CV > SWC) (Hopkins, 2004).

3.4 Results

Reliability for the variables is displayed in Tables 3.1 and 3.2 for CMJ and PP respectively. Tables 3.1 and 3.2 also show SWC (%), CV (%), sensitivity and ICC of each metric. For CMJ, most measures maintained below the threshold of CV < 5%. Despite this, only mean force, peak power and mean power could detect SWC. Conversely, only mean force exhibited acceptable reliability and sensitivity with CV < SWC in PP.

Table 3.1 Results of selected countermovement jump variables

	SWC %	CV % (CL)	Sensitivity	ICC (CL)	ICC range
Jump height	2.3	5.0 (3.8, 7.2)	Poor	0.86 (0.70, 0.94)	High
Flight time	1.1	3.7 (2.8, 5.3)	Poor	0.72 (0.43, 0.87)	Moderate
Flight time: contraction time ratio	2.8	10.2 (7.8, 15.0)	Poor	0.70 (0.41, 0.86)	Moderate
Peak force	3.0	4.0 (3.1, 5.8)	Poor	0.94 (0.87, 0.98)	Very high
Mean force	2.7	1.0 (0.7, 1.4)	Good	1.00 (0.99, 1.00)	Extremely high
Peak power	3.4	3.0 (2.3, 4.4)	Good	0.97 (0.94, 0.99)	Very high
Mean power	3.2	2.7 (2.1, 3.8)	Good	0.98 (0.95, 0.99)	Very high

SWC = smallest worthwhile change; CV = coefficient of variation; CL = confidence limit; ICC = intraclass correlation coefficient

Table 3.2 Results of selected plyometric push up variables

	SWC %	CV % (CL)	Sensitivity	ICC (CL)	ICC range
Push height	9.5	37.1 (27.7, 57.4)	Poor	0.70 (0.41, 0.86)	Moderate
Flight time	8.7	24.5 (18.5, 37.0)	Poor	0.81 (0.59, 0.91)	High
Flight time: contraction time ratio	4.2	21.0 (15.9, 31.6)	Poor	0.57 (0.20, 0.79)	Moderate
Peak force	3.0	15.7 (11.9, 23.3)	Poor	0.53 (0.15, 0.77)	Moderate
Mean force	2.9	2.2 (1.7, 3.2)	Good	0.98 (0.95, 0.99)	Very high
Peak power	5.2	15.7 (11.9, 23.2)	Poor	0.78 (0.54, 0.90)	High
Mean power	4.6	11.0 (8.4, 16.1)	Poor	0.84 (0.66, 0.93)	High

SWC = smallest worthwhile change; CV = coefficient of variation; CL = confidence limit; ICC = intraclass correlation coefficient

3.5 Discussion

The purpose of the present study was to assess the between-day reliability and sensitivity of selected metrics in CMJ and PP in well-trained youth field hockey athletes. This investigation demonstrated that the majority of CMJ measures were reliable. Compared to PP, only mean force exhibited sufficient reliability. Accordingly, CMJ mean force (CMJMF), CMJPP and CMJMP were sensitive metrics in male youth field hockey players. Only PP mean force (PPMF) exhibited an acceptable level of sensitivity. These findings enable practitioners to select sensitive markers so they may employ objective indicators to assess progress and training programme for different applications (e.g. fatigue monitoring) in similar populations.

A previous investigation reported that CMJ flight time: contraction time ratio was not a reliable measure whereas, PP peak power, flight time, peak force and mean force were reliable in elite male youth rugby union players (Roe et al., 2016a). Johnston et al. (2015) used peak power during both CMJ and PP to monitor fatigue in male sub-elite youth rugby players. Another study by Johnston et al. (2013b) monitored peak power and peak force in CMJ and PP in amateur male rugby league players. These data suggest the reliability of the CMJ and PP variables must be addressed specifically to the population as not all variables are sensitive to determine neuromuscular function (McLean et al., 2010; Taylor et al., 2012). This reinforces to practitioners and sport scientists that they must utilise reliability data from players of the same sport and status (i.e. amateur or professional). Training status, gender, duration of test, time between trials and factors unique to specific tests (e.g. arm swing during CMJ) are elements that must be considered (Hopkins et al., 2001).

It should be noted that reliability data concerning the PP are still limited in youth populations compared to CMJ measures (Hogarth, Deakin, & Sinclair, 2013; Roe et al., 2016a). Hogarth et al. (2013) demonstrated mean force and impulse were reliable in a study involving 14 sub-elite rugby league players (SWC not reported), whereas flight time, peak force and mean force were reliable with only mean force able to detect SWC in elite rugby union players aged 17.6 ± 0.5 years (Roe et al., 2016a). Only mean force was reliable and able to detect SWC in the present study. It has been stated that in addition to the reproducibility of a test (i.e. ICC), practitioners conducting assessments must consider the SWC to ascertain if an observed value actually reflects true change (Negrete et al., 2010). The ICC only indicates the consistency in the rank of an individual within the group and may be influenced by the heterogeneity between the individuals tested (Hopkins, 2000). Thus computing the SWC provides additional information in regard to routine monitoring of changes in an individual (Hopkins, 2015b). With this information, practitioners can be confident that changes in the SWC represent true gain that exceeds measurement error to better direct interpretation of performance outcome. SWC is essential when monitoring the progress of athletes because inter-trial variation may incorrectly suggest a change that has not exceeded the threshold of error. This calculation can play an important role in goal setting for strength and conditioning professionals.

Al Haddad et al. (2015) reported that CMJ jump height, assessed with a force platform, was reliable for monitoring changes in trained male youth footballers (13 - 17 years old). However, the players jump performance improved slightly by ~6% across the assessment period. The investigators could not identify if these responses were associated with training and/or maturation and growth. In contrast Lloyd, Oliver, Hughes, and Williams (2009) reported poor reliability of CMJ height (CV = 13%) in untrained males aged 13.5 ± 0.5 assessed with a contact mat. Therefore, comparison between studies is difficult due to factors such as different equipment used for testing. In fact, young boys exhibit increases in vertical jump height during maturation (Quatman et al., 2006). Consequently, the evidence shows that discrepancies exist in maturity timing and physical performance among players of the same chronological age within the same team (Figueiredo, Coelho e Silva, Cumming, & Malina, 2010). This is observed in biomechanical (i.e. kinematics, kinetics) and neuromuscular (i.e. energy absorption, stiffness, and muscle strength) dissimilarities between players which can affect jumping performance (Chappell, Yu, Kirkendall, & Garrett, 2002; Decker, Torry, Wyland, Sterett, & Steadman, 2003; Ford, Myer, & Hewett, 2003; Hewett, Stroupe, Nance, & Noyes, 1996). Caution is needed when directly comparing force plate reliability measures in youth populations. Variability in the performance of stretch–shortening cycle tasks is greatest in younger participants and recedes as they move towards adulthood as specialised movement skill such as CMJ is dependent on age, experience, and practice (Gerodimos et al., 2008).

This investigation examined the between-day reliability and sensitivity of the selected measures in CMJ and PP in male youth field hockey athletes. These evaluations allow a relatively easy mode of performing a comprehensive analysis of kinetic and kinematic variables. In addition, both assessments require minimal time and effort to perform. The tests can be incorporated before a regular training session as part of a team sports monitoring programme. This is essential as youth athletes are vulnerable to injury risk due to maturation. Further research should investigate the reliability and sensitivity of

CMJ and PP in youth athletes across different sports, between sexes and maturity levels to optimise training programme monitoring.

3.6 Practical application

This research showed that CMJMF, CMJPP, CMJMP and PPMF obtained both acceptable reliability (CV < 5%) and sensitivity in male youth field hockey athletes. The measures obtained displayed consistency when performance status unchanged. Based on the findings, practitioners can utilise the suggested force and power metrics to ascertain whether a change is real or is due to testing error. This is essential for the precise quantification of functional capacity for monitoring purposes. In addition to CV, it is recommended that sports scientists and practitioners calculate the SWC to ascertain the sensitivity of the observed data to detect the smallest practical change.

Chapter 4 Acute Response to Two Different Muscular Endurance Resistance Training Sessions Monitored Through Neuromuscular Function, Endocrine and Wellness Assessments in Youth Athletes

4.1 Overview

A search of the literature (Chapter 2) revealed minimal information regarding the impact and the subsequent recovery profiles after a muscular endurance training session. Also, the findings in Chapter 3 justify the inclusion of CMJMF, CMJMP, CMJPP and PPMF to evaluate neuromuscular function following a muscular endurance training session in youth field hockey athletes. The primary objective of this randomised cross-over study was to investigate the neuromuscular function, endocrine and perceptual wellness responses following two different muscular endurance resistance training sessions in trained youth field hockey athletes. Profiling these measures will provide valuable information for both practitioners and athletes when considering the implementation of this type of training during programme design.

4.2 Introduction

Resistance training is widely used to optimise sports performance and minimise injury (Halson, 2014). When programmed with appropriate training intensity and volume, resistance training furnishes a potent stimulus for the development of strength, power, hypertrophy and muscular endurance (Kraemer & Ratamess, 2004) across different populations (Bartolomei et al., 2014; Cheema, Chan, Fahey, & Atlantis, 2014; Kennis et al., 2013; Tavares et al., 2017). In particular, the designed exercise programme has the potential to disrupt homeostasis, which is then reinstated, through recovery, following the training session (Borresen & Lambert, 2009; Kraemer, Ratamess, & Nindl, 2016). An optimal balance between training session loads and recovery is critical to ensure that the athlete's physiological systems are appropriately stimulated to adapt and recover. This equilibrium is of interest because athletes train with other training modalities concurrently (e.g. technical, tactical and physical conditioning) to enhance performance (Weakley et al., 2017b). Therefore, demands of numerous components of training could temporarily diminish an athlete's performance (Barnett, 2006). This impairment may be acute, lasting minutes or hours after training, or more chronic, lasting several days (Barnett, 2006). Of note, insufficient recovery could facilitate muscle fatigue and may modify motor coordination, decrease movement stability and alter kinetic and kinematic variability (Johnston et al., 2013a; Knicker et al., 2011).

Data from several studies suggest that the magnitude of fatigue could rely on the stimulus imposed, which is the exercise or training protocol itself (Aboodarda, George, Mokhtar, & Thompson, 2011; Villanueva, Villanueva, Lane, & Schroeder, 2012). Byrne and Eston (2002) observed a decrease in knee extensor torque and jump height 72 hours following a high volume (10 sets x 10 repetitions x 70% body mass) back squat exercise in moderately active participants, while Flores et al. (2011) demonstrated a significant decrement in peak torque 96 hours subsequent to performing a high volume elbow flexion protocol (8 sets x 10RM) in physical education students. Recently, Bartolomei et al. (2017) reported that CMJPP was impaired for up to 48 hours in resistance-trained men after performing eight sets of 10 repetitions at 70% of 1RM in back squat exercise. In a similar fashion, Hiscock, Dawson, Clarke, and Peeling (2017) examined the acute influence of hypertrophy training session on CMJ performance (mean and peak power; mean and peak velocity). Twelve trained team sport athletes executed a workout (3 sets x 10 repetitions x 70% 1RM) incorporating four exercises (i.e. bench press, back squat, deadlift, prone bench pull). The data suggested that CMJ performance recovered 72 hours following the training session. Behm, Reardon, Fitzgerald, and Drinkwater (2002) reported that peak twitch significantly decreased (32.08%) in male college students following a single set of 20RM dumbbell elbow flexion performed to failure. Also, MVC, muscle activation and temporal twitch properties did not recover within three minutes of recovery. These studies have focused on the neuromuscular function in either novice or trained adults (González-Badillo et al., 2015a; Hakkinen & Pakarinen, 1993). Therefore, minimal information regarding neuromuscular function, endocrine and perceptual wellness responses following a muscular endurance resistance training programme in youth athletes exists.

Importantly, positive effects of muscular endurance resistance training are well documented in training studies (de Lima et al., 2012; Rhea et al., 2003). Nevertheless, the post-training responses to a single muscular endurance training session remains unclear. Gaining insight into the responses after a muscular endurance resistance training session in youth athletes may better inform training design to optimise adaptations. In fact, the magnitude and nature of fatigue could determine the recovery time required, thus affecting loads of concurrent training modalities such as physical or technical indices. Knowledge regarding neuromuscular function, endocrine and perceptual wellness after a muscular endurance training session could assist practitioners to make informed decisions in the design of subsequent training sessions. Also, the information obtained could minimise the detrimental effects that may occur because of the accumulated fatigue from various practice sessions.

Resistance training initiates a multifaceted response within a human biological system (González-Badillo et al., 2015a; Izquierdo et al., 2006). As such, the purpose of this investigation was to examine the effect of two distinct muscular endurance resistance training sessions on neuromuscular function, endocrine and perceptual wellness measures in trained youth athletes. The research hypothesis was that a similar response pattern would be observed between the muscular endurance resistance training conditions.

4.3 Methods

4.3.1 Experimental approach to the problem

Each participant served as their own control in a randomised cross-over design in which they completed both protocols, separated by a minimum of seven days. In each session, participants were evaluated before (T0), immediately post exercise, 15 minutes post exercise (T15) and 24 (T24), 48 (T48), and 72 (T72) hours post exercise. The two-contrasting muscular endurance resistance training sessions were completed during the pre-season phase, in which each participant performed nine training sessions a week including both physical preparation and sports specific training. Participants continued their normal schedule and did not perform any strenuous lower- or upper-body exercise 48 hours prior to any testing session to minimise the influence of fatigue. Maturity status was self-reported (Tanner stage) by the participants.

4.3.2 Participants

Twelve male trained youth field hockey athletes (mean ± SD age = 16.4 ± 0.5 years, height = 1.66 ± 0.07 m, body mass = 60.1 ± 7.3 kg, Tanner scale = 4.67 ± 0.50) were recruited. All participants were from the national sports school in Malaysia, resided in dormitories and were exposed to similar nutrition conditions. The participants were subjected to five days a week of supervised training, with two daily sessions and no weekend training commitments. Training was programmed daily at 06:30 - 08:00 h and 16:00 - 18:00 h. The participants attended academic lessons between 09:30 and 14:30

h. All participants were fully informed of the procedures, possible risks and purpose of the study. Each signed an informed consent and parental consent was also obtained before the study commenced. Ethics approval was granted by the University's ethics committee. All participants were non-smokers with a minimum of two years' resistance training experience. Participants were instructed to continue their normal diet through the duration of the investigation to minimise the possibility of potential confounders resulting from nutritional changes during participation.

4.3.3 Procedures

The participants completed a muscular endurance resistance training session that consisted of eight exercises (Table 4.1) in two different protocols: 3 sets of 25RM or 3 sets of 15RM.

Table 4.1 Exercises and rest between sets during training

No	Exercise	Rest (minutes)
1	Half squat	1-2
2	Bench press	1-2
3	Abdominal exercise	3 sets of 20 reps
4	Seated calf raise	1-2
5	Latissimus pull-down	1-2
6	Lying back extension	3 sets of 20 reps
7	Leg curl	1-2
8	Bicep curl	1-2

The muscular endurance resistance training and monitoring sessions were completed at the same time of the day (± 1 hour) to attenuate variation of findings generated by diurnal fluctuations (Souissi et al., 2012). A schematic of the experimental design is presented in Figure 4.1.

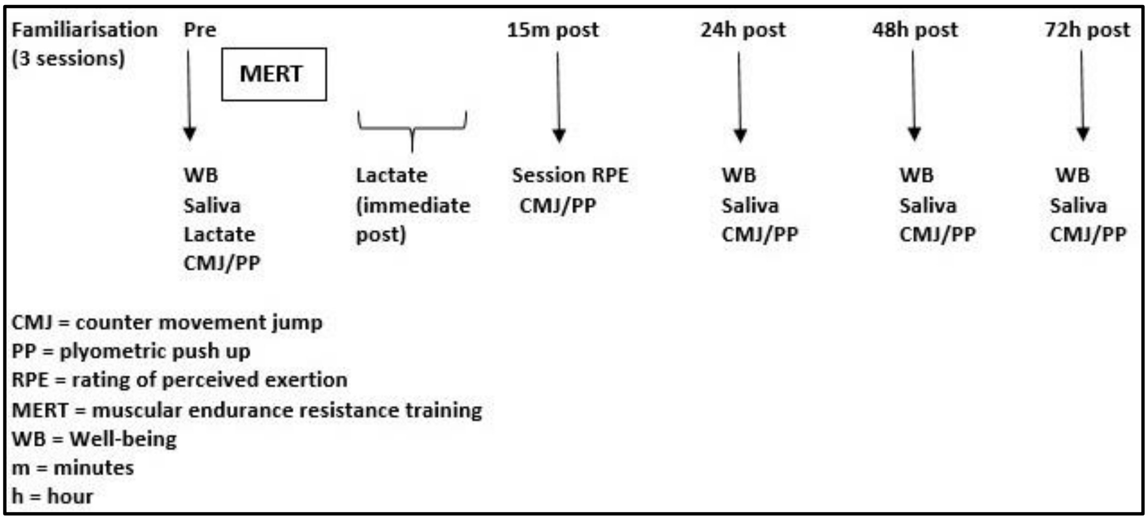

Figure 4.1 Schematic of the experimental design

The participants attended three sessions to familiarise themselves with the warm up procedures, exercises, Borg CR-10 scale, well-being questionnaire, CMJ, PP, saliva collection protocols and estimate the training loads for the exercises in this study. Body positioning, grip width and squat depth utilised by participants were individualised and standardised during familiarisation (Singh et al., 2007). The warm-up incorporated 2 minutes of easy self-paced jogging; 2 × 10 metres of walking lunges, high knee skips and heel flicks; 10 × bodyweight squats; 10 x bodyweight push ups; 2 × run-throughs/accelerations over 30 metres at perceived 75% of maximal sprint speed; 2 sets of 3 unloaded jumps at 80–90% of perceived maximal effort.

Following familiarisation, a muscular endurance resistance training session was performed preceded with at least 48 hours of rest. Upon arrival at the testing centre, participants were assessed for well-being (sleep, fatigue, muscle soreness, stress and mood) using the daily well-being questionnaire (Antualpa et al., 2017). Next, saliva samples were collected. Afterwards, blood lactate was measured (Lactate Pro, ARK Corp, Japan). Then the training commenced with previously mentioned warm up procedures. After warming up, baseline neuromuscular tests via CMJ and PP were conducted. The muscular endurance resistance training session was then performed with the exercises listed in Table 4.1. All exercises were completed to repetition failure (Drinkwater et al., 2005). If the prescribed number of repetitions per set was not achieved, the load was decreased in the following set to allow the completion of the appropriate number of repetitions (Dankel et al., 2016; Feigenbaum & Pollock, 1999). This was to ensure a similar stimulus within each individual, as this likely recruits all fibres within the active muscles towards the end of each set (Marcotte, West, & Baar, 2015). Immediately, upon completion of the muscular endurance resistance training session, post exercise blood lactate was measured (Calixto et al., 2014). Then 15 minutes following the session, CMJ and PP were repeated to assess the influence of the session on neuromuscular function (Howatson, Brandon, & Hunter, 2016). Lastly, participants provided session RPE, using the Borg CR-10 scale. To examine recovery following the muscular endurance sessions, participants returned to the testing centre 24, 48 and 72 hours after the training session to record well-being status and to give saliva samples. Lastly, CMJ and PP were performed following the warm up procedure.

4.3.4 Neuromuscular function

CMJ and PP were utilised to detect lower- and upper- body neuromuscular fatigue, respectively (Roe et al., 2016a). CMJ was assessed using a portable uniaxial force platform (400 Series Performance Plate, Fitness Technology, Adelaide, Australia) connected to a computer running software (Ballistic Measurement System, Fitness Technology, Adelaide, Australia) that recorded vertical ground reaction forces at 600 Hz. The participants kept their hands akimbo for the entire jump. Countermovement depth was self-selected to minimise technique interference, and to ensure a practicable application when testing time was limited (Cormack et al., 2008b). The participants performed two practices before executing three maximum CMJ, interspersed with 30 second recovery periods between efforts.

The PP was also assessed using the uniaxial force platform (400 Series Performance Plate, Fitness Technology, Adelaide, Australia). The participants began in a push up position, with their hands on the force platform in a self-selected position with arms extended. On the start signal, participants lowered their body by flexing their elbows to a self-selected depth before extending the elbows as fast as possible so that their hands left the force platform simultaneously. The participants performed two practice runs before performing three maximum PP trials, with 30 second recovery periods. Metrics of interest were CMJMF, CMJMP, CMJPP and PPMF employed from the findings in Chapter 3. The ICC and CV % of these measures ranged from 0.97 - 0.99 and 1.0 - 3.0 %, respectively.

4.3.5 Daily well-being questionnaire

A five-item Likert scale questionnaire was utilised to rate each of the following: sleep, fatigue, muscle soreness, stress and mood which have all been shown to be sensitive in detecting fatigue in youth rugby players (Oliver et al., 2015a). Each item was rated from one to five in one score increments and overall wellbeing was summated by adding up all five scores.

4.3.6 Rating of perceived exertion

Session RPE was obtained 15 minutes after each training session to determine if either training session would produce significantly lower RPE ratings (Weakley et al., 2017b). This was to minimise the influence of difficult or easy elements of training experienced toward the end of the session (Hiscock, Dawson, & Peeling, 2015; Singh et al., 2007). Standard instructions and anchoring procedures were explained to establish the visual-cognitive link during familiarisation (Noble & Robertson, 1996; Robertson et al., 2003). A rating of 0 was related to no effort (rest) and a rating of 10 was recognised as maximal effort and associated with the greatest exertion experienced during exercise (Day et al., 2004). Participants rated the global intensity of each training session using the Borg CR-10 scale developed by answering a question "How hard was your workout?" (Foster, 1998). The product of the session RPE and repetitions were calculated to obtain the session load (McGuigan & Foster, 2004).

4.3.7 Endocrine responses

Resting salivary samples were collected at a standardised time. Participants were instructed not to eat, drink (except water), or brush teeth at least 2 hours before collection (Papacosta & Nassis, 2011). After rinsing their mouth with water (O'Connor, Morgan, & Raglin, 1991) participants sat in a quiet room where visual and verbal contact with other participants was minimised. Ten minutes following the rinse (Salimetrics, PA, USA) participants leaned forward, with their heads tilted down, and drooled an unstimulated saliva sample into a pre-labelled sterile tube. Care was taken to allow saliva to dribble into the collection vial with minimal orofacial movement. Samples were immediately stored at relatively 4^{0}C in a polystyrene container with ice (Pritchard, Stanton, Lord, Petocz, & Pepping, 2017). Subsequently it was stored in the laboratory freezer at -20°C until analysis for unbound testosterone and cortisol. To avoid between assay variations the samples were assayed in duplicate using a commercial enzyme-immunoassay kit (Salimetrics, PA, USA) according to manufacturer specifications. Saliva was measured on a fully automated 2-Plate ELISA Processing System analyser (Dynex Technologies Inc, VA, USA). The sensitivity, interassay and intraassay reproducibility were 1.0 pg/ml, 8.12 and 12.33% respectively, for cortisol, and 0.007 µg/dL, 11.37 and 11.43% for testosterone. The T:C ratio was calculated as: *T:C ratio* = *T/C* X 100 (Painter et al., 2018).

4.3.8 Statistical analysis

All data were reported as mean ± SD. Normal distribution of the data was assessed by visual inspection and analysed by the Shapiro-Wilk statistic. If data were not normally distributed log transformation were administered and data re-examined for normality before conducting parametric tests. Sphericity was checked with Mauchly's test and a Greenhouse-Geisser correction was applied when necessary. Differences between sessions for CMJ and PP were examined using a two factor (2 sessions × 5 time-points) repeated measures analysis of variance (ANOVA) with Bonferroni *post-hoc* to explore interactions and main effects, with one time point less for perceived ratings of wellness, testosterone and cortisol responses. If significant session x time interactions were identified, each group was analysed separately by a one-way ANOVA with repeated measures on time point. Between session RPE, between session post exercise lactate and differences at baseline level were tested with a paired sample t-test. Pearson's product-moment coefficient of correlation was calculated for session RPE and total volume load from both sessions. Total volume load was calculated as sets x repetitions x load (kilogram). Hedges *g* ES for small sample sizes, and the 95% lower and upper confidence intervals (CI) were reported (Ialongo, 2016). ES ≤ 0.2, 0.2 to 0.5, 0.5 – 0.8 and ≥ 0.8 were classified as trivial, small, moderate and large respectively (Cohen, 1988). Percent change was computed as: [(post-exercise mean - pre-exercise mean)/pre-exercise mean] x 100. Level of significance was set at $p \leq 0.05$. Data were examined with the IBM SPSS Statistical for Windows software (Version 21.0, Armonk, NY: IBM Corp).

4.4 Results

There were no differences in the pre-session data demonstrating that the participants were in similar physical condition between the two different training sessions (Height $p = 0.767$, ES = 0.00, CI = -0.80, 0.80; body mass $p = 0.478$, ES = 0.01, CI = -0.79, 0.82;

CMJMF p = 0.861, ES = -0.01, CI = -0.81, 0.79; CMJMP p = 0.190, ES = 0.16, CI = -0.65, 0.97; CMJPP p = 0.052, ES = 0.14, CI = -0.67, 0.95; PPMF p = 0.847, ES = -0.02, CI = -0.82, 0.78; lactate p = 0.180, ES = -0.46, CI = -1.24, 0.32; testosterone p = 0.558, ES = 0.19, CI = -0.62, 1.00; cortisol p = 0.146, ES = -0.55, CI = -1.32, 0.23).

Post-session RPE was higher (p = 0.000, ES = 2.42, CI = 1.51, 3.33), after the 25RM session (8.08 ± 1.08 AU) versus the 15RM session (5.75 ± 0.75 AU). Similarly, the total volume load was higher (p = 0.000, ES = 2.75, CI = 1.82, 3.68), for the 25RM session (12512.25 ± 1726.38 kg) versus the 15RM session (8892.33 ± 495.93 kg). Also, lactate value was higher (p = 0.033, ES = 0.97, CI = 0.13, 1.82) following the 25RM session (7.46 ± 1.41 mmol/L) versus the 15RM session (6.30 ± 0.81 mmol/L). A positive relationship (r = 0.80, p = 0.000) between total volume load and session RPE was detected (Figure 4.2).

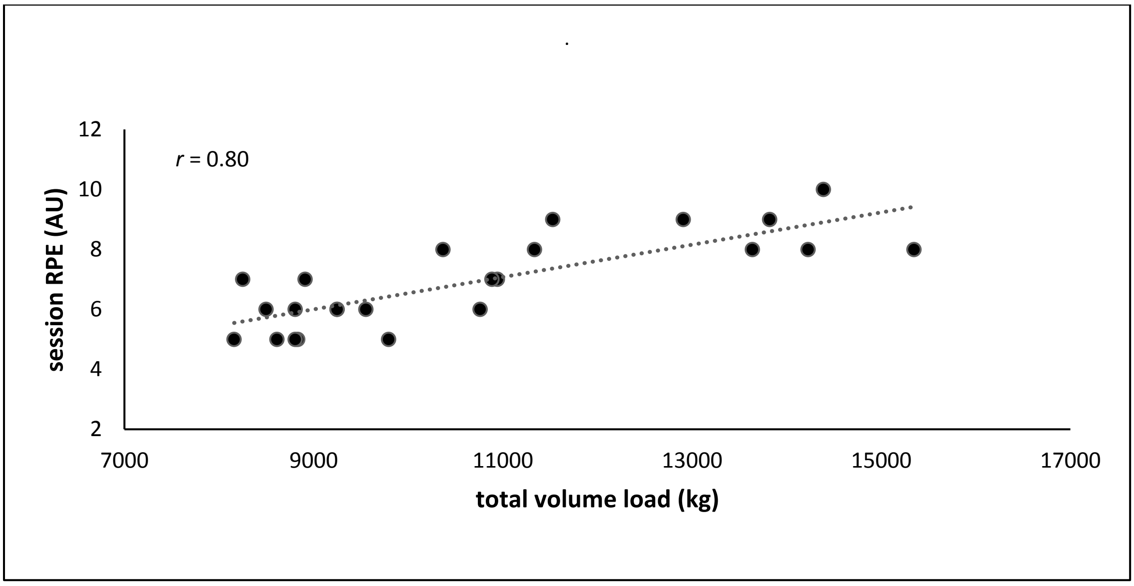

Figure 4.2 Pearson correlation between total volume load and session RPE

4.4.1 Neuromuscular function

Neuromuscular data for both training sessions are presented in Table 4.2. CMJMF showed a significant session-by-time interaction (F = 3.60, p = 0.009) with no between-session main effect (F = 0.00, p = 0.999). A one-way ANOVA with repeated measures revealed that there was a significant decrease at T15 (p = 0.002) and T24 (p = 0.001) when compared to T0 in the 15RM session. T48 significantly increased from T15 (p = 0.000) and T24 (p = 0.003). Similarly, T72 significantly increased from T15 (p = 0.003) and T24 (p = 0.001). A similar analysis was performed between T24 and T48 within the 25RM session that demonstrated a significant increase (p = 0.008).

Neither significant interaction effect nor significant between- session effect was detected for CMJMP (p = 0.220; p = 0.765) and CMJPP (p = 0.401; p = 0.858). However, a main effect for time was noted for CMJMP (F = 12.11, p = 0.000). A Bonferroni pairwise comparison revealed that there was a significant decrease between T0-T24 (p = 0.000) whereas, T24-T48 (p = 0.007), T24-T72 (p = 0.000) and T15-T72 (p = 0.003) showed a significant increase. Similarly, there was a significant main effect for time in CMJPP (F = 6.05, p = 0.000). Pooled mean scores significantly increased between T0-T24 (p = 0.026), T24-T48 (p = 0.009) and T24-T72 (p = 0.034).

No significant interaction (F = 0.70, p = 0.463) and between-session main effect (F = 0.10, p = 0.921) was observed for PPMF. Conversely a significant main effect for time (F = 5.29, p = 0.017) was detected. Pairwise comparison showed that there was a significant decrease between T0-T24 (p = 0.000) and significant increase between T24-T48 (p = 0.000). In addition, differences between T0-T15, T15-T24, T24-T72 approached significance p = 0.052, p = 0.055 and p = 0.052 respectively.

Table 4.2 Neuromuscular responses compared to T0 for 15RM and 25RM training sessions

Assessment	Time Point	Session 15RM	% Δ	ES (95%CI)	Session 25RM	% Δ	ES (95%CI)
CMJMF (Newtons)	T0	603.5 ± 69.2			602.9 ±71.4		
	T15	594.3 ± 66.8*	-1.52	-0.13 (-0.92, 0.66)	598.8 ± 69.2	-0.68	-0.06 (-0.85, 0.74)
	T24	593.2 ± 66.4*	-1.71	-0.15 (-0.94, 0.65)	596.7 ± 69.1	-1.03	-0.09 (-0.88, 0.71)
	T48	605.1± 70.3^[$]	0.27	0.02 (-0.78, 0.82)	601.5 ± 70.4^	-0.23	-0.02 (-0.82, 0.78)
	T72	604.4 ± 69.7[@]	0.15	0.01 (-0.79, 0.81)	600.7 ± 67.1	-0.36	-0.03 (-0.83, 0.77)
CMJMP (Watts)	T0	902.7 ± 121.0			923.46 ± 133.3		
	T15	879.2 ± 123.5	-2.60	-0.18 (-0.98, 0.61)	911.1 ± 124.6	-1.34	-0.09 (-0.89, 0.70)
	T24	873.4 ± 110.3	-3.25	-0.24 (-1.03, 0.54)	892.8 ± 134.4	-3.32	-0.22 (-1.01, 0.57)
	T48	910.1 ± 128.1	0.82	0.06 (-0.75, 0.86)	919.3 ± 136.1	-0.45	-0.03 (-0.83, 0.77)
	T72	936.9 ± 131.7	3.79	0.26 (-0.55, 1.07)	932.3 ± 118.1	0.96	0.07 (-0.74, 0.87)
CMJPP (Watts)	T0	3494.4 ± 546.9			3602.9 ± 589.8		
	T15	3446.6 ± 505.5	-1.37	-0.09 (-0.88, 0.71)	3505.6 ± 572.9	-2.70	-0.12 (-0.91, 0.67)
	T24	3376.2 ± 525.3	-3.38	-0.21 (-1.00, 0.58)	3441.4 ± 556.9	-4.48	-0.23 (-1.02, 0.56)
	T48	3551.1 ± 650.6	1.62	0.09 (-0.71, 0.90)	3608.8 ± 605.5	0.16	0.05 (-0.75, 0.85)
	T72	3583.4 ± 589.8	2.55	0.15 (-0.66, 0.96)	3525.5 ± 575.1	-2.15	-0.09 (-0.88, 0.71)
PPMF (Newtons)	T0	383.0 ± 45.5			382.2 ± 48.7		
	T15	375.2 ± 46.2	-2.04	-0.16 (-0.96, 0.63)	376.5 ± 49.3	-1.49	-0.12 (-0.92, 0.67)
	T24	366.9 ± 43.7	-4.20	-0.35 (-1.13, 0.43)	371.5 ± 47.9	-2.80	-0.21 (-1.00, 0.58)
	T48	383.9 ± 49.6	0.23	0.02 (-0.78, 0.82)	379.0 ± 45.0	-0.84	-0.08 (-0.87, 0.72)
	T72	383.8 ± 49.9	0.21	0.02 (-0.78, 0.82)	392.8 ± 48.7	2.77	0.20 (-0.61, 1.01)

*significantly different to T0; ^significantly different to T24; [$]significantly different to T15; [@]significantly different to T15 and T24; $p \leq .05$; % Δ percentage change from T0; ES (95%CI) Effect size (95% confidence interval); T0 baseline; T15 15-minute post; T24 24-hour post; T48 48-hour post; T72 72-hour post; CMJMF countermovement jump mean force; CMJMP countermovement jump mean power; CMJPP countermovement jump peak power; PPMF plyometric push up mean force.

4.4.2 Endocrine

The endocrine responses for both training sessions are presented in Table 4.3. The interaction effect between session and time was not significant for cortisol (F = 2.89, $p = 0.067$). Likewise, the main effect between sessions was not significant (F = 0.38, $p = 0.545$). However, there was a significant main effect for time (F = 12.13, $p = 0.000$) decreasing from T0-T72 ($p = 0.044$). The mean pooled cortisol significantly decreased between T0-T48 ($p = 0.044$), T24-T48 ($p = 0.000$) and T24 to T72 ($p = 0.000$), however there was no difference between T0-T24 ($p = 0.830$).

There were no significant within-session (F = 2.08 $p = 0.132$), between-session main effect (F = 0.02, $p = 0.885$) or interaction effect (F = 1.19, $p = 0.316$) detected for testosterone. Also, there were no significant differences between sessions (F = 0.27 $p = 0.608$), significant session-by-time interaction (F = 2.51 $p = 0.102$) and main effect for time (F = 1.26 $p = 0.292$) for T:C ratio.

Table 4.3 Endocrine responses compared to T0 for 15RM and 25RM training sessions

Assessment	Time Point	Session 15RM	% Δ	ES (95%CI)	Session 25RM	% Δ	ES (95%CI)
	T0	107.16 ± 44.14			118.24 ± 65.11		
Testosterone	T24	104.74 ± 57.93	-2.26	-0.04 (-0.84, 0.75)	103.01 ± 23.36	-12.88	-0.30 (-1.09, 0.48)
(pmol/L)	T48	104.56 ± 41.63	-2.43	-0.06 (-0.86, 0.74)	83.75 ± 26.37	-29.17	-0.67 (-1.44, 0.10)
	T72	92.58 ± 40.62	-13.61	-0.33 (-1.12, 0.45)	95.49 ± 39.90	-19.24	-0.41 (-1.19, 0.37)
	T0	2.15 ± 1.18			1.55 ± 0.82		
Cortisol	T24	2.89 ± 1.93	34.42	0.34 (-0.48, 1.16)	2.04 ± 1.79	31.61	0.20 (-0.61, 1.01)
(nmol/L)	T48	1.25 ± 0.62	-41.86	-0.92 (-1.67, 0.16)	1.23 ± 0.80	-20.65	-0.64 (-1.41, 0.12)
	T72	1.33 ± 1.21	-38.14	-0.72 (-1.49, 0.04)	1.23 ± 0.55	-20.65	-0.76 (-1.52, 0.00)
	T0	5.58 ± 2.49			12.29 ± 15.98		
T:C Ratio	T24	4.85 ± 3.88	-13.08	-0.22 (-1.01, 0.57)	8.02 ± 4.90	-34.74	-0.35 (-1.13, 0.43)
	T48	12.11 ± 14.87	117.03	0.59 (-0.24, 1.42)	8.52 ± 3.78	-30.68	-0.31 (-1.10, 0.47)
	T72	8.74 ± 5.41	56.63	0.72 (-0.11, 1.56)	7.41 ± 2.93	-39.71	-0.41 (-1.19, 0.37)

% Δ percentage change from T0; ES (95%CI) Effect size (95% confidence interval) from T0; T0 baseline; T24 24-hour post; T48 48-hour post; T72 72-hour post.

4.4.3 Wellness

Overall perceptual wellness scores for each session are presented in Table 4.4. There was a significant main effect for time (F = 5.06, *p* = 0.011). Closer inspection revealed T24-T72 (*p* = 0.002) significantly increased. There were no differences between T0-T24 and T24-T48 (*p* = 0.079 and *p* = 0.085) respectively. Likewise, no interaction (F = 2.13, *p* = 0.133) or between session effect (F = 0.018, *p* = 0.894) was observed.

Significant session-by-time interaction (F = 3.26, *p* = 0.040) was detected in fatigue scores. A one-way ANOVA with repeated measures revealed that in the 15RM session (F = 3.25, *p* = 0.034), T24-T72 approached statistical significance (*p* = 0.070). A similar analysis performed in the 25RM session showed no differences between time scores (F = 3.04, *p* = 0.070). Significant main effect for time in fatigue scores was observed (F = 3.07, *p* = 0.048). A Bonferroni pairwise comparison revealed statistical increases between T24-T72 (*p* = 0.032). However, no between-session effect (F = 0.40, *p* = 0.533) was observed.

Main effect for time was identified in general muscle soreness (F = 8.88, *p* = 0.000). The Bonferroni pairwise comparison disclosed a statistical decrease between T0-T24 (*p* = 0.021) while statistical increase was noted between T24-T72 (*p* = 0.000) and T48-T72 (*p* = 0.011). There was no notable difference between T24-T48 (*p* = 0.074). Nevertheless, no significant difference was observed between session (F = 0.21**,** *p* = 0.652) nor main interaction effect (F = 0.66, *p* = 0.579).

A two factor (2 sessions x 4 time-points) repeated measures ANOVA did not reveal any significant within-session (*p* = 0.237 to 0.871), between-session (*p* = 0.484 to 1.000) or interaction effect (*p* = 0.110 to 0.226) for stress, mood and sleep.

