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Training load quantification in professional Australian basketball and the use of the reactive strength index as a monitoring tool.

William Markwick
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Abstracts

Study 1: The intraday reliability of the reactive strength index (RSI) calculated from a drop jump in professional men's basketball.

Purpose: To evaluate the reliability of the reactive strength index (RSI) and jump height (JH) performance from multiple drop heights with elite basketball players. ***Methods***: Thirteen professional basketball players (mean ±SD: age 25.8 ± 3.5 y, height 1.96 ± 0.07 m, mass 94.8 ± 8.2 kg) completed 3 maximal drop jump attempts on to a jump mat at 4 randomly assigned box heights and 3 counter movement jump (CMJ) trials. ***Results*****:** No statistical difference was observed between three trials for both the RSI and JH variable at all the tested drop heights. The RSI for drop jump heights from 20 cm resulted in a coefficient of variation (CV) = 3.1% and an intraclass correlation (ICCα) =0.96, 40 cm resulted in a CV = 3.0% and an ICCα = 0.95, 50 cm resulted in a CV = 2.1% and an ICCα = 0.99. The JH variable at the 40 cm drop jump height resulted in the highest reliability CV = 2.8% and an ICCα = 0.98. ***Conclusion*****:** When assessing the RSI the 20, 40 and 50 cm drop heights are recommended with this population. When assessing large groups it appears that only one trial is required when assessing the RSI variable from the 20, 40 and 50 cm drop heights.

Study 2: Does session RPE relate with reactive strength qualities? A case study investigation within the National Basketball League

This investigation aimed to establish the relationship between training loads derived from the sessional rating of perceived exertion (sRPE) and the reactive strength index (RSI) over a 27-week competitive season in elite basketball players. Fourteen professional male basketball players (26 ± 3.6 years; 95.8 ± 9.0 kg; 197.3 ± 7.3 cm) participated in this study. Training load data were modeled against the RSI over a 27-week competitive season with the use of a linear mixed model. The relationship between RSI and training load was only significantly different from baseline (Week 1) at Week 24 ($p < 0.05$) and Week 26 ($p < 0.01$). These primarily findings suggest that sRPE and RSI have a weak relationship, whilst the RSI does not appear to accurately reflect the changes in training load that occur during an in-season periodized training program in professional male basketball.

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Publications related to thesis

In press:

Markwick WJ, Bird SP, Tufano JJ, Seitz LB, and Haff GG. The intraday reliability of the reactive strength index (RSI) calculated from a drop jump in professional men's basketball. *International Journal of Sports Physiology and Performance* 10: 482-488, 2015.

In Review:

Markwick, W. J, Govus, A. D, Woods C. T, Seitz. L, Tufano, J. J, Bird, S.P, and Haff, G. G. Does session RPE relate with reactive strength qualities? A case study investigation within the National Basketball League. *Journal of Strength and Conditioning Research (In Review)*

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List of Abbreviations

RSI = Reactive strength index

sRPE = Sessional ratings of perceived exertion (sRPE)

RPE = Rate of perceived exertion

HR = Heart rate

TRIMP = Training impulse

SHRZS = summated heart rate zone score

Bla = blood lactate

DOMS = delayed onset of muscles soreness,

CK = creatine kinase,

sCort = salivary cortisol,

PRFD = peak rate force development

PP = peak power

PF = peak force

T = testosterone

C = cortisol

CMJ = countermovement jump

TL = training load

OM = official match

SM = simulated match

IgA = immunoglobulin A.

A.U = arbitrary unit

LT Zone – lactate threshold zone

OT = odds ratio

TL = training load

RESTQ = recovery-stress state questionnaire

VL = Volume load in kilogram

GPS = Global positioning system

1RM = One repetition maximum

t:c = testosterone to cortisol ratio

HSR = High speed running

5on5 = five players versus five players.

NBL = National Basketball League

CR-10 = Borg’s category ratio 10 scale

Chapter 1 - Introduction

Background to the research

Training load quantification is an integral component of athlete monitoring in elite sport with much research specifically examining internal and external training load measures. Approaching training load quantification in a scientific fashion has emerged as a necessity in high performance sport [1] as it allows for greater understanding of the interaction between training load measures. These measures taken individually or collectively will typically assess some aspect of fatigue that would likely infer to the likely performance capability or outcome [2]. Scientific literature reporting training load quantification within professional sports has predominantly focussed on the popular football codes such as Rugby League, Australian Football and Football (Soccer). Investigations in Rugby League and Australian Football has established that there are strong relationships between external and internal training loads [3, 4] and that training load has an influence on the rate of injury occurrences [5, 6]. A commonly used method to measure training load is the sessional rating of perceived exertion (sRPE), which is a representation of internal training load. It has been reported that the sRPE has a strong relationship with physiological measures, such as heart rate, and external training load measures such as running distance and speed. Therefore, it is generally suggested that the sRPE is a valid index of global training load [4, 7]. Within the scientific literature sRPE has been investigated with basketball populations for the purpose of quantifying training load and to aid in the analysis of the training process [7, 8]. Recently, the sRPE has been investigated in Australian basketball at the semi-professional level where it was found to have significant moderate relationships between internal and external training load measured via accelerometer technology ($r_{42} = 0.49$, 95% CI = 0.23-0.69, $p < 0.001$)[9]. Collectively, these investigations serve as a strong foundation for the future of training load monitoring for professional basketball.