Table 4.4 Perceptual wellness responses compared to T0 for 15RM and 25RM training sessions

Assessment	Time Point	Session 15RM	% Δ	ES (95%CI)	Session 25RM	% Δ	ES (95%CI)
Overall	T0	19.17 ± 1.27			17.92 ± 2.07		
	T24	17.17 ± 2.17	-10.43	-1.09 (-1.83, 0.34)	17.33 ± 2.67	-3.29	-0.24 (-1.03, 0.55)
	T48	18.00 ± 2.26	-6.10	-0.62 (-1.38, 0.15)	18.92 ± 2.81	5.58	0.39 (-0.43, 1.21)
	T72	18.67 ± 2.39	-2.61	-0.25 (-1.04, 0.54)	19.25 ± 2.73	7.42	0.53 (-0.30, 1.36)
Soreness	T0	3.67 ± 0.49			3.42 ± 1.00		
	T24	2.75 ± 0.87	-25.07	-1.26 (-1.99, 0.52)	2.83 ± 0.94	-17.25	-0.59 (-1.36, 0.18)
	T48	3.42 ± 0.52	-6.81	-0.48 (-1.25, 0.30)	3.08 ± 1.00	-9.94	-0.33 (-1.11, 0.46)
	T72	3.67 ± 0.65	0.00	0.00 (-0.80, 0.80)	3.75 ± 0.75	9.65	0.36 (-0.46, 1.18)
Fatigue	T0	3.75 ± 0.45			3.33 ± 0.49		
	T24	3.08 ± 0.79	-17.87	-1.01 (-1.75, 0.26)	3.42 ± 0.79	2.70	0.13 (-0.67, 0.94)
	T48	3.33 ± 0.65	-11.20	-0.73 (-1.49, 0.04)	3.83 ± 0.72	15.02	0.78 (-0.05, 1.62)
	T72	3.67 ± 0.78	-2.13	-0.12 (-0.92, 0.67)	3.75 ± 0.62	12.61	0.73 (-0.11, 1.56)
Stress	T0	3.75 ± 0.45			3.58 ± 0.51		
	T24	3.58 ± 0.51	-4.53	-0.34 (-1.12, 0.44)	3.58 ± 0.51	0.00	0.00 (-0.80, 0.80)
	T48	3.58 ± 0.67	-4.53	-0.29 (-1.07, 0.50)	3.92 ± 0.67	9.50	0.55 (-0.28, 1.38)
	T72	3.58 ± 0.79	-4.53	-0.26 (-1.04, 0.53)	3.92 ± 0.67	9.50	0.55 (-0.28, 1.38)
Mood	T0	4.08 ± 0.29			3.83 ± 0.58	0.00	0.00 (-0.80, 0.80)
	T24	3.83 ± 0.58	-6.53	-0.53 (-1.30, 0.25)	3.83 ± 0.58	0.00	0.00 (-0.80, 0.80)
	T48	3.92 ± 0.29	-4.08	-0.53 (-1.31, 0.24)	4.08 ± 0.29	6.13	0.53 (-0.30, 1.35)
	T72	3.92 ± 0.29	-4.08	-0.53 (-1.31, 0.24)	4.00 ± 0.43	4.25	0.32 (-0.49, 1.14)
Sleep	T0	3.92 ± 0.29			3.75 ± 0.45		
	T24	3.92 ± 0.51	0.00	0.00 (-0.80, 0.80)	3.67 ± 0.65	-2.18	-0.14 (-0.93, 0.66)
	T48	3.75 ± 0.62	-4.53	-0.34 (-1.12, 0.44)	4.00 ±0.60	6.25	0.46 (-0.37, 1.28)
	T72	3.83 ± 0.39	-2.35	-0.25 (-1.04, 0.53)	3.83 ±0.72	2.09	0.13 (-0.68, 0.94)

% Δ percentage change from T0; ES (95%CI) Effect size (95% confidence interval); T0 baseline; T24 24-hour post; T48 48-hour post; T72 72-hour post.

4.5 Discussion

This study investigated neuromuscular function, endocrine and perceptual wellness responses to distinct muscular endurance resistance training (3 x 15RM vs. 3 x 25RM) in trained youth athletes. The training protocol design was similar to previous research by Rhea et al. (2003) and de Lima et al. (2012). The data from this study showed that there may be a prolonged reduction of up to 24 hours post session in CMJMP, CMJPP and PPMF, within the contrasting muscular endurance resistance training sessions. CMJMF decreased at 15 minute and 24 hours following the 15RM exercise session but, no significant difference was observed at 15 minutes and 24 hours after the 25RM session. In contrast, a significant increase was noted in CMJMF between 24 hours and 48 hours post the 25RM session. A significant reduction was detected in cortisol concentrations at 48 and 72 hours with no significant changes observed in testosterone concentration following both sessions. T:C ratio indicated a moderate (0.72) and small ES (- 0.41) following both the 15RM and 25RM sessions. Overall perceptual wellness, fatigue and soreness scores reflected changes in neuromuscular function, whereas stress, sleep and mood did not show any differences. The findings support the hypothesis that a similar response pattern would be observed post session regardless of muscular endurance resistance training protocols. These results have practical importance for practitioners as prior experiments have focused on responses to upper- or lower-body exercises only, or on a combination of both, to monitor responses from a single hypertrophy, strength or power training session.

Neuromuscular fatigue is characterised as the inability to sustain the requisite force, or as a decline in the force generating capability of the neuromuscular system (Bigland-Ritchie & Woods, 1984). However, fatigue is suggested to be associated not only with the intensity, but also the degree of stress imposed during different resistance training protocols (Hakkinen & Pakarinen, 1993; Komi & Viitasalo, 1977). This was evident by the contrasting responses in CMJMF between the two-muscular endurance resistance training sessions. CMJMF was statistically decreased 15 minutes after the 15RM session. This could be related to the greater force production required to overcome a heavy load in the session which develops high muscle tension (McGuigan et al., 2008; Suminski et al., 1997). High muscle tension could decrease the efficacy of the excitation-contraction coupling (Pincivero, Gear, Sterner, & Karunakara, 2000). Contractile elements of the loaded muscles may have been impaired thus affecting the CMJMF production (Linnamo, Häkkinen, & Komi, 1998). It has been suggested that low muscle pH may restrict the rate of cross-bridge binding and myosin adenosine triphosphatase activity and decrease Ca^{2+} and therefore attenuating CMJMF (Warren, Ingalls, Lowe, & Armstrong, 2001). Also, CMJMF was statistically impaired 24 hours following the 15RM scheme. A similar observation has been reported following a maximum strength training session in elite track and field athletes (Howatson et al., 2016). Howatson and colleagues (2016) observed a reduction in maximal voluntary contraction with no change in the central activation ratio that indicates the predominance of peripheral fatigue. This could be associated with the fatigue and muscle soreness scores which indicated a large ES (-1.01 and - 1.26 respectively) at 24 hours following the 15RM exercise session. Muscle damage could be an element contributing to fatigue and reduction in the force production potential following the 15RM exercise session (Komi, 2000).

No significant changes were observed in CMJMF up to 24 hours following the 25RM session but a significant increase was noted between 24 hours and 48 hours post session. Willardson (2007) suggested this might be related to the delay in high threshold recruitment of motor units' (i.e. type IIx muscle fibres). Of note, de Ruiter, Elzinga, Verdijk, van Mechelen, and de Haan (2005) reported substantially increased motor unit discharge rates immediately following intermittent sub-maximal contractions at 50% maximal force contractions of the knee extensors. Similarly Jensen, Pilegaard, and Sjøgaard (2000) noted an increase in the supraspinatus motor unit discharge rate subsequent to shoulder abduction at 12% maximal voluntary contractions. This may demonstrate that an increase in motor unit discharge rate with modest reduction in motor unit recruitment threshold can sustain force output (de Ruiter et al., 2005; Jensen et al., 2000). Furthermore Gorassini, Yang, Siu, and Bennett (2002) noted that the threshold for the recruitment of a particular motor unit is lowered once a motor unit is recruited, thus less activation is required for it to be recruited during exercise. Likewise Ploutz, Tesch, Biro, and Dudley (1994) demonstrated that less stimuli is needed to produce a certain level of force in trained individuals.

It seems possible that CMJMF was maintained due to altered movement strategies, which aligned with the concept of dynamic systems theory (Gathercole et al., 2015a; Seifert et al., 2013). This is likely as several muscles and joints are required to perform the CMJ (Rodacki, Fowler, & Bennett, 2002) and this could allow differentiation in the jump technique to coordinate the movement (Knicker et al., 2011). Collectively, these reports may explain the maintenance of CMJMF after the 25RM session in the present study. It is also important to highlight that training status may have affected the recovery rates in CMJPP, CMJMP and PPMF following both training sessions. Trained participants were recruited and so chronic adaptations may have occurred as a result of previous training sessions prior to this study. Thus, the participants likely recovered 24 hours after both experimental protocols (Kraemer & Ratamess, 2004).

Bartolomei et al. (2017) showed a significant reduction in CMJPP up to 48 hours in resistance trained men. Participants performed the parallel barbell squat exercise with eight sets of 10 repetitions at 70% of 1RM with rest periods between sets of 1.25 minutes. A significant reduction in CMJ height up to 72 hours post exercise was reported in novice adult participants (Byrne & Eston, 2002) using the parallel barbell squat performed with 10 sets of 10 repetitions with the load corresponding to 70% of individual body mass. Flores et al. (2011) observed a reduction in peak torque of up to 96 hours in unilateral elbow flexion in untrained participants. The differences in recovery rates could be attributed to differences in the protocol utilised. It should be noted that previously mentioned studies investigated the effects of single exercise protocols with extreme conditions focusing on isolated lower- or upper-body muscle groups only. These extreme conditions can lead to greater magnitudes of peripheral fatigue and intramuscular metabolic disturbances. Thus, high levels of muscle damage have been identified as a contributing factor for the decreased force production and increased plasma creatine kinase activity (Taipale et al., 2014). Also, it has been suggested that muscle recovery is delayed in untrained participants (Gibala et al., 2000). In the present muscular endurance resistance training study, the response to a full body exercise protocol within a training session was investigated, with two distinct protocols. This training performed to “repetition failure” with different muscle groups within a session may have affected skeletal muscle afferent fibre activation and/or muscular contraction to a more distinctive degree than in previous studies. Importantly, training with different muscle groups in a session could more accurately reflect a typical training situation encountered by trained youth athletes. Hunter, Duchateau, and Enoka (2004) suggested that exercising to “repetition failure” is different compared to “maximal fatigue”. This is due to the muscle not becoming completely fatigued at the point of failure, rather it cannot continue to move the given load beyond a critical joint angle in a particular set (Elliott, Wilson, & Kerr, 1989).

A significant reduction in cortisol concentrations was detected at post 48 and 72 hours compared to baseline values. In addition, a trend for decline in testosterone concentration was observed in this study. The discrepancies in endocrine responses following 3 x 15RM and 3 x 25RM muscular endurance resistance training sessions could be attributed to the physical and psychological strain experienced by the participants. First, in the current investigation, every participant performed all exercises to "repetition failure". Second, they maintained their normal routine that incorporates sports specific training up to 48 hours before the commencement of this investigation. Next, all volunteers were preparing for mid-term academic examinations that may have induced psychological stress. It is likely that this may have accumulated as a non-training stress which was not reflected in the neuromuscular and perceptual wellness, specifically in the sleep, stress and mood ratings (Halson & Jeukendrup, 2004). Similarly, there is some evidence that resting hormone concentration decreases after high volume resistance training (Häkkinen & Pakarinen, 1991; Häkkinen et al., 1987b; Kraemer et al., 2006). It has been proposed that this may be a marker of overreaching/overtraining (Hakkinen & Pakarinen, 1993).

Kraemer and Ratamess (2005) have noted that resistance training induces significant acute hormonal responses and that these acute responses are important for muscular adaptations compared to resting hormonal changes. This stems from the fact that training with high volume, moderate to high intensity coupled with short rest intervals incorporating large muscle mass, seems to induce metabolic stress and significantly increase acute hormonal release (Ahtiainen, Pakarinen, Kraemer, & Hakkinen, 2003;

Bartolomei et al., 2017; Gonzalez et al., 2015). For example, Gotshalk et al. (1997) observed a significant elevation in testosterone immediately and 60 minutes following three sets of eight exercises using 10RM with 60 seconds recovery between sets in recreationally resistance trained men. This finding is in line with previous research that demonstrated acute elevation of testosterone concentration after high intensity training involving large muscle groups in elite junior and men strength athletes (Kraemer et al., 1992; Kraemer et al., 1991). Even though testosterone concentration is the principal circulating androgen, it is not the single known factor for muscular adaptations following resistance training (Kraemer & Ratamess, 2005). Testosterone induces protein synthesis through androgen receptors by increasing DNA transcription to regulate androgen-specific gene expression. Ratamess et al. (2005) stated that resistance training could modulate the availability of androgen binding sites in muscles. As such, an elevation in androgen receptors may enhance the sensitivity of muscle tissues to circulating androgens (Bamman et al., 2001). For this reason, the volunteers in the current study performed both resistance training sessions to failure. Thus, upregulation of androgen receptors could have ensued within the muscle fibres indicating the trend for decline in testosterone concentration observed in this study. Also, other known factors such as luteinising hormone (Raastad, Bjøro, & Hallen, 2000) and sex hormone-binding globulin (Kraemer et al., 1998), may have mediated the hormonal alterations. These changes, however, were not measured in this study. Of note, previous experiments did not observe significant resting hormonal modifications despite improvements in performance after resistance training (Ahtiainen, Pakarinen, Alen, Kraemer, & Häkkinen, 2003; Hickson, Hidaka, Foster, Falduto, & Chatterton Jr, 1994; Potteiger et al., 1995). The reason for this is not clear but may be attributed to the stimulation of a variety of possible signal transduction systems that seems to lead to activation of many important processes for improved performance highlighting the potential limitation of circulating levels of androgen (Hooper et al., 2017; Mitchell et al., 2013).

The T:C ratio increased with a moderate ES (0.72) after the 15RM session while a decrease with small ES (- 0.41) was observed following the 25RM session. These findings suggest that practitioners may design and taper the 25RM session differently, as the endocrine profile recovered slower after this training strategy. This could have implications to subsequent training sessions such as motivation to train (Crewther et al., 2011a) and cognitive function (Crewther et al., 2011a; Hansen, McAuliffe, Goldfarb, & Carré, 2017). Importantly, Selye (1936) stated that stress could exhibit itself as a specific syndrome (e.g. changes in hormone concentration) even if it was not specifically induced. Taken together, factors such as environmental, physical or emotional stressors could have contributed to the different responses from the neuromuscular, endocrine and wellness measures in this study. Practitioners should consider incorporating other monitoring strategies to make informed decisions about the design of training programmes that will best optimise psychophysiological adaptations.

Certain measures of the perceptual wellness (overall score, fatigue and soreness) in this study mirrored changes in the neuromuscular function, whereas stress, sleep and mood did not show any differences. It should be noted that this investigation compared responses to a single resistance training session monitored up to 72 hours. Given that prior studies have utilised a period of longer than six weeks to observe accumulated significant changes in stress, sleep or mood (Noon et al., 2015; Sarabia et al., 2015; Van Ryswyk et al., 2017) the short period in this study may have limited impact on stress, sleep and mood. For example, Hooper, MacKinnon, and Hanrahan (1997) investigated psychological disturbance and negative affective states in elite male and female swimmers for six months to determine whether athletes who are stale show different values from those who are intensely trained but not stale. Data were collected at five-time points: three times during training (pre-, mid-, and late-season), during tapering prior to, and then shortly after major competitions using the POMS. The findings suggest that mood and stress were significantly correlated to the training intensity. Halson et al. (2002) monitored trained cyclists over six weeks utilising POMS and DALDA. The outcome suggests a 29% increase in global disturbance in conjunction with a significant decline in maximum power output (p = 0.005) and a 9.8% increase in time to complete a simulated time trial. Morgan et al. (1988) observed sport specific training of 12 college swimmers for 12 consecutive days to monitor mood disturbance before, during and after ten days of increased training distance, while maintaining intensity at 94% of VO_2 max. Several instruments were utilised (POMS, 7-point scale of general wellbeing, muscle soreness and sleep pattern). Increases in training load reflected the degree of stress experienced by the swimmers. This finding suggests monitoring of mood states during a period of increased training can be of value in detecting overreaching. Also, high training and competition demands likely put trained youth athletes at risk of non-functional overreaching. It has been suggested that perception of well-being is a valuable way to identify this vulnerable situation. Importantly, studies have reported a relationship between declining perceptions of well-being and non-functional overreaching in young team sports athletes (Brink, Visscher, Coutts, & Lemmink, 2012; Schmikli, Brink, De Vries, & Backx, 2011). However, decrements in mood state were observed in the absence of decline in performance measure (O'Connor et al., 1991). Similarly, studies of team sports athletes indicated that perceptual well-being declined towards the end of the season with no alterations in sports specific physical performance tests (Faude, Kellmann, Ammann, Schnittker, & Meyer, 2011). Thus a combination of perceptual wellness and measures of performance tests may be periodically necessary to identify individuals who are potentially close to non-functional overreaching and overtraining (Halson & Jeukendrup, 2004).

The purpose of the present investigation was to analyse the short-term responses to two different muscular endurance resistance training sessions. Differences in total work performed between the two contrasting sessions were noted. The 25RM session yielded higher total volume load compared to the 15RM session. Similarly, session RPE and lactate were significantly higher in the 25RM session compared to the 15RM session. Importantly, a positive significant relationship between total volume load and session RPE was detected (r = 0.80). This corroborates previous studies that reported training to be more exhausting when a greater volume of work was performed (Genner & Weston, 2014; Kraft, Green, & Thompson, 2014; Pritchett et al., 2009). During resistance training, acute elevation of blood lactate concentration may lead to intramuscular metabolic acidosis (Kraemer et al., 1987). This acidic milieu can stimulate the free nerve endings in the muscle cell, generating discomfort, pain and fatigue (Stamford & Noble, 1974). Thus, the greater volume load performed in the 25RM session may have been perceived to be more demanding than the 15RM session. This finding conflicts with previous studies which have reported session RPE as primarily mediated by exercise intensity (Day et al., 2004; Hiscock et al., 2017; Singh et al., 2007; Sweet et al., 2004). These studies employed resistance training sets with a known and achievable end point. For example, Day et al. (2004) compared high (4-5 repetitions at 90% 1RM), moderate (10 repetitions at 70% 1RM) and low (15 repetitions at 50% 1RM) intensity training performed with only one set. The findings suggest RPE was high after the high protocol (RPE = 6.9 ± 1.4 AU), in which participants attempted to complete a maximum of five repetitions. However, some participants attained failure upon reaching the fourth repetition, but the moderate and low schemes were not performed to failure. Therefore, differences in the perception of effort may have occurred. Despite allowing variation in the total amount of work performed between sessions, the investigators suggested the training intensity impacted the RPE ratings. It was likely that the participants were instantly able to detect the heavy resistance training variation between trials (Gearhart et al., 2002). This differed from the present study in which the training sessions were conducted to repetition failure. Greater time under load may have influenced session RPE (Hiscock et al., 2015) and contributed to the positive relationship obtained in the current investigation. The greater RPE scores may have been based on the physiological changes and the related sensation of fatigue (Gonzalez et al., 2015). Previous research had indicated that various physiological elements could contribute to an individual's RPE (Eston, 2012). However in the present investigation, the data suggested that the session RPE in the 25RM session, may have been impacted by the acid-base balance to a greater extent than other factors like neuromotor activity, as evaluated by electromyography (Lagally et al., 2002b), or greater motor unit recruitment and firing frequency (Gearhart et al., 2002). Overall, the evidence from this study indicated that session RPE is a valuable tool to track internal training load. Nonetheless, more research is needed to elucidate the causative link to RPE, which could provide greater insights into the mediating element and allow practitioners to design and monitor training with greater precision.

Overall, data from this study showed that neuromuscular function, endocrine and perceptual fatigue measures maintained similar biological responses following 3 x 15RM or 3 x 25RM muscular endurance resistance training sessions. Importantly, these findings were obtained from trained youth participants who were familiar with the exercises used in this study. As fatigue is multifaceted, practitioners should not rely on a single monitoring tool. The monitoring should encompass both physiological and psychological aspects. Further inquiries should investigate the muscular endurance resistance training consequences in youth athletes across different sports, between sexes, and maturity levels to optimise training programme monitoring.

4.6 Practical application

Optimal athletic performance is the ultimate goal for a sports practitioner. Thus, it is essential to design a periodised training programme that achieves functional overreaching at certain time-points without attaining overtraining and associated performance decrease. The data from this study show that force and power measures (CMJMF, CMJMP, CMJPP and PPMF), endocrine and perceptual wellness scores recovered 48 hours after both muscular endurance resistance training programmes. These findings may assist practitioners to design across a training cycle more effectively. Moreover, practitioners should consider session RPE. This measure could monitor internal training load and regulate external training load that, in turn, may improve the quality of the training sessions performed. More importantly, practitioners should proactively recognise the present fatigue levels and readiness of their youth athletes for subsequent training sessions.

Chapter 5 Comparison of Resistance Training Progression Models to Develop Muscular Endurance in Youth Athletes

5.1 Overview

In Chapter 2 the justification to investigate two resistance training progression models to develop muscular endurance was established. Furthermore, the findings from Chapter 4 substantiated the inclusion of neuromuscular function, endocrine and perceptual wellness measures to monitor a periodised muscular endurance resistance training protocol. Therefore, the primary objective of this study was to compare the effects of LP and UP on selected performance, physiological and psychological variables in team sports youth athletes. The secondary objective was to describe the different physiological, neuromuscular and perceptual responses to these training models. Accordingly, this study provided insight into the optimal periodised resistance training strategies, while the various monitoring approaches furnished information regarding the efficiency of the compared resistance training progression models.

5.2 Introduction

Resistance training has been established as a safe and effective strategy to improve health, psycho-social skills, well-being and reduce the severity and incidence of injuries (Behm, Faigenbaum, Falk, & Klentrou, 2008; Faigenbaum et al., 2009; Lloyd et al., 2016; Lloyd et al., 2014a). Research suggests that resistance training has the potential to improve muscular strength, power, endurance, agility, balance and stability, coordination and sprint performance in youth athletes (Harries et al., 2012; Lesinski et al., 2016). Resistance training prepares young athletes to develop complex skills and increase their resilience to the demands of training and competition (Lloyd & Oliver, 2012; Myer et al., 2011). An integrative training approach, inclusive of resistance training, not only optimises a young athlete's talent, but maximises sports performance and reduces the risk of sports-related injuries (Mountjoy et al., 2008). Recently, there has been an increasing interest in the limitations of early sports specialisation at the expense of multilateral training (Faigenbaum et al., 2015). Therefore, to optimise training adaptations, resistance training programmes are typically structured into different training phases, known as periodisation (Afonso et al., 2017).

Periodisation is utilised to structure the training programmes into more manageable segments (Matveyev & Zdornyj, 1981). This allows manipulation of training variables (i.e. volume, intensity) to elicit positive improvements in physiological, technical and tactical, thereby improving sports performance (Bompa, 1999). Importantly, varying training variables can also help to manage fatigue, eliminate monotony in training routines, optimise recovery and avoid plateaus in fitness levels (Cunanan et al., 2018; Suchomel et al., 2018). Extensive research has shown that periodised resistance training is more effective at increasing performance gains than non-periodised programmes (Fleck, 1999; Kraemer et al., 2000; Williams et al., 2017).

LP features initial high training volume and low intensity with gradual increments in training intensity and decreases in volume over time (Rhea et al., 2002). Conversely, RLP uses a reverse order approach (Prestes et al., 2009a). Instead of progressively lowering training volume and increasing intensity, RLP gradually increases volume and decreases intensity (Rhea et al., 2003). UP is characterised by more regular daily, weekly or bi-weekly variation of intensity and volume (Hoffman et al., 2003). Studies have predominantly assessed these models in resistance training to develop muscular hypertrophy, strength and/or power (Harries et al., 2015a; Moraes et al., 2013; Simao et al., 2012) in untrained adult men and women (Fleck, 1999). BP, which is generally employed by elite athletes (Ronnestad et al., 2018), utilises highly concentrated loads that are organised into three blocks: accumulation, transmutation and realization (DeWeese et al., 2015b). Limited information is available on the responses to the previously mentioned training models to develop muscular endurance, particularly in youth athlete populations (Moraes et al., 2013).

One investigation has reported larger percent change in RLP (72 %) to improve muscular endurance compared to LP (56 %) and daily UP (55 %) after 15 weeks training in untrained adult men and women (Rhea et al., 2003). By contrast, another study found that daily UP resulted in greater increases in muscular endurance than LP in untrained women following 12 weeks training (de Lima et al., 2012). Accordingly, minimal evidence is available on the efficacy of LP and UP to develop muscular endurance in youth athletes. Of note, resistance training seems to improve muscle coordination and motor unit recruitment patterns (Guglielmo et al., 2009; Kaikkonen et al., 2000). In addition, muscular endurance training improves muscle buffer capacity and/or decreases accumulation of end products of anaerobic metabolism, therefore likely improving locomotor efficiency (Denadai & Greco, 2018; Hoff et al., 2002; Johnston et al., 1997). Therefore, the primary aim of this study was to compare the effects of these two models (LP vs. UP) on selected performance, physiological and psychological variables in youth athletes. The secondary aim was to describe the different physiological, neuromuscular and perceptual responses within this process to the training stimulus. This information is essential for understanding the internal responses of trained athletes elicited by this training strategy. The information could enable strength and conditioning coaches to monitor and assess the efficiency of a training programme to optimise the stimulus-adaptation process.

5.3 Methods

5.3.1 Experimental approach to the problem

This randomised, parallel-group repeated-measures design, compared LP and UP resistance training models to examine differential adaptations following muscular endurance training. Youth team sport athletes were recruited and randomly assigned to two training groups. Following randomisation, the participants trained three sessions per week during the 12 weeks' experimental period. Trained youth athletes were used as participants in an attempt to minimise the effect of initial neural adaptations on the performance measures (Schlumberger et al., 2001). This research took place four weeks following the fasting month (i.e. Ramadan) and during an off-season training period for all participants.

5.3.2 Participants

Twenty male youth team sport (field hockey, basketball and volleyball) athletes were recruited from the national sports school in Malaysia. This investigation was approved by the University's ethics committee. The participants and their legal guardians were advised of the purpose, possible risks, procedures, and advantages of periodised resistance training and were given an opportunity to ask questions. Subsequently, signed informed consents along with parental consents were obtained before commencing the study. Each participant resided in a hostel within the school. The participants trained approximately six to eight hours per week during the experimental period, involving activities appropriate to off-season training. All participants had experience, as part of the typical sport specific training, of using free weights and machine resistance prior to the start of the study. One participant withdrew due to reasons not related to the investigation. A total of 19 participants completed the training study.

5.3.3 Familiarisation

All participants completed three familiarisation sessions to practice the correct technique and estimate the training loads required for exercises to be completed in the study. Also, to ensure test-reliability, the depth required for the back squat was determined during these sessions according to each participant's 90° knee angle (determined by a goniometer), recorded and reproduced throughout the study. The testing and training procedures for the study are summarised in Figure 5.1.

5.3.4 Anthropometry characteristics

Standing height (metres) and body mass (kilograms) were measured with a digital scale (Model 769, SECA, Hamburg, Germany). Body fat (%) was estimated with bioelectrical impedance analysis analyser (InBody 770, Inbody, Australia).

5.3.5 Sexual maturity

Maturity status was self-reported (Tanner stage), in private, by the participants. An evaluation report was returned to the investigator in a sealed envelope at T0 (Figure 5.1).

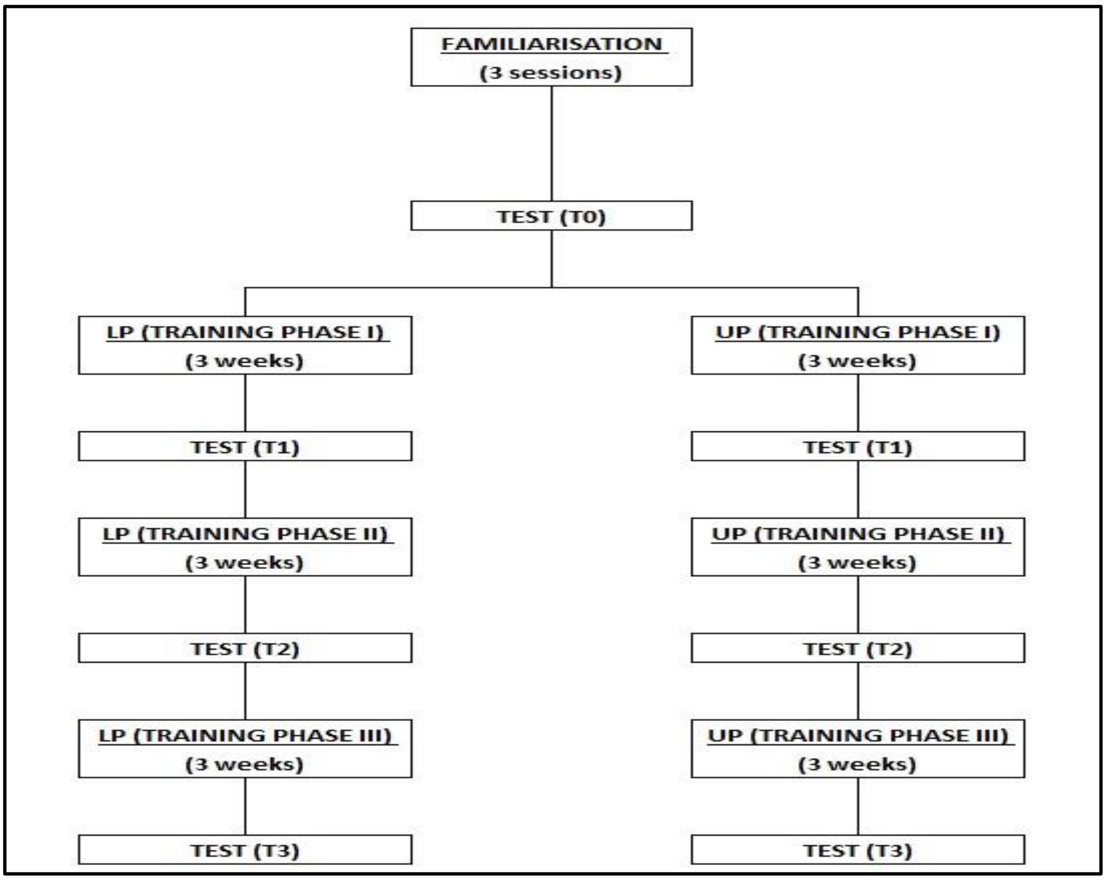

Figure 5.1 Testing and training schedule of Linear Periodisation (LP) and Undulating Periodisation (UP) groups

5.3.6 Strength assessment

Back squat and bench press five repetition maximum (5RM) assessments were utilised to determine maximal strength. The back squat utilised an Olympic bar and weights in a squat rack. During each repetition, participants were required to eccentrically lower to a knee angle of 90° and touch the elastic cord (placed behind the participant) before concentrically squatting the barbell (McCaulley et al., 2009). The bench press utilised a flat bench with an Olympic bar and weights (Harries et al., 2015a). All participants performed a standardised dynamic warm up, which comprised skipping, body weight lunges and dynamic stretches. Thereafter, three to five warm up sets of five to 10 repetitions with an unloaded bar were used to familiarise participants with the exercises. Participants then completed the 5RM assessments, progressively increasing the load each set so that a 5RM was obtained from three to five sets. Three to five minutes rest was provided between attempts. Test-retest reliability coefficients (ICC) have been previously reported as 0.96 and 0.97 for the back squat and bench press, respectively (Assunção et al., 2016).

5.3.7 Muscular endurance test

Muscular endurance tests were performed at least 48 hours after the 5RM tests. Back squat and bench press were utilised. One and a half minutes after a specific warm-up, the participants executed the highest number of repetitions possible with 70% of the estimated 1RM load until concentric failure (Dorgo, King, & Rice, 2009). Estimated 1RM was calculated with Tucker's equation (Harries et al., 2015a) (constant error between predicted and actual 1RM of 0.4 ± 3.0 kg; and ICC 0.93) for predicting 1RM from repetitions to fatigue (1RM (kg) = 1.139 × Weight + [0.352 × reps] + 0.243). This load was maintained for the subsequent tests to accurately measure improvements in muscular endurance. Test-retest ICC has been previously reported as 0.94 and 0.88 for the bench press and back squat muscular endurance test, respectively (Assunção et al., 2016).

5.3.8 Power tests

The SLJ was adapted from Moraes et al. (2013). The SLJ was evaluated with a mat (Gill Athletics Standing Long Jump Testing Mat, Champaign, IL) made of rubber and marked with the distance from the starting line. The participant stood with their toes just behind a starting line with their feet approximately hip width apart. A forward jump was executed using an arm swing. The distance of the jump (metres) was measured as the distance from the take-off line to the point where the back of the heel nearest to the take-off line landed. The best score from three attempts was used for analysis.

Upper-body power was evaluated by the seated medicine ball throw (MBT) using a 4 kg medicine ball (Kraemer & Fleck, 2007). Each participant sat on the floor (legs spread apart comfortably) with their back against a wall, holding the ball (i.e. maintained at chest level). Chalk was placed on the ball before each throw to provide measurement accuracy (i.e., to determine where the ball landed). The distance in metres from the edge of the wall to where the back of the medicine ball hit the floor was measured. The best score from three attempts was used for analysis. Test-retest ICC has been previously reported as 0.98 (Moraes et al., 2013) for SLJ and 0.80 (Ignjatovic, Markovic, & Radovanovic, 2012) for MBT.

5.3.9 Monitoring the training response (perceptual measures)

Rating of perceived exertion

Session RPE was obtained 15 minutes after each training session (Singh et al., 2007). The participants rated the global intensity of each training session using the Borg CR-10 scale developed by answering a question "How hard was your workout?" (Foster, 1998). The product of the session RPE and repetitions was computed to obtain the session load. The session load was averaged over each week of training. Then, the training monotony was computed from the mean training load by dividing the standard deviation of the training load over a one-week period. Finally the product of training load and training monotony was used to yield the training strain (Foster, 1998). Previous investigations have demonstrated the validity and utility of this approach with young athletes (Freitas et al., 2014a; Gomes, Moreira, Lodo, Capitani, & Aoki, 2015).

Daily well-being questionnaire

A five-item Likert scale questionnaire was distributed before each training session to rate the following: sleep, fatigue, muscle soreness, stress and mood (Antualpa et al., 2017). This questionnaire is sensitive in detecting fatigue in adult and youth rugby players (McLean et al., 2010; Oliver et al., 2015a). Each item was rated from one to five in one score increments and overall wellbeing was summated by adding up all five scores.

5.3.10 Neuromuscular performance

CMJ and PP were utilised to detect lower- and upper-body neuromuscular fatigue respectively (Roe et al., 2016a). Tests were conducted every week, before commencing the first training session in a microcycle (de Freitas Cruz et al., 2018). Test equipment and procedures were the same as described in Chapter 4. However only CMJMF (CV 1.3% < SWC 3.1 %) and PPMF (CV 2.7% = SWC 2.7%) were utilised to monitor neuromuscular fatigue in lower- and upper- body respectively.

5.3.11 Monitoring the training response (endocrine markers)

Resting salivary samples were collected at baseline (T0) and after each of the training phases (T1, T2, and T3). The saliva collection protocol was the same as for Chapter 4. Samples were collected at a standardised time (Tsai et al., 2012), 24–48 hours after the last training session (Passelergue & Lac, 2012). Samples were immediately stored at 4^{o}C in a polystyrene container with ice. The samples were subsequently stored in the laboratory freezer at -20°C until analysis for unbound testosterone and cortisol. Samples were assayed in duplicate using a commercial enzyme-immunoassay kit (Salimetrics, PA, USA) following the manufacturer’s instructions, in the same series to avoid between assay variations. All samples were processed on a fully automated 2-Plate ELISA Processing System analyser (Dynex Technologies Inc, VA, USA). The sensitivity, interassay and intraassay reproducibility were 1.0 pg/ml, 2.95% and 10.63% respectively, for cortisol, and 0.0007 µg/dL, 8.59 and 10.37% for testosterone. The T:C ratio was calculated as: *T:C ratio* = *T/C* X 100 (Painter et al., 2018).

5.3.12 Monitoring of volume load

The volume load (sets x repetitions x load) performed by each participant was recorded in a training log during each training session (Kraft et al., 2014). Training logs were collected and analysed every week.

5.3.13 Training procedures

For 12 weeks, each participant was assigned to a training programme that lasted approximately 60 minutes, for three sessions per week. Participants trained with both free weights and weight training machines. After familiarisation, baseline tests (T0) were conducted. Participants were pair matched on the back squat muscular endurance scores and randomly assigned into LP or UP training groups. This approach reduces the bias related with randomisation, since it decreases the likelihood of differences between experimental groups at baseline (Vincent, 2005). Subsequent to randomisation, the participants performed the exercises with the exercise volume defined in Figure 5.2. Differentiation in loading protocols between the LP and UP intervention groups was based on the results of previous investigations which had produced significant increases in muscular endurance (de Lima et al., 2012; Rhea et al., 2003).

LP group	**Weeks 1 - 3**	**Weeks 5 - 7**	**Weeks 9 - 11**
	3 x 25RM	**3 x 20RM**	**3 x 15RM**
UP group	**Day 1**	**Day 2**	**Day 3**
	3 x 25RM	**3 x 20RM**	**3 x 15RM**

Figure 5.2 Schedule of exercise volume for Linear Periodisation (LP) and Undulating Periodisation (UP) groups

The training loads were estimated during the familiarisation sessions. Previous training logs of the participants were utilised as a guide in these sessions. The information gained during the familiarisation sessions was used to ensure that participants could execute the prescribed volume from set to set until “repetition failure” during training. For example, if the prescribed training was 3 x 15RM, the participants would be unable to go beyond 15 repetitions per set. Therefore "repetition failure" was defined as being incapable of doing additional repetitions beyond those prescribed (Lawton, Cronin, Drinkwater, Lindsell, & Pyne, 2004).

After baseline measurements (T0), participants were randomised to either LP or UP training groups. After randomisation both groups trained with exercises listed in Table 5.1.

Table 5.1 Exercises and rest between sets during training

No	Exercise	Rest (minutes)
1	Half squat	1-2
2	Bench press	1-2
3	Abdominal exercise	3 sets of 20 reps
4	Seated calf raise	1-2
5	Latissimus pull-down	1-2
6	Lying back extension	3 sets of 20 reps
7	Leg curl	1-2
8	Bicep curl	1-2

For LP, participants performed three sets of 25RM (weeks 1-3), three sets of 20RM (weeks 5-7), and three sets of 15RM (weeks 9-11). The training volume and intensity were varied during each session for the UP group (i.e. three sets of 25RM, three sets of 20RM and three sets of 15RM). Recovery and testing occurred on weeks 4 (T1), 8 (T2) and 12 (T3) for both groups. Mean volume (total repetitions performed) and intensity over the entire 12 weeks was equated for the LP and UP groups. The difference between groups was the structure of the periodised programmes. All sessions were supervised by the primary researcher. Before commencing each prescribed training session, the participants started with a light standardised dynamic warm up without static stretching

(Carvalho et al., 2012). They were instructed not to engage in other supplemental resistance training programmes during the experimental period. After each training session, the participants performed a cool down with five minutes of full body stretching.

5.3.14 Statistical analysis

Baseline characteristics were examined for normality. Following randomisation, an independent t-test was conducted to determine if any significant differences in baseline characteristics existed between groups. Following the intervention, outcomes were analysed using Generalised Linear Mixed Models, fitted with an unstructured covariance structure. Training groups (i.e. LP and UP) were treated as the between-participant factor, time was treated as the repeated within-participants factor, group x time was treated as the interaction and participant was treated as a random effect. Hedges *g* ES for small sample sizes, and the 95% lower and upper CI were reported (Ialongo, 2016). ES ≤0.20, 0.21 to 0.49, 0.50 to 0.79 and ≥0.80 were classified as trivial, small, moderate and large respectively (Cohen, 1988). Pearson's product-moment correlation coefficient was calculated between session RPE and total volume load from both groups. Where relevant, percent change was computed as: [(post-exercise mean - pre-exercise mean)/pre-exercise mean] x 100. The normalised volume index was calculated to determine workloads relative to body mass as follows: volume load/body mass$^{0.67}$ (Haff, 2010). Challis (1999) and Folland, McCauley, and Williams (2008) suggested that strength levels are proportional to body mass and how that muscle mass is distributed. Hence, to normalise strength measures, allometric scaling is recommended to remove the influence of body mass (Folland et al., 2008; Jaric, 2002; Jaric, Ugarkovic, & Kukoli, 2002). The level of significance was set at $p \le 0.05$. All data were reported as mean ± SD unless otherwise specified. Biochemical data were reported as mean ± SEM. Statistical analysis was completed using the IBM SPSS Statistics for Windows software (Version 21.0, Armonk, NY: IBM Corp).

5.4 Results

There were no significant pre-training differences between the two training groups. The baseline characteristics of the participants are shown in Table 5.2.

Table 5.2 Baseline characteristics of the participants

Variable	**LP (n = 10)**	**UP (n = 9)**	***p***	**ES (95%CI)**
Height (m)	1.77 ± 0.09	1.74 ± 0.08	0.44	-0.35 (-1.26, 0.56)
Body mass (kg)	73.76 ± 15.16	70.79 ± 11.09	0.64	-0.21 (-1.11, 0.69)
Age (years)	16.8 ± 0.42	17.0 ± 0.50	0.36	0.42 (-0.49, 1.33)
Tanner (stage)	4.70 ± 0.48	4.56 ± 0.53	0.54	-0.27 (-1.17, 0.64)
BPME (repetition)	15.40 ± 2.12	14.00 ± 1.94	0.15	-0.66 (-1.58, 0.27)
BSME (repetition)	15.20 ± 3.94	14.89 ± 4.48	0.87	-0.07 (-0.97, 0.83)
5RMBS (kg)	81.56 ± 10.29	83.96 ± 12.28	0.65	0.20 (-0.70, 1.11)
5RMBP (kg)	55.42 ± 7.53	50.98 ± 6.13	0.18	-0.61 (-1.54, 0.32)

m = metre; kg = kilogram; LP = Linear Periodisation; UP = Undulating Periodisation; BPME = bench press muscular endurance; BSME = back squat muscular endurance; 5RMBS = 5RM back squat; 5RMBP = 5RM bench press; ES (95%CI) = effect size (95% confidence interval)

5.4.1 Training volume and intensity

The experimental groups were designed for participants to undergo the identical number of training sessions (n = 27), sets (n = 486) and repetitions (n = 9720). Total training volume load between LP (429568.01 ± 33164.41kg) and UP (375783.77 ± 44659.16kg) were not significantly different (p = 0.587). After adjusting for participant body mass, the outcome revealed greater total work performed in the LP group. There was a significant (Figure 5.3) group x time interaction effect (p = 0.002). LP demonstrated higher training volume load at week 3 (p = 0.002) and week 6 (p = 0.049), whereas training volume load was higher for UP at week 7 (p = 0.006), week 8 (p = 0.010) and week 9 (p = 0.009). There were also significant main effects for time (p = 0.000). The pairwise comparison showed volume load at week 4 (p = 0.010), week 5 (p = 0.000), week 6 (p = 0.000), week 7 (p = 0.000), week 8 (p = 0.000) and week 9 (p = 0.000) were higher than at week 1. There was no significant difference exhibited between week 2 (p = 0.598) and week 3 (p = 0.095) and week 1. Participants recorded 100% training compliance.

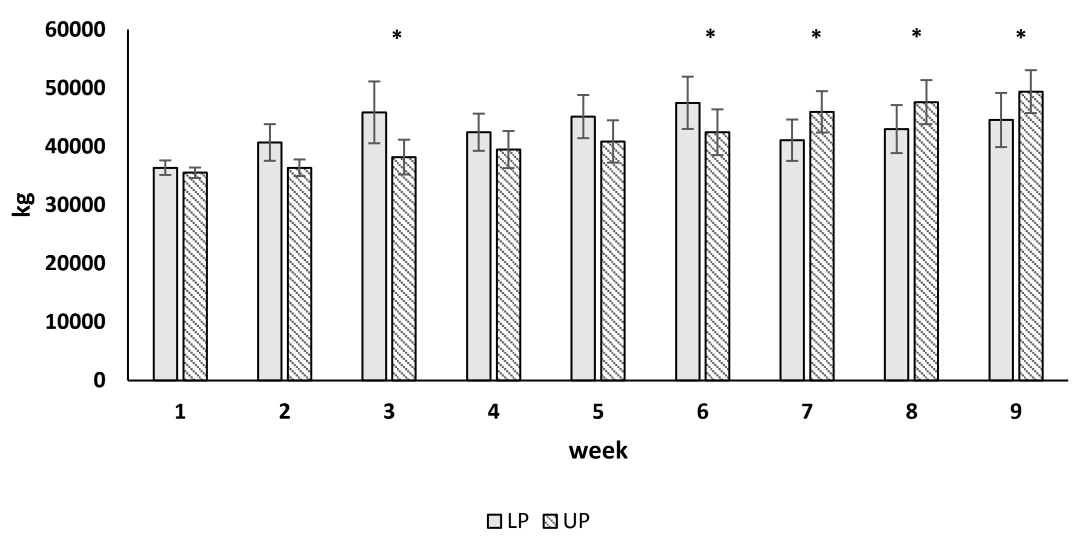

Figure 5.3 Weekly volume load between the periodised training groups
(mean ± SD); * significantly different at $p \leq 0.05$

5.4.2 Muscular endurance

Table 5.3 displays the lower- and upper-body muscular endurance results. No significant differences were observed post-training between groups nor was there any significant group-by-time interaction effect detected in the back squat and bench press muscular endurance protocols. However, there was a significant main effect of time for back squat (p = 0.000). Back squat muscular endurance was significantly greater at T2 (p = 0.000) and T3 (p = 0.001) compared to T0. Scores at T1 (p = 0.234) were not significantly different when compared to T0. UP demonstrated large ES from T0 to T3 compared to LP in the back squat muscular endurance. There was also a significant main effect of time for the bench press muscular endurance (p = 0.017), with T1 (p = 0.038), T2 (p = 0.018) and T3 (p = 0.000) significantly different to T0. As with the back squat muscular endurance, UP demonstrated a large ES from T0 to T3 compared to LP in bench press muscular endurance.

Table 5.3 Lower- and upper-body muscular endurance values at each time point

Assessment	Time Point	LP (n = 10) Mean ± SD	% Δ	ES[a] (95%CI)	ES[b] (95%CI)	UP (n = 9) Mean ± SD	% Δ	ES[a] (95%CI)	ES[b] (95%CI)
Back squat (repetitions)	T0	15.20 ± 3.94				15.78 ± 2.91			
	T1	17.40 ± 4.97	14.47	0.47 (-0.43, 1.37)	0.47 (-0.43, 1.37)	16.89 ± 2.42	7.03	0.40 (-0.55, 1.34)	0.40 (-0.55, 1.34)
	T2	22.40 ± 4.06	47.37	1.72 (0.76, 2.69)	1.06 (0.12, 1.99)	21.11 ± 2.80	33.78	1.78 (0.76, 2.80)	1.54 (0.53, 2.54)
	T3	18.40 ± 4.90	21.05	0.69 (-0.22, 1.60)	-0.85 (-1.68, -0.02)	22.67 ± 4.92	43.66	1.62 (0.61, 2.64)	0.37 (-0.57, 1.32)
Bench press (repetitions)	T0	15.40 ± 2.12				12.44 ± 1.74			
	T1	17.20 ± 3.61	11.69	0.58 (-0.33, 1.49)	0.58 (-0.33, 1.49)	16.56 ± 2.96	33.12	1.62 (0.60, 2.63)	1.62 (0.60, 2.63)
	T2	19.70 ± 4.11	27.92	1.26 (0.32, 2.20)	0.62 (-0.29, 1.53)	17.44 ± 3.50	40.19	1.72 (0.70, 2.74)	0.26 (-0.68, 1.20)
	T3	21.70 ± 4.47	40.91	1.72 (0.76, 2.69)	0.45 (-0.45, 1.35)	20.33 ± 5.74	63.42	1.77 (0.75, 2.79)	0.58 (-0.38, 1.54)

% Δ = percentage change from T0; ES[a] (95%CI) = Effect size (95% confidence interval) from T0; ES[b] (95%CI) = Effect size (95% confidence interval) from preceding test.

5.4.3 Strength

Both training groups showed significant increases (p = 0.000) from T0 to T3 in lower- and upper-body strength measures with large ES (Table 5.4). The pairwise comparison detected statistically significant differences between T0-T1, T0-T2 and T0-T3 in both the 5RM back squat and bench press. Although both training groups improved strength, this did not result in a statistically significant difference between groups or main interaction effect.

Table 5.4 Lower- and upper-body 5RM strength values at each time point

Assessment	Time Point	LP (n = 10)				UP (n = 9)			
		Mean ± SD	% Δ	ES[a] (95%CI)	ES[b] (95%CI)	Mean ± SD	% Δ	ES[a] (95%CI)	ES[b] (95%CI)
5RM back squat (kg)	T0	81.56 ± 10.29				83.96 ± 12.28			
	T1	86.73 ± 7.77	6.34	0.54 (-0.36, 1.45)	0.54 (-0.36, 1.45)	88.83 ± 10.94	5.80	0.40 (-0.55, 1.35)	0.40 (-0.55, 1.35)
	T2	90.44 ± 9.37	10.89	0.86 (-0.06, 1.79)	0.41 (-0.49, 1.31)	93.07 ± 10.27	10.85	0.76 (-0.20, 1.73)	0.38 (-0.57, 1.33)
	T3	94.70 ± 10.08	16.11	1.24 (0.29, 2.18)	0.42 (-0.48, 1.32)	98.00 ± 10.31	16.72	1.18 (0.19, 2.17)	0.46 (-0.49, 1.41)
5RM bench press (kg)	T0	55.42 ± 7.53				50.98 ± 6.13			
	T1	59.28 ± 7.61	6.96	0.48 (-0.41, 1.39)	0.48 (-0.41, 1.39)	55.27 ± 7.22	8.42	0.61 (-0.35, 1.57)	0.61 (-0.35, 1.57)
	T2	60.36 ± 8.54	8.91	0.59 (-0.32, 1.50)	0.13 (-0.76, 1.01)	57.29 ± 8.10	12.38	0.84 (-0.13, 1.81)	0.25 (-0.69, 1.19)
	T3	64.42 ± 8.33	16.24	1.09 (0.15, 2.02)	0.46 (-0.44, 1.36)	60.44 ± 9.57	18.56	1.12 (0.13, 2.11)	0.34 (-0.60, 1.28)

kg = kilogram; % Δ = percentage change from T0; ES[a] (95%CI) = Effect size (95% confidence interval) from T0; ES[b] (95%CI) = Effect size (95% confidence interval) from preceding test.

5.4.4 Anthropometric characteristics

There were no significant differences between the intervention groups (i.e. LP and UP), significant group-by-time interaction nor time effect observed in body mass and body fat measures (Table 5.5).

Table 5.5 Changes in anthropometric characteristics at each time point

Assessment	Time Point	LP (n = 10) Mean ± SD	% Δ	ES^a (95%CI)	ES^b (95%CI)	UP (n = 9) Mean ± SD	% Δ	ES^a (95%CI)	ES^b (95%CI)
Body mass (kg)	T0	74.64 ± 14.56				70.79 ± 11.09			
	T1	75.13 ± 14.68	0.66	0.03 (-0.85, 0.91)	0.03 (-0.85, 0.91)	71.13 ± 10.82	0.49	0.03 (-0.90, 0.96)	0.03 (-0.90, 0.96)
	T2	75.27 ± 14.83	0.84	0.04 (-0.84, 0.92)	0.009 (-0.868, 0.886)	71.33 ± 9.13	0.77	0.05 (-0.88, 0.98)	0.02 (-0.91, 0.94)
	T3	75.66 ± 15.31	1.37	0.07 (-0.81, 0.95)	0.03 (-0.85, 0.90)	70.98 ± 9.10	0.27	0.01 (-0.91, 0.94)	-0.04 (-0.96, 0.88)
Body fat (percent)	T0	16.11 ± 6.09				15.02 ± 5.36			
	T1	15.73 ± 6.02	-2.36	-0.06 (-0.93, 0.81)	-0.06 (-0.93, 0.81)	15.27 ± 6.05	1.63	0.04 (-0.89, 0.97)	0.04 (-0.89, 0.97)
	T2	15.59 ± 6.22	-3.23	-0.08 (-0.95, 0.79)	-0.02 (-0.90, 0.85)	14.94 ± 5.22	-0.52	-0.01 (-0.94, 0.91)	-0.05 (-0.98, 0.87)
	T3	15.11 ± 6.32	-6.21	-0.15 (-1.02,0.71)	-0.07 (-0.95, 0.80)	14.33 ± 5.85	-4.59	-0.12 (-1.03, 0.80)	-0.10 (-1.02, 0.81)

% Δ = percentage change from T0; ES^a (95%CI) = Effect size (95% confidence interval) from T0; ES^b (95%CI) = Effect size (95% confidence interval) from preceding test.

5.4.5 Power

There were no significant differences between the experimental groups, significant group-by-time interaction or main effect for time (Table 5.6).

Table 5.6 Lower- and upper-body power at each time point

Assessment	Time Point	LP (n = 10)				UP (n = 9)			
		Mean ± SD	% Δ	ES[a] (95%CI)	ES[b] (95%CI)	Mean ± SD	% Δ	ES[a] (95%CI)	ES[b] (95%CI)
Standing long jump (m)	T0	2.36 ± 0.29				2.43 ± 0.13			
	T1	2.42 ± 0.22	2.46	0.22 (-0.67, 1.11)	0.22 (-0.67, 1.11)	2.43 ± 0.16	0.33	0.05 (-0.88, 0.98)	0.05 (-0.88, 0.98)
	T2	2.41 ± 0.17	1.82	0.18 (-0.71, 1.06)	-0.07 (-0.95, 0.80)	2.42 ± 0.18	-0.33	-0.05 (-0.97, 0.87)	-0.09 (-1.01, 0.83)
	T3	2.39 ± 0.18	1.23	0.12 (-0.77, 1.00)	-0.08 (-0.95, 0.79)	2.41 ± 0.18	-0.82	-0.12 (-1.04, 0.80)	-0.06 (-0.98, 0.86)
Medicine ball throw (m)	T0	5.53 ± 0.54				5.54 ± 0.60			
	T1	5.53 ± 0.63	0.13	0.01 (-0.87, 0.889)	0.01 (-0.87, 0.89)	5.41 ± 0.53	-2.31	-0.22 (-1.13, 0.70)	-0.22 (-1.13, 0.70)
	T2	5.68 ± 0.50	2.79	0.29 (-0.61, 1.18)	0.25 (-0.64, 1.137)	5.51 ± 0.59	-0.49	-0.04 (-0.97, 0.88)	0.17 (-0.76, 1.11)
	T3	5.65 ± 0.49	2.23	0.23 (-0.66, 1.12)	-0.06 (-0.93, 0.81)	5.57 ± 0.58	0.58	0.05 (-0.88, 0.98)	0.10 (-0.83, 1.03)

m = metre; % Δ = percentage change from T0; ES[a] (95%CI) = Effect size (95% confidence interval) from T0; ES[b] (95%CI) = Effect size (95% confidence interval) from preceding test.

5.4.6 Endocrine markers

A significant group x time interaction ($p = 0.015$) was detected for testosterone (Table 5.7), that revealed UP had a significantly higher testosterone increase (31.47%) from baseline compared to LP (-8.73%). When collapsed across groups, a main effect for time was detected in the testosterone response. Pairwise comparisons showed T3 was significantly different from T0 ($p = 0.006$). Despite changes in salivary testosterone concentration, there were no significant differences between groups, significant group-by-time interaction or main effect of time for cortisol and T:C ratio.

Table 5.7 Testosterone, cortisol and testosterone: cortisol ratio responses at each time point

Assessment	Time Point	LP (n = 10) Mean ± SEM	% Δ	ES[a] (95%CI)	ES[b] (95%CI)	UP (n = 9) Mean ± SEM	% Δ	ES[a] (95%CI)	ES[b] (95%CI)
Testosterone (pmol/L)	T0	139.52 ± 12.74				206.04 ± 16.32			
	T1	126.45 ± 11.09	-9.37	-0.33 (-1.19, 0.53)	-0.33 (-1.19, 0.53)	176.12 ± 47.81	-14.52	-0.27 (-1.17, 0.64)	-0.27 (-1.17, 0.64)
	T2	125.43 ± 15.03	-10.10	-0.31 (-1.17, 0.55)	-0.02 (-0.90, 0.85)	177.70 ± 47.60	-13.75	-0.25 (-1.16, 0.66)	0.01 (-0.91, 0.94)
	T3	127.34 ± 12.92	-8.73	-0.29 (-1.15, 0.57)	0.04 (-0.84, 0.92)	270.89 ± 24.78	31.47	0.98 (0.00, 1.96)	0.78 (-0.19, 1.75)
Cortisol (nmol/L)	T0	1.32 ± 0.18				2.69 ± 0.46			
	T1	1.23 ± 0.19	-6.82	-0.15 (-1.02, 0.72)	-0.15 (-1.02, 0.72)	1.98 ± 0.47	-26.39	-0.49 (-1.38, 0.41)	-0.49 (-1.38, 0.41)
	T2	1.40 ± 0.17	6.06	0.14 (-0.74, 1.02)	0.29 (-0.60, 1.18)	2.65 ± 0.43	-1.49	-0.03 (-0.95, 0.89)	0.47 (-0.48, 1.42)
	T3	1.63 ± 0.20	23.48	0.49 (-0.41, 1.40)	0.37 (-0.52, 1.27)	3.34 ± 0.38	24.16	0.49 (-0.46, 1.44)	0.54 (-0.41, 1.50)
T:C Ratio	T0	12.30 ± 1.79				8.80 ± 0.95			
	T1	11.39 ± 1.07	-7.40	-0.19 (-1.05, 0.68)	-0.19 (-1.05, 0.68)	8.93 ± 0.62	1.48	0.05 (-0.88, 0.98)	0.05 (-0.88, 0.98)
	T2	9.56 ± 1.13	-22.38	-0.55 (-1.40, 0.29)	-0.50 (-1.35, 0.34)	6.95 ± 1.12	-21.02	-0.57 (-1.46, 0.33)	-0.69 (-1.58, 0.19)
	T3	8.90 ± 1.26	-27.64	-0.67 (-1.50, 0.17)	-0.17 (-1.03, 0.70)	8.64 ± 0.76	-1.82	-0.06 (-0.98, 0.86)	0.56 (-0.40, 1.52)

SEM standard error of the mean; % Δ percentage change from T0; ES[a] (95%CI) Effect size (95% confidence interval) from T0; ES[b] (95%CI) Effect size (95% confidence interval) from preceding test.

5.4.7 Neuromuscular performance

Weekly neuromuscular fatigue assessments (Figure 5.4 and Figure 5.5) did not reveal any statistically significant main effect for time, between training groups and interaction effect in CMJMF (p = 0.445, p = 0.610 and p = 0.741) and PPMF (p = 0.338, p = 0.860 and p = 0.368).

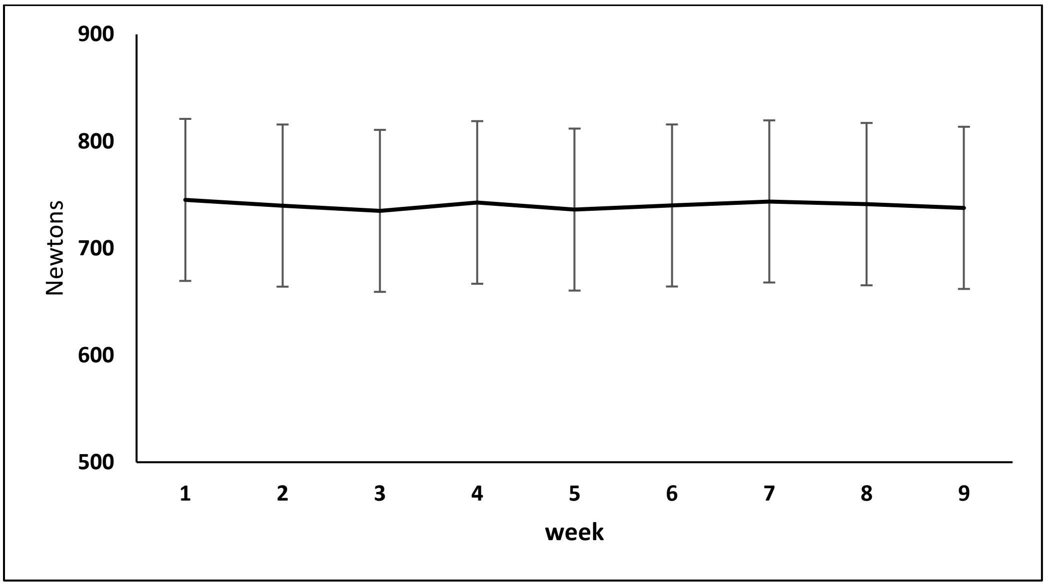

Figure 5.4 Main effect of time for countermovement jump mean force (mean ± SD)

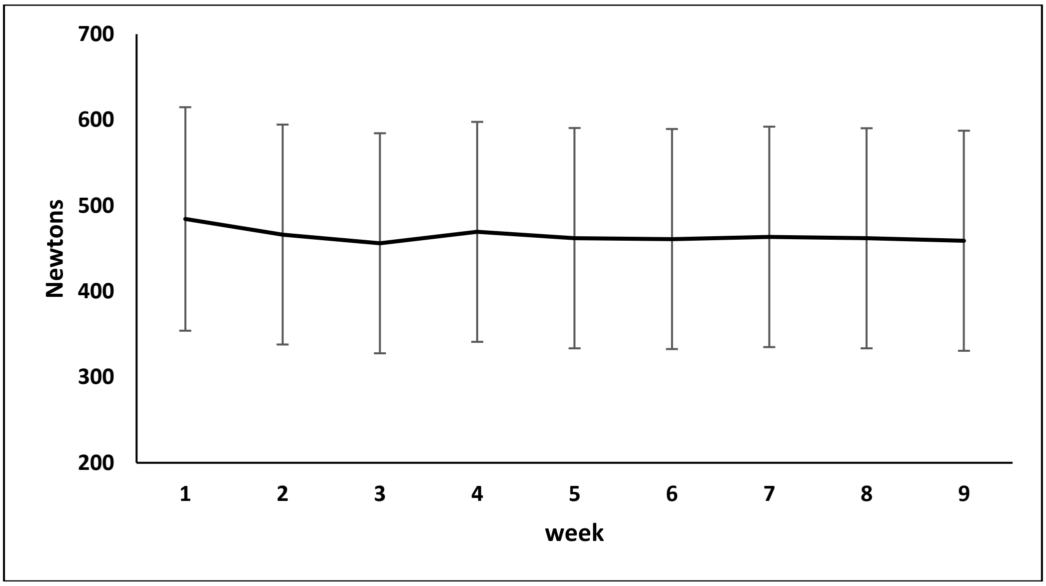

Figure 5.5 Main effect of time for plyometric push up mean force (mean ± SD)

5.4.8 Perceptual measures

Rating of perceived exertion

No statistically significant differences between training groups (*p* = 0.105) or main interaction effect (*p* = 0.981) was detected in session RPE ratings. There was a main effect (*p* = 0.007) for time (Figure 5.6). There was a relationship between session RPE and total volume load (*r* = 0.79, *p* = 0.074).

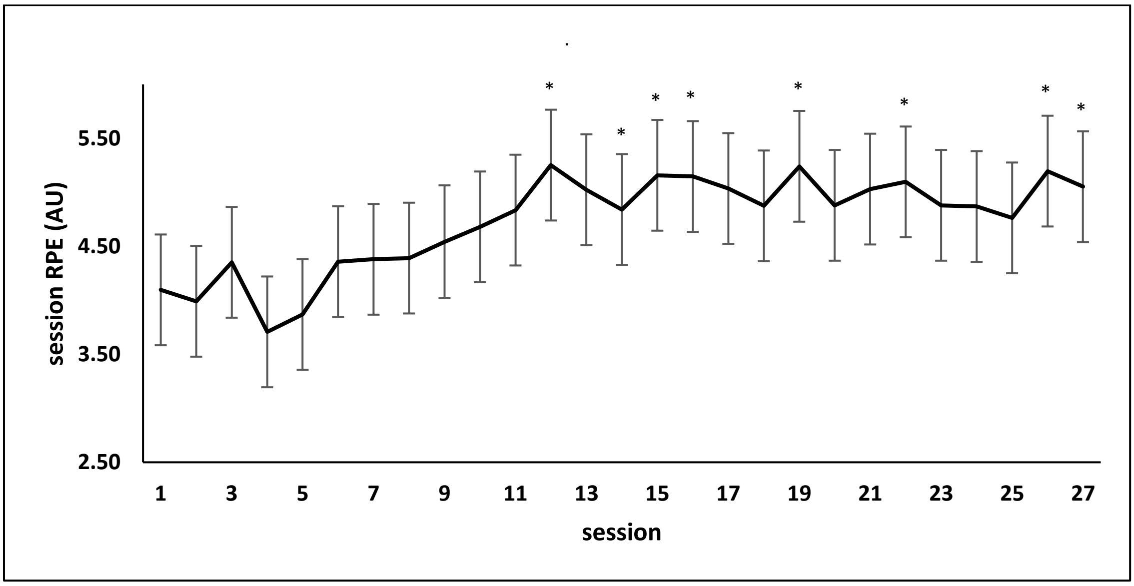

Figure 5.6 Main effect of time for session rating of perceived exertion
(mean ± SD); $p \leq 0.05$; * significantly different from session 1

Monotony

Weekly training monotony showed a significant group-by-time interaction (p = 0.024) and main effect (p = 0.032) for time. Specifically, LP exhibited statistically higher monotony scores during week 3 (p = 0.036), 6 (p = 0.017), 7 (p = 0.002) and 8 (p = 0.024) compared to UP. However, no significant between-group main effect (p = 0.131) was detected (Figure 5.7).

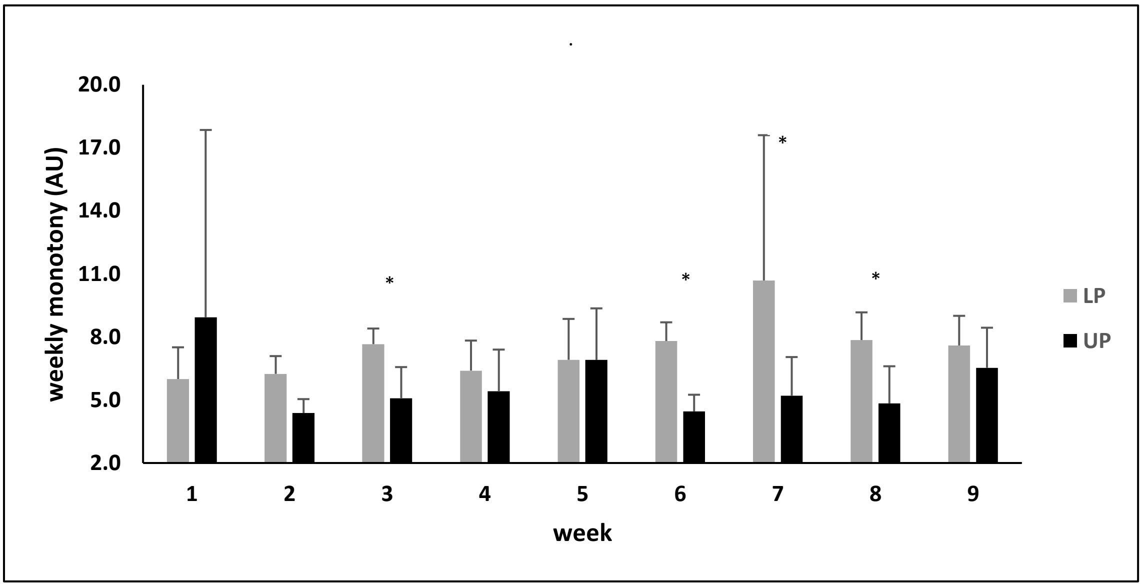

Figure 5.7 Weekly training monotony between the periodised training groups (mean ± SD); * significantly different at $p \leq 0.05$

Strain

Weekly training strain showed a significant group-by-time interaction ($p = 0.043$) and main effect ($p = 0.016$) for time. Specifically, LP exhibited statistically higher strain scores during weeks 2 ($p = 0.008$), 3 ($p = 0.001$), 6 ($p = 0.005$), 7 ($p = 0.003$) and 8 ($p = 0.043$) compared to UP. However, no significant between-group main effect ($p = 0.173$) was detected (Figure 5.8).

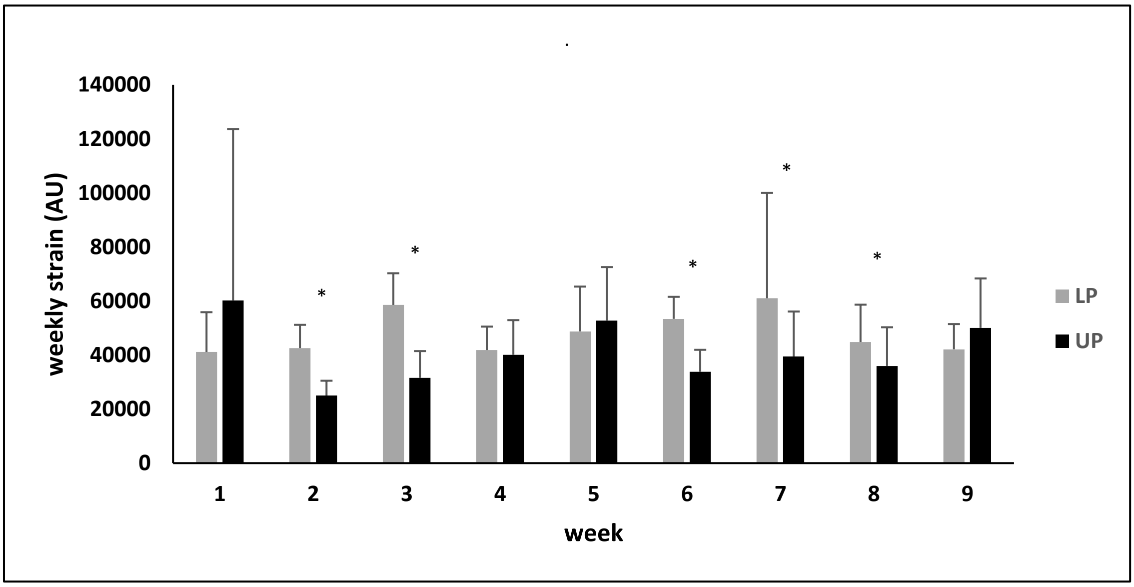

Figure 5.8 Weekly training strain between the periodised training groups (mean ± SD); * significantly different at $p \leq 0.05$

Fatigue

No statistically significant differences were detected between training groups ($p = 0.319$) or main interaction effect ($p = 0.834$) in fatigue scores prior to each training session. However, a main effect for time ($p = 0.027$) was observed (Figure 5.9).

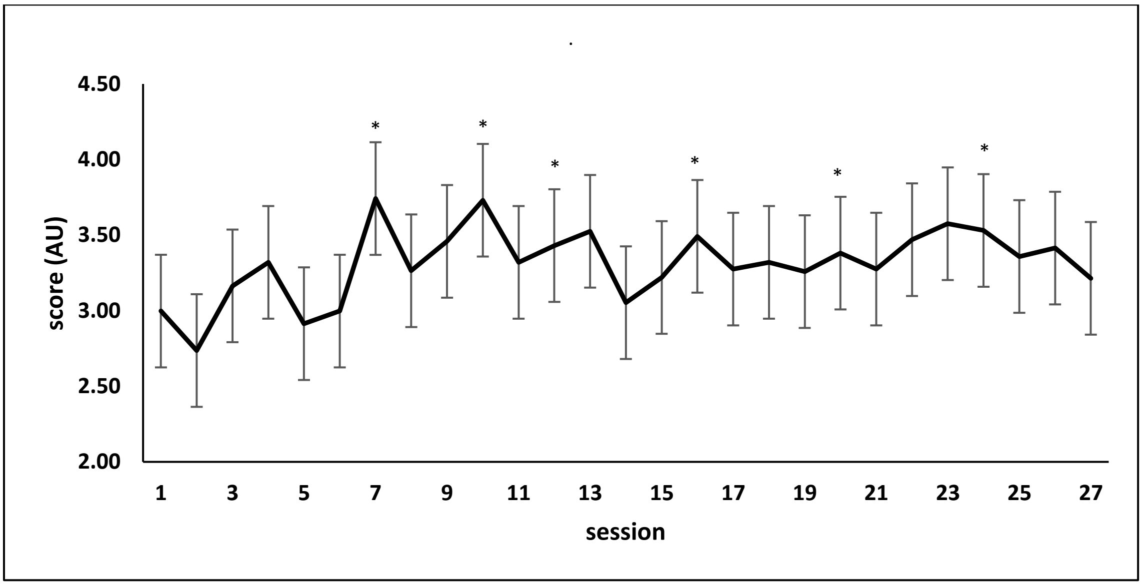

Figure 5.9 Main effect of time for fatigue score
(mean ± SD); $p \leq 0.05$; * significantly different from session 1

Soreness

Main effect for time (p = 0.000) was detected in muscle soreness scores (Figure 5.10). No statistically significant differences were found between training groups (p = 0.531) or main interaction effect (p = 0.723).

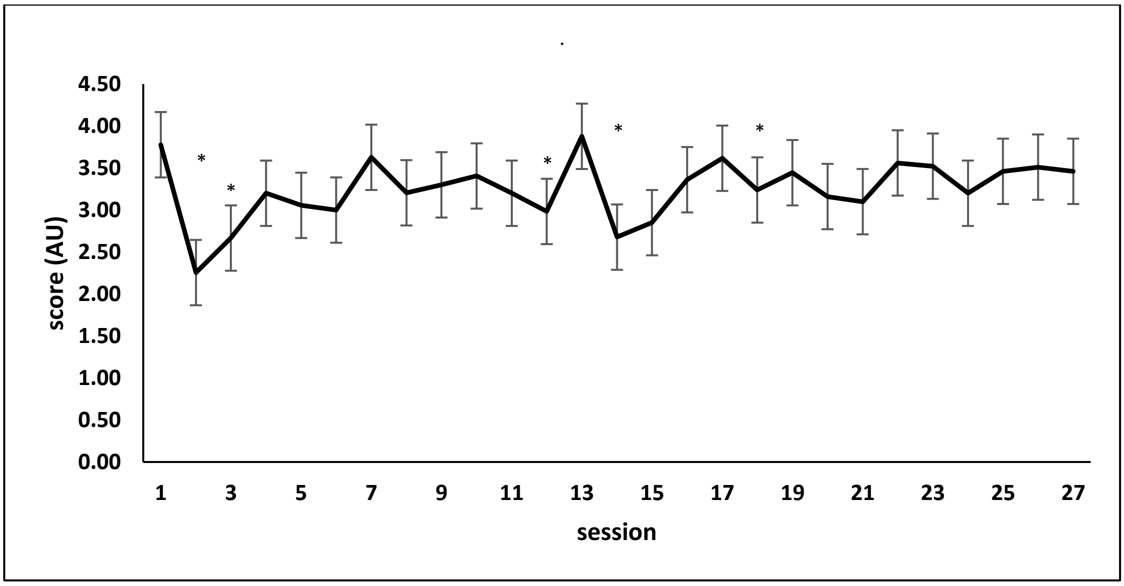

Figure 5.10 Main effect of time for soreness score
(mean ± SD); $p \leq 0.05$; * significantly different from session 1

Mood

Group x time (p = 0.766) was not significant for mood scores. Also, the main effect between groups (p = 0.641) was not significant, but a significant main effect for time (p = 0.008) was detected in mood scores (Figure 5.11).

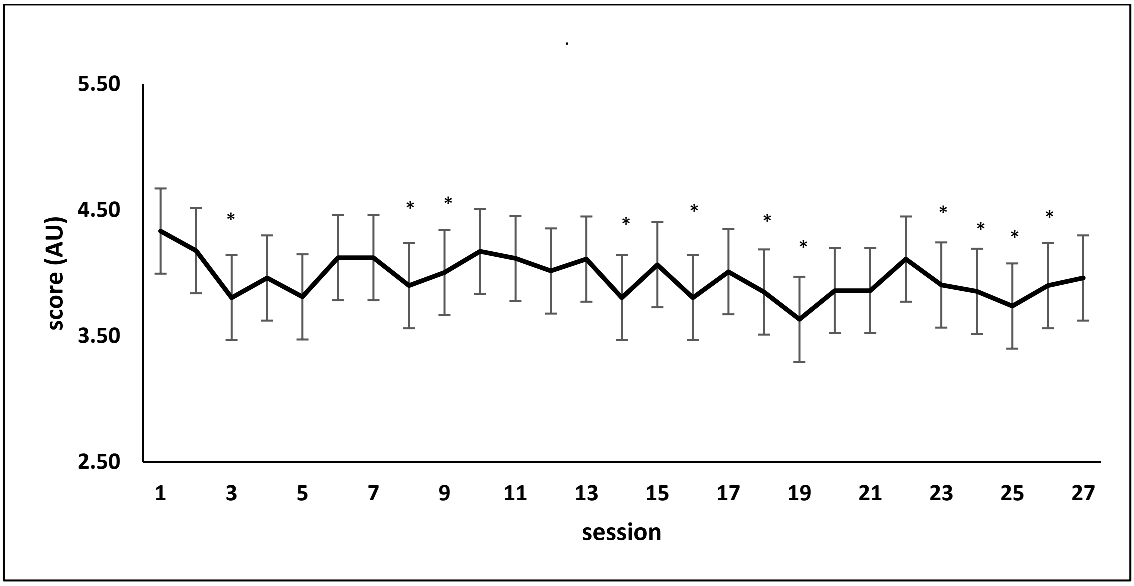

Figure 5.11 Main effect of time for mood score
(mean ± SD); $p \leq 0.05$; * significantly different from session 1

Stress

No significant differences were found between training groups (p = 0.327) or main interaction effect (p = 0.410) in stress scores. However, a main effect for time (p = 0.048) was shown for the stress scores (Figure 5.12).

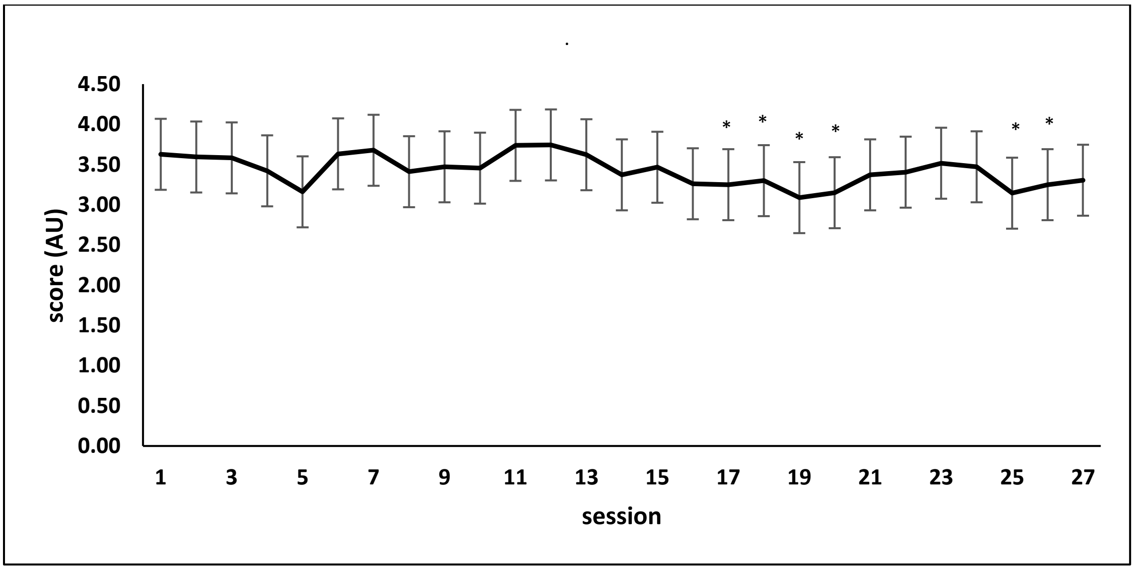

Figure 5.12 Main effect of time for stress score
(mean ± SD); $p \leq 0.05$; * significantly different from session 1

Sleep

No significant differences between training groups (p = 0.717) or main interaction (p = 0.460) was detected for the sleep scores. There was a main effect (p = 0.032) for time (Figure 5.13).

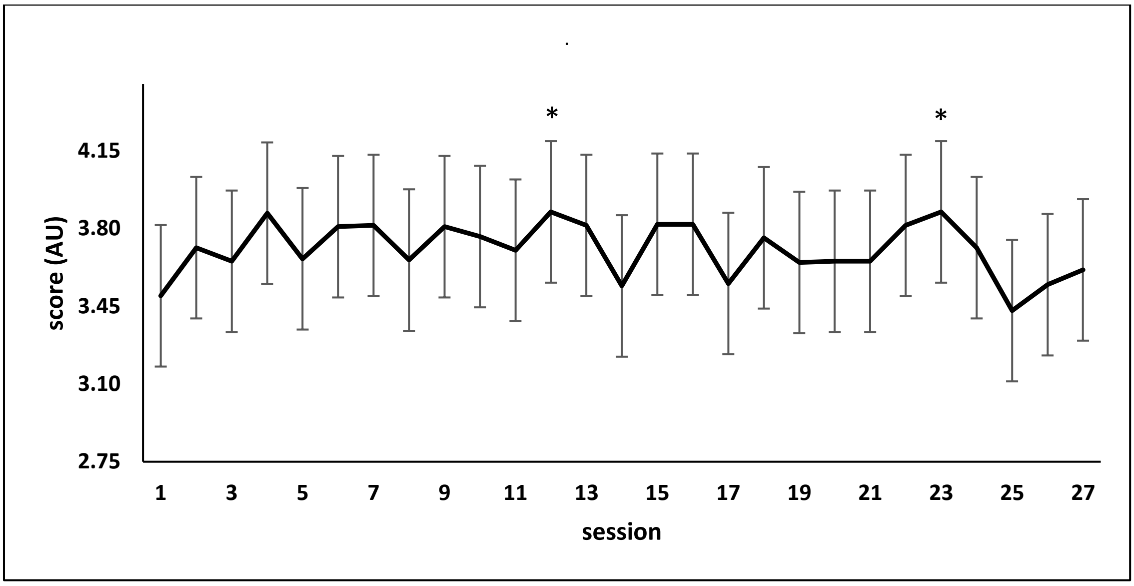

Figure 5.13 Main effect of time for sleep score
(mean ± SD); $p \leq 0.05$; * significantly different from session 1

Overall well-being score

Group x time was not significant for overall well-being (p = 0.245). Similarly, the main effect between groups (p = 0.355) was not significant. There was a significant main effect for time (p = 0.037) (Figure 5.14).

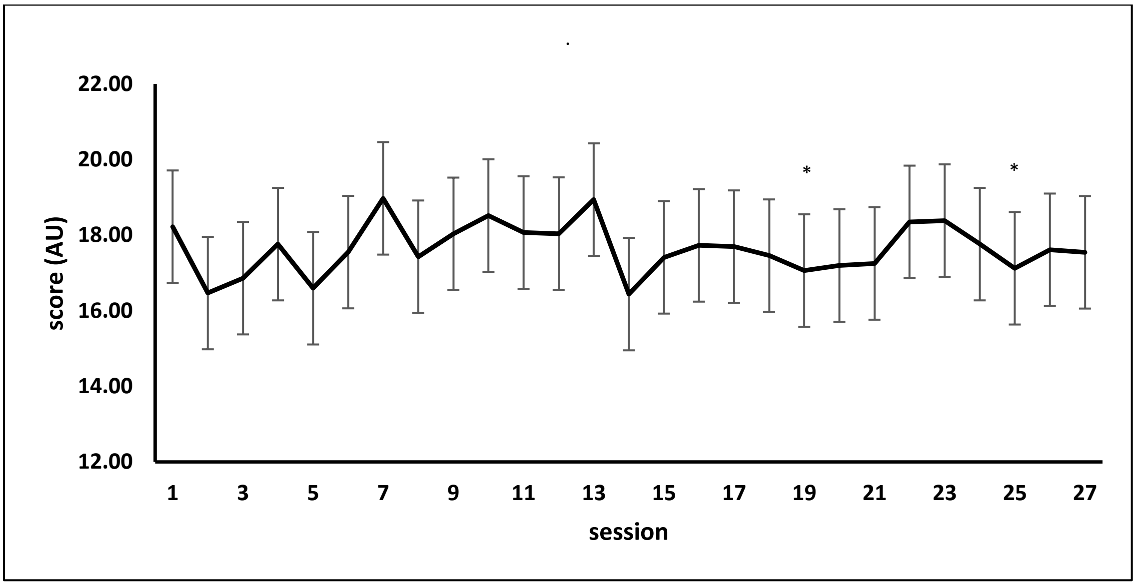

Figure 5.14 Main effect of time for overall well-being score
(mean ± SD); $p \leq 0.05$; * significantly different from session 1

5.5 Discussion

The primary aim of this investigation was to compare two different training models (LP vs. UP) for developing muscular endurance in trained youth athletes. The main finding was that both training groups significantly improved muscular endurance performance. Specifically, the UP training group achieved large gains in lower- and upper-body muscular endurance. It appears that daily adjustments in training volume and intensity improved muscular endurance (back squat ES = 1.62; bench press ES = 1.77) in comparison to LP (back squat ES = 0.69; bench press ES = 1.72). The findings are in line with those of de Lima et al. (2012) who found that daily UP appears to be more effective for developing muscular endurance than LP. However, Rhea et al. (2003) reported no differences between daily UP and LP training models, but suggested RLP was superior for enhancing muscular endurance. The efficacy of RLP could be attributed to the greater training volume performed during the 15 weeks' experimental period, as training volume is highly associated with muscular endurance performance (Miranda et al., 2011).

The current investigation showed that UP, performed with high repetitions per set, improves muscular endurance in male youth athletes. It is likely that the UP training programme introduced higher variability on the neuromuscular system, which may have yielded greater adaptations, subsequently increasing muscle performance in trained individuals (Monteiro et al., 2009). The high training volume in the UP group during the last three weeks may also have contributed to the improvements in muscular endurance assessments after the training period (de Lima et al., 2012; Rhea et al., 2003).

5.5.1 Muscular endurance

The magnitude of gains in muscular endurance achieved in both training groups in this study is in accordance with previous findings (de Lima et al., 2012; Rhea et al., 2003). Rhea and colleagues (2003) showed improvements of 53.85% and 53.51% in LP and daily UP respectively following 15 weeks (two days per week) of leg extension exercise in untrained men and women. de Lima and colleagues (2012) also examined muscular endurance changes in untrained women, involving various resistance training exercises, performed four days per week. They reported gains in bench press (LP 62.20%; daily UP 127.04%) and leg press (LP 90.15%; daily UP 127.66%) after 12 weeks of training. The greater percentage increases in muscular endurance exhibited in previous studies may in part be explained by the training history of the participants. Untrained participants show greater improvement after short-term training because of rapid neural factor gains (Hakkinen & Komi, 1985). They will benefit significantly from a periodised training programme regardless of the amount and method of training because they are at the lower end of their training potential curve (Hartmann et al., 2015; Rhea & Alderman, 2004). The improvements obtained in lower- and upper-body muscular endurance in the current study showed moderate to large ES in previously trained youth athletes. The training load combined with the concept of periodisation acted as new stimuli to the participants and thus improved their lower- and upper-body muscular endurance at rates that were comparable to untrained individuals. Considering all of this evidence, it seems that a different training programme (in terms of intensity, volume, duration, or modality) would elicit positive neuromuscular adaptations (Pickering & Kiely, 2018), and induce greater muscular endurance gains in previously trained youth athletes.

Differentiation in loading protocols between the LP and UP intervention groups was based on the results of previous investigations which had produced significant increases in muscular endurance (de Lima et al., 2012; Rhea et al., 2003). It should be noted that no significant differences in muscular endurance were detected between the LP and UP groups. For both groups, there were no recovery weeks planned between mesocycles. Indeed, Apel et al. (2011) suggested that accumulated muscle soreness and fatigue in relation to the extended periods of training in both studies may have failed to detect any statistically significant differences. Thus, in the present study, a recovery week was planned every fourth week to overcome this limitation.

Also, during this investigation, the participants executed the prescribed volume from set to set until repetition failure (Hunter et al., 2004). Training to repetition failure likely standardised the exertion level, thus providing a similar training stimulus between the participants (Dankel et al., 2016; Willardson, 2007). It can therefore be assumed that UP elicited greater increases in muscular endurance compared to LP which corroborates de Lima and colleagues' findings. Similarly, Kraemer et al. (2000) and Rhea et al. (2002) proposed daily UP to develop strength in both women and men.

5.5.2 Strength

The current study found a large increase for back squat strength test in LP (ES = 1.24), whereas bench press performance was superior in UP (ES = 1.12) (Table 5.4). However, no statistical differences were found between the training groups. It is believed that reductions in the training volume during the final training phase may have mediated the strength gains in LP (Fleck, 1999; Nunes, Ribeiro, Schoenfeld, & Cyrino, 2017; Willoughby, 1993). The training programme (3 x 15RM) for LP during the final training phase performed to repetition failure may have permitted the participants to maximise the number of active motor units and subsequently the magnitude of changes to the nervous system. Similarly, Cesar et al. (2009) utilised a resistance training programme with three sets of 15RM performed with a 60 second recovery between sets in untrained female university students. Following the 12-week experimental period, significant maximal strength improvements were yielded in eight exercise tests. It was likely that the second and the third sets began under pre-fatigued conditions, as recovery between sets does not allow for a full recovery of the muscles. It has been suggested that repeated submaximal contractions (i.e. mechanical stress) during training might have evoked fatigue in the active motor units, thus requiring additional motor units to be progressively recruited to sustain force output (Vandenburgh, 1987). There is a possibility that this mechanism could induce greater overall muscular stress and, consequently, improve adaptation in the contractile elements. Working under pre-fatigued conditions may induce motor unit rotation such that previously unrecruited motor units will be activated (Campos et al., 2002; Enoka & Stuart, 1992). Therefore, training to repetition failure likely activated a maximal number of motor units, thus facilitating strength development (Dankel et al., 2016). Of note, even though fatigue during multiple-set resistance training may impair technique and coordination which reduces the force-generating capabilities on the contractile level, it also might lead to some kind of neural reorganization, which could induce a positive influence on strength adaptations (Danion, Latash, Li, & Zatsiorsky, 2000; Shinohara, Kouzaki, Yoshihisa, & Fukunaga, 1998).

5.5.3 Neural adaptation and performance

Various studies suggest that adaptations within the nervous system, in contrast to muscle hypertrophy, may contribute to strength increases following resistance training (Sale, 1988; Selvanayagam, Riek, & Carroll, 2011). In the current investigation, this is likely as there were significant improvements in lower- and upper-body strength with no significant changes observed in body mass and body fat measures (Table 5.5). Previously, significant improvements in strength have been reported, accompanied by little or no hypertrophic responses (Christou et al., 2006; Dudley, Tesch, Miller, & Buchanan, 1991; Ishida, Moritani, & Itoh, 1990; Jones & Rutherford, 1987; Lehnert et al., 2017; Staron et al., 1990). It seems possible that these results are due to the exercise modalities performed during training. Complex exercises, such as bench press and back squat, that integrate movements at more than one joint, utilise stabilizers and synergists muscles to support the prime movers and may develop their ability to activate and coordinate contractions (McCaw & Friday, 1994; Schwanbeck, Chilibeck, & Binsted, 2009). Thus, learning and coordination becomes the major factor contributing to early improvements in strength (Rutherford & Jones, 1986; Taube et al., 2007). The training design may also be a contributing element in the present study. Before the experiment began, participants were performing resistance training twice a week. The subsequent increase in training frequency during this investigation may have optimised inter- and intra-muscular coordination, thus enhancing lifting ability (Schlumberger et al., 2001). Furthermore Chilibeck, Calder, Sale, and Webber (1998) indicated that a period of more than 10 weeks may be required to observe significant changes in muscle hypertrophy following training programmes involving complex exercises. A study by Schoenfeld et al.

(2016) yielded significant improvements in upper- and lower-body muscle thickness after training with a daily UP programme that incorporated muscular endurance (3 x 20-30RM), three sessions per week for eight weeks. Significant increases were seen in both bench press and back squat 1RM. It should be noted that the participants in the study were experienced (4.7 ± 3.2 years) resistance trained males. It is therefore difficult to compare that investigation with the current findings because of dissimilarities in the design, such as training duration, training status of the participants, load intensity and type of exercises.

As indicated previously, this study revealed a significant increase in muscular endurance, and strength but no significant changes in body mass. Hypothetically, these findings may be optimal for endurance dominated sports performance (Campos et al., 2002; Jürimäe et al., 2010) or sports that require high strength to body mass ratio (Sale, 1988). For example, improvements in running and cycling economy were observed in distance runners and competitive cyclists following eight to ten weeks of resistance training (Blagrove et al., 2018; Storen, Helgerud, Stoa, & Hoff, 2008; Sunde et al., 2010). Increases in strength improved the biomechanical aspects of running and cycling which, in turn, enabled the participants to do less work at a certain submaximal speeds. Judge, Moreau, and Burke (2003) proposed that this could be a training strategy to improve technical abilities without affecting body composition in highly trained athletes. Again, alterations in the motor unit recruitment pattern (i.e. size principle) may improve strength adaptation with neuromuscular coordination underlying the technical aspects of athletic skill performance. It should be noted, however, morphological changes may occur if resistance training is performed for longer than 12 weeks (Staron et al., 1994).

5.5.4 Power

No significant changes were detected in the lower- and upper-body power measures. This is likely due to the high repetitions performed, which have been shown to be sub-optimal to improve power (González-Badillo et al., 2015b). Thus, the experimental design does not lend sufficient training stimulus to develop power because explosive ballistic exercises utilising lower repetitions were not incorporated into the training programmes (Behm et al., 2017). Ostrowski, Wilson, Weatherby, Murphy, and Lyttle (1997) also reported no significant differences among resistance trained men in vertical jump height and power output following 10 weeks of high volume, periodised multiple set resistance training. Moraes et al. (2013) observed no significant changes in CMJ and SLJ assessments after 12 weeks of daily UP resistance training in untrained male youth. These authors did not specifically utilise any high velocity training movements to develop power. Therefore, significant changes were not observed in this quality. It has been demonstrated that to improve power, training should be performed using explosive ballistic actions, with low repetitions to optimise motor unit recruitment (Kraemer & Ratamess, 2004). For instance, multi-joint closed-kinetic chain exercises, such as power cleans and power snatches, performed at high intensity velocity are an effective method to improve upper- and lower-body power (Haff & Stone, 2015; Kraemer, 1997; Marx et al., 2001; Stone et al., 1998). Another point to consider is that performing training to repetition failure may inhibit power improvements (Izquierdo et al., 2006). Fatigue may concurrently reduce the force that a muscle can produce and affect rate of force development (Sanborn et al., 2000; Sanchez-Medina & González-Badillo, 2011). Therefore, to develop power, each exercise repetition should be performed explosively with adequate rest (e.g. five to eight minutes) between sets to minimise fatigue, allowing maximal effort during each repetition (Bird, Tarpenning, & Marino, 2005).

Hartmann et al. (2009) observed a significant increase in Vmax in the bench press throw after training with a daily UP programme (three sessions/week) for 14 weeks in male university students. The researchers had integrated a muscular endurance training scheme (5 x 20-25RM) with 1.5 minutes of recovery between sets and alternated with strength-power and hypertrophy training within the whole periodised programme. In contrast, Izquierdo et al. (2006) designed a 16 week training programme comparing training leading to failure and training not leading to failure in adult male 'Basque ball' players. The protocol comprised ballistic exercises, such as countermovement vertical jumps, loaded vertical jumps, sprints and different throwing exercises during the last five weeks of the training programme. Again, the investigators reported that both training programmes led to significant gains in muscular power. It appears that training specificity is essential to the development of strength qualities such as strength, hypertrophy, power or muscular endurance. The principle of specificity states that all training adaptations are specific to the stimulus applied (Kraemer et al., 2004b; Kraemer & Ratamess, 2004). Minimal changes could be observed within the muscles and metabolic pathways that were not directly recruited during training (Millet et al., 2002). Likewise, a recent meta-analysis confirms this tendency for training specificity to develop power (Behm et al., 2017). Therefore, the methodology to develop muscular endurance is distinct from power. When designing training programmes to facilitate a desired outcome, practitioners need to consider the inclusion of specific methods of progression, appropriate to the training objective.

5.5.5 Endocrine response

Periodised resistance training could improve muscular performance across a long term training cycle (Bompa, 1996). To gain insights into the underlying mechanisms that may influence adaptations to periodised muscular endurance resistance training, resting salivary testosterone and cortisol concentrations were examined. The daily variation in the training programme design elicited increases in resting testosterone at T3 by 31.41% compared to baseline values. In contrast, beginning the training with high volume/low intensity and progressing towards low volume/high intensity (i.e. LP) demonstrated an 8.73% decrease. For salivary cortisol concentration, both protocols produced a non-significant increase of 24.16% and 23.48% for UP and LP respectively. The T:C ratio also yielded a non-significant decrease by 27.64% and 1.82% for LP and UP, respectively. Considering this, the present study raises the possibility that UP was more efficient at developing muscular endurance and minimising the likelihood of non-functional overreaching. These results reflect those of de Lima et al. (2012) that reported daily UP was more effective for developing muscular endurance in untrained young women.

Testosterone

It has been proposed that acute increase in circulating testosterone concentration indicates upregulation of muscle androgen receptors after short term resistance training (Spiering et al., 2009) and appears to potentiate improvements in strength (Gentil et al., 2016; Kvorning, Andersen, Brixen, & Madsen, 2006), rate of force development, power output, muscle mass and lean body mass (Crewther et al., 2011a) following chronic resistance training. Furthermore, it has been suggested that an increase in testosterone concentration may positively affect the subsequent physical performance of young athletes (Miloski et al., 2015; Nemet et al., 2012). Villanueva et al. (2012) reported significant increases in the acute serum testosterone response coupled with non-significant changes in the serum cortisol response following four total body exercises with a hypertrophy protocol coupled with short rest intervals (60 and 90 seconds) in recreationally trained men. Similarly, Crewther et al. (2008) showed significant increases in salivary testosterone and cortisol concentration collected immediately and up to 60 minutes following an acute hypertrophic loading protocol with two lower-body exercises in recreationally trained men. Scudese et al. (2016) showed significant total testosterone decreases while cortisol did not change at 15 and 30 minutes after five sets of three repetitions at 85% of 1RM interspersed with a one-minute rest period between sets in a bench press workout in resistance trained men. Crewther et al. (2008), McCaulley et al. (2009) and Hooper et al. (2017) suggested that performing training with a high glycolytic component, such as moderate intensity (65-85% 1RM), high volume (3-5 sets x 10-15 repetitions) and short recovery periods (1-2 minutes) may influence the modifications in testosterone and cortisol responses following resistance training. However, Hakkinen and Pakarinen (1993) observed no changes in testosterone concentration following high intensity back squats (20 sets x 1RM) with long rest intervals between sets (3 minutes) in male strength athletes (power lifters, body builders, weight lifters). Considering the evidence, it seems that these responses are protocol dependent (i.e. hypertrophy, strength or muscular endurance). The manipulation of training programme variables, such as exercise modality, exercise order, training frequency, intensity and rest periods may prevail and these acute hormonal responses would not result in comparable variation to resting hormone levels (Hooper et al., 2017; Kraemer & Ratamess, 2005). Also, differences in training age, training status and level of participants could help explain the conflicting findings (Painter et al., 2018).

In the present investigation pooled resting salivary testosterone concentration significantly increased at week 12. Previous research has established that longer training durations were needed to observe comparable rises in resting testosterone in elite weightlifters (Hakkinen et al., 1988). Conversely, Häkkinen et al. (1987b) suggested that long term resistance training in elite male weight lifters may not induce any significant alteration to testosterone and cortisol concentration. Kraemer et al. (1998) indicated that at the initial stage of training, adaptations may occur following six weeks of resistance training in untrained men. It is apparent that the training status of the participants may have contributed to the observations of this early phase adaptation. This may indicate that minimal exposure to the training stimuli might be required to engage the mechanisms that mediate exercise induced increases in testosterone in untrained participants. Another point to consider is that when an exercise stimulus is novel, it is likely that resistance training could induce a significant testosterone response in trained individuals (Hooper et al., 2017). Together, these studies indicate that the exercise stimulus may need to be varied to continue to achieve adaptations. Therefore, the large testosterone ES obtained in the present investigation corroborates the notion that frequent changes in training variables in UP are perhaps more efficient in developing muscular endurance compared to LP.

Adolescence is a critical period characterised by accelerated changes in body size, shape, and composition (Rogol, Roemmich, & Clark, 2002). Testosterone and other growth factors increase bone and muscle size that, in turn, can positively influence physical performance (Baldari et al., 2009; Crewther, Obminski, & Cook, 2016; Crewther, Obmiński, & Cook, 2018; Moreira et al., 2013). For example, Pullinen et al. (2011) and Pullinen et al. (2002) observed concurrent increases in testosterone concentrations and strength following resistance training in male youths even though the basal testosterone concentrations were lower than in men. These findings suggest resistance training may induce an optimal environment in which to develop muscle mass and strength and so it is reasonable to surmise that resistance training could positively influence performance in youth (Hooper et al., 2017). In fact, testosterone concentrations have been associated with regeneration of neurons, increase in neural cell body size and dendrite length (Crewther et al., 2011a; Fargo & Sengelaub, 2004) affecting neural factors that could impact trainability and performance subsequent to resistance training. Also, it is noteworthy that basal testosterone concentrations perhaps display the present condition of muscle tissue in which the elevation or decrease could happen at various time points, depending on the substantial changes in training volume and intensity (Hakkinen et al., 1988) or training history of youth athletes (Kraemer et al., 1992). In a similar vein, resting testosterone levels might be affected by a number of mechanisms including psychological (Cook & Beaven, 2013), social (Archer, 1991) and physiological (Urhausen et al., 1995) factors.

Despite the anabolic properties of testosterone, several studies have reported no association between basal levels of testosterone and changes in performance (Fry et al., 2000; Mitchell et al., 2013; Tsolakis, Vagenas, & Dessypris, 2004). Other known factors such as luteinising hormone (Raastad et al., 2000) and sex hormone-binding globulin (Kraemer et al., 1998) may have mediated the changes in performance. Also, Mitchell et al. (2013) suggested that the interaction between testosterone and their target tissue receptors could influence changes in performance to a greater degree than testosterone concentrations per se. Nevertheless, increased hormone levels seem to elevate the possibility of hormone-receptor interaction and perhaps lead to acute or chronic muscular adaptations (Falk & Eliakim, 2014). It seems that the knowledge on the effects of resistance training on the hormonal milieu could provide important insights into the chronic effects of training programmes.

Cortisol

As previously stated, there was a non-significant increase in cortisol concentration for both experimental groups compared to baseline. This could be due to the final examination period that coincided with the final phase of training. Greater training strain combined with other stresses, such as emotional stress, could influence the endocrine system thereby altering cortisol concentration (Lewis et al., 2008; Weekes et al., 2006). In fact, significantly higher stress and mood scores were reported by the participants in phase III. Kraemer et al. (1995) showed a rise in serum testosterone and cortisol following 12 weeks of high-intensity resistance and endurance training in US army volunteers. The investigators suggested that the increment in the absolute work related to the concurrent training and could have showed a type of overtraining response, which corresponded to the modest increase in strength in the concurrent training group. Hence, the researchers suggested that a decrease in training volume is necessary to potentially enhance the recovery-adaptation process and reduce the probability of overtraining.

Likewise Kraemer et al. (2003) reported significant increases in resting testosterone and cortisol over a nine month period following a daily UP resistance training in women collegiate tennis players. In this study, the changes in resting testosterone concentration may have mediated the observed adaptations in muscular performance (hand grip and Wingate test) and improved jump height and tennis ball velocities in serve, forehand and backhand strokes. Thus, the investigators proposed that periodised resistance training is superior to non-periodised training despite similar weekly training volume. However, it is important to highlight that the increase in cortisol had been attributed to the influence of stress from tennis practice and competition. Specifically, the participants were concurrently undergoing regular activities related to tennis training during the nine-month experimental period. The authors speculated that a decrease in cortisol concentration might be observed following the designed resistance training in both experimental groups. The hypothalamic-pituitary-adrenal axis could be more stress-sensitive in participants from both resistance training groups and thus tennis practice and matches had a superior effect on cortisol secretion. Overall, there seems to be some evidence to indicate that practitioners should be cautious when dealing with youth athletes who attend school and sports specific training concurrently. Training loads should be carefully planned during sensitive periods such as examinations to avoid overtraining (Phibbs et al., 2018).

Testosterone: cortisol ratio

The current study found no statistically significant T:C ratio changes following the 12-week experimental period. Despite this, the LP group showed a moderate ES (- 0.67) decrease compared to UP (- 0.06). This raises the possibility that UP training might provide a more favourable internal milieu within this cohort. Several studies have shown that monitoring T:C ratio is more beneficial for fatigue management and could better furnish an individual's estimate of "anabolic environment" than concentrations of testosterone and cortisol alone (Busso et al., 1992; Handziski et al., 2006). Maresh et al. (1994) observed non-significant alterations in T:C ratio during 21 weeks of training and competition in trained distance swimmers. However, testosterone concentrations progressively increased while cortisol decreased from pre- to post-test, consistent with reduction in training load. Tracking T:C ratio seems to be a useful strategy for monitoring hormonal profile changes that likely reflect training responses. Of note, Mujika, Chatard, Padilla, Guezennec, and Geyssant (1996) proposed that trivial ES differences in testosterone and T:C ratio could possibly indicate practical significance even though no statistically significant changes were detected from pre- to post-test. In their study, the T:C ratio was correlated to swimming performances during 12 and 4 weeks of intense training and tapering, respectively, in trained swimmers. The investigators indicated that systematically monitoring T:C ratio would be beneficial to regulating the training programme in accordance with the physiological alterations. More importantly, a non-significant increase in T:C ratio, coupled with significant improvements in performance, was observed after 16 weeks of periodised heavy resistance training and four weeks of tapering in strength athletes (Izquierdo et al., 2007). Recently, Painter et al. (2018) reported no differences in T:C ratio alterations between ten weeks of daily UP or BP groups involving Division I track and field athletes. However, the investigators noted consistently high relationships between performance data and T:C ratio in the BP group that points to the advantage of tracking hormonal ratio with sports performance. While the modifications in T:C ratio are quite subtle, the evidence from these studies supports the notion that monitoring training with these indices could provide for a better training load management. Periods of prolonged high-volume training can likely result in negative effects on the neuroendocrine system and a decrement in T:C ratio. Accordingly, a chronic decrease in T:C ratio likely accumulates fatigue and blunt muscle adaptations, increasing injury potential and eventually overtraining.

5.5.6 Internal training load

High training volume, high stress levels and poor recovery in youth athletes are precursors to injury (Hartwig et al., 2009). It is also believed that a sudden increase in training load may increase injury risk (Hulin et al., 2014). Thus, a strategic balance between external and internal training loads is essential in training programmes. Session RPE has been proposed as an effective tool to quantify resistance training programmes (Day et al., 2004; Sweet et al., 2004). Correlation analysis indicated a positive relationship between session RPE and total volume load (r = 0.79, p = 0.074). In fact, training phases II and III revealed that 45% of the reported session RPE values were higher than baseline. This corresponds to the increase in the external training load during each phase. Similarly, Miloski et al. (2015) and Nunes et al. (2014) reported that the session RPE mirrored the changes in the periodised training plan, indicating an increase during overloading phase and a decrease during the tapering phase in youth and female basketball players, respectively. Also, a notable decrement in the internal training load during the tapering phase in comparison to overloading phase has been observed in adult rugby league players and elite youth soccer players (Coutts, Reaburn, Piva, & Rowsell, 2007; Freitas et al., 2014a). These findings attest to the sensitivity of the session RPE to monitor the internal training load in team sport athletes. Likewise, the results from the current study indicated that the session RPE may provide information following a resistance training session during short and long training periods in team sport athletes.

In accordance with the literature (Faigenbaum, 2017; Faigenbaum & Myer, 2010; Lloyd et al., 2016), no injuries occurred in either training groups during the resistance training. However, a statistically significant interaction highlighted that LP demonstrated high weekly training monotony and strain scores compared to UP. Therefore, the risk of injury and illness within this training group is likely high (Foster, 1998; McGuigan & Foster, 2004). Even though the basic tenet of periodisation is to enhance training variation, LP produces a more monotonous training stimulus following 12 weeks of resistance training, which may increase overall injury risk. Distinct relationships between strength and power training loads to incidence of strength and power injuries ($r = 0.63$) have been reported in adult sub-elite rugby league players (Gabbett & Jenkins, 2011). Gabbett and Jenkins (2011) suggested that it is essential to monitor and manage fluctuations in internal and external training loads. Considerable competition and training time would be lost if the athletes are injured, fall sick or succumb to mental stress (Gabbett & Domrow, 2005). Over time, loss of talent due to early retirement and resources (e.g. financial, time) may occur (Halson, 2014; Murray, 2017).

5.5.7 Neuromuscular function and fatigue

CMJ and PP may be utilised to detect short-term and accumulated fatigue to regulate the training load in order to minimise injury risk in youth athletes (Johnston et al., 2013b). The weekly lower- and upper-body neuromuscular fatigue assessment in this study did not yield any significant changes during the experimental period in both training groups. Tests were conducted 48 hours following the last training session (McLean et al., 2010). CMJ and PP performance can lack sensitivity subject to the participants' training status. Participants may have become accustomed to completing both concentric and eccentric contractions as part of their normal training, thereby inducing a protective effect (Chen et al., 2012; Kennedy & Drake, 2017). This protective effect appears to result from neural (McHugh, 2003), mechanical (Koh & Brooks, 2001), cellular (Nosaka & Saldanha Aoki, 2011) or a combination of these factors (McHugh, 2003; McHugh, Connolly, Eston, & Gleim, 1999), due to prior training. Similar observations have been reported by Freitas et al. (2014b) in male volleyball athletes. The investigators indicated that the large training volume performed during the first phase of training increased the creatine kinase levels without affecting the neuromuscular performance. This could be due to the multiple number of jumps performed during volleyball training and competition, which had minimised the loss in muscle function. Likewise, Coutts et al. (2007) and Miloski, de Freitas, Nakamura, Francine, and Bara-Filho (2016) did not report any shift in lower limb power subsequent to training load intensification in male rugby and professional futsal players, with increased creatine kinase levels. It may have been that the participants altered the movement technique to perform the CMJ and PP. The altered movement strategy may have adopted longer contraction time frames to achieve the required impulse in response to the prolonged impairment in eccentric function that was induced by the stretch shortening cycle (Kennedy & Drake, 2017). Likewise, Legg et al. (2017) observed an increase in CMJ depth to achieve the necessary force and power output to maintain jump height during the period of peak training load in elite female basketball players. Also, it has been indicated that trained athletes, regardless of any underlying fatigue condition, could exhibit near maximal efforts, potentially due to motivational factors (Higgins, Cameron, & Climstein, 2012). Taken together, these results suggest that future investigations should investigate other variables related to the mechanics of the jump/push when attempting to examine neuromuscular fatigue following a periodised resistance training. Assessments might be performed before every resistance training session to better understand the fatigue mechanism.

5.5.8 Wellness

The ability to recover from the demands of athletic training is key to attaining optimal performance. In the present study, the overall well-being, fatigue, soreness and sleep scores indicated that the participants were able to cope with the periodised training to develop muscular endurance. However, mood and stress scores were found to be sensitive to the changes in the variety of sources of stress the participants encountered, such as examinations. In addition, these changes were congruent with the non-significant increase in the cortisol. Research has suggested that adolescence is a period of increasing competence and resilience but, at the same time, a period of risk and vulnerability (Gunnar et al., 2009). Thus, youth athletes are at heightened risk of emotional and behavioural disorders. Practitioners working with this population should be cautious and incorporate supportive elements like decreased training load, psychology and emotional support during the long-term training plan to avoid overtraining and minimise non-functional overreaching.

Previous research in athletes aged 15.1 ± 2.0 years from 19 different sports has established that poor sleep habits and general tiredness resulting from training were associated with non-functional overreaching (Matos et al., 2011). Matos and colleagues (2011) suggested that physical and psychosocial stressors outside of sports training were the likely contributing factors. Recently, Suppiah, Low, and Chia (2016) reported that sleep debt over five nights in academy youth athletes significantly impacted psychomotor performance. Similarly, poor sleep quality likely leads to muscle degradation thereby attenuating regeneration from exercise (Dattilo et al., 2011) and has been related to harmful consequences after a sport-related concussion (Sufrinko et al., 2015). On the other hand, improvements in athletic performance have been reported as a result of increased sleep quality (Mah, Mah, Kezirian, & Dement, 2011). Together, these studies indicate that accrued sleep deficit can affect performance, competitive success and threaten career longevity (Harris et al., 2017; Watson, 2017). The present periodised muscular endurance resistance training study had minimal impact on overall well-being, fatigue, soreness and sleep scores. A possible explanation for this might be that the participants were in a controlled school environment and subject to academic, training and boarding school regulations. Regardless, practitioners working with this population should be cognisant of the unique challenge of balancing sports and academic commitments when sleep is often compromised by the latter (Kennedy, Tamminen, & Holt, 2013; Sum & Ma, 2014).

The present findings suggest that the well-being questionnaire may be a useful way to monitor resistance training load manipulation in youth athletes and to provide essential data in relation to their perceived wellbeing along with any possible alteration in their emotional or behavioural state (Antualpa et al., 2017). Indeed, the well-being questionnaire could provide an understanding of an athlete's readiness to train (Sawczuk et al., 2018). Similarly, the ability of perceptual measures to detect well-being is in line with previous research in adult and youth rugby players (McLean et al., 2010; Oliver et al., 2015a).

The present investigation was designed to compare the effects of LP and UP to develop muscular endurance in youth athletes. Accordingly, this study suggests that UP was more effective than LP. It is recommended that practitioners identify which monitoring tools are applicable and viable for their athletes and take an integrative approach to resistance training monitoring to help inform their practice. This would reduce the risk of overtraining, minimise injury risk and optimise the well-being of youth athletes.

5.6 Practical application

Practitioners working with team sports youth athletes, such as field hockey, volleyball or basketball players, desiring to improve muscular endurance can reach this goal most effectively by utilising a UP strategy, performed in conjunction with sport specific training. Additionally, hormonal responses, session RPE, and well-being data may provide practitioners with the fatigue/recovery status which could direct appropriate sequencing of training loads and result in optimal physical performance. Further research, employing specifically endurance-trained populations, is needed to substantiate the findings of the current study.

Chapter 6 Summary, Practical Applications and Future Research Directions

6.1 Summary

The overarching aim of this thesis was to investigate the efficacy of two resistance training progression models and to elucidate the best method to vary the exercise stimulus to develop muscular endurance in which the training volume and intensity were equated in trained youth athletes. Initially, the literature review was conducted to examine the different resistance training progression models and selected monitoring measures. Following this, three investigations were conducted to address the aims of the thesis.

The first experimental study (Chapter 3) sought to establish the between-day repeatability and sensitivity of the commonly utilised CMJ and PP variables within the literature, in well trained youth field hockey athletes. The test-retest data indicated that CMJMF (CV = 1.0%, ICC = 1.00), CMJPP (3.4%, 0.97), CMJMP (3.2%, 0.98) and PPMF (2.9%, 0.98) showed acceptable reliability and sensitivity in male youth field hockey athletes. These findings concur with the proposition that differences in anthropometry, physical characteristics and level of skill may exist between studies. Population focused reliability data can address this (Roe et al., 2016a). The above variables were utilised in the second study of this thesis to map neuromuscular function recovery profile following an acute muscular endurance resistance training session.

The second experimental study (Chapter 4) examined the acute effects of eight exercises in two distinct muscular endurance resistance training sessions (3 sets of 25RM and 3 sets of 15RM) on neuromuscular function, endocrine and perceptual wellbeing measures in male youth field hockey athletes. The results indicated a possible prolonged reduction of up to 24 hours post session in CMJMP, CMJPP and PPMF, within the contrasting training schemes. CMJMF decreased at 15 minutes ($p = 0.002$) and 24 hours ($p = 0.001$) following the 15RM exercise session, whereas no significant difference was observed at these time points for the 25RM session. In contrast, a significant increase ($p = 0.008$) was noted in CMJMF between 24 hours and 48 hours following the 25RM session. A significant reduction ($p \leq 0.05$) was detected in salivary cortisol concentrations at 48 and 72 hours, with no significant changes observed in salivary testosterone concentration following both sessions. At 72 hours, T:C ratio indicated a moderate increase (ES = 0.72) after the 15RM session while a small decrease (ES = - 0.41) was observed following the 25RM session. Overall perceptual wellbeing, fatigue and soreness scores reflected changes in neuromuscular function, whereas stress, sleep and mood did not show any differences. A positive relationship ($r = 0.80$) was detected between session RPE and volume load. The results obtained from the youth athletes in this study showed that neuromuscular function, endocrine and perceptual wellbeing measures maintained similar biological responses irrespective of muscular endurance resistance training protocols. Importantly, as fatigue is multifaceted, practitioners should not rely on a single monitoring tool and should encompass both physiological and psychological aspects. This study offers some important insights regarding the acute post-training responses to a single muscular endurance training session in trained youth athletes. However, short-term investigations, such as this study, do not necessarily reflect responses following a long-term muscular endurance resistance training. Of particular concern is how these monitoring approaches would reflect responses to discriminate an appropriate periodisation strategy to best develop muscular endurance in youth athletes. Therefore, the monitoring measures from the second experimental study (Chapter 4) were incorporated into the training study (Chapter 5) to investigate the effects of two different resistance training progression models in trained youth team sports athletes.

Periodisation is employed to macro manage the training programme design, and to micro manage the training variables to induce the desired psycho-physiological adaptations (Cunanan et al., 2018). Previous research has investigated the effects of a periodised muscular endurance resistance training in untrained males and females (de Lima et al., 2012; Rhea et al., 2003). However, limited information is available regarding this strength quality in trained youth athletes. Therefore, the primary aim of the 12-week training study (Chapter 5) was to investigate the effects of two different resistance training models (LP vs. UP) on selected performance, physiological and psychological variables in trained youth team sport athletes. The secondary aim was to describe the different responses within this process (i.e. physiological, neuromuscular, perceptual) to the training stimulus. Muscular endurance measures revealed that UP (back squat ES = 1.62; bench press ES = 1.77) was more effective than LP (back squat ES = 0.69; bench press ES = 1.72). The normalised volume index revealed that greater total work was performed by the LP (429568.01 ± 33164.41kg) compared to the UP (375783.77 ± 44659.16kg) group. Both models exhibited significant (p = 0.001) improvements in 5RM strength. No significant differences were observed in body composition and power. Resting salivary testosterone concentration increased in the UP (31.47%) compared to the LP (- 8.73%) group, whereas salivary cortisol concentration and T:C ratio remained unchanged. Session RPE, mood and stress scores were frequently higher during training in phases II and III compared to phase I. Conversely, no changes were detected in neuromuscular function. Based on these findings, if a practitioner is working with team youth sport athletes such as field hockey, volleyball or basketball players and wants to improve muscular endurance, they can reach this goal most effectively by using UP, performed in conjunction with sport specific training. Hormonal responses, session RPE, and well-being data may provide practitioners with information on the fatigue/recovery status of youth athletes. Considering the thesis findings, it is highly recommended that practitioners incorporate a suitable monitoring measure to ensure appropriate sequencing of training loads to achieve optimal physical performance.

6.2 Practical Applications

While periodisation is known to improve training adaptations, it was unclear which periodisation approach would most effectively develop muscular endurance in trained youth populations. This thesis has provided detailed insight into the resistance training progression models most commonly utilised by practitioners seeking to improve muscular endurance in their athletes. Identifying the optimal resistance training progression model for youth athletes is critical to promoting favourable psychological and physiological adaptations, reducing the likelihood of illness and injury and, ultimately, increasing the possibility of success during competition. Previous investigations have reported similar findings in untrained adult men and women (Rhea et al., 2003) and untrained women (de Lima et al., 2012). This thesis, however, reinforces the idea that periodised training significantly improves muscular endurance in trained youth athletes. As one of the aims of this thesis was to provide practitioners with evidence of the utility of the selected resistance training monitoring measures, the following recommendations are made to improve practice:

1. UP may be considered to develop muscular endurance in trained youth male athletes. The findings from this thesis showed significant increases in muscular endurance, strength and no significant changes in body mass utilising UP. Thus,

UP could be a useful training strategy for endurance dominated sports (Campos et al., 2002; Jürimäe et al., 2010).

2. UP should be considered for periodising muscular endurance resistance training in team sport athletes as it induces low training monotony and strain. This highlights the efficiency of this training progression model for minimising non-functional overreaching and overtraining. Importantly, UP demonstrated greater increases in muscular endurance with low total volume load performed compared to LP.
3. Fatigue is a complex phenomenon that involves a plethora of mechanisms. Therefore, adapting a holistic monitoring strategy may enhance programme design and optimise the stimulus-adaptation process (Halson, 2014; Hendricks et al., 2018). Practitioners should consider incorporating different monitoring measures to map recovery profiles to identify vulnerable periods where athletes are susceptible to injury and may exhibit signs of non-functional overreaching.
4. Customised wellness questionnaires are likely to be beneficial in youth sport settings, especially because of the academic, social, and maturational labyrinth youth athletes must circumnavigate and the impact of same on their well-being (Mountjoy et al., 2008). Therefore, practitioners should incorporate perceptual wellness measures to identify sensitive periods to update any possible alteration in emotional and behavioural disorders. With this information, informed decisions can be made to regulate future training loads (Antualpa et al., 2017).
5. Session RPE can be used by practitioners to monitor training. The results in Chapter 4 and 5 supported previous findings of a positive relationship between training load and session RPE (Genner & Weston, 2014; Lodo et al., 2012; Pritchett et al., 2009). Importantly, the session RPE approach may enable

practitioners to objectively identify excessive training load and subsequently design training plans to improve physical resilience, while at the same time decreasing the likelihood of negative outcomes such as prolonged impaired wellness in young athletes (Lathlean et al., 2018b).

6. Based on the findings in Chapter 4, practitioners working with team youth sport athletes could plan subsequent intense sessions, such as technical or tactical, 48 hours after a muscular endurance training session. Specifically, neuromuscular, endocrine and perceptual wellness measures recovered 48 hours following both muscular endurance resistance training programmes. Therefore, practitioners should implement appropriate recovery strategies to improve adaptations after a muscular endurance training session.
7. Practitioners should consider establishing the between day reliability of the neuromuscular function variables to monitor training as these are population specific (Roe et al., 2016a). Specifically, differences in anthropometry, physical characteristics and level of skill of athletes may exist between different research cohorts within the literature. Adopting the reliability from a different cohort may not reflect accurate outcomes within the cohort under investigation.

6.3 Future Research Directions

The findings and limitations from this thesis provide the following insights for future research:

1. Currently, limited information is available regarding the optimal training progression model to develop muscular endurance in youth athlete populations (Harries et al., 2015b). Therefore, future studies might explore the two training progression models within this thesis across different sports, gender and

maturity levels. More information on these training progression models would help practitioners to accurately plan and schedule training.

2. Since the training study was limited to 12 weeks, further research should be undertaken to explore the physiological and psychological responses to the two training progression models within this thesis over a prolonged training period such as six months or more. Long-term interventions are required to examine the advantage of greater training variation in UP (Buford et al., 2007; Hoffman et al., 2003; Miranda et al., 2011; Peterson et al., 2008). Furthermore, longer training durations may inform practitioners regarding the sensitivity of the monitoring strategies employed.
3. A limitation of this thesis is that upper- and lower-body neuromuscular fatigue was measured weekly. Of note, de Freitas Cruz et al. (2018) employed a similar method and suggested that CMJ was sensitive to detect neuromuscular function during the competition period in young volleyball players. Future research should consider incorporating neuromuscular fatigue assessments prior to every resistance training session to map the neuromuscular recovery profiles.
4. Further research examining training progression models should consider monitoring other neuromuscular function variables, as there are a multitude of factors which might impair performance (Gathercole et al., 2015a). Future investigations could also investigate other training induced hormones such as catecholamines and inflammatory cytokines in response to intense concentric and eccentric contractions (Izquierdo et al., 2009) as they likely play a role in tissue remodelling following training (Smith, 2000).
5. Measures such as ultrasound or electromyography could be utilised to explore in detail both the muscle architecture changes and electrical activity produced

by skeletal muscle. These measures could further elucidate the underlying mechanisms that induce muscular adaptations when following a periodised muscular endurance resistance training.

Appendices

Appendix I Ethics approval

AUTEC Secretariat

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

26 February 2016

Michael McGuigan
Faculty of Health and Environmental Sciences

Dear Michael

Re Ethics Application: **16/13 Comparison of resistance training progression models to develop muscular endurance in youth athletes: Applications for athlete monitoring.**

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

Your ethics application has been approved for three years until 25 February 2019.

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

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 25 February 2019;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 25 February 2019 or on completion of the project.

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

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

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

All the very best with your research,

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

Cc: Shankaralingam Ramalingam fqt0415@aut.ac.nz, Deborah Dulson

Appendix II Participant consent forms

Parent/Guardian Consent Form

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Project title: **Response to an acute muscular endurance resistance exercise monitored through neuromuscular function, endocrine and fatigue assessments**

Project Supervisor: Professor Michael McGuigan

Researcher: Shankaralingam Ramalingam

○ I have read and understood the information provided about this research project in the Information Sheet dated 24 December 2015.

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

○ I understand that notes will be taken during the interviews and that they will also be audio-taped and transcribed.

○ I understand that I may withdraw my child/children and/or myself or any information that we have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

○ If my child/children and/or I withdraw, I understand that all relevant information including tapes and transcripts, or parts thereof, will be destroyed.

○ I agree to my child/children taking part in this research.

○ I wish to receive a copy of the summary of findings from the research (please tick one):

Yes○ No○

Child/children's name/s: ……………………………………………………………………………………

………..

Parent/Guardian's signature: ………………………………………………………………………………………

Parent/Guardian's name: ………………………………………………………………………………………

Parent/Guardian's Contact Details (if appropriate):

………………………………………………………………………………………..

………………………………………………………………………………………..

………………………………………………………………………………………..

………………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 26 February 2016 AUTEC Reference number 16/13

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

Appendix III Participant assent forms

Assent Form

Project title: **Response to an acute muscular endurance resistance exercise monitored through neuromuscular function, endocrine and fatigue assessments**

Project Supervisor: Professor Michael McGuigan

Researcher: Shankaralingam Ramalingam

○ I have read and understood the sheet telling me what will happen in this study and why it is important.

○ I have been able to ask questions and to have them answered.

○ I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance, or any infection.

○ I agree to give blood samples for blood lactate measurements.

○ I understand that while the information is being collected, I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.

○ If I stop being part of the study, I understand that all information about me, including the recordings or any part of them that include me, will be destroyed.

○ I agree to take part in this research.

○ I wish to receive a copy of the summary of findings from the research (please tick one):

Yes ○ No ○

○ I wish to receive my own results from this study (please tick one): Yes ○ No ○

○ I agree my results to be shared with my coach (please tick one): Yes ○ No ○

Participant's signature: ....

Participant's name: ....

Participant Contact Details (if appropriate):

....

....

....

....

Date:

Approved by the Auckland University of Technology Ethics Committee on 26 February 2016 AUTEC Reference number 16/13

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

Parent/Guardian Consent Form

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Project title: **Comparison of resistance training progression models to develop muscular endurance in youth athletes**

Project Supervisor: Professor Michael McGuigan

Researcher: Shankaralingam Ramalingam

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 24 December 2015.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that notes will be taken during the interviews and that they will also be audio-taped and transcribed.
- ○ I understand that I may withdraw my child/children and/or myself or any information that we have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ○ If my child/children and/or I withdraw, I understand that all relevant information including tapes and transcripts, or parts thereof, will be destroyed.
- ○ I agree to my child/children taking part in this research.
- ○ I wish to receive a copy of the summary of findings from the research (please tick one):

  Yes○ No○

Child/children's name/s: ……………………………………………………………………………………

……

Parent/Guardian's signature: ……………………………………………………………………………………

Parent/Guardian's name: ……………………………………………………………………………………

Parent/Guardian's Contact Details (if appropriate):

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

Date:

Approved by the Auckland University of Technology Ethics Committee on 26 February 2016 AUTEC Reference number 16/13

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

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Assent Form

Project title: **Comparison of resistance training progression models to develop muscular endurance in youth athletes**

Project Supervisor: Professor Michael McGuigan

Researcher: Shankaralingam Ramalingam

○ I have read and understood the sheet telling me what will happen in this study and why it is important.

○ I have been able to ask questions and to have them answered.

○ I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance, or any infection.

○ I understand that while the information is being collected, I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.

○ If I stop being part of the study, I understand that all information about me, including the recordings or any part of them that include me, will be destroyed.

○ I agree to take part in this research.

○ I wish to receive a copy of the summary of findings from the research (please tick one):

Yes ○ No ○

○ I wish to receive my own results from this study (please tick one): Yes ○ No ○

○ I agree my results to be shared with my coach (please tick one): Yes ○ No ○

Participant's signature: ....

Participant's name: ....

Participant Contact Details (if appropriate):

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 26 February 2016 AUTEC Reference number 16/13

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

References

Abernethy, P., Wilson, G., & Logan, P. (1995). Strength and power assessment. Issues, controversies and challenges. *Sports Medicine, 19*(6), 401-417.

Aboodarda, S. J., George, J., Mokhtar, A. H., & Thompson, M. (2011). Muscle strength and damage following two modes of variable resistance training. *Journal of Sports Science and Medicine, 10*(4), 635-642.

Adirim, T. A., & Cheng, T. L. (2003). Overview of injuries in the young athlete. *Sports Medicine, 33*(1), 75-81.

Afonso, J., Nikolaidis, P. T., Sousa, P., & Mesquita, I. (2017). Is empirical research on periodization trustworthy? A comprehensive review of conceptual and methodological issues. *Journal of Sports Science and Medicine, 16*(1), 27-34.

Ahtiainen, J. P., Pakarinen, A., Alen, M., Kraemer, W. J., & Häkkinen, K. (2003). Muscle hypertrophy, hormonal adaptations and strength development during strength training in strength-trained and untrained men. *European Journal of Applied Physiology, 89*(6), 555-563.

Ahtiainen, J. P., Pakarinen, A., Kraemer, W. J., & Hakkinen, K. (2003). Acute hormonal and neuromuscular responses and recovery to forced vs. maximum repetitions multiple resistance exercises. *International Journal of Sports Medicine, 24*(6), 410-418.

Al Haddad, H., Simpson, B. M., & Buchheit, M. (2015). Monitoring changes in jump and sprint performance: Best or average values? *International Journal of Sports Physiology and Performance, 10*(7), 931-934.

Alix-Sy, D., Le Scanff, C., & Filaire, E. (2008). Psychophysiological responses in the pre-competition period in elite soccer players. *Journal of Sports Science and Medicine, 7*(4), 446-454.

American College of Sports Medicine. (2010). *ACSM's resource manual for guidelines for exercise testing and prescription* (6th ed.). Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins.

Andre, M. J., Fry, A. C., Luebbers, P. E., Hudy, A., Dietz, P. R., & Cain, G. J. (2018). Weekly salivary biomarkers across a season for elite men collegiate basketball players. *International Journal of Exercise Science, 11*(6), 439-451.

Antualpa, K., Aoki, M. S., & Moreira, A. (2017). Salivary steroids hormones, well-being, and physical performance during an intensification training period followed by a tapering period in youth rhythmic gymnasts. *Physiology and Behavior, 179*, 1-8.

Aoki, M. S., Arruda, A. F., Freitas, C. G., Miloski, B., Marcelino, P. R., Drago, G., . . . Moreira, A. (2017). Monitoring training loads, mood states, and jump performance over two periodized training mesocycles in elite young volleyball players. *International Journal of Sports Science and Coaching, 12*(1), 130-137.

Apel, J. M., Lacey, R. M., & Kell, R. T. (2011). A comparison of traditional and weekly undulating periodized strength training programs with total volume and intensity equated. *Journal of Strength and Conditioning Research, 25*(3), 694-703.

Archer, J. (1991). The influence of testosterone on human aggression. *British Journal of Psychology, 82*(1), 1-28.

Arruda, A. F., Aoki, M. S., Freitas, C. G., Spigolon, L. M., Franciscon, C., & Moreira, A. (2015). Testosterone concentration and lower limb power over an entire competitive season in elite young soccer players. *Journal of Strength and Conditioning Research, 29*(12), 3380-3385.

Assunção, A. R., Bottaro, M., Ferreira-Junior, J. B., Izquierdo, M., Cadore, E. L., & Gentil, P. (2016). The chronic effects of low-and high-intensity resistance training on muscular fitness in adolescents. *PloS one, 11*(8), e0160650. doi:10.1371/journal.pone.0160650.

Atkinson, G., & Nevill, A. M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine, 26*(4), 217-238.

Babault, N., Pousson, M., Ballay, Y., & Van Hoecke, J. (2001). Activation of human quadriceps femoris during isometric, concentric, and eccentric contractions. *Journal of Applied Physiology, 91*(6), 2628-2634.

Baker, D. (1993). Periodization of strength training for sports: A review. *Strength & Conditioning Coach, 1*(3), 15-21.

Baker, D. (2007). Cycle-length variants in periodized strength/power training. *Strength & Conditioning Journal, 29*(4), 10-17.

Baker, D., Wilson, G., & Carlyon, R. (1994). Periodization: The effect on strength of manipulating volume and intensity. *Journal of Strength and Conditioning Research, 8*(4), 235-242.

Baldari, C., Di Luigi, L., Emerenziani, G. P., Gallotta, M. C., Sgrò, P., & Guidetti, L. (2009). Is explosive performance influenced by androgen concentrations in young male soccer players? *British Journal of Sports Medicine, 43*(3), 191-194.

Bamman, M. M., Shipp, J. R., Jiang, J., Gower, B. A., Hunter, G. R., Goodman, A., . . . Urban, R. J. (2001). Mechanical load increases muscle IGF-I and androgen receptor mRNA concentrations in humans. *American Journal of Physiology-Endocrinology and Metabolism, 280*(3), E383-E390.

Bangsbo, J., Mohr, M., Poulsen, A., Perez-Gomez, J., & Krustrup, P. (2006). Training and testing the elite athlete. *Journal of Exercise Science and Fitness, 4*(1), 1-14.

Barnett, A. (2006). Using recovery modalities between training sessions in elite athletes: Does it Help? *Sports Medicine, 36*(9), 781-796.

Bartolomei, S., Hoffman, J. R., Merni, F., & Stout, J. R. (2014). A comparison of traditional and block periodized strength training programs in trained athletes. *Journal of Strength and Conditioning Research, 28*(4), 990-997.

Bartolomei, S., Sadres, E., Church, D. D., Arroyo, E., Gordon III, J. A., Varanoske, A. N., . . . Stout, J. R. (2017). Comparison of the recovery response from high-intensity and high-volume resistance exercise in trained men. *European Journal of Applied Physiology, 117*(7), 1287-1298.

Behm, D. G., Faigenbaum, A. D., Falk, B., & Klentrou, P. (2008). Canadian Society for Exercise Physiology position paper: Resistance training in children and adolescent. *Applied Physiology, Nutrition, Metabolic, 33*, 547-561.

Behm, D. G., Reardon, G., Fitzgerald, J., & Drinkwater, E. (2002). The effect of 5, 10, and 20 repetition maximums on the recovery of voluntary and evoked contractile properties. *Journal of Strength and Conditioning Research, 16*(2), 209-218.

Behm, D. G., Young, J. D., Whitten, J. H., Reid, J. C., Quigley, P. J., Low, J., . . . Chaouachi, A. (2017). Effectiveness of traditional strength vs. Power training on muscle strength, power and speed with youth: A systematic review and meta-analysis. *Frontiers in Physiology, 8*(423), 1-37.

Behringer, M., Heede, A. v., Matthews, M., & Mester, J. (2011). Effects of strength training on motor performance skills in children and adolescents: A meta-analysis. *Pediatric Exercise Science, 23*(2), 186-206.

Behringer, M., vom Heede, A., Yue, Z., & Mester, J. (2010). Effects of resistance training in children and adolescents: A meta-analysis. *Pediatrics, 126*(5), e1199-e1210.

Bergeron, M. F., Mountjoy, M., Armstrong, N., Chia, M., Côté, J., Emery, C. A., . . . Léglise, M. (2015). International Olympic Committee consensus statement on youth athletic development. *British Journal of Sports Medicine, 49*(13), 843-851.

Bigland-Ritchie, B., & Woods, J. J. (1984). Changes in muscle contractile properties and neural control during human muscular fatigue. *Muscle & Nerve, 7*(9), 691-699.

Bird, S. P., Tarpenning, K. M., & Marino, F. E. (2005). Designing resistance training programs to enhance muscular fitness. *Sports Medicine, 35*(10), 841-851.

Blagrove, R. C., Howe, L. P., Cushion, E. J., Spence, A., Howatson, G., Pedlar, C. R., & Hayes, P. R. (2018). Effects of strength training on postpubertal adolescent distance runners. *Medicine and Science in Sports and Exercise, 50*(6), 1224-1232.

Blazevich, A. J., Gill, N., & Newton, R. U. (2002). Reliability and validity of two isometric squat tests. *Journal of Strength and Conditioning Research, 16*(2), 298-304.

Bompa, T. O. (1990). Periodization of strength: The most effective methodology of strength training. *National Strength and Conditioning Association Journal, 12*(5), 49-52.

Bompa, T. O. (1996). Variations of periodization of strength. *Strength and Conditioning, 18*(3), 58-61.

Bompa, T. O. (1999). *Periodization: Theory and methodology of training* (4th ed.). Champaign, IL Human Kinetics.

Bompa, T. O. (2000). *Total Training for Young Champions*. Champaign, IL: Human Kinetics.

Bompa, T. O., & Carrera, M. C. (2005). *Periodization Training for Sports*. Champaign, IL: Human Kinetics.

Bompa, T. O., & Haff, G. G. (2009). *Periodization: Theory and methodology of training* (5th ed.). Champaign, IL: Human Kinetics.

Borg, G. (1998). *Borg's Perceived Exertion and Pain Scales*. Champaign, IL: Human Kinetics.

Borresen, J., & Lambert, M. I. (2009). The quantification of training load, the training response and the effect on performance. *Sports Medicine, 39*(9), 779-795.

Bosco, C., Colli, R., Bonomi, R., von Duvillard, S. P., & Viru, A. (2000). Monitoring strength training: Neuromuscular and hormonal profile. *Medicine and Science in Sports and Exercise, 32*(1), 202-208.

Bouaziz, T., Makni, E., Passelergue, P., Tabka, Z., Lac, G., Moalla, W., . . . Elloumi, M. (2016). Multifactorial monitoring of training load in elite rugby sevens players: Cortisol/cortisone ratio as a valid tool of training load monitoring. *Biology of Sport, 33*(3), 231-239.

Bourdon, P. C., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M. C., . . . Cable, T. (2017). Monitoring athlete training loads: Consensus statement. *International Journal of Sports Physiology and Performance, 12*(Suppl 2), S2-161-170.

Breil, F. A., Weber, S. N., Koller, S., Hoppeler, H., & Vogt, M. (2010). Block training periodization in alpine skiing: Effects of 11-day HIT on VO2max and performance. *European Journal of Applied Physiology, 109*(6), 1077-1086.

Brink, M., Visscher, C., Coutts, A., & Lemmink, K. (2012). Changes in perceived stress and recovery in overreached young elite soccer players. *Scandinavian Journal of Medicine and Science in Sports, 22*(2), 285-292.

Brink, M. S., Nederhof, E., Visscher, C., Schmikli, S. L., & Lemmink, K. A. (2010a). Monitoring load, recovery, and performance in young elite soccer players. *Journal of Strength and Conditioning Research, 24*(3), 597-603.

Brink, M. S., Visscher, C., Arends, S., Zwerver, J., Post, W. J., & Lemmink, K. A. (2010b). Monitoring stress and recovery: New insights for the prevention of injuries and illnesses in elite youth soccer players. *British Journal of Sports Medicine, 44*(11), 809-815.

Brito, J., Hertzog, M., & Nassis, G. P. (2016). Do match-related contextual variables influence training load in highly trained soccer players? *Journal of Strength and Conditioning Research, 30*(2), 393-399.

Brooks, J. H., Fuller, C. W., Kemp, S. P., & Reddin, D. B. (2008). An assessment of training volume in professional rugby union and its impact on the incidence, severity, and nature of match and training injuries. *Journal of Sports Sciences, 26*(8), 863-873.

Brown, L. E., & Greenword, M. (2005). Periodization essentials and innovations in resistance training. *Strength and Conditioning Journal, 27*(4), 80-85.

Brown, L. E., Whitehurst, M., & Findley, B. W. (2005). Reliability of rate of velocity development and phase measures on an isokinetic device. *Journal of Strength and Conditioning Research, 19*(1), 189-192.

Brownlee, T. E., Murtagh, C. F., Naughton, R. J., Whitworth-Turner, C. M., O'Boyle, A., Morgans, R., . . . Drust, B. (2018). Isometric maximal voluntary force evaluated using an isometric mid-thigh pull differentiates English Premier League youth soccer players from a maturity-matched control group. *Science and Medicine in Football, 2*(3), 209–215.

Buchheit, M., Lefebvre, B., Laursen, P. B., & Ahmaidi, S. (2011). Reliability, usefulness, and validity of the 30–15 intermittent ice test in young elite ice hockey players. *Journal of Strength and Conditioning Research, 25*(5), 1457-1464.

Buchheit, M., Racinais, S., Bilsborough, J. C., Bourdon, P. C., Voss, S. C., Hocking, J., . . . Coutts, A. J. (2013). Monitoring fitness, fatigue and running performance during a pre-season training camp in elite football players. *Journal of Science and Medicine in Sport, 16*(6), 550-555.

Buckner, S. L., Mouser, J. G., Dankel, S. J., Jessee, M. B., Mattocks, K. T., & Loenneke, J. P. (2017). The general adaptation syndrome: Potential misapplications to resistance exercise. *Journal of Science and Medicine in Sport, 20*(11), 1015-1017.

Buford, T. W., Rossi, S. J., Smith, D. B., & Warren, A. J. (2007). A comparison of periodization models during nine weeks with equated volume and intensity for strength. *Journal of Strength and Conditioning Research, 21*(4), 1245-1250.

Burgess, D. J., & Naughton, G. A. (2010). Talent development in adolescent team sports: A review. *International Journal of Sports Physiology and Performance, 5*(1), 103-116.

Busso, T., Häkkinen, K., Pakarinen, A., Kauhanen, H., Komi, P., & Lacour, J. (1992). Hormonal adaptations and modelled responses in elite weightlifters during 6 weeks of training. *European Journal of Applied Physiology and Occupational Physiology, 64*(4), 381-386.

Byrne, C., & Eston, R. (2002). The effect of exercise-induced muscle damage on isometric and dynamic knee extensor strength and vertical jump performance. *Journal of Sports Sciences, 20*(5), 417-425.

Caine, D., Caine, C., & Maffulli, N. (2006). Incidence and distribution of pediatric sport-related injuries. *Clinical Journal of Sport Medicine, 16*(6), 500-513.

Cairns, S. P., Knicker, A. J., Thompson, M. W., & Sjøgaard, G. (2005). Evaluation of models used to study neuromuscular fatigue. *Exercise and Sport Sciences Reviews, 33*(1), 9-16.

Cairns, S. P., Taberner, A. J., & Loiselle, D. S. (2009). Changes of surface and t-tubular membrane excitability during fatigue with repeated tetani in isolated mouse fast-and slow-twitch muscle. *Journal of Applied Physiology, 106*(1), 101-112.

Calixto, R., Verlengia, R., Crisp, A., Carvalho, T., Crepaldi, M., Pereira, A., . . . Lopes, C. (2014). Acute effects of movement velocity on blood lactate and growth hormone responses after eccentric bench press exercise in resistance-trained men. *Biology of Sport, 31*(4), 289-294.

Campos, G. E. R., Luecke, T. J., Wendeln, H. K., Toma, K., Hagerman, F. C., Murray, T. F., . . . Staron, R. S. (2002). Muscular adaptations in response to three different resistance-training regimens: Specificity of repetition maximum training zones. *European Journal of Applied Physiology, 88*, 50-60.

Carvalho, F. L. P., Carvalho, M. C. G. A., Simão, R., Gomes, T. M., Costa, P. B., Neto, L. B., . . . Dantas, E. H. M. (2012). Acute effects of a warm-up including active, passive, and dynamic stretching on vertical jump performance. *Journal of Strength and Conditioning Research, 26*(9), 2447-2452.

Cesar, M. C., Borin, J. P., Gonelli, P. R. G., Simoes, R. A., Souza, T. M. F., & Montebelo, M. I. L. (2009). The effect of local muscular endurance training on cardiorespiratory capacity in young women. *Journal of Strength and Conditioning Research, 23*(6), 1637-1643.

Challis, J. H. (1999). The appropriate scaling of weightlifting performance. *Journal of Strength and Conditioning Research, 13*(4), 367-371.

Chamari, K., Haddad, M., Wong, D. P., Dellal, A., & Chaouachi, A. (2012). Injury rates in professional soccer players during Ramadan. *Journal of Sports Sciences, 30*(sup1), S93-S102.

Chambers, C., Noakes, T., Lambert, E., & Lambert, M. (1998). Time course of recovery of vertical jump height and heart rate versus running speed after a 90-km foot race. *Journal of Sports Sciences, 16*(7), 645-651.

Chapman, P. P., Whitehead, J. R., & Binkert, R. H. (1998). The 225-lb reps-to-fatigue test as a submaximal estimate of 1-RM bench press performance in college football players. *Journal of Strength and Conditioning Research, 12*(4), 258-261.

Chappell, J. D., Yu, B., Kirkendall, D. T., & Garrett, W. E. (2002). A comparison of knee kinetics between male and female recreational athletes in stop-jump tasks. *American Journal of Sports Medicine, 30*(2), 261-267.

Charniga, A., Gambetta, V., Kraemer, W., Newton, H., O'Bryant, H., Palmieri, G., . . . Stone, M. (1986). Periodization: Part 2. *National Strength and Conditioning Association Journal, 8*(6), 17-24.

Cheema, B. S., Chan, D., Fahey, P., & Atlantis, E. (2014). Effect of progressive resistance training on measures of skeletal muscle hypertrophy, muscular strength and health-related quality of life in patients with chronic kidney disease: A systematic review and meta-analysis. *Sports Medicine, 44*(8), 1125-1138.

Chen, H.-L., Nosaka, K., & Chen, T. C. (2012). Muscle damage protection by low-intensity eccentric contractions remains for 2 weeks but not 3 weeks. *European Journal of Applied Physiology, 112*(2), 555-565.

Chennaoui, M., Bougard, C., Drogou, C., Langrume, C., Miller, C., Gomez-Merino, D., & Vergnoux, F. (2016). Stress biomarkers, mood states, and sleep during a major competition:"Success" and "Failure" athlete's profile of high-level swimmers. *Frontiers in Physiology, 7*(94), 1-10.

Chilibeck, P. D., Calder, A. W., Sale, D. G., & Webber, C. E. (1998). A comparison of strength and muscle mass increases during resistance training in young women. *European Journal of Applied Physiology and Occupational Physiology, 77*(1), 170-175.

Chiodo, S., Tessitore, A., Lupo, C., Ammendolia, A., Cortis, C., & Capranica, L. (2012). Effects of official youth taekwondo competitions on jump and strength performance. *European Journal of Sport Science, 12*(2), 113-120.

Christou, M., Smilios, I., Sotiropoulos, K., Volaklis, K., Pilianidis, T., & Tokmakidis, S. P. (2006). Effects of resistance training on the physical capacities of adolescent soccer players. *Journal of Strength and Conditioning Research, 20*(4), 783-791.

Claudino, J. G., Cronin, J., Mezêncio, B., McMaster, D. T., McGuigan, M., Tricoli, V., . . . Serrão, J. C. (2016a). Review: The countermovement jump to monitor neuromuscular status: A meta-analysis. *Journal of Science and Medicine in Sport, 20*(4), 397-402.

Claudino, J. G., Cronin, J. B., Mezencio, B., Pinho, J. P., Pereira, C., Mochizuki, L., . . . Serrao, J. C. (2016b). Auto-regulating jump performance to induce functional overreaching. *Journal of Strength and Conditioning Research, 30*(8), 2242-2249.

Cobley, S., Baker, J., Wattie, N., & McKenna, J. (2009). Annual age-grouping and athlete development. *Sports Medicine, 39*(3), 235-256.

Cohen, J. (1988). *Statistical Power Analysis for Behavioral Science* (2nd ed.). Hillsdale, NJ: Erlbaum.

Colado, J. C., Garcia-Masso, X., Triplett, N. T., Calatayud, J., Flandez, J., Behm, D., & Rogers, M. E. (2014). Construct and concurrent validation of a new resistance intensity scale for exercise with thera-band® elastic bands. *Journal of Sports Science and Medicine, 13*(4), 758.

Conlon, J. A., Newton, R. U., Tufano, J. J., Banyard, H. G., Hopper, A. J., Ridge, A. J., & Haff, G. G. (2016). Periodization strategies in older adults: Impact on physical function and health. *Medicine and Science in Sports and Exercise, 48*(12), 2426-2436.

Conroy, B. P., Kraemer, W. J., Maresh, C. M., Fleck, S. J., Stone, M. H., Fry, A. C., . . . Dalsky, G. P. (1993). Bone mineral density in elite junior Olympic weightlifters. *Medicine and Science in Sports and Exercise, 25*(10), 1103-1109.

Cook, C. J., & Beaven, C. M. (2013). Salivary testosterone is related to self-selected training load in elite female athletes. *Physiology and Behavior, 116*, 8-12.

Cormack, S. J., Newton, R. U., & McGuigan, M. R. (2008a). Neuromuscular and endocrine responses of elite players to an Australian rules football match. *International Journal of Sports Physiology and Performance, 3*(3), 359-374.

Cormack, S. J., Newton, R. U., McGuigan, M. R., & Doyle, T. L. A. (2008b). Reliability of measures obtained during single and repeated countermovement jumps. *International Journal of Sports Physiology and Performance, 3*, 131-144.

Coutts, A. J., Reaburn, P., Piva, T. J., & Rowsell, G. J. (2007). Monitoring for overreaching in rugby league players. *European Journal of Applied Physiology, 99*(3), 313-324.

Crewther, B., Cronin, J., Keogh, J., & Cook, C. (2008). The salivary testosterone and cortisol response to three loading schemes. *Journal of Strength and Conditioning Research, 22*(1), 250-255.

Crewther, B., Keogh, J., Cronin, J., & Cook, C. (2006). Possible stimuli for strength and power adaptation: Acute hormonal responses. *Sports Medicine, 36*(3), 215-238.

Crewther, B., Obminski, Z., & Cook, C. (2016). The effect of steroid hormones on the physical performance of boys and girls during an Olympic weightlifting competition. *Pediatric Exercise Science, 28*(4), 580-587.

Crewther, B. T., Cook, C., Cardinale, M., Weatherby, R. P., & Lowe, T. (2011a). Two emerging concepts for elite athletes. *Sports Medicine, 41*(2), 103-123.

Crewther, B. T., Heke, T., & Keogh, J. W. (2011b). The effects of training volume and competition on the salivary cortisol concentrations of Olympic weightlifters. *Journal of Strength and Conditioning Research, 25*(1), 10-15.

Crewther, B. T., Lowe, T., Weatherby, R. P., Gill, N., & Keogh, J. (2009). Neuromuscular performance of elite rugby union players and relationships with salivary hormones. *Journal of Strength and Conditioning Research, 23*(7), 2046-2053.

Crewther, B. T., Obmiński, Z., & Cook, C. J. (2018). Serum cortisol as a moderator of the relationship between serum testosterone and Olympic weightlifting performance in real and simulated competitions. *Biology of Sport, 35*(2), 215-221.

Cronin, J. B., & Hansen, K. T. (2005). Strength and power predictors of sports speed. *Journal of Strength and Conditioning Research, 19*(2), 349-357.

Cronin, J. B., Hing, R. D., & McNair, P. J. (2004). Reliability and validity of a linear position transducer for measuring jump performance. *Journal of Strength and Conditioning Research, 18*(3), 590-593.

Cunanan, A. J., DeWeese, B. H., Wagle, J. P., Carroll, K. M., Sausaman, R., Hornsby, W. G., . . . Stone, M. H. (2018). The general adaptation syndrome: A foundation for the concept of periodization. *Sports Medicine, 48*(4), 787-797.

Danion, F., Latash, M., Li, Z., & Zatsiorsky, V. (2000). The effect of fatigue on multifinger co-ordination in force production tasks in humans. *The Journal of Physiology, 523*(2), 523-532.

Dankel, S. J., Jessee, M. B., Mattocks, K. T., Mouser, J. G., Counts, B. R., Buckner, S. L., & Loenneke, J. P. (2016). Training to fatigue: The answer for standardization when assessing muscle hypertrophy? *Sports Medicine, 47*(6), 1021-1027.

Dattilo, M., Antunes, H. K. M., Medeiros, A., Neto, M. M., Souza, H. S. d., Tufik, S., & De Mello, M. (2011). Sleep and muscle recovery: Endocrinological and molecular basis for a new and promising hypothesis. *Medical Hypotheses, 77*(2), 220-222.

Davids, K., Glazier, P., Araújo, D., & Bartlett, R. (2003). Movement systems as dynamical systems. *Sports Medicine, 33*(4), 245-260.

Day, M. L., McGuigan, M., Brice, G., & Foster, C. (2004). Monitoring exercise intensity during resistance training using the session RPE scale. *Journal of Strength and Conditioning Research, 18*(2), 353-358.

de Freitas Cruz, I., Pereira, L. A., Kobal, R., Kitamura, K., Cedra, C., Loturco, I., & Abad, C. C. C. (2018). Perceived training load and jumping responses following nine weeks of a competitive period in young female basketball players. *PeerJ, 6*, e5225. doi:10.7717/peerj.5225.

de Lima, C., Boullosa, D. A., Frollini, A. B., Donatto, F. F., Leite, R. D., Gonelli, P. R. G., . . . Cesar, M. C. (2012). Linear and daily undulating resistance training periodisations have differential beneficial effects in young sedentary women. *International Journal of Sports Medicine, 33*(9), 723-727.

de Ruiter, C. J., Elzinga, M. J. H., Verdijk, P. W. L., van Mechelen, W., & de Haan, A. (2005). Changes in force, surface and motor unit EMG during post-exercise development of low frequency fatigue in vastus lateralis muscle. *European Journal of Applied Physiology, 94*(5), 659-669.

De Souza, E. O., Tricoli, V., Rauch, J., Alvarez, M. R., Laurentino, G., Aihara, A. Y., . . . Ugrinowitsch, C. (2018). Different patterns in muscular strength and hypertrophy adaptations in untrained individuals undergoing nonperiodized and periodized strength regimens. *Journal of Strength and Conditioning Research, 32*(5), 1238-1244.

DeBeliso, M., Harris, C., Spitzer-Gibson, T., & Adams, K. (2005). A comparison of periodised and fixed repetition training protocol on strength in older adults. *Journal of Science and Medicine in Sport, 8*(2), 190-199.

Decker, M. J., Torry, M. R., Wyland, D. J., Sterett, W. I., & Steadman, J. R. (2003). Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. *Clinical Biomechanics, 18*(7), 662-669.

Denadai, B. S., & Greco, C. C. (2018). Resistance training and exercise tolerance during high-intensity exercise: Moving beyond just running economy and muscle strength. *Journal of Applied Physiology, 124*(2), 526-528.

Dennis, R., Finch, C. F., & Farhart, P. (2005). Is bowling workload a risk factor for injury to Australian junior cricket fast bowlers? *British Journal of Sports Medicine, 39*(11), 843-846.

DeWeese, B. H., Hornsby, G., Stone, M., & Stone, M. H. (2015a). The training process: Planning for strength–power training in track and field. Part 1: Theoretical aspects. *Journal of Sport and Health Science, 4*(4), 308-317.

DeWeese, B. H., Hornsby, G., Stone, M., & Stone, M. H. (2015b). The training process: Planning for strength–power training in track and field. Part 2: Practical and applied aspects. *Journal of Sport and Health Science, 4*(4), 318-324.

Dhahbi, W., Chaouachi, A., Ben, D. A., Cochrane, J., Chèze, L., Burnett, A., & Chamari, K. (2016). Variation of plyometric push-ups affects force application kinetics and perception of intensity. *International Journal of Sports Physiology and Performance, 12*(2), 190-197.

DiFiori, J. P., Benjamin, H. J., Brenner, J. S., Gregory, A., Jayanthi, N., Landry, G. L., & Luke, A. (2014). Overuse injuries and burnout in youth sports: A position statement from the American Medical Society for Sports Medicine. *Clinical Journal of Sports Medicine, 24*, 3 -20.

Dorgo, S., King, G. A., & Rice, C. A. (2009). The effects of manual resistance training on improving muscular strength and endurance. *Journal of Strength and Conditioning Research, 23*(1), 293-303.

Douris, P. C., White, B. P., Cullen, R. R., & Keltz, W. E. (2006). The relationship between maximal repetition performance and muscle fiber type as estimated by noninvasive technique in the quadriceps of untrained women. *Journal of Strength and Conditioning Research, 20*(3), 699.

Drinkwater, E. J., Lawton, T. W., Lindsell, R. P., Pyne, D. B., Hunt, P. H., & McKenna, M. J. (2005). Training leading to repetition failure enhances bench press strength gains in elite junior athletes. *Journal of Strength and Conditioning Research, 19*(2), 382-388.

Dudley, G. A., Tesch, P., Miller, B., & Buchanan, P. (1991). Importance of eccentric actions in performance adaptations to resistance training. *Aviation, Space and Environmental Medicine, 62*(6), 543-550.

Egan, A. D., Winchester, J. B., Foster, C., & McGuigan, M. (2006). Using session RPE to monitor different methods of resistance exercise. *Journal of Sports Science and Medicine, 5*, 289-295.

Egan, B., & Zierath, J. R. (2013). Exercise metabolism and the molecular regulation of skeletal muscle adaptation. *Cell Metabolism, 17*(2), 162-184.

Elliott, B. C., Wilson, G. J., & Kerr, G. K. (1989). A biomechanical analysis of the sticking region in the bench press. *Medicine and Science in Sports and Exercise, 21*(4), 450-462.

Elloumi, M., Makni, E., Moalla, W., Bouaziz, T., Tabka, Z., Lac, G., & Chamari, K. (2012). Monitoring training load and fatigue in rugby sevens players. *Asian Journal of Sports Medicine, 3*(3), 175.

Enoka, R. M. (1995). Mechanisms of muscle fatigue: Central factors and task dependency. *Journal of Electromyography and Kinesiology, 5*(3), 141-149.

Enoka, R. M., & Stuart, D. G. (1992). Neurobiology of muscle fatigue. *Journal of Applied Physiology, 72*(5), 1631-1648.

Eston, R. (2012). Use of ratings of perceived exertion in sports. *International Journal of Sports Physiology and Performance, 7*, 175-182.

Faigenbaum, A. (2017). Resistance exercise and youth: Survival of the strongest. *Pediatric Exercise Science, 29*(1), 14-18.

Faigenbaum, A., McFarland, J. E., Johnson, L., Kang, J., Bloom, J., Ratamess, N., & Hoffman, J. (2007). Preliminary evaluation of an after-school resistance training program for improving physical fitness in middle school-age boys. *Perceptual and Motor Skills, 104*, 407-415.

Faigenbaum, A. D., Kraemer, W. J., Blimkie, C. J., Jeffreys, I., Micheli, L. J., Nitka, M., & Rowland, T. W. (2009). Youth resistance training: Updated position statement paper from the National Strength and Conditioning Association. *Journal of Strength and Conditioning Research, 23*, S60-S79.

Faigenbaum, A. D., Lloyd, R. S., MacDonald, J., & Myer, G. D. (2015). Citius, Altius, Fortius: Beneficial effects of resistance training for young athletes. *British Journal of Sports Medicine, 50*(1), 3-7.

Faigenbaum, A. D., & Myer, G. D. (2010). Resistance training among young athletes: Safety, efficacy and injury prevention effects. *British Journal of Sports Medicine, 44*(1), 56-63.

Falk, B., & Eliakim, A. (2014). Endocrine response to resistance training in children. *Pediatric Exercise Science, 26*(4).

Falvo, M. J., Schilling, B. K., & Weiss, L. W. (2006). Techniques and considerations for determining isoinertial upper-body power. *Sports Biomechanics, 5*(2), 293-311.

Fargo, K. N., & Sengelaub, D. R. (2004). Exogenous testosterone prevents motoneuron atrophy induced by contralateral motoneuron depletion. *Journal of Neurobiology, 60*(3), 348-359.

Faude, O., Kellmann, M., Ammann, T., Schnittker, R., & Meyer, T. (2011). Seasonal changes in stress indicators in high level football. *International Journal of Sports Medicine, 32*(4), 259-265.

Feigenbaum, M. S., & Pollock, M. L. (1999). Prescription of resistance training for health and disease. *Medicine and Science in Sports and Exercise, 31*(1), 38-45.

Figueiredo, A. J., Coelho e Silva, M. J., Cumming, S. P., & Malina, R. M. (2010). Size and maturity mismatch in youth soccer players 11-to 14-years-old. *Pediatric Exercise Science, 22*(4), 596-612.

Fisher, J., Steele, J., Bruce-Low, S., & Smith, D. (2011). Evidence-based resistance training recommendations. *Medicina Sportiva, 15*(3), 147-162.

Fleck, S. J. (1988). Cardiovascular adaptations to resistance training. *Medicine and Science in Sports and Exercise, 20*, S146-S151.

Fleck, S. J. (1999). Periodized strength training: A critical review. *Journal of Strength and Conditioning Research, 13*(1), 82-89.

Fleck, S. J., & Kraemer, W. J. (1997). *Designing Resistance Training Programs* (2nd ed.). Champaign, IL: Human Kinetics.

Fleck, S. J., & Kraemer, W. J. (2004). *Designing Resistance Training Programs* (3rd ed.). Champaign, IL: Human Kinetics.

Flores, D. F., Gentil, P., Brown, L. E., Pinto, R. S., Carregaro, R. L., & Bottaro, M. (2011). Dissociated time course of recovery between genders after resistance exercise. *Journal of Strength and Conditioning Research, 25*(11), 3039-3044.

Folland, J. P., McCauley, T. M., & Williams, A. G. (2008). Allometric scaling of strength measurements to body size. *European Journal of Applied Physiology, 102*(6), 739-745.

Ford, K. R., Myer, G. D., & Hewett, T. E. (2003). Valgus knee motion during landing in high school female and male basketball players. *Medicine and Science in Sports and Exercise, 35*(10), 1745-1750.

Ford, P., Croix, M. D. S., Lloyd, R., Meyers, R. O. B., Moosavi, M., Oliver, J. O. N., . . . Williams, C. (2011). The long-term athlete development model: Physiological evidence and application. *Journal of Sports Sciences, 29*(4), 389-402.

Foster, C. (1998). Monitoring training in athletes with reference to overtraining syndrome. *Medicine and Science in Sports and Exercise, 30*(7), 1164-1168.

Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., . . . Dodge, C. (2001). A new approach to monitoring exercise training. *Journal of Strength and Conditioning Research, 15*(1), 109-115.

Foster, C., Hector, L. L., Welsh, R., Schrager, M., Green, M. A., & Snyder, A. C. (1995). Effects of specific versus cross-training on running performance. *European Journal of Applied Physiology and Occupational Physiology, 70*(4), 367-372.

Fowles, J. R. (2006). Technical issues in quantifying low-frequency fatigue in athletes. *International Journal of Sport Physiology and Performance, 1*(2), 169-171.

Freitas, C. G., Aoki, M. S., Franciscon, C. A., Arruda, A. F., Carling, C., & Moreira, A. (2014a). Psychophysiological responses to overloading and tapering phases in elite young soccer players. *Pediatric Exercise Science, 26*(2), 195-202.

Freitas, V. H., Nakamura, F. Y., Miloski, B., Samulski, D., & Bara-Filho, M. G. (2014b). Sensitivity of physiological and psychological markers to training load intensification in volleyball players. *Journal of Sports Science and Medicine, 13*(3), 571.

Frost, H. M. (2000). Muscle, bone and the Utah paradigm: A 1999 overview. *Medicine and Science in Sports and Exercise, 32*(5), 911-917.

Fry, A., Kraemer, W., & Ramsey, L. (1998). Pituitary-adrenal-gonadal responses to high-intensity resistance exercise overtraining. *Journal of Applied Physiology, 85*(6), 2352-2359.

Fry, A. C., & Kraemer, W. J. (1997). Resistance exercise overtraining and overreaching. *Sports Medicine, 23*(2), 106-129.

Fry, A. C., Kraemer, W. J., Gordon, S. E., Stone, M. H., Warren, B. J., Fleck, S. J., & Kearney, J. T. (1994). Endocrine responses to overreaching before and after 1 year of weightlifting. *Canadian Journal of Applied Physiology, 19*(4), 400-410.

Fry, A. C., Kraemer, W. J., Stone, M. H., Koziris, L. P., Thrush, J. T., & Fleck, S. J. (2000). Relationships between serum testosterone, cortisol, and weightlifting performance. *Journal of Strength and Conditioning Research, 14*(3), 338-343.

Fry, A. C., Kraemer, W. J., Stone, M. H., Warren, B. J., Kearney, J. T., Maresh, C. M., . . . Fleck, S. J. (1993). Endocrine and performance responses to high volume training and amino acid supplementation in elite junior weightlifters. *International Journal of Sport Nutrition, 3*(3), 306-322.

Fullagar, H. H., Govus, A., Hanisch, J., & Murray, A. (2017). The time course of perceptual recovery markers after match play in Division I-A college American football. *International Journal of Sports Physiology and Performance, 12*(9), 1264-1266.

Fuller, J. T., Bellenger, C. R., Thewlis, D., Arnold, J., Thomson, R. L., Tsiros, M. D., . . . Buckley, J. D. (2017). Tracking performance changes with running-stride variability when athletes are functionally overreached. *International Journal of Sports Physiology and Performance, 12*(3), 357-363.

Gabbett, T. J., & Domrow, N. (2005). Risk factors for injury in subelite rugby league players. *The American Journal of Sports Medicine, 33*(3), 428-434.

Gabbett, T. J., & Jenkins, D. G. (2011). Relationship between training load and injury in professional rugby league players. *Journal of Science and Medicine in Sport, 14*(3), 204-209.

Gabbett, T. J., Whyte, D. G., Hartwig, T. B., Wescombe, H., & Naughton, G. A. (2014). The relationship between workloads, physical performance, injury and illness in adolescent male football players. *Sports Medicine, 44*(7), 989-1003.

Gallahue, D. L. (1989). *Understanding Motor Development: Infants, Children, Adolescents*. Indianapolis: Benchmark Press.

Gamble, P. (2006). Periodization of training for team sports athletes. *Strength and Conditioning Journal, 28*(5), 56-66.

Gamble, P. (2008). Approaching physical preparation for youth team sports players. *Strength and Conditioning Journal, 30*(1), 29-42.

Gamble, P. (2013). *Strength and Conditioning for Team Sports* (2nd ed.). Oxfordshire, England: Routledge.

Gandevia, S. C. (2001). Spinal and supraspinal factors in human muscle fatigue. *Physiological Reviews, 81*(4), 1725-1789.

Garcıa-Pallares, J., Garcia-Fernandez, M., Sanchez-Medina, L., & Izquierdo, M. (2010). Performance changes in world-class kayakers following two different training periodization models. *European Journal of Applied Physiology, 110*, 99-107.

Gastin, P. B., Bennett, G., & Cook, J. (2013). Biological maturity influences running performance in junior Australian football. *Journal of Science and Medicine in Sports, 16*(2), 140-145.

Gathercole, R., Sporer, B., Stellingwerff, T., & Sleivert, G. (2015a). Alternative countermovement jump analysis to quantify acute neuromuscular fatigue. *International Journal of Sports Physiology and Performance, 10*, 84-92.

Gathercole, R. J., Stellingwerff, T., & Sporer, B. C. (2015b). Effect of acute fatigue and training adaptation on countermovement jump performance in elite snowboard cross athletes. *Journal of Strength and Conditioning Research, 29*(1), 37-46.

Gearhart, R. F., Goss, F. L., Lagally, K. M., Jakicic, J. M., Gallagher, J., Gallagher, K. I., & Robertson, R. J. (2002). Ratings of perceived exertion in active muscle during high-intensity and low-intensity resistance exercise. *Journal of Strength and Conditioning Research, 16*(1), 87-91.

Genner, K. M., & Weston, M. (2014). A comparison of workload quantification methods in relation to physiological responses to resistance exercise. *Journal of Strength and Conditioning Research, 28*(9), 2621-2627.

Gentil, P., Steele, J., Pereira, M. C., Castanheira, R. P., Paoli, A., & Bottaro, M. (2016). Comparison of upper body strength gains between men and women after 10 weeks of resistance training. *PeerJ, 4*, e1627. doi: 10.7717/peerj.1627.

Gerodimos, V., Zafeiridis, A., Perkos, S., Dipla, K., Manou, V., & Kellis, S. (2008). The contribution of stretch-shortening cycle and arm-swing to vertical jumping performance in children, adolescents and adult basketball players. *Pediatric Exercise Science, 20*(4), 379-389.

Gibala, M. J., Interisano, S. A., Tarnopolsky, M. A., Roy, B. D., MacDonald, J. R., Yarasheski, K. E., & MacDougall, J. D. (2000). Myofibrillar disruption following acute concentric and eccentric resistance exercise in strength-trained men. *Canadian Journal of Physiology and Pharmacology*(8), 656.

Gil-Rey, E., Lezaun, A., & Los Arcos, A. (2015). Quantification of the perceived training load and its relationship with changes in physical fitness performance in junior soccer players. *Journal of Sports Sciences, 33*(20), 2125-2132.

Girard, O., & Millet, G. P. (2009). Neuromuscular fatigue in racquet sports. *Physical Medicine and Rehabilitation Clinics of North America, 20*(1), 161-173.

Gold, P. W., Loriaux, D. L., Roy, A., Kling, M. A., Calabrese, J. R., Kellner, C. H., . . . Gallucci, W. (1986). Responses to corticotropin-releasing hormone in the hypercortisolism of depression and Cushing's disease. *New England Journal of Medicine, 314*(21), 1329-1335.

Gomes, R. V., Moreira, A., Lodo, L., Capitani, C. D., & Aoki, M. S. (2015). Ecological validity of session RPE method for quantifying internal training load in tennis. *International Journal of Sports Science and Coaching, 10*(4), 729-737.

Gomes, R. V., Moreira, A., Lodo, L., Nosaka, K., Coutts, A., & Aoki, M. S. (2013). Monitoring training loads, stress, immune-endocrine responses and performance in tennis players. *Biology of Sport, 30*(3), 173-180.

González-Badillo, J., Rodríguez-Rosell, D., Sánchez-Medina, L., Ribas, J., López-López, C., Mora-Custodio, R., . . . Pareja-Blanco, F. (2015a). Short-term recovery following resistance exercise leading or not to failure. *International Journal of Sports Medicine, 37*(4), 295-304.

González-Badillo, J. J., Pareja-Blanco, F., Rodríguez-Rosell, D., Abad-Herencia, J. L., del Ojo-López, J. J., & Sánchez-Medina, L. (2015b). Effects of velocity-based resistance training on young soccer players of different ages. *Journal of Strength and Conditioning Research, 29*(5), 1329-1338.

Gonzalez, A. M., Hoffman, J. R., Townsend, J. R., Jajtner, A. R., Boone, C. H., Beyer, K. S., . . . Robinson, E. H. (2015). Intramuscular anabolic signaling and endocrine response following high volume and high intensity resistance exercise protocols in trained men. *Physiological Reports, 3*(7), 1-15.

Gorassini, M., Yang, J. F., Siu, M., & Bennett, D. J. (2002). Intrinsic activation of human motoneurons: Reduction of motor unit recruitment thresholds by repeated contractions. *Journal of Neurophysiology, 87*(4), 1859-1866.

Gorostiaga, E., Izquierdo, M., Ruesta, M., Iribarren, J., Gonzalez-Badillo, J., & Ibanez, J. (2004). Strength training effects on physical performance and serum hormones in young soccer players. *European Journal of Applied Physiology, 91*(5-6), 698-707.

Gorostiaga, E. M., Izquierdo, M., Iturralde, P., Ruesta, M., & Ibáñez, J. (1999). Effects of heavy resistance training on maximal and explosive force production, endurance and serum hormones in adolescent handball players. *European Journal of Applied Physiology and Occupational Physiology, 80*(5), 485-493.

Gotshalk, L. A., Loebel, C. C., Nindl, B. C., Putukian, M., Sebastianelli, W. J., Newton, R. U., . . . Kraemer, W. J. (1997). Hormonal responses of multiset versus single-set heavy-resistance exercise protocols. *Canadian Journal of Applied Physiology, 22*(3), 244-255.

Gozansky, W., Lynn, J., Laudenslager, M., & Kohrt, W. (2005). Salivary cortisol determined by enzyme immunoassay is preferable to serum total cortisol for assessment of dynamic hypothalamic–pituitary–adrenal axis activity. *Clinical Endocrinology, 63*(3), 336-341.

Granacher, U., Lesinski, M., Büsch, D., Muehlbauer, T., Prieske, O., Puta, C., . . . Behm, D. G. (2016). Effects of resistance training in youth athletes on muscular fitness and athletic performance: A conceptual model for long-term athlete development. *Frontiers in Physiology, 7*, 164.

Granhed, H., Jonson, R., & Hansson, T. (1987). The loads on the lumbar spine during extreme weight lifting. *Spine, 12*(2), 146-149.

Grisbrook, T. L., Gittings, P. M., Wood, F. M., & Edgar, D. W. (2017). The effectiveness of session rating of perceived exertion to monitor resistance training load in acute burns patients. *Burns, 43*(1), 169-175.

Guezennec, Y., Leger, L., Lhoste, F., Aymonod, M., & Pesquies, P. (1986). Hormone and metabolite response to weight-lifting training sessions. *International Journal of Sports Medicine, 7*(2), 100-105.

Guglielmo, L., Greco, C., & Denadai, B. (2009). Effects of strength training on running economy. *International Journal of Sports Medicine, 30*(01), 27-32.

Gunnar, M. R., Wewerka, S., Frenn, K., Long, J. D., & Griggs, C. (2009). Developmental changes in hypothalamus–pituitary–adrenal activity over the transition to adolescence: Normative changes and associations with puberty. *Development and Psychopathology, 21*(1), 69-85.

Gunter, K. B., Almstedt, H. C., & Janz, K. F. (2012). Physical activity in childhood may be the key to optimizing lifespan skeletal health. *Exercise and Sport Sciences Reviews, 40*(1), 13.

Haddad, M., Stylianides, G., Djaoui, L., Dellal, A., & Chamari, K. (2017). Session-RPE method for training load monitoring: Validity, ecological usefulness, and influencing factors. *Frontiers in Neuroscience, 11*, 612.

Haff, G. G. (2004). Roundtable discussion: Periodization of training-Part 1. *Strength and Conditioning Journal, 26*(1), 50-69.

Haff, G. G. (2010). Quantifying workloads in resistance training: A brief review. *Strength and Conditioning, 10*, 31-40.

Haff, G. G. (2014). Periodization strategies for youth development. In R. S. Lloyd & J. L. Oliver (Eds.), *Strength and Conditioning for Young Athletes*. London, England: Routledge.

Haff, G. G. (2016). Periodization. In G. Haff & N. T. Triplett (Eds.), *Essentials of Strength Training and Conditioning* (4th ed.). Champaign, IL: Human Kinetics.

Haff, G. G., & Haff, E. E. (2012). Training integration and periodization. In J. Hoffman (Ed.), *NSCA's Guide to Program Design*. Champaign, IL: Human Kinetics.

Haff, G. G., & Stone, M. H. (2015). Methods of developing power with special reference to football players. *Strength and Conditioning Journal, 37*(6), 2-16.

Haff, G. G., Stone, M. H., Jackson, J. R., Kawamori, N., Carlock, J. M., Hartman, M. J., . . . Sands, W. A. (2008). Force-time curve characteristics and hormonal alterations during an eleven-week training period in elite women weightlifters. *Journal of Strength and Conditioning Research, 22*(2), 433-446.

Hagerman, F., & Staron, R. (1983). Seasonal variables among physiological variables in elite oarsmen. *Canadian Journal of Applied Sport Sciences, 8*(3), 143-148.

Haines, B. R., Bourdon, P. C., & Deakin, G. (2016). Reliability of common neuromuscular performance tests in adolescent athletes. *Journal of Australian Strength and Conditioning, 24*(4), 16-22.

Hakkinen, K., & Komi, P. V. (1985). Changes in electrical and mechanical behaviour of leg extensors muscle during heavy resistance strength training. *Scandinavian Journal of Sports Science, 7*, 55-64.

Häkkinen, K., Komi, P. V., Alén, M., & Kauhanen, H. (1987a). EMG, muscle fibre and force production characteristics during a 1 year training period in elite weight-lifters. *European Journal of Applied Physiology and Occupational Physiology, 56*(4), 419-427.

Hakkinen, K., & Pakarinen, A. (1993). Acute hormonal responses to two different fatiguing heavy-resistance protocols in male athletes. *Journal of Applied Physiology, 74*(2), 882-887.

Häkkinen, K., & Pakarinen, A. (1991). Serum hormones in male strength athletes during intensive short term strength training. *European Journal of Applied Physiology and Occupational Physiology, 63*(3), 194-199.

Hakkinen, K., Pakarinen, A., Alen, M., Kauhanen, H., & Komi, P. (1988). Neuromuscular and hormonal adaptations in athletes to strength training in two years. *Journal of Applied Physiology, 65*(6), 2406-2412.

Häkkinen, K., Pakarinen, A., Alen, M., Kauhanen, H., & Komi, P. (1987b). Relationships between training volume, physical performance capacity, and serum hormone concentrations during prolonged training in elite weight lifters. *International Journal of Sports Medicine, 8*(S1), S61-S65.

Halson, S. L. (2014). Monitoring training load to understand fatigue in athletes. *Sports Medicine, 44*(2), 139-147.

Halson, S. L., Bridge, M. W., Meeusen, R., Busschaert, B., Gleeson, M., Jones, D. A., & Jeukendrup, A. E. (2002). Time course of performance changes and fatigue markers during intensified training in trained cyclists. *Journal of Applied Physiology, 93*(3), 947-956.

Halson, S. L., & Jeukendrup, A. E. (2004). Does overtraining exist? *Sports Medicine, 34*(14), 967-981.

Hamill, B. (1994). Relative safety of weightlifting and weight training. *Journal of Strength and Conditioning Research, 8*(1), 53-57.

Hamlin, M. J., Wilkes, D., Elliot, C. A., Lizamore, C. A., & Kathiravel, Y. (2019). Monitoring training loads and perceived stress in young elite university athletes. *Frontiers in Physiology, 10*, 34. doi: 10.3389/fphys.2019.00034.

Handziski, Z., Maleska, V., Petrovska, S., Nikolik, S., Mickoska, E., Dalip, M., & Kostova, E. (2006). The changes of ACTH, cortisol, testosterone and testosterone/cortisol ratio in professional soccer players during a competition half-season. *Bratislavské lekárske listy, 107*(6/7), 259-263.

Hansen, S., McAuliffe, J., Goldfarb, B., & Carré, J. M. (2017). Testosterone influences volitional, but not reflexive orienting of attention in human males. *Physiology and Behavior, 175*, 82-87.

Harries, S. K., Lubans, D. R., Buxton, A., MacDougall, T. H., & Callister, R. (2018). Effects of 12-week resistance training on sprint and jump performances in competitive adolescent rugby union players. *Journal of Strength and Conditioning Research, 32*(10), 2762-2769.

Harries, S. K., Lubans, D. R., & Callister, R. (2012). Resistance training to improve power and sports performance in adolescent athletes: A systematic review and meta-analysis. *Journal of Science and Medicine in Sports, 15*(6), 532-540.

Harries, S. K., Lubans, D. R., & Callister, R. (2015a). Comparison of resistance training progression models on maximal strength in sub-elite adolescent rugby union players. *Journal of Science and Medicine in Sports, 19*(2), 163-169.

Harries, S. K., Lubans, D. R., & Callister, R. (2015b). Systematic review and meta-analysis of linear and undulating periodized resistance training programs on muscular strength. *Journal of Strength and Conditioning Research, 29*(4), 1113-1125.

Harris, A., Gundersen, H., Andreassen, P. M., Thun, E., Bjorvatn, B., & Pallesen, S. (2017). A comparative study of sleep and mood between young elite athletes and age-matched controls. *Journal of Physical Activity and Health, 14*(6), 465-473.

Harris, N., Cronin, J., & Keogh, J. (2007). Contraction force specificity and its relationship to functional performance. *Journal of Sports Sciences, 25*(2), 201-212.

Hartmann, H., Bob, A., Wirth, K., & Schmidtbleicher, D. (2009). Effects of different periodization models on rate of force development and power ability of the upper extremity. *Journal of Strength and Conditioning Research, 23*(7), 1921-1932.

Hartmann, H., Wirth, K., Keiner, M., Mickel, C., Sander, A., & Szilvas, E. (2015). Short-term periodization models: Effects on strength and speed-strength performance. *Sports Medicine, 45*(10), 1373-1386.

Hartwig, T. B., Naughton, G., & Searl, J. (2009). Load, stress, and recovery in adolescent rugby union players during a competitive season. *Journal of Sports Sciences, 27*(10), 1087-1094.

Hawkins, D., & Metheny, J. (2001). Overuse injuries in youth sports: Biomechanical considerations. *Medicine and Science in Sports and Exercise, 33*(10), 1701-1707.

Hendricks, S., Till, K., Oliver, J., Johnston, R., Attwood, M., Brown, J., . . . Jones, B. (2018). The rating of perceived challenge as a measure of internal load for technical skill performance. *British Journal of Sports Medicine, Published Online First: 17 November 2018*. doi:10.1136/bjsports-2018-099871

Hermans, E. J., Ramsey, N. F., & van Honk, J. (2008). Exogenous testosterone enhances responsiveness to social threat in the neural circuitry of social aggression in humans. *Biological Psychiatry, 63*(3), 263-270.

Herrick, A. B., & Stone, W. J. (1996). The effects of periodization versus progressive resistance exercise on upper and lower body strength in women. *Journal of Strength and Conditioning Research, 10*(2), 72-76.

Hewett, T. E., Myer, G. D., Ford, K. R., & Slauterbeck, J. R. (2006). Preparticipation physical examination using a box drop vertical jump test in young athletes: The effects of puberty and sex. *Clinical Journal of Sport Medicine, 16*(4), 298-304.

Hewett, T. E., Stroupe, A. L., Nance, T. A., & Noyes, F. R. (1996). Plyometric training in female athletes decreased impact forces and increased hamstring torques. *American Journal of Sports Medicine, 24*(6), 765-773.

Hickson, R., Hidaka, K., Foster, C., Falduto, M., & Chatterton Jr, R. (1994). Successive time courses of strength development and steroid hormone responses to heavy-resistance training. *Journal of Applied Physiology, 76*(2), 663-670.

Higgins, T., Cameron, M., & Climstein, M. (2012). Evaluation of passive recovery, cold water immersion, and contrast baths for recovery, as measured by game performances markers, between two simulated games of rugby union. *Journal of Strength and Conditioning Research, Published ahead-of-print: 11 June 2012*. doi: 10.1519/JSC.0b013e31825c32b9.

Hiscock, D. J., Dawson, B., Clarke, M., & Peeling, P. (2017). Can changes in resistance exercise workload influence internal load, countermovement jump performance and the endocrine response? *Journal of Sports Sciences, 36*(2), 191-197.

Hiscock, D. J., Dawson, B., & Peeling, P. (2015). Perceived exertion responses to changing resistance training programming variables. *Journal of Strength and Conditioning Research, 29*(6), 1564-1569.

Hoeger, W. W., Barette, S. L., Hale, D. F., & Hopkins, D. R. (1987). Relationship between repetitions and selected percentages of one repetition maximum. *Journal of Applied Sport Science Research, 1*(1), 11-13.

Hoeger, W. W., Hopkins, D. R., Barette, S. L., & Hale, D. F. (1990). Relationship between repetitions and selected percentages of one repetition maximum: A comparison between untrained and trained males and females. *Journal of Applied Sport Science Research, 4*(2), 47-54.

Hoff, J., Gran, A., & Helgerud, J. (2002). Maximal strength training improves aerobic endurance performance. *Scandinavian Journal of Medicine Science and Sports, 12*(5), 288-295.

Hoffman, J. R., Fry, A. C., Howard, R., Maresh, C. M., & Kraemer, W. J. (1991). Strength, speed and endurance changes during the course of a division I basketball season. *Journal of Strength and Conditioning Research, 5*(3), 144-149.

Hoffman, J. R., & Kaminsky, M. (2000). Use of performance testing for monitoring overtraining in elite youth basketball players. *Strength and Conditioning Journal, 22*(6), 54-62.

Hoffman, J. R., Wendell, M., Cooper, J., & Kang, J. (2003). Comparison between linear and non linear in season training programs in freshman football players. *Journal of Strength and Conditioning Research, 17*(3), 561-565.

Hogarth, L. W., Deakin, G., & Sinclair, W. (2013). Are plyometric push-ups a reliable power assessment tool? *Journal of Australian Strength and Conditioning, 21*(1), 67-69.

Hollander, D. B., Durand, R. J., Trynicki, J. L., Larock, D., Castracane, V. D., Hebert, E. P., & Kraemer, R. R. (2003). RPE, pain, and physiological adjustment to concentric and eccentric contractions. *Medicine and Science in Sports and Exercise, 35*(6), 1017-1025.

Hooper, D. R., Kraemer, W. J., Focht, B. C., Volek, J. S., DuPont, W. H., Caldwell, L. K., & Maresh, C. M. (2017). Endocrinological roles for testosterone in resistance exercise responses and adaptations. *Sports Medicine, 47*(9), 1709-1720.

Hooper, S. L., MacKinnon, L. T., & Hanrahan, S. (1997). Mood states as an indication of staleness and recovery. *International Journal of Sport Psychology, 28*(1), 1-12.

Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine, 30*(1), 1-15.

Hopkins, W. G. (2004). *How to interpret changes in an athletic performance test*. Retrieved October, 2015, from http://www.sportsci.org/jour/04/wghtests.htm

Hopkins, W. G. (2015a). Analysis of Reliability with a Spreadsheet (Excel Spreadsheet). Retrieved September 2015 sportsci.org/resource/stats/xrely.xls

Hopkins, W. G. (2015b). Spreadsheets for analysis of validity and reliability. *Sportscience, 19*, 36-42.

Hopkins, W. G., Schabort, E. J., & Hawley, J. A. (2001). Reliability of power in physical performance tests. *Sports Medicine, 31*(3), 211-234.

Hori, N., Newton, R. U., Kawamori, N., McGuigan, M. R., Kraemer, W. J., & Nosaka, K. (2009). Reliability of performance measurements derived from ground reaction force data during countermovement jump and the influence of sampling frequency. *Journal of Strength and Conditioning Research, 23*(3), 874-882.

Howatson, G., Brandon, R., & Hunter, A. (2016). The response to, and recovery from maximum strength and power training in elite track and field athletes. *International Journal of Sports Physiology and Performance, 11*(3), 356-362.

Howatson, G., & Milak, A. (2009). Exercise-induced muscle damage following a bout of sport specific repeated sprints. *Journal of Strength and Conditioning Research, 23*(8), 2419-2424.

Hrysomallis, C., & Kidgell, D. (2001). Effect of heavy dynamic resistive exercise on acute upper-body power. *Journal of Strength and Conditioning Research, 15*(4), 426-430.

Hulin, B. T., Gabbett, T. J., Blanch, P., Chapman, P., Bailey, D., & Orchard, J. W. (2014). Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. *British Journal of Sports Medicine, 48*(8), 708-712.

Hunter, S. K., Duchateau, J., & Enoka, R. M. (2004). Muscle fatigue and the mechanisms of task failure. *Exercise and Sport Sciences Reviews, 32*(2), 44-49.

Huxley, D. J., O'Connor, D., & Healey, P. A. (2014). An examination of the training profiles and injuries in elite youth track and field athletes. *European Journal of Sport Science, 14*(2), 185-192.

Ialongo, C. (2016). Understanding the effect size and its measures. *Biochemia Medica, 26*(2), 150-163.

Ignjatovic, A. M., Markovic, Z. M., & Radovanovic, D. S. (2012). Effects of 12-week medicine ball training on muscle strength and power in young female handball players. *Journal of Strength and Conditioning Research, 26*(8), 2166-2173.

Impellizzeri, F. M., Rampinini, E., Coutts, A. J., Sassi, A., & Marcora, S. M. (2004). Use of RPE-based training load in soccer. *Medicine and Science in Sports and Exercise, 36*(6), 1042-1047.

Ishida, K., Moritani, T., & Itoh, K. (1990). Changes in voluntary and electrically induced contractions during strength training and detraining. *European Journal of Applied Physiology and Occupational Physiology, 60*(4), 244-248.

Issurin, V. (2008). Block periodization versus traditional training theory: A review. *The Journal of Sports Medicine and Physical Fitness, 48*(1), 65.

Issurin, V., & Yessis, M. (2008). *Block Periodization: Breakthrough in Sports Training*. Muskegon, MI: Ultimate Athlete Concepts.

Issurin, V. B. (2009). Generalized training effects induced by athletic preparation. A review. *The Journal of Sports Medicine and Physical Fitness, 49*(4), 333-345.

Issurin, V. B. (2010). New horizons for the methodology and physiology of training periodization. *Sports Medicine, 40*(9), 803-807.

Issurin, V. B. (2016). Benefits and limitations of block periodized training approaches to athletes' preparation: A review. *Sports Medicine, 46*(3), 329-338.

Izquierdo, M., Ibañez, J., Calbet, J. A., Navarro-Amezqueta, I., González-Izal, M., Idoate, F., . . . Almar, M. (2009). Cytokine and hormone responses to resistance training. *European Journal of Applied Physiology, 107*(4), 397.

Izquierdo, M., Ibanez, J., Gonzalez-Badillo, J. J., Hakkinen, K., Ratamess, N., Kraemer, W. J., . . . Gorostiaga, E. M. (2006). Differential effects of strength training leading to failure versus not to failure on hormonal responses, strength and muscle power gains. *Journal of Applied Physiology, 100*, 1647-1656.

Izquierdo, M., Ibañez, J., Gonzalez-Badillo, J. J., Ratamess, N. A., Kraemer, W. J., Häkkinen, K., . . . Gorostiaga, E. M. (2007). Detraining and tapering effects on hormonal responses and strength performance. *Journal of Strength and Conditioning Research, 21*(3), 768-775.

Jackowski, S., Baxter-Jones, A., Gruodyte-Raciene, R., Kontulainen, S., & Erlandson, M. (2015). A longitudinal study of bone area, content, density, and strength development at the radius and tibia in children 4–12 years of age exposed to recreational gymnastics. *Osteoporosis International, 26*(6), 1677-1690.

Jaric, S. (2002). Muscle strength testing. *Sports Medicine, 32*(10), 615-631.

Jaric, S., Ugarkovic, D., & Kukoli, M. (2002). Evaluation of methods for normalizing muscle strength in elite and young athletes. *Journal of Sports Medicine and Physical Fitness, 42*(2), 141-151.

Jayanthi, N. A., LaBella, C. R., Fischer, D., Pasulka, J., & Dugas, L. R. (2015). Sports-specialized intensive training and the risk of injury in young athletes: A clinical case-control study. *American Journal of Sports Medicine, 43*(4), 794-801.

Jensen, B., Pilegaard, M., & Sjøgaard, G. (2000). Motor unit recruitment and rate coding in response to fatiguing shoulder abductions and subsequent recovery. *European Journal of Applied Physiology, 83*(2), 190-199.

Johnston, R. D., Gabbett, T. J., & Jenkins, D. G. (2013a). Influence of an intensified competition on fatigue and match performance in junior rugby league players. *Journal of Science and Medicine in Sport, 16*(5), 460-465.

Johnston, R. D., Gabbett, T. J., Jenkins, D. G., & Hulin, B. T. (2015). Influence of physical qualities on post-match fatigue in rugby league players. *Journal of Science and Medicine in Sport, 18*(2), 209-213.

Johnston, R. D., Gabbett, T. J., Jenkins, D. G., & Speranza, M. J. (2016). Effect of different repeated-high-intensity-effort bouts on subsequent running, skill performance, and neuromuscular function. *International Journal of Sports Physiology and Performance, 11*(3), 311-318.

Johnston, R. D., Gibson, N. V., Twist, C., Gabbett, T. J., MacNay, S. A., & MacFarlane, N. G. (2013b). Physiological responses to an intensified period of rugby league competition. *Journal of Strength and Conditioning Research, 27*(3), 643-654.

Johnston, R. E., Quinn, T. J., Kertzer, R., & Vroman, N. B. (1997). Strength training in female distance runners: Impact on running economy. *Journal of Strength and Conditioning Research, 11*(4), 224-229.

Jones, D., & Rutherford, O. (1987). Human muscle strength training: The effects of three different regimens and the nature of the resultant changes. *The Journal of Physiology, 391*(1), 1-11.

Judge, L., Moreau, C., & Burke, J. (2003). Neural adaptations with sport-specific resistance training in highly skilled athletes. *Journal of Sports Sciences, 21*(5), 419-427.

Jürimäe, T., Perez-Turpin, J. A., Cortell-Tormo, J. M., Chinchilla-Mira, I. J., Cejuela-Anta, R., Mäestu, J., . . . Jürimäe, J. (2010). Relationship between rowing ergometer performance and physiological responses to upper and lower body exercises in rowers. *Journal of Science and Medicine in Sport, 13*(4), 434-437.

Kaikkonen, H., Yrjämä, M., Siljander, E., Byman, P., & Laukkanen, R. (2000). The effect of heart rate controlled low resistance circuit weight training and endurance training on maximal aerobic power in sedentary adults. *Scandinavian Journal of Medicine and Science in Sports, 10*(4), 211-215.

Keiner, M., Sander, A., Wirth, K., Caruso, O., Immesberger, P., & Zawieja, M. (2013). Trainability of adolescents and children in the back and front squat. *Journal of Strength and Conditioning Research, 27*(2), 357-362.

Kell, R. T. (2011). The influence of periodized resistance training on strength changes in men and women. *Journal of Strength and Conditioning Research, 25*(3), 735-744.

Kellmann, M., Altfeld, S., & Mallett, C. J. (2016). Recovery–stress imbalance in Australian Football League coaches: A pilot longitudinal study. *International Journal of Sport and Exercise Psychology, 14*(3), 240-249.

Kellmann, M., & Günther, K. D. (2000). Changes in stress and recovery in elite rowers during preparation for the Olympic Games. *Medicine and Science in Sports and Exercise, 32*(3), 676-683.

Kennedy, M. D., Tamminen, K. A., & Holt, N. L. (2013). Factors that influence fatigue status in Canadian university swimmers. *Journal of Sports Sciences, 31*(5), 554-564.

Kennedy, R. A., & Drake, D. (2017). The effect of acute fatigue on countermovement jump performance in rugby union players during preseason. *The Journal of Sports Medicine and Physical Fitness, 57*(10), 1261.

Kennis, E., Verschueren, S. M., Bogaerts, A., Van Roie, E., Boonen, S., & Delecluse, C. (2013). Long-term impact of strength training on muscle strength characteristics in older adults. *Archives of Physical Medicine and Rehabilitation, 94*(11), 2054-2060.

Kentta, G., & Hassmen, P. (1998). Overtraining and recovery: A conceptual model. *Sports Medicine, 26*(1), 1-16.

Kiely, J. (2010). New horizons for the methodology and physiology of training periodization. *Sports Medicine, 40*(9), 803-807.

Kiely, J. (2012). Periodization paradigms in the 21st century: Evidence-led or tradition-driven. *International Journal of Sports Physiology, 7*, 242-250.

Kiely, J. (2018). Periodization theory: Confronting an inconvenient truth. *Sports Medicine, 48*(4), 753-764.

Knicker, A. J., Renshaw, I., Oldham, A. R., & Cairns, S. P. (2011). Interactive processes link the multiple symptoms of fatigue in sport competition. *Sports Medicine, 41*(4), 307-328.

Koh, T. J., & Brooks, S. V. (2001). Lengthening contractions are not required to induce protection from contraction-induced muscle injury. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 281*(1), R155-R161.

Komi, P. (1986). Training of muscle strength and power: Interaction of neuromotoric, hypertrophic, and mechanical factors. *International Journal of Sports Medicine, 7*(S1), S10-S15.

Komi, P. V. (2000). Stretch-shortening cycle: A powerful model to study normal and fatigued muscle. *Journal of Biomechanics, 33*(10), 1197-1206.

Komi, P. V., & Viitasalo, J. T. (1977). Changes in motor unit activity and metabolism in human skeletal muscle during and after repeated eccentric and concentric contractions. *Acta Physiologica, 100*(2), 246-254.

Koutedakis, Y., Boreham, C., Kabitsis, C., & Sharp, N. (1992). Seasonal deterioration of selected physiological variables in elite male skiers. *International Journal of Sports Medicine, 13*(07), 548-551.

Koutedakis, Y., Ridgeon, A., Sharp, N., & Boreham, C. (1993). Seasonal variation of selected performance parameters in épée fencers. *British Journal of Sports Medicine, 27*(3), 171-174.

Kraemer, W., Fry, A., Warren, B., Stone, M., Fleck, S., Kearney, J., . . . Triplett, N. (1992). Acute hormonal responses in elite junior weightlifters. *International Journal of Sports Medicine, 13*(02), 103-109.

Kraemer, W., Noble, B., Clark, M., & Culver, B. (1987). Physiologic responses to heavy-resistance exercise with very short rest periods. *International Journal of Sports Medicine, 8*(04), 247-252.

Kraemer, W. J. (1997). A series of studies: The physiological basis for strength training in American football: Fact over philosophy. *Journal of Strength and Conditioning Research, 11*(3), 131-142.

Kraemer, W. J., Deschenes, M. R., & Fleck, S. J. (1988). Physiological adaptations to resistance exercise: Implications for athletic conditioning. *Sports Medicine, 6*(4), 246-256.

Kraemer, W. J., & Fleck, S. J. (2007). *Optimizing Strength Training*. Champaign, IL: Human Kinetics.

Kraemer, W. J., French, D. N., Paxton, N. J., Hakkinen, K., Volek, J. S., Sebastianelli, W. J., . . . Gómez, A. L. (2004a). Changes in exercise performance and hormonal concentrations over a big ten soccer season in starters and nonstarters. *Journal of Strength and Conditioning Research, 18*(1), 121-128.

Kraemer, W. J., Gordon, S., Fleck, S., Marchitelli, L., Mello, R., Dziados, J., . . . Fry, A. (1991). Endogenous anabolic hormonal and growth factor responses to heavy resistance exercise in males and females. *International Journal of Sports Medicine, 12*(02), 228-235.

Kraemer, W. J., Häkkinen, K., Newton, R. U., Nindl, B. C., Volek, J. S., McCormick, M., . . . Campbell, W. W. (1999). Effects of heavy-resistance training on hormonal response patterns in younger vs. older men. *Journal of Applied Physiology, 87*(3), 982-992.

Kraemer, W. J., Hakkinen, K., Triplett-McBride, N. T., Fry, A. C., Koziris, L. P., Ratamess, N. A., . . . Newton, R. U. (2003). Physiological changes with periodized resistance training in women tennis players. *Medicine and Science in Sports and Exercise, 35*(1), 157-168.

Kraemer, W. J., Nindl, B. C., Ratamess, N. A., Gotshalk, L. A., Volek, J. S., Fleck, S. J., . . . Häkkinen, K. (2004b). Changes in muscle hypertrophy in women with periodized resistance training. *Medicine and Science in Sports and Exercise, 36*(4), 697-708.

Kraemer, W. J., Patton, J. F., Gordon, S. E., Harman, E. A., Deschenes, M. R., Reynolds, K., . . . Dziados, J. E. (1995). Compatibility of high-intensity strength and endurance training on hormonal and skeletal muscle adaptations. *Journal of Applied Physiology, 78*(3), 976-989.

Kraemer, W. J., Ratamess, N., Fry, A. C., Triplett-McBride, T., Koziris, L. P., Bauer, J. A., . . . Fleck, S. J. (2000). Influence of resistance training volume and periodization on physiological and performance adaptations in collegiate women tennis players. *American Journal of Sports Medicine, 28*(5), 626-633.

Kraemer, W. J., & Ratamess, N. A. (2004). Fundamentals of resistance training: Progression and exercise prescription. *Medicine and Science in Sports and Exercise, 36*(4), 674-688.

Kraemer, W. J., & Ratamess, N. A. (2005). Hormonal responses and adaptations to resistance exercise and training. *Sports Medicine, 35*(4), 339-361.

Kraemer, W. J., Ratamess, N. A., & Nindl, B. C. (2016). Recovery responses of testosterone, growth hormone, and IGF-1 after resistance exercise. *Journal of Applied Physiology, 122*(3), 549-558.

Kraemer, W. J., Ratamess, N. A., Volek, J. S., Häkkinen, K., Rubin, M. R., French, D. N., . . . Dioguardi, F. S. (2006). The effects of amino acid supplementation on hormonal responses to resistance training overreaching. *Metabolism, 55*(3), 282-291.

Kraemer, W. J., Staron, R. S., Hagerman, F. C., Hikida, R. S., Fry, A. C., Gordon, S. E., . . . Marx, J. O. (1998). The effects of short-term resistance training on endocrine function in men and women. *European Journal of Applied Physiology and Occupational Physiology, 78*(1), 69-76.

Kraft, J. A., Green, J. M., & Thompson, K. R. (2014). Session ratings of perceived exertion responses during resistance training bouts equated for total work but differing in work rate. *Journal of Strength and Conditioning Research, 28*(2), 540-545.

Kramer, J. B., Stone, M. H., O'Bryant, H. S., Conley, M. S., Johnson, R. L., Nieman, D. C., . . . Hoke, T. P. (1997). Effects of single vs. multiple sets of weight training: Impact of volume, intensity and variation. *Journal of Strength and Conditioning Research, 11*(3), 143-147.

Kvorning, T., Andersen, M., Brixen, K., & Madsen, K. (2006). Suppression of endogenous testosterone production attenuates the response to strength training: A randomized, placebo-controlled, and blinded intervention study. *American Journal of Physiology-Endocrinology and Metabolism, 291*(6), E1325-E1332.

Lagally, K. M., & Robertson, R. J. (2006). Construct validity of the OMNI resistance exercise scale. *Journal of Strength and Conditioning Research, 20*(2), 252-256.

Lagally, K. M., Robertson, R. J., Gallagher, K. I., Gearhart, R. F., & Goss, F. L. (2002a). Ratings of perceived exertion during low- and high-intensity resistance exercise by young adults. *Perceptual and Motor Skills, 94*, 723-731.

Lagally, K. M., Robertson, R. J., Gallagher, K. I., Goss, F. L., Jakicic, J. M., Lephart, S. M., . . . Goodpaster, B. (2002b). Perceived exertion, electromyography, and blood lactate during acute bouts of resistance exercise. *Medicine and Science in Sports and Exercise, 34*(3), 552-559.

Laplante, M., & Sabatini, D. M. (2009). mTOR signaling at a glance. *Journal of Cell Science, 122*(20), 3589-3594.

Lathlean, T. J., Gastin, P. B., Newstead, S., & Finch, C. F. (2018a). Elite junior Australian football players experience significantly different loads across levels of competition and training modes. *Journal of Strength and Conditioning Research, 32*(7), 2031-2038.

Lathlean, T. J., Gastin, P. B., Newstead, S. V., & Finch, C. F. (2018b). A prospective cohort study of load and wellness (sleep, fatigue, soreness, stress and mood) in elite junior Australian football players. *International Journal of Sports Physiology and Performance*, 1-39.

Lawton, T., Cronin, J., Drinkwater, E., Lindsell, R., & Pyne, D. (2004). The effect of continuous repetition training and intra-set rest training on bench press strength and power. *Journal of Sports Medicine and Physical Fitness, 44*(4), 361-367.

Legg, J., Pyne, D. B., Semple, S., & Ball, N. (2017). Variability of jump kinetics related to training load in elite female basketball. *Sports, 5*(4), 85.

Lehmann, M., Lormes, W., Opitz-Gress, A., Steinacker, J., Netzer, N., Foster, C., & Gastmann, U. (1997). Training and overtraining: An overview and experimental results in endurance sports. *Journal of Sports Medicine and Physical Fitness, 37*(1), 7-17.

Lehnert, M., Sigmund, M., Lipinska, P., Vařeková, R., Hroch, M., Xaverova, Z., . . . Zmijewski, P. (2017). Training-induced changes in physical performance can be achieved without body mass reduction after eight week of strength and injury prevention oriented programme in volleyball female players. *Biology of Sport, 34*(2), 205-213.

Leite, N. M., & Sampaio, J. E. (2012). Long-term athletic development across different age groups and gender from Portuguese basketball players. *International Journal of Sports Science and Coaching, 7*(2), 285-300.

Leite, R., Prestes, J., Rosa, C., De Salles, B., Maior, A., Miranda, H., & Simão, R. (2011). Acute effect of resistance training volume on hormonal responses in trained men. *Journal of Sports Medicine and Physical Fitness, 51*(2), 322-328.

Lesinski, M., Prieske, O., & Granacher, U. (2016). Effects and dose–response relationships of resistance training on physical performance in youth athletes: A systematic review and meta-analysis. *British Journal of Sports Medicine, 50*(13), 781-795.

Lewis, R. S., Nikolova, A., Chang, D. J., & Weekes, N. Y. (2008). Examination stress and components of working memory. *Stress, 11*(2), 108-114.

Lian-Yee, K., Hamer, P. W., & Bishop, D. J. (2009). Enhancing muscular qualities in untrained women: Linear versus undulating periodization. *Medicine and Science in Sports and Exercise, 41*(9), 1797-1807.

Lindsay, F. H., Hawley, J. A., Myburgh, K. H., Schomer, H. H., Noakes, T. D., & Dennis, S. C. (1996). Improved athletic performance in highly trained cyclists after interval training. *Medicine and Science in Sports and Exercise, 28*(11), 1427-1434.

Linnamo, V., Häkkinen, K., & Komi, P. (1998). Neuromuscular fatigue and recovery in maximal compared to explosive strength loading. *European Journal of Applied Physiology and Occupational Physiology, 77*(1), 176-181.

Lloyd, R. S., Cronin, J. B., Faigenbaum, A. D., Haff, G. G., Howard, R., Kraemer, W. J., . . . Oliver, J. L. (2016). The National Strength And Conditioning Association position statement on long-term athletic development. *Journal of Strength and Conditioning Research, 30*(6), 1491-1509.

Lloyd, R. S., Faigenbaum, A. D., Stone, M. H., Oliver, J. L., Jeffreys, I., Moody, J. A., . . . Myer, G. D. (2014a). Position statement on youth resistance training: The 2014 international consensus. *British Journal of Sports Medicine, 48*, 498-505.

Lloyd, R. S., & Oliver, J. L. (2012). The youth physical development model: A new approach to long-term athletic development. *Strength and Conditioning Journal, 34*(3), 61-72.

Lloyd, R. S., Oliver, J. L., Faigenbaum, A. D., Myer, G. D., & De Ste Croix, M. B. A. (2014b). Chronological age vs. biological maturation: Implications for exercise programming in youth. *Journal of Strength and Conditioning Research, 28*(5), 1454-1464.

Lloyd, R. S., Oliver, J. L., Hughes, M. G., & Williams, C. A. (2009). Reliability and validity of field-based measures of leg stiffness and reactive strength index in youths. *Journal of Sports Sciences, 27*(14), 1565-1573.

Lloyd, R. S., Oliver, J. L., Radnor, J. M., Rhodes, B. C., Faigenbaum, A. D., & Myer, G. D. (2015). Relationships between functional movement screen scores, maturation and physical performance in young soccer players. *Journal of Sports Sciences, 33*(1), 11-19.

Lodo, L., Moreira, A., Zavanela, P., Newton, M., McGuigan, M., & Aoki, M. S. (2012). Is there a relationship between the total volume of load lifted in bench press exercise and the rating of perceived exertion? *The Journal of Sports Medicine and Physical Fitness, 52*(5), 483-488.

Loebel, C. C., & Kraemer, W. J. (1998). A brief review: Testosterone and resistance exercise in men. *Journal of Strength and Conditioning Research, 12*(1), 57-63.

Lovell, G., Galloway, H., Hopkins, W., & Harvey, A. (2006). Osteitis pubis and assessment of bone marrow edema at the pubic symphysis with MRI in an elite junior male soccer squad. *Clinical Journal of Sport Medicine, 16*(2), 117-122.

Lupo, C., Capranica, L., & Tessitore, A. (2014). The validity of the session-RPE method for quantifying training load in water polo. *International Journal of Sports Physiology and Performance, 9*(4), 656-660.

Lupo, C., Tessitore, A., Gasperi, L., & Gomez, M. (2017). Session-RPE for quantifying the load of different youth basketball training sessions. *Biology of Sport, 34*(1), 11-17.

Lyman, S., Fleisig, G. S., Waterbor, J. W., Funkhouser, E. M., Pulley, L., Andrews, J. R., . . . Roseman, J. M. (2001). Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Medicine and Science in Sports and Exercise, 33*(11), 1803-1810.

Lyttle, A. D., Wilson, G. J., & Ostrowski, K. J. (1996). Enhancing performance: Maximal power versus combined weights and plyometrics training. *Journal of Strength and Conditioning Research, 10*(3), 173-179.

Mah, C. D., Mah, K. E., Kezirian, E. J., & Dement, W. C. (2011). The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep, 34*(7), 943-950.

Malina, R. M., & Bouchard, C. (1991). *Growth, Maturation & Physical Activity*. Champaign, IL: Human Kinetics.

Malone, J. J., Murtagh, C. F., Morgans, R., Burgess, D. J., Morton, J. P., & Drust, B. (2015). Countermovement jump performance is not affected during an in-season training microcycle in elite youth soccer players. *Journal of Strength and Conditioning Research, 29*(3), 752-757.

Manzi, V., D'ottavio, S., Impellizzeri, F. M., Chaouachi, A., Chamari, K., & Castagna, C. (2010). Profile of weekly training load in elite male professional basketball players. *Journal of Strength and Conditioning Research, 24*(5), 1399-1406.

Marcotte, G. R., West, D. W. D., & Baar, K. (2015). The molecular basis for load-induced skeletal muscle hypertrophy. *Calcified Tissue International, 96*(3), 196-210.

Maresh, C. M., Armstrong, L. E., Bergeron, M. F., Gabaree, C. L., Hoffman, J. R., Hannon, D. R., & Pasqualicchio, A. A. (1994). Plasma cortisol and testosterone responses during a collegiate swim season. *Journal of Strength and Conditioning Research, 8*(1), 1-4.

Markovic, G., Dizdar, D., Jukic, I., & Cardinale, M. (2004). Reliability and factorial validity of squat and countermovement jump tests. *Journal of Strength and Conditioning Research, 18*(3), 551-555.

Markwick, W. J., Bird, S. P., Tufano, J. J., Seitz, L. B., & Haff, G. G. (2015). The intraday reliability of the reactive strength index calculated from a drop jump in professional men's basketball. *International Journal of Sports Physiology and Performance, 10*(4), 482-488.

Martha, P. M., Rogol Jr, A. D., Veldhuis, J. D., Kerrigan, J. R., Goodman, D. W., & Blizzard, R. M. (1989). Alterations in the pulsatile properties of circulating growth hormone concentrations during puberty in boys. *Journal of Clinical Endocrinology and Metabolism, 69*(3), 563-570.

Marx, J. O., Ratamess, N. A., Nindl, B. C., Gotshalk, L. A., Volek, J. S., Dohi, K., . . . Kraemer, W. J. (2001). Low-volume circuit versus high-volume periodized resistance training in women. *Medicine and Science in Sports and Exercise, 33*(4), 635-643.

Maso, F., Lac, G., Filaire, E., Michaux, O., & Robert, A. (2004). Salivary testosterone and cortisol in rugby players: Correlation with psychological overtraining items. *British Journal of Sports Medicine, 38*(3), 260-263.

Matos, N., & Winsley, R. J. (2007). Trainability of young athletes and overtraining. *Journal of Sports Science & Medicine, 6*(3), 353.

Matos, N. F., Winsley, R. J., & Williams, C. A. (2011). Prevalence of nonfunctional overreaching/overtraining in young English athletes. *Medicine and Science in Sports and Exercise, 43*(7), 1287-1294.

Matthews, B. L., Bennell, K. L., McKay, H. A., Khan, K. M., Baxter-Jones, A. D. G., Mirwald, R. L., & Wark, J. D. (2006). Dancing for bone health: a 3-year longitudinal study of bone mineral accrual across puberty in female non-elite dancers and controls. *Osteoporosis International, 17*(7), 1043-1054.

Mattocks, K. T., Dankel, S. J., Buckner, S. L., Jessee, M. B., Counts, B. R., Mouser, J. G., . . . Loenneke, J. P. (2016). Periodization: What is it good for? *Journal of Trainology, 5*(1), 6-12.

Matveyev, L. (1992). Modern procedures for the construction of macrocycles. *Modern Athlete and Coach, 30*, 32-34.

Matveyev, L., & Zdornyj, A. P. (1981). *Fundamentals of Sports Training*. Union of Soviet Socialist Republic: Progress Publishers.

McBride, J. M., McCaulley, G. O., Cormie, P., Nuzzo, J. L., Cavill, M. J., & Triplett, N. T. (2009). Comparison of methods to quantify volume during resistance exercise. *Journal of Strength and Conditioning Research, 23*(1), 106-110.

McCaulley, G. O., McBride, J. M., Cormie, P., Hudson, M. B., Nuzzo, J. L., Quindry, J. C., & Triplett, N. T. (2009). Acute hormonal and neuromuscular responses to hypertrophy, strength and power type resistance exercise. *European Journal of Applied Physiology, 105*(5), 695-704.

McCaw, S. T., & Friday, J. J. (1994). A comparison of muscle activity between a free weight and machine bench press. *Journal of Strength and Conditioning Research, 8*(4), 259-264.

McGee, D., Jessee, T. C., Stone, M. H., & Blessing, D. (1992). Leg and hip endurance adaptations to three weight training programs. *Journal of Applied Sport Science Research, 6*(2), 92-95.

McGuigan, M., Al Dayel, A., Tod, D., Foster, C., Newton, R. U., & Pettigrew, S. (2008). Use of session rating of perceived exertion for monitoring resistance exercise in children who are overweight or obese. *Pediatric Exercise Science, 20*, 333-341.

McGuigan, M., & Foster, C. (2004). A new approach to monitoring resistance training. *Strength and Conditioning Journal, 26*(6), 42-47.

McGuigan, M. R., Cormack, S., & Newton, R. U. (2009). Long-term power performance of elite Australian rules football players. *Journal of Strength and Conditioning Research, 23*(1), 26-32.

McGuigan, M. R., Cormack, S. J., & Gill, N. D. (2013). Strength and power profiling of athletes: Selecting tests and how to use the information for program design. *Strength and Conditioning Journal, 35*(6), 7-14.

McGuigan, M. R., Doyle, T. L. A., Newton, M., Edwards, D. J., Nimphius, S., & Newton, R. U. (2006). Eccentric utilization ratio: Effect of sport and phase of training. *Journal of Strength and Conditioning Research, 20*(4), 992-995.

McGuigan, M. R., Egan, A. D., & Foster, C. (2004). Salivary cortisol responses and perceived exertion during high intensity and low intensity bouts of resistance exercise. *Journal of Sports Science and Medicine, 3*(1), 8-15.

Mcguigan, M. R., Newton, M. J., Winchester, J. B., & Nelson, A. G. (2010). Relationship between isometric and dynamic strength in recreationally trained men. *Journal of Strength and Conditioning Research, 24*(9), 2570-2573.

McGuigan, M. R., & Winchester, J. B. (2008). The relationship between isometric and dynamic strength in college football players. *Journal of Sports Science and Medicine, 7*(1), 101-105.

McHugh, M. P. (2003). Recent advances in the understanding of the repeated bout effect: The protective effect against muscle damage from a single bout of eccentric exercise. *Scandinavian Journal of Medicine and Science in Sports, 13*(2), 88-97.

McHugh, M. P., Connolly, D. A., Eston, R. G., & Gleim, G. W. (1999). Exercise-induced muscle damage and potential mechanisms for the repeated bout effect. *Sports Medicine, 27*(3), 157-170.

McKay, D., Broderick, C., & Steinbeck, K. (2016). The adolescent athlete: A developmental approach to injury risk. *Pediatric Exercise Science, 28*(4), 488-500.

McLaren, S. J., Graham, M., Spears, I. R., & Weston, M. (2016). The sensitivity of differential ratings of perceived exertion as measures of internal load. *International Journal of Sports Physiology and Performance, 11*(3), 404-406.

McLaren, S. J., Smith, A., Spears, I. R., & Weston, M. (2017). A detailed quantification of differential ratings of perceived exertion during team-sport training. *Journal of Science and Medicine in Sport, 20*(3), 290-295.

McLean, B. D., Coutts, A. J., Kelly, V., McGuigan, M. R., & Cormack, S. J. (2010). Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *International Journal of Sports Physiology and Performance, 5*(3), 367-383.

McLean, B. D., Petrucelli, C., & Coyle, E. F. (2012). Maximal power output and perceptual fatigue responses during a Division I female collegiate soccer season. *Journal of Strength and Conditioning Research, 26*(12), 3189-3196.

McLellan, C. P., Lovell, D. I., & Gass, G. C. (2011a). Markers of postmatch fatigue in professional rugby league players. *Journal of Strength and Conditioning Research, 25*(4), 1030-1039.

McLellan, C. P., Lovell, D. I., & Gass, G. C. (2011b). The role of rate of force development on vertical jump performance. *Journal of Strength and Conditioning Research, 25*(2), 379-385.

McMaster, D. T., Gill, N., Cronin, J., & McGuigan, M. (2014). A brief review of strength and ballistic assessment methodologies in sport. *Sports Medicine, 44*(5), 603-623.

McNamara, D. J., Gabbett, T. J., Naughton, G., Farhart, P., & Chapman, P. (2013). Training and competition workloads and fatigue responses of elite junior cricket players. *International Journal of Sports Physiology and Performance, 8*(5), 517-526.

McNamara, J. M., & Stearne, D. J. (2010). Flexible nonlinear periodization in a beginner college weight training class. *Journal of Strength and Conditioning Research, 24*(1), 17-22.

Meerson, F. (1965). Intensity of function of structures of the differentiated cell as a determinant of activity of its genetic apparatus. *Nature, 206*(4983), 483-484.

Meeusen, R., Urhausen, A., Duclos, M., Foster, C., Fry, A., Gleeson, M., . . . Steinacker, J. (2013). Prevention, diagnosis, and treatment of the overtraining syndrome: Joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Medicine and Science in Sports and Exercise, 45*(1), 186-205.

Meyers, R. W., Oliver, J. L., Hughes, M. G., Cronin, J. B., & Lloyd, R. S. (2015). Maximal sprint speed in boys of increasing maturity. *Pediatric Exercise Science, 27*(1), 85-94.

Mikkola, J., Rusko, H., Nummela, A., Pollari, T., & Häkkinen, K. (2007). Concurrent endurance and explosive type strength training improves neuromuscular and anaerobic characteristics in young distance runners. *International Journal of Sports Medicine, 28*(07), 602-611.

Miller, M. G., Cheatham, C. C., & Patel, N. D. (2010). Resistance training for adolescents. *Pediatric Clinics of North America, 57*, 671-682.

Millet, G. P., Candau, R. B., Barbier, B., Busso, T., Rouillon, J. D., & Chatard, J. C. (2002). Modelling the transfers of training effects on performance in elite triathletes. *International Journal of Sports Medicine, 23*(1), 55-63.

Millet, G. Y., & Lepers, R. (2004). Alterations of neuromuscular function after prolonged running, cycling and skiing exercises. *Sports Medicine, 34*(2), 105-116.

Miloski, B., Aoki, M. S., de Freitas, C. G., de Arruda, A. F. S., de Moraes, H. S., Drago, G., . . . Moreira, A. (2015). Does testosterone modulate mood states and physical performance in young basketball players? *Journal of Strength and Conditioning Research, 29*(9), 2474-2481.

Miloski, B., de Freitas, V. H., Nakamura, F. Y., Francine, C., & Bara-Filho, M. G. (2016). Seasonal training load distribution of professional futsal players: Effects on physical fitness, muscle damage and hormonal status. *Journal of Strength and Conditioning Research, 30*(6), 1525-1533.

Minuto, F., Barreca, A., Del Monte, P., Fortini, P., Resentini, M., Morabito, F., & Giordano, G. (1988). Spontaneous growth hormone and somatomedin-C/insulin-like growth factor-l secretion in obese subjects during puberty. *Journal of Endocrinological Investigation, 11*(7), 489-495.

Miranda, F., Simão, R., Rhea, M., Bunker, D., Prestes, J., Leite, R. D., . . . Novaes, J. (2011). Effects of linear vs. daily undulatory periodized resistance training on maximal and submaximal strength gains. *Journal of Strength and Conditioning Research, 25*(7), 1824-1830.

Miranda, H., Scudese, E., Paz, G. A., Salerno, V. P., Vigário, P., & Willardson, J. (2018). Acute hormone responses subsequent to agonist-antagonist paired set vs. traditional straight set resistance training. *Journal of Strength and Conditioning Research, Published ahead-of-print: 02 July 2018*. doi:10.1519/JSC.0000000000002633.

Mirwald, R. L., Baxter-Jones, A. D., Bailey, D. A., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. *Medicine and Science in Sports and Exercise, 34*(4), 689-694.

Mitchell, C. J., Churchward-Venne, T. A., Bellamy, L., Parise, G., Baker, S. K., & Phillips, S. M. (2013). Muscular and systemic correlates of resistance training-induced muscle hypertrophy. *PloS one, 8*(10), e78636. doi:10.1371/journal.pone.0078636.

Moir, G., Button, C., Glaister, M., & Stone, M. H. (2004). Influence of familiarization on the reliability of vertical jump and acceleration sprinting performance in physically active men. *Journal of Strength and Conditioning Research, 18*(2), 276-280.

Moir, G., Sanders, R., Button, C., & Glaister, M. (2005). The influence of familiarization on the reliability of force variables measured during unloaded and loaded vertical jumps. *Journal of Strength and Conditioning Research, 19*(1), 140.

Monteiro, A. G., Aoki, M. S., Evangelista, A. L., Alveno, D. A., Monteiro, G. A., Picarro, I. D. C., & Ugrinowitsch, C. (2009). Nonlinear periodization maximizes strength gains in split resistance training routines. *Journal of Strength and Conditioning Research, 23*(4), 1321-1326.

Moraes, E., Fleck, S. J., Dias, M. R., & Simao, R. (2013). Effects on strength, power and flexibility in adolescents of nonperiodized vs. daily nonlinear periodized weight training. *Journal of Strength and Conditioning Research, 27*(12), 3310-3321.

Moreira, A., Mortatti, A., Aoki, M., Arruda, A., Freitas, C., & Carling, C. (2013). Role of free testosterone in interpreting physical performance in elite young Brazilian soccer players. *Pediatric Exercise Science, 25*(2), 186-197.

Morgan, W. P., Costill, D. L., Flynn, M. G., Raglin, J. S., & O'connor, P. J. (1988). Mood disturbance following increased training in swimmers. *Medicine and Science in Sports and Exercise, 20*(4), 408-414.

Morishita, S., Tsubaki, A., Takabayashi, T., & Fu, J. B. (2018). Relationship between the rating of perceived exertion scale and the load intensity of resistance training. *Strength and Conditioning Journal, 40*(2), 94-109.

Mountjoy, M., Andersen, L. B., Armstrong, N., Biddle, S., Boreham, C., Bedenbeck, H. P. B., . . . van Mechelen, W. (2011). International Olympic Committee consensus statement on the health and fitness of young people through physical activity and sport. *British Journal of Sports Medicine, 45*(11), 839-848.

Mountjoy, M., Armstrong, N., Bizzini, L., Blimkie, C., Evans, J., Gerrard, D., . . . Sangenis, P. (2008). IOC consensus statement:"Training the elite child athlete". *British Journal of Sports Medicine, 42*(3), 163-164.

Mudie, K. L., Gupta, A., Green, S., & Clothier, P. J. (2016). Adaptation of lower limb movement patterns when maintaining performance in the presence of muscle fatigue. *Human Movement Science, 48*, 28-36.

Mujika, I., Chatard, J.-C., Padilla, S., Guezennec, C. Y., & Geyssant, A. (1996). Hormonal responses to training and its tapering off in competitive swimmers: Relationships with performance. *European Journal of Applied Physiology and Occupational Physiology, 74*(4), 361-366.

Murray, A. (2017). Managing the training load in adolescent athletes. *International Journal of Sports Physiology and Performance, 12*(Suppl 2), S2-42-49.

Myer, G. D., Faigenbaum, A. D., Chu, D. A., Falkel, J., Ford, K. R., Best, T. M., & Hewett, T. E. (2011). Integrative training for children and adolescents: Techniques and practices for reducing sports-related injuries and enhancing athletic performance. *The Physician and Sportsmedicine, 39*(1), 74-84.

Naclerio, F., Faigenbaum, A. D., Larumbe-Zabala, E., Perez-Bibao, T., Kang, J., Ratamess, N. A., & Triplett, N. T. (2013). Effects of different resistance training volumes on strength and power in team sport athletes. *Journal of Strength and Conditioning Research, 27*(7), 1832–1840.

Naughton, G., Farpour-Lambert, N. J., Carlson, J., Bradney, M., & Praagh, E. V. (2000). Physiological issues surrounding the performance of adolescent athletes. *Sports Medicine, 30*(5), 309-325.

Neary, J., Malbon, L., & McKenzie, D. (2002). Relationship between serum, saliva and urinary cortisol and its implication during recovery from training. *Journal of Science and Medicine in Sport, 5*(2), 108-114.

Nédélec, M., McCall, A., Carling, C., Legall, F., Berthoin, S., & Dupont, G. (2013). Recovery in soccer. *Sports Medicine, 43*(1), 9-22.

Negrete, R. J., Hanney, W. J., Kolber, M. J., Davies, G. J., Ansley, M. K., McBride, A. B., & Overstreet, A. L. (2010). Reliability, minimal detectable change, and normative values for tests of upper extremity function and power. *Journal of Strength and Conditioning Research, 24*(12), 3318-3325.

Nelson, A. G., Winchester, J. B., Stewart, L. K., & Stone, M. H. (2009). Hormonal markers and physical performance during a peak-taper cycle in elite track and field athletes. *Medicine and Science in Sports and Exercise, 41*(5), 336-337.

Nemet, D., Portal, S., Zadik, Z., Pilz-Burstein, R., Adler-Portal, D., Meckel, Y., & Eliakim, A. (2012). Training increases anabolic response and reduces inflammatory response to a single practice in elite male adolescent volleyball players. *Journal of Pediatric Endocrinology and Metabolism, 25*(9-10), 875-880.

Newton, R. U., & Dugan, E. (2002). Application of strength diagnosis. *Strength and Conditioning Journal, 24*(5), 50-59.

Nicol, C., Avela, J., & Komi, P. V. (2006). The stretch-shortening cycle: A model to study naturally occurring neuromuscular fatigue. *Sports Medicine, 36*(11), 977-999.

Nindl, B. C., Kraemer, W. J., Deaver, D. R., Peters, J. L., Marx, J. O., Heckman, J. T., & Loomis, G. A. (2001). LH secretion and testosterone concentrations are blunted after resistance exercise in men. *Journal of Applied Physiology, 91*(3), 1251-1258.

Noakes, T. D. (2012). Fatigue is a brain-derived emotion that regulates the exercise behavior to ensure the protection of whole body homeostasis. *Frontiers in Physiology, 3*, 82. doi:10.3389/fphys.2012.00082.

Noble, B. J., & Robertson, R. J. (1996). *Perceived exertion*: Champaign, IL : Human Kinetics.

Noon, M. R., James, R. S., Clarke, N. D., Akubat, I., & Thake, C. D. (2015). Perceptions of well-being and physical performance in English elite youth footballers across a season. *Journal of Sports Sciences, 33*(20), 2106-2115.

Nosaka, K., & Saldanha Aoki, M. (2011). Repeated bout effect: Research update and future perspective. *Brazilian Journal of Biomotricity, 5*(1), 5-15.

Nunes, J. A., Moreira, A., Crewther, B. T., Nosaka, K., Viveiros, L., & Aoki, M. S. (2014). Monitoring training load, recovery-stress state, immune-endocrine responses and physical performance in elite female basketball players during a periodized training program. *Journal of Strength and Conditioning Research, 28*(10), 2973-2980.

Nunes, J. P., Ribeiro, A. S., Schoenfeld, B. J., & Cyrino, E. S. (2017). Comment on:“Comparison of periodized and non-periodized resistance training on maximal strength: A meta-analysis”. *Sports Medicine*, 1-4.

O'Bryant, H. S., Byrd, R., & Stone, M. H. (1988). Cycle ergometer performance and maximum leg and hip strength adaptations to two different methods of weight-training. *Journal of Applied Sport Science Research, 2*(2), 27-30.

O'Connor, P. J., & Corrigan, D. L. (1987). Influence of short-term cycling on salivary cortisol levels. *Medicine and Science in Sports and Exercise, 19*(3), 224-228.

O'Connor, P. J., Morgan, W. P., & Raglin, J. S. (1991). Psychobiologic effects of 3 d of increased training in female and male swimmers. *Medicine and Science in Sports and Exercise, 23*(9), 1055-1061.

Oliver, J., Armstrong, N., & Williams, C. (2008). Changes in jump performance and muscle activity following soccer-specific exercise. *Journal of Sports Sciences, 26*(2), 141-148.

Oliver, J. L., Lloyd, R. S., & Whitney, A. (2015a). Monitoring of in-season neuromuscular and perceptual fatigue in youth rugby players. *European Journal of Sport Science, 15*(6), 514-522.

Oliver, J. M., Abt, J. P., Sell, T. C., Beals, K., Wood, D. E., & Lephart, S. M. (2015b). Salivary hormone response to 12-week block-periodized training in naval special warfare operators. *Journal of Strength and Conditioning Research, 29*(1), 66-73.

Ostrowski, K. J., Wilson, G. J., Weatherby, R., Murphy, P. W., & Lyttle, A. D. (1997). The effect of weight training volume on hormonal output and muscular size and function. *Journal of Strength and Conditioning Research, 11*(1), 148-154.

Painter, K. B., Haff, G. G., Ramsey, M. W., McBride, J., Triplett, T., Sands, W. A., . . . Stone, M. H. (2012). Strength gains: Block versus daily undulating periodization weight training among track and field athletes. *International Journal of Sport Physiology and Performance, 7*, 161-169.

Painter, K. B., Haff, G. G., Triplett, N. T., Stuart, C., Hornsby, G., Ramsey, M. W., . . . Stone, M. H. (2018). Resting hormone alterations and injuries: Block vs. DUP weight-training among D-1 track and field athletes. *Sports, 6*(1), 3.

Palmer-Green, D. S., Stokes, K. A., Fuller, C. W., England, M., Kemp, S. P., & Trewartha, G. (2015). Training activities and injuries in English youth academy and schools rugby union. *The American Journal of Sports Medicine, 43*(2), 475-481.

Papacosta, E., & Nassis, G. P. (2011). Saliva as a tool for monitoring steroid, peptide and immune markers in sport and exercise science. *Journal of Science and Medicine in Sport, 14*(5), 424-434.

Papir-Kricheli, D., & Feldman, S. (1983). Modifications in single cell activity in the rat midbrain during the iontophoretic application of cortisol. *Experimental Neurology, 79*(2), 576-581.

Passaquin, A. C., Lhote, P., & Rüegg, U. T. (1998). Calcium influx inhibition by steroids and analogs in C2C12 skeletal muscle cells. *British Journal of Pharmacology, 124*(8), 1751-1759.

Passelergue, P. A., & Lac, G. (2012). Salivary hormonal responses and performance changes during 15 weeks of mixed aerobic and weight training in elite junior wrestlers. *Journal of Strength and Conditioning Research, 26*(11), 3049-3058.

Paul, D. J., & Nassis, G. P. (2015). Testing strength and power in soccer players: The application of conventional and traditional methods of assessment. *Journal of Strength and Conditioning Research, 29*(6), 1748-1758.

Perrey, S., Racinais, S., Saimouaa, K., & Girard, O. (2010). Neural and muscular adjustments following repeated running sprints. *European Journal of Applied Physiology, 109*(6), 1027-1036.

Peterson, D. M., Dodd, D. J., Alvar, B. A., Rhea, M. R., & Favre, M. (2008). Undulation training for the development of hierarchical fitness and improved fire fighter job performance. *Journal of Strength and Conditioning Research, 22*(5), 1683-1695.

Peterson, M. D., Pistilli, E., Haff, G. G., Hoffman, E. P., & Gordon, P. M. (2011). Progression of volume load and muscular adaptation during resistance exercise. *European Journal of Applied Physiology, 111*(6), 1063-1071.

Peterson, M. D., Rhea, M. R., & Alvar, B. A. (2004). Maximizing strength development in athletes: A meta-analysis to determine the dose-response relationship. *Journal of Strength and Conditioning Research, 18*(2), 377-382.

Phibbs, P. J., Jones, B., Roe, G., Read, D., Darrall-Jones, J., Weakley, J., . . . Till, K. (2018). The organised chaos of English adolescent rugby union: Influence of weekly match frequency on the variability of match and training loads. *European Journal of Sport Science, 18*(3), 341-348.

Pickering, C., & Kiely, J. (2018). Do non-responders to exercise exist—and if so, what should we do about them? *Sports Medicine, 49*(1), 1-7.

Pincivero, D. M., Gear, W. S., Sterner, R. L., & Karunakara, R. G. (2000). Gender differences in the relationship between quadriceps work and fatigue during high-intensity exercise. *Journal of Strength and Conditioning Research, 14*(2), 202-206.

Place, N., Maffiuletti, N. A., Martin, A., & Lepers, R. (2007). Assessment of the reliability of central and peripheral fatigue after sustained maximal voluntary contraction of the quadriceps muscle. *Muscle and Nerve, 35*(4), 486-495.

Plisk, S. S., & Stone, M. H. (2003). Periodization strategies. *Strength and Conditioning Journal, 25*(6), 19-37.

Ploutz, L. L., Tesch, P. A., Biro, R. L., & Dudley, G. A. (1994). Effect of resistance training on muscle use during exercise. *Journal of Applied Physiology, 76*(4), 1675-1681.

Potteiger, J. A., Judge, L. W., Cerny, J. A., & Potteiger, V. M. (1995). Effects of altering training volume and intensity on body mass, performance, and hormonal concentrations in weight-event athletes. *Journal of Strength and Conditioning Research, 9*(1), 55-58.

Prestes, J., De Lima, C., Frollini, A. B., Donatto, F. F., & Conte, M. (2009a). Comparison of linear and reverse linear periodization effects on maximal strength and body composition. *Journal of Strength and Conditioning Research, 23*(1), 266-274.

Prestes, J., Frollini, A. B., de Lima, C., Donatto, F. F., Foschini, D., de Cássia Marqueti, R., . . . Fleck, S. J. (2009b). Comparison between linear and daily undulating periodized resistance training to increase strength. *Journal of Strength and Conditioning Research, 23*(9), 2437-2442.

Pritchard, B. T., Stanton, W., Lord, R., Petocz, P., & Pepping, G. J. (2017). Factors affecting measurement of salivary cortisol and secretory immunoglobulin A in field studies of athletes. *Frontiers in Endocrinology, 8*, 168. doi:10.3389/fendo.2017.00168.

Pritchett, R. C., Green, J. M., Wickwire, P. J., & Kovacs, M. (2009). Acute and session RPE responses during resistance training: Bouts to failure at 60% and 90% of 1RM. *South African Journal of Sports Medicine, 21*(1), 23-26.

Pua, Y.-H., Koh, M. T.-H., & Teo, Y.-Y. (2006). Effects of allometric scaling and isokinetic testing methods on the relationship between countermovement jump and quadriceps torque and power. *Journal of Sports Sciences, 24*(4), 423-432.

Pullinen, T., Mero, A., Huttunen, P., Pakarinen, A., & Komi, P. (2011). Resistance exercise-induced hormonal response under the influence of delayed onset muscle soreness in men and boys. *Scandinavian Journal of Medicine and Science in Sports, 21*(6), e184-e194.

Pullinen, T., Mero, A., Huttunen, P., Pakarinen, A., & Komi, P. V. (2002). Resistance exercise-induced hormonal responses in men, women, and pubescent boys. *Medicine and Science in Sports and Exercise, 34*(5), 806-813.

Pupo, J. D., Dias, J. A., Gheller, R. G., Detanico, D., & Santos, S. G. D. (2013). Stiffness, intralimb coordination, and joint modulation during a continuous vertical jump test. *Sports Biomechanics, 12*(3), 259-271.

Putman, P., Antypa, N., Crysovergi, P., & van der Does, W. A. (2010). Exogenous cortisol acutely influences motivated decision making in healthy young men. *Psychopharmacology, 208*(2), 257-263.

Pyne, D. B. (2003). *Interpreting the results of fitness testing*. Presented at the meeting of the International Science and Football Symposium, Victorian Institute of Sport, Melbourne, Australia.

Pyne, D. B., & Martin, D. T. (2011). Fatigue-Insights from individual and team sports. In F. E. Marino (Ed.), *Regulation of Fatigue in Exercise*. New York: Nova Science.

Quatman, C. E., Ford, K. R., Myer, G. D., & Hewett, T. E. (2006). Maturation leads to gender differences in landing force and vertical jump performance a longitudinal study. *The American Journal of Sports Medicine, 34*(5), 806-813.

Raastad, T., Bjøro, T., & Hallen, J. (2000). Hormonal responses to high-and moderate-intensity strength exercise. *European Journal of Applied Physiology, 82*(1-2), 121-128.

Randall, F., Gearhart, R. F., Goss, F. L., Lagally, K. M., Jakicic, J. M., Gallagher, J., . . . Robertson, R. J. (2002). Ratings of perceived exertion in active muscle during high-intensity and low-intensity resistance exercise. *Journal of Strength and Conditioning Research, 16*(1), 87-91.

Ratamess, N. A., Kraemer, W. J., Volek, J. S., Maresh, C. M., VanHeest, J. L., Sharman, M. J., . . . Silvestre, R. (2005). Androgen receptor content following heavy resistance exercise in men. *The Journal of Steroid Biochemistry and Molecular Biology, 93*(1), 35-42.

Requena, B., González-Badillo, J. J., de Villareal, E. S. S., Ereline, J., García, I., Gapeyeva, H., & Pääsuke, M. (2009). Functional performance, maximal strength and power characteristics in isometric and dynamic actions of lower extremities in soccer players. *Journal of Strength and Conditioning Research, 23*(5), 1391-1401.

Rhea, M. R., & Alderman, B. L. (2004). A meta-analysis of periodized versus nonperiodized strength and power training programs. *Research Quarterly for Exercise and Sport, 75*(4), 413-422.

Rhea, M. R., Ball, S. D., Phillips, W. T., & Burkett, L. N. (2002). A comparison of linear and daily undulating periodized programs with equated volume and intensity for strength. *Journal of Strength and Conditioning Research, 16*(2), 250-255.

Rhea, M. R., Phillips, W. T., Burkett, L. N., Stone, W. J., Ball, S. D., Alvar, B. A., & Thomas, A. B. (2003). A comparison of linear and daily undulating periodized programs with equated volume and intensity for local muscular endurance. *Journal of Strength and Conditioning Research, 17*(1), 82-87.

Rilling, J. K., Worthman, C. M., Campbell, B. C., Stallings, J. F., & Mbizva, M. (1996). Ratios of plasma and salivary testosterone throughout puberty: Production versus bioavailability. *Steroids, 61*(6), 374-378.

Robertson, R. J. (2004). *Perceived Exertion for Practioneers*. Champaign, IL: Human Kinetics.

Robertson, R. J., Goss, F. L., Rutkowski, J., Lenz, B., Dixon, C., Timmer, J., . . . Andreacci, J. (2003). Concurrent validation of the OMNI perceived exertion scale for resistance exercise. *Medicine and Science in Sports and Exercise, 35*(2), 333-341.

Rodacki, A. L. F., Fowler, N. E., & Bennett, S. J. (2002). Vertical jump coordination: Fatigue effects. *Medicine and Science in Sports and Exercise, 34*(1), 105-116.

Roe, G., Darrall-Jones, J., Till, K., Phibbs, P., Read, D., Weakley, J., & Jones, B. (2016a). Between-day reliability and sensitivity of common fatigue measures in rugby players. *International Journal of Sports Physiology and Performance, 11*, 581-586.

Roe, G., Till, K., Darrall-Jones, J., Phibbs, P., Weakley, J., Read, D., & Jones, B. (2016b). Changes in markers of fatigue following a competitive match in elite academy rugby union players. *South African Journal of Sports Medicine, 28*, 1-4.

Rogol, A. D., Roemmich, J. N., & Clark, P. A. (2002). Growth at puberty. *Journal of Adolescent Health, 31*(6), 192-200.

Ronay, R., & Hippel, W. v. (2010). The presence of an attractive woman elevates testosterone and physical risk taking in young men. *Social Psychological and Personality Science, 1*(1), 57-64.

Ronnestad, B., Hansen, J., & Ellefsen, S. (2014). Block periodization of high-intensity aerobic intervals provides superior training effects in trained cyclists. *Scandinavian Journal of Medicine and Science in Sports, 24*(1), 34-42.

Ronnestad, B. R., Hansen, J., Thyli, V., Bakken, T. A., & Sandbakk, Ø. (2016). 5-week block periodization increases aerobic power in elite cross-country skiers. *Scandinavian Journal of Medicine and Science in Sports, 26*(2), 140-146.

Ronnestad, B. R., Ofsteng, S. J., & Ellefsen, S. (2018). Block periodization of strength and endurance training is superior to traditional periodization in ice-hockey players. *Scandinavian Journal of Medicine and Science in Sports, 29*(2), 180-188.

Ross, A., Leveritt, M., & Riek, S. (2001). Neural influences on sprint running. *Sports Medicine, 31*(6), 409-425.

Rushall, B. S. (1990). A tool for measuring stress tolerance in elite athletes. *Journal of Applied Sport Psychology, 2*(1), 51-66.

Rutherford, O., & Jones, D. (1986). The role of learning and coordination in strength training. *European Journal of Applied Physiology and Occupational Physiology, 55*(1), 100-105.

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

Sale, D. G. (1988). Neural adaptation to resistance training. *Medicine and Science in Sports and Exercise, 20*(5 Suppl), S135-145.

Sale, M. V., Ridding, M. C., & Nordstrom, M. A. (2008). Cortisol inhibits neuroplasticity induction in human motor cortex. *Journal of Neuroscience, 28*(33), 8285-8293.

Sanborn, K., Boros, R., Hruby, J., Schilling, B., OBryant, H., Johnson, R., . . . Stone, M. H. (2000). Short-term performance effects of weight training with multiple sets not to failure vs. a single set to failure in women. *Journal of Strength and Conditioning Research, 14*(3), 328-331.

Sanchez-Medina, L., & González-Badillo, J. J. (2011). Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Medicine and Science in Sports and Exercise, 43*(9), 1725-1734.

Sander, A., Keiner, M., Wirth, K., & Schmidtbleicher, D. (2013). Influence of a 2-year strength training programme on power performance in elite youth soccer players. *European Journal of Sport Science, 13*(5), 445-451.

Sapolsky, R. M., Romero, L. M., & Munck, A. U. (2000). How do glucocorticoids influence stress responses? Integrating permissive, suppressive, stimulatory and preparative actions. *Endocrine Reviews, 21*(1), 55-89.

Sarabia, J. M., Fernandez-Fernandez, J., Juan-Recio, C., Hernández-Davó, H., Urbán, T., & Moya, M. (2015). Mechanical, hormonal and psychological effects of a non-failure short-term strength training program in young tennis players. *Journal of Human Kinetics, 45*(1), 81-91.

Saw, A. E., Main, L. C., & Gastin, P. B. (2015a). Monitoring athletes through self-report: Factors influencing implementation. *Journal of Sports Science and Medicine, 14*(1), 137-146.

Saw, A. E., Main, L. C., & Gastin, P. B. (2015b). Monitoring the athlete training response: Subjective self-reported measures trump commonly used objective measures: A systematic review. *British Journal of Sports Medicine, 50*(5), 281-291.

Sawczuk, T., Jones, B., Scantlebury, S., & Till, K. (2018). Relationships between training load, sleep duration, and daily well-being and recovery measures in youth athletes. *Pediatric Exercise Science, 30*, 345-352.

Sawczuk, T., Jones, B., Scantlebury, S., Weakley, J., Read, D., Costello, N., . . . Till, K. (2017). Between-day reliability and usefulness of a fitness testing battery in youth sport athletes: Reference data for practitioners. *Measurement in Physical Education and Exercise Science, 22*(1), 11-18.

Scantlebury, S., Till, K., Sawczuk, T., Phibbs, P., & Jones, B. (2018). Validity of retrospective session rating of perceived exertion to quantify training load in youth athletes. *Journal of Strength and Conditioning Research, 32*(7), 1975-1980.

Schiotz, M. K., Potteiger, J. A., Huntsinger, P. G., & Denmark, D. C. (1998). The short-term effects of periodized and constant-intensity training on body composition, strength and performance. *Journal of Strength and Conditioning Research, 12*(3), 173-178.

Schlumberger, A., Stec, J., & Schmidtbleicher, D. (2001). Single- vs. multiple-set strength training in women. *Journal of Strength and Conditioning Research, 15*(3), 284-289.

Schmikli, S., Brink, M., De Vries, W., & Backx, F. (2011). Can we detect non-functional overreaching in young elite soccer players and middle-long distance runners using field performance tests? *British Journal of Sports Medicine, 45*(8), 631-636.

Schoenfeld, B. J. (2010). The mechanisms of muscle hypertrophy and their application to resistance training. *Journal of Strength and Conditioning Research, 24*(10), 2857-2872.

Schoenfeld, B. J., Contreras, B., Ogborn, D., Galpin, A., Krieger, J., & Sonmez, G. T. (2016). Effects of varied versus constant loading zones on muscular adaptations in trained men. *International Journal of Sports Medicine, 37*(6), 442-447.

Schwanbeck, S., Chilibeck, P. D., & Binsted, G. (2009). A comparison of free weight squat to Smith machine squat using electromyography. *Journal of Strength and Conditioning Research, 23*(9), 2588-2591.

Scott, B. R., Duthie, G. M., Thornton, H. R., & Dascombe, B. J. (2016). Training monitoring for resistance exercise: Theory and applications. *Sports Medicine, 46*(5), 687-698.

Scott, T. J., Black, C. R., Quinn, J., & Coutts, A. J. (2013). Validity and reliability of the session-RPE method for quantifying training in Australian football: A comparison of the CR10 and CR100 scales. *Journal of Strength and Conditioning Research, 27*(1), 270-276.

Scudese, E., Simao, R., Senna, G., Vingren, J. L., Willardson, J. M., Baffi, M., & Miranda, H. (2016). Long rest interval promotes durable testosterone responses in high-intensity bench press. *Journal of Strength and Conditioning Research, 30*(5), 1275-1286.

Seifert, L., Button, C., & Davids, K. (2013). Key properties of expert movement systems in sport. *Sports Medicine, 43*(3), 167-178.

Selvanayagam, V. S., Riek, S., & Carroll, T. J. (2011). Early neural responses to strength training. *Journal of Applied Physiology, 111*(2), 367-375.

Selye, H. (1936). A syndrome produced by diverse nocuous agents. *Nature, 138*, 32.

Selye, H. (1938). Experimental evidence supporting the conception of "adaptation energy". *American Journal of Physiology-Legacy Content, 123*(3), 758-765.

Seynnes, O. R., Erskine, R. M., Maganaris, C. N., Longo, S., Simoneau, E. M., Grosset, J.-F., & Narici, M. V. (2009). Training-induced changes in structural and mechanical properties of the patellar tendon are related to muscle hypertrophy but not to strength gains. *Journal of Applied Physiology, 107*(2), 523-530.

Shimano, T., Kraemer, W. J., Spiering, B. A., Volek, J. S., Hatfield, D. L., Silvestre, R., . . . Fleck, S. J. (2006). Relationship between the number of repetitions and selected percentages of one repetition maximum in free weight exercises in trained and untrained men. *Journal of Strength and Conditioning Research, 20*(4), 819-823.

Shinohara, M., Kouzaki, M., Yoshihisa, T., & Fukunaga, T. (1998). Efficacy of tourniquet ischemia for strength training with low resistance. *European Journal of Applied Physiology, 77*(1-2), 189-191.

Simao, R., Spineti, J., de Salles, B. F., Matta, T., Fernandes, L., Fleck, S. J., . . . Strom-Olsen, H. E. (2012). Comparison between nonlinear and linear periodized resistance training: Hypertrophic and strength effects. *Journal of Strength and Conditioning Research, 26*(5), 1389-1395.

Singh, F., Foster, C., Tod, D., & McGuigan, M. R. (2007). Monitoring different types of resistance training using session rating of perceived exertion. *International Journal of Sport Physiology and Performance, 2*, 34-45.

Skurvydas, A., Mamkus, G., Dudonienė, V., Kamandulis, S., Mickeviciene, D., Masiulis, N., . . . Streckis, V. (2007). The time-course of voluntary and electrically evoked muscle performance during and after stretch-shortening exercise is different. *Journal of Sports Science and Medicine, 6*(4), 408-416.

Smith, D. J. (2003). A framework for understanding the training process leading to elite performance. *Sports Medicine, 33*(15), 1103-1126.

Smith, L. L. (2000). Cytokine hypothesis of overtraining: A physiological adaptation to excessive stress? *Medicine and Science in Sports and Exercise, 32*(2), 317.

Souissi, H., Chtourou, H., Chaouachi, A., Dogui, M., Chamari, K., Souissi, N., & Amri, M. (2012). The effect of training at a specific time-of-day on the diurnal variations of short-term exercise performances in 10-to 11-year-old boys. *Pediatric Exercise Science, 24*, 84-99.

Souza, E. O., Ugrinowitsch, C., Tricoli, V., Roschel, H., Lowery, R. P., Aihara, A. Y., . . . Wilson, J. M. (2014). Early adaptation to six weeks of non-periodized and periodized strength training regimens in recreational males. *Journal of Sports Science and Medicine, 13*, 604-609.

Spiering, B. A., Kraemer, W. J., Vingren, J. L., Ratamess, N. A., Anderson, J. M., Armstrong, L. E., . . . Maresh, C. M. (2009). Elevated endogenous testosterone concentrations potentiate muscle androgen receptor responses to resistance exercise. *The Journal of Steroid Biochemistry and Molecular Biology, 114*(3), 195-199.

Stamford, B. A., & Noble, B. J. (1974). Metabolic cost and perception of effort during bicycle ergometer work performance. *Medicine and Science in Sports, 6*(4), 226-231.

Staron, R., Karapondo, D., Kraemer, W., Fry, A., Gordon, S., Falkel, J. E., . . . Hikida, R. (1994). Skeletal muscle adaptations during early phase of heavy-resistance training in men and women. *Journal of Applied Physiology, 76*(3), 1247-1255.

Staron, R., Malicky, E., Leonardi, M., Falkel, J., Hagerman, F., & Dudley, G. (1990). Muscle hypertrophy and fast fiber type conversions in heavy resistance-trained women. *European Journal of Applied Physiology and Occupational Physiology, 60*(1), 71-79.

Steinacker, J., Lormes, W., Kellmann, M., & Liu, Y. (2000). Training of junior rowers before world championships. Effects on performance, mood state and selected hormonal and metabolic responses. *Journal of Sports Medicine and Physical Fitness, 40*(4), 327-335.

Steinacker, J. M., Lormes, W., Lehmann, M., & Altenburg, D. (1998). Training of rowers before world championships. *Medicine and Science in Sports and Exercise, 30*(7), 1158-1163.

Steinhofer, D. (1997). Terminology and differentiation of training methods. *Modern Athlete and Coach, 35*, 15-21.

Stone, M., & Wathen, D. (2001). Letter to the editor. *Strength and Conditioning Journal, 23*(5), 7.

Stone, M. H., & O'Bryant, H. S. (1995). Letter to the editor. *Journal of Strength and Conditioning Research, 9*(2), 125-126.

Stone, M. H., O'Bryant, H., Garhammer, J., McMillan, J., & Rozenek, R. (1982). A theoretical model for strength training. *NSCA Journal, 4*(4), 36-39.

Stone, M. H., O'Bryant, H., & Garhammer, J. A. (1981). A hypothetical model for strength training. *Journal of Sports Medicine, 21*, 342-351.

Stone, M. H., O'Bryant, H. S., Schilling, B. K., Johnson, R. L., Pierce, K. C., Haff, G. G., . . . Stone, M. (1999a). Periodization. Part 1: Effects of manipulating volume and intensity. *Strength and Conditioning Journal, 21*(2), 56-62.

Stone, M. H., O'Bryant, H. S., Schilling, B. K., Johnson, R. L., Pierce, K. C., Haff, G. G., . . . Stone, M. E. (1999b). Periodization. Part 2: Effects of manipulating volume and intensity. *Strength and Conditioning Journal, 21*(3), 54-60.

Stone, M. H., Plisk, S. S., Stone, M. E., Schilling, B. K., O'bryant, H. S., & Pierce, K. C. (1998). Athletic performance development: Volume load---1 set vs. multiple sets, training velocity and training variation. *Strength and Conditioning Journal, 20*(6), 22-31.

Stone, M. H., Potteiger, J. A., Pierce, K. C., Proulx, C. M., O'Bryant, H. S., Johnson, R. L., & Stone, M. E. (2000). Comparison of the effects of three different weight-training programs on the one repetition maximum squat. *Journal of Strength and Conditioning Research, 14*(3), 332-337.

Stone, M. H., Stone, M., & Sands, W. A. (2007). *Principles and Practise of Resistance Training*. Champaign, IL: Human Kinetics.

Storen, O., Helgerud, J., Stoa, E. M., & Hoff, J. (2008). Maximal strength training improves running economy in distance runners. *Medicine and Science in Sports and Exercise, 40*(6), 1087-1092.

Storey, A., Birch, N., Fan, V., & Smith, H. (2016). Stress responses to short-term intensified and reduced training in competitive weightlifters. *Scandinavian Journal of Medicine and Science in Sports, 26*(1), 29-40.

Stowers, T., McMillan, J., Scala, D., Davis, V., Wilson, D., & Stone, M. (1983). The short term effects of three different strength power training methods. *National Strength and Conditioning Association Journal, 5*(3), 24-27.

Suchomel, T. J., Nimphius, S., Bellon, C. R., & Stone, M. H. (2018). The importance of muscular strength: Training considerations. *Sports Medicine, 48*(4), 765-785.

Sufrinko, A., Pearce, K., Elbin, R., Covassin, T., Johnson, E., Collins, M., & Kontos, A. P. (2015). The effect of preinjury sleep difficulties on neurocognitive impairment and symptoms after sport-related concussion. *The American Journal of Sports Medicine, 43*(4), 830-838.

Sum, R. K. W., & Ma, M. M. (2014). A plea for support for elite student athletes in Hong Kong secondary schools. *Asia Pacific Journal of Sport and Social Science, 3*(2), 95-107.

Suminski, R. R., Robertson, R. J., Arslanian, S., Kang, J., Utter, A. C., DaSilva., S. G., . . . Metz, K. F. (1997). Perception of effort during resistance exercise. *Journal of Strength and Conditioning Research, 11*(4), 261-265.

Sunde, A., Støren, Ø., Bjerkaas, M., Larsen, M. H., Hoff, J., & Helgerud, J. (2010). Maximal strength training improves cycling economy in competitive cyclists. *Journal of Strength and Conditioning Research, 24*(8), 2157-2165.

Suppiah, H. T., Low, C. Y., & Chia, M. (2016). Effects of sport-specific training intensity on sleep patterns and psychomotor performance in adolescent athletes. *Pediatric Exercise Science, 28*(4), 588-595.

Suzuki, S., Sato, T., Maeda, A., & Takahashi, Y. (2006). Program design based on a mathematical model using rating of perceived exertion for an elite Japanese sprinter: A case study. *Journal of Strength and Conditioning Research, 20*(1), 36-42.

Suzuki, S., Sato, T., & Takahasi, Y. (2003). Diagnosis of training program for a Japanese rower by using the index of monotony. *Canadian Journal of Appllied Physiology, 28*, 105-106.

Sweet, T. W., Foster, C., McGuigan, M. R., & Brice, G. (2004). Quantitation of resistance training using the session rating of perceived exertion method. *Journal of Strength and Conditioning Research, 18*(4), 796-802.

Taipale, R. S., Schumann, M., Mikkola, J., Nyman, K., Kyröläinen, H., Nummela, A., & Häkkinen, K. (2014). Acute neuromuscular and metabolic responses to combined strength and endurance loadings: the "order effect" in recreationally endurance trained runners. *Journal of Sports Sciences, 32*(12), 1155-1164.

Tan, B. (1999). Manipulating resistance training program variables to optimize maximum strength in men: A review. *Journal of Strength and Conditioning Research, 13*(3), 289-304.

Tanimoto, M., Sanada, K., Yamamoto, K., Kawano, H., Gando, Y., Tabata, I., . . . Miyachi, M. (2008). Effects of whole-body low-intensity resistance training with slow movement and tonic force generation on muscular size and strength in young men. *Journal of Strength and Conditioning Research, 22*(6), 1926-1938.

Tanner, J. M. (1962). *Growth At Adolescence* (2nd ed.). Oxford, UK: Blackwell Scientific Publications.

Tanner, J. M. (1990). *Foetus into Man: Physical Growth, from Conception to Maturity*. Cambridge, MA: Harvard University Press.

Taube, W., Kullmann, N., Leukel, C., Kurz, O., Amtage, F., & Gollhofer, A. (2007). Differential reflex adaptations following sensorimotor and strength training in young elite athletes. *International Journal of Sports Medicine, 28*(12), 999-1005.

Tavares, L. D., de Souza, E. O., Ugrinowitsch, C., Laurentino, G. C., Roschel, H., Aihara, A. Y., . . . Tricoli, V. (2017). Effects of different strength training frequencies during reduced training period on strength and muscle cross-sectional area. *European Journal of Sport Science, 17*(6), 665-672.

Taylor, K., Chapman, D. W., Cronin, J. B., Newton, M. J., & Gill, N. (2012). Fatigue monitoring in high performance sport: A survey of current trends. *Journal of Australian Strength and Conditioning, 20*(1), 12-23.

Theodorou, A., & Cooke, C. B. (1998). Evaluation of the validity and reliability of a 30s vertical jump test. *Journal of Sports Sciences, 16*(1), 30-31.

Thomas, C., Dos'Santos, T., Comfort, P., & Jones, P. A. (2017). Between session reliability of common strength and power related measures in adolescent athletes. *Sports, 5*(1), 15.

Thorlund, J. B., Aagaard, P., & Madsen, K. (2009). Rapid muscle force capacity changes after soccer match play. *International Journal of Sports Medicine, 30*(04), 273-278.

Thorpe, R., & Sunderland, C. (2012). Muscle damage, endocrine, and immune marker response to a soccer match. *Journal of Strength and Conditioning Research, 26*(10), 2783-2790.

Thorpe, R. T., Atkinson, G., Drust, B., & Gregson, W. (2017a). Monitoring fatigue status in elite team-sport athletes: Implications for practice. *International Journal of Sports Physiology and Performance, 12*(Suppl 2), S2-27-34.

Thorpe, R. T., Strudwick, A. J., Buchheit, M., Atkinson, G., Drust, B., & Gregson, W. (2017b). The influence of changes in acute training load on daily sensitivity of morning-measured fatigue variables in elite soccer players. *International Journal of Sports Physiology and Performance, 12*(Suppl 2), S2-107-113.

Tibana, R. A., Prestes, J., da Cunha Nascimento, D., Martins, O. V., Frederico Santos de Santana, F. S., & Balsamo, S. (2012). Higher muscle performance in adolescents compared with adults after a resistance training session with different rest intervals. *Journal of Strength and Conditioning Research, 26*(4), 1027-1032.

Till, K., Morris, R., Stokes, K., Trewartha, G., Twist, C., Dobbin, N., . . . Jones, B. (2018). Validity of an isometric midthigh pull dynamometer in male youth athletes. *Journal of Strength and Conditioning Research, 32*(2), 490-493.

Towlson, C., Cobley, S., Parkin, G., & Lovell, R. (2018). When does the influence of maturation on anthropometric and physical fitness characteristics increase and subside? *Scandinavian Journal of Medicine and Science in Sports, 28*(8), 1946-1955.

Tran, Q. T., Docherty, D., & Behm, D. (2006). The effects of varying time under tension and volume load on acute neuromuscular responses. *European Journal of Applied Physiology, 98*(4), 402-410.

Tsai, M.-L., Li, T.-L., Chou, L.-W., Chang, C.-K., Huang, S.-Y., & Fang, S.-H. (2012). Resting salivary levels of IgA and cortisol are significantly affected during intensive resistance training periods in elite male weightlifters. *Journal of Strength and Conditioning Research, 26*(8), 2202-2208.

Tsolakis, C., Messinis, D., Stergioulas, A., & Dessypris, A. (2000). Hormonal responses after strength training and detraining in prepubertal and pubertal boys. *Journal of Strength and Conditioning Research, 14*(4), 399-404.

Tsolakis, C. K., Vagenas, G. K., & Dessypris, A. G. (2004). Strength adaptations and hormonal responses to resistance training and detraining in preadolescent males. *Journal of Strength and Conditioning Research, 18*(3), 625-629.

Turner, A. (2011). The science and practice of periodization: A brief review. *Strength and Conditioning Journal, 33*(1), 34-46.

Turner, A. N., Bishop, C., Marshall, G., & Read, P. (2015). How to monitor training load and mode using sRPE. *Professional Strength and Conditioning*(39), 15-20.

Turner, A. N., Buttigieg, C., Marshall, G., Noto, A., Phillips, J., & Kilduff, L. (2017). Ecological validity of the session rating of perceived exertion for quantifying internal training load in fencing. *International Journal of Sports Physiology and Performance, 12*(1), 124-128.

Twist, C., & Highton, J. (2013). Monitoring fatigue and recovery in rugby league players. *International Journal of Sports Physiology and Performance, 8*(5), 467-474.

Twist, C., Waldron, M., Highton, J., Burt, D., & Daniels, M. (2012). Neuromuscular, biochemical and perceptual post-match fatigue in professional rugby league forwards and backs. *Journal of Sports Sciences, 30*(4), 359-367.

Uchida, M. C., Teixeira, L. F., Godoi, V. J., Marchetti, P. H., Conte, M., Coutts, A. J., & Bacurau, R. F. (2014). Does the timing of measurement alter session-RPE in boxers? *Journal of Sports Science and Medicine, 13*(1), 59-65.

Urhausen, A., Gabriel, H., & Kindermann, W. (1995). Blood hormones as markers of training stress and overtraining. *Sports Medicine, 20*(4), 251-276.

van Borselen, F., Vos, N. H., Fry, A. C., & Kraemer, W. J. (1992). The role of anaerobic exercise in overtraining. *National Strength and Conditioning Journal, 14*(3), 74-79.

Van Ryswyk, E., Weeks, R., Bandick, L., O'Keefe, M., Vakulin, A., Catcheside, P., . . . Wallace, J. (2017). A novel sleep optimisation programme to improve athletes' well-being and performance. *European Journal of Sport Science, 17*(2), 144-151.

Vandenburgh, H. H. (1987). Motion into mass: how does tension stimulate muscle growth? *Medicine and Science in Sports and Exercise, 19*(5 Suppl), S142-149.

Velez, A., Golem, D. L., & Arent, S. M. (2010). The impact of a 12-week resistance training program on strength, body composition and self-concept of Hispanic adolescents. *Journal of Strength and Conditioning Research, 24*(4), 1065-1073.

Verhoshansky, Y. (1999). The end of “periodization” in the training of high peformance sport. *Modern Athlete and Coach, 37*(2), 14-18.

Vicente-Rodríguez, G. (2006). How does exercise affect bone development during growth? *Sports Medicine, 36*(7), 561-569.

Villanueva, M. G., Villanueva, M. G., Lane, C. J., & Schroeder, E. T. (2012). Influence of rest interval length on acute testosterone and cortisol responses to volume-load equated total body hypertrophic and strength protocols. *Journal of Strength and Conditioning Research, 26*(10), 2755-2764.

Vincent, W. J. (2005). *Statistics in Kinesiology* (3rd ed.). Champaign, IL: Human Kinetics.

Vingren, J. L., Kraemer, W. J., Ratamess, N. A., Anderson, J. M., Volek, J. S., & Maresh, C. M. (2010). Testosterone physiology in resistance exercise and training. *Sports Medicine, 40*(12), 1037-1053.

Viru, A. (1984). The mechanism of training effects: A hypothesis. *International Journal of Sports Medicine, 5*(5), 219-227.

Viru, A., Loko, J., Harro, M., Volver, A., Laaneots, L., & Viru, M. (1999). Critical periods in the development of performance capacity during childhood and adolescence. *European Journal of Physical Education, 4*(1), 75-119.

Viru, A., & Viru, M. (2004). Cortisol - Essential adaptation hormone in exercise. *International Journal of Sports Medicine, 25*(6), 461-464.

Viru, A., Viru, M., & Bosco, C. (2003). Hormones in short-term exercises: Resistance and power exercises. *Strength and Conditioning Journal, 25*(5), 7-15.

Visnes, H., & Bahr, R. (2013). Training volume and body composition as risk factors for developing jumper's knee among young elite volleyball players. *Scandinavian Journal of Medicine and Science in Sports, 23*(5), 607-613.

Vittek, J., L'Hommedieu, D. G., Gordon, G. G., Rappaport, S. C., & Southren, A. L. (1985). Direct radioimmunoassay (RIA) of salivary testosterone: Correlation with free and total serum testosterone. *Life Sciences, 37*(8), 711-716.

Wallace, L. K., Slattery, K. M., & Coutts, A. J. (2014). A comparison of methods for quantifying training load: Relationships between modelled and actual training responses. *European Journal of Applied Physiology, 114*(1), 11-20.

Wang, R., Hoffman, J. R., Tanigawa, S., Miramonti, A. A., La Monica, M. B., Beyer, K. S., . . . Stout, J. R. (2016). Isometric mid-thigh pull correlates with strength, sprint, and agility performance in collegiate rugby union players. *Journal of Strength and Conditioning Research, 30*(11), 3051-3056.

Warren, G. L., Ingalls, C. P., Lowe, D. A., & Armstrong, R. (2001). Excitation-contraction uncoupling: Major role in contraction-induced muscle injury. *Exercise and Sport Sciences Reviews, 29*(2), 82-87.

Watkins, C. M., Barillas, S. R., Wong, M. A., Archer, D. C., Dobbs, I. J., Lockie, R. G., . . . Brown, L. E. (2017). Determination of vertical jump as a measure of neuromuscular readiness and fatigue. *Journal of Strength and Conditioning Research, 31*(12), 3305-3310.

Watson, A. M. (2017). Sleep and athletic performance. *Current Sports Medicine Reports, 16*(6), 413-418.

Weakley, J. J., Till, K., Darrall-Jones, J., Roe, G. A., Phibbs, P. J., Read, D. B., & Jones, B. L. (2017a). The influence of resistance training experience on the between-day reliability of commonly used strength measures in male youth athletes. *Journal of Strength and Conditioning Research, 31*(7), 2005-2010.

Weakley, J. J., Till, K., Read, D. B., Roe, G. A., Darrall-Jones, J., Phibbs, P. J., & Jones, B. (2017b). The effects of traditional, superset, and tri-set resistance training structures on perceived intensity and physiological responses. *European Journal of Applied Physiology, 117*(9), 1877-1889.

Weekes, N., Lewis, R., Patel, F., Garrison-Jakel, J., Berger, D. E., & Lupien, S. J. (2006). Examination stress as an ecological inducer of cortisol and psychological responses to stress in undergraduate students. *Stress, 9*(4), 199-206.

Wehbe, G., Gabbett, T., Dwyer, D., McLellan, C., & Coad, S. (2015). Monitoring neuromuscular fatigue in team-sport athletes using a cycle-ergometer test. *International Journal of Sports Physiology and Performance, 10*(3), 292-297.

Wernbom, M., Augustsson, J., & Thomee, R. (2007). The influence of frequency, intensity, volume and mode of strength training on whole muscle cross-sectional area in humans. *Sports Medicine, 37*(3), 225-264.

West, D. J., Cook, C. J., Stokes, K. A., Atkinson, P., Drawer, S., Bracken, R. M., & Kilduff, L. P. (2014a). Profiling the time-course changes in neuromuscular function and muscle damage over two consecutive tournament stages in elite rugby sevens players. *Journal of Science and Medicine in Sport, 17*(6), 688-692.

West, D. J., Cunningham, D. J., Finn, C. V., Scott, P. M., Crewther, B. T., Cook, C. J., & Kilduff, L. P. (2014b). The metabolic, hormonal, biochemical, and neuromuscular function responses to a backward sled drag training session. *Journal of Strength and Conditioning Research, 28*(1), 265-272.

West, D. J., Finn, C. V., Cunningham, D. J., Shearer, D. A., Jones, M. R., Harrington, B. J., . . . Kilduff, L. P. (2014c). Neuromuscular function, hormonal, and mood responses to a professional rugby union match. *Journal of Strength and Conditioning Research, 28*(1), 194-200.

Weston, M., Siegler, J., Bahnert, A., McBrien, J., & Lovell, R. (2015). The application of differential ratings of perceived exertion to Australian Football League matches. *Journal of Science and Medicine in Sport, 18*(6), 704-708.

Willardson, J. M. (2007). The application of training to failure in periodized multiple-set resistance exercise programs. *Journal of Strength and Conditioning Research, 21*(2), 628-631.

Williams, T. D., Tolusso, D. V., Fedewa, M. V., & Esco, M. R. (2017). Comparison of periodized and non-periodized resistance training on maximal strength: A meta-analysis. *Sports Medicine, 47*(10), 2083-2100.

Willoughby, D. (1991). Training volume equated - A comparison of periodized and progressive resistance weight training-programs. *Journal of Human Movement Studies, 21*(5), 233-248.

Willoughby, D. S. (1993). The effects of mesocycle length weight training programs involving periodization and partially equated volumes on upper and lower body strength. *Journal of Strength and Conditioning Research, 7*(1), 2-8.

Wilson, G. J., & Murphy, A. J. (1996). The use of isometric tests of muscular function in athletic assessment. *Sports Medicine, 22*(1), 19-37.

Wilson, G. J., Murphy, A. J., & Giorgi, A. (1996). Weight and plyometric training: Effects on eccentric and concentric force production. *Canadian Journal of Applied Physiology, 21*(4), 301-315.

Wilson, G. J., Walshe, A. D., & Fisher, M. R. (1997). The development of an isokinetic squat device: Reliability and relationship to functional performance. *European Journal of Applied Physiology and Occupational Physiology, 75*(5), 455-461.

Wilson, J. M., Marin, P. J., Rhea, M. R., Wilson, S. M., Loenneke, J. P., & Anderson, J. C. (2012). Concurrent training: A meta-analysis examining interference of aerobic and resistance exercises. *Journal of Strength and Conditioning Research, 26*(8), 2293-2307.

Wing, C. (2018). Monitoring athlete load: Data collection methods and practical recommendations. *Strength and Conditioning Journal, 40*(4), 26-39.

Wong, P.-l., Chamari, K., & Wisløff, U. (2010). Effects of 12-week on-field combined strength and power training on physical performance among U-14 young soccer players. *Journal of Strength and Conditioning Research, 24*(3), 644-652.

Wu, C.-L., Hung, W., Wang, S.-Y., & Chang, C.-K. (2008). Hormonal responses in heavy training and recovery periods in an elite male weightlifter. *Journal of Sports Science and Medicine, 7*(4), 560.

Yesalis, C. E. (1993). *Anabolic Steroids in Sports and Exercise*. Champaign, IL: Human Kinetics.

Zakas, A., Mandroukas, K., Karamouzis, G., & Panagiotopoulou, G. (1994). Physical training, growth hormone and testosterone levels and blood pressure in prepubertal, pubertal and adolescent boys. *Scandinavian Journal of Medicine and Science in Sports, 4*(2), 113-118.

Zatsiorsky, V. M. (1992). Intensity of strength training facts and theory: Russian and Eastern Europe approach. *National Strength and Conditioning Journal, 14*(5), 46-57.

Zatsiorsky, V. M., & Kraemer, W. J. (2006). *Science and Practice of Strength Training* (2nd ed.). Champaign, IL: Human Kinetics.