One of the primary aims of training load quantification is to develop a multi-faceted approach that monitors how an athlete is responding to the prescribed training dose. A strategy that is often used in professional sport to is to incorporate specific performance tests pre and post training, and competitive matches in order to give a more comprehensive picture of how the athlete is responding to training or competition loads [2]. The purpose of these tests is to identify how the prescribed training or match demands impacts subsequent performance, with results often used as an indicator of fatigue. Often the evaluated tests are movement tasks that are closely related to the movement demands of the sport. The task

must be reliable, easy to collect and specifically isolate a specific neuromuscular performance [10]. An example of the employment of this type of model can be found in professional Australian Football where a counter movement jump was performed on a force plate in order to determine which variables are indicative of fatigue. Specifically, the authors reported a decrement in the flight time to contraction time ratio from pre to post match (ES −0.65 ± 0.28), suggesting that the use of a simple vertical jump test could be used as a load monitoring tool [10]. Additionally, this investigation illustrated that neuromuscular monitoring with a jumping task was an effective strategy for monitoring the physiological demands of match play and potentially inform future recovery interventions. An alternative movement task that has been suggested as a potential monitoring tool is the drop jump. The drop jump is typically performed onto a force plate or jump mat in order to measure jump height and ground contact time. The ratio between these two variable is referred to as the reactive strength index (RSI) [11]. The quantification of the RSI with a drop jump is an effective assessment of plyometric conditions as successful performance of this task is heavily reliant on the contribution from the stretch shortening cycle (SSC). The SSC is involved in performing athletic movements such as running and jumping; repetition of these movements induces the onset of SSC fatigue which is associated with deleterious physiological side-affects that can last for 48-72 hours [12, 13]. This understanding has led to the contention that the RSI may be an effective assessment in observing neuromuscular fatigue.

What constitutes best practice in training load monitoring is an ongoing point of discussion within the sport science literature, as each sport poses unique challenges that will influence what methods are used to quantify training load. It does appear that an effective strategy must incorporate both internal load measures and external measures [2], and to further strengthen athlete monitoring capabilities tests of neuromuscular performance have potential for inclusion.

Of interest to this particular thesis is to quantify training load via the sRPE method and to establish whether any relationship is apparent with the quantification of the RSI from a drop jump test. Specifically, when analysing the various components that contribute to the training prescription (tactical training, skills development, strength and power training and matches) is the RSI sensitive to the changes in exposures to these components through the time course of a professional season.

Purpose of research

The present study aims to quantify training load in professional basketball across a competitive season. Specifically this thesis aims to establish whether training load derived via the sRPE method of is related to the RSI measurement assessed from a drop jump.

Therefore, experimental study 1 aimed to determine the intraday reliability of the RSI from a drop jump when performed from multiple drop heights. While experimental study 2 aimed to determine the relationship between the RSI and training load throughout the course of a professional basketball season.

Significance of the research

To the authors knowledge there are no known investigations in the scientific literature, which examine training load quantification with professional men's basketball in Australia. This thesis aims to provide a more precise understanding of the monitoring tools used to measure training load with basketball athletes' and highlight the complexities of a unique professional league. This knowledge will potentially identify a method to accurately measure training load in basketball, allowing strength and conditioning coaches to improve training prescription and improve the ability to monitor individual athletes within a team environment.

This thesis aims to identify a simple performance test (RSI) that is sensitive to changes in training load in order to allow for an indirect analysis of the success of the training prescription, gauge physiological recovery status and guide future training prescription. Importantly, this may provide a framework for an athlete-monitoring program that can minimise negative physiological and performance outcomes and maximise athlete preparedness and successful basketball performance.

Research Questions

Does the quantification of the RSI from multiple drop jump heights express acceptable levels of reliability (Experimental study one)?

Is the RSI and training load derived via sRPE related in professional basketball athletes throughout the course of the competitive season (Experimental study two)?

Hypotheses

Hypothesis 1 – The RSI will express acceptable reliability from all drop heights with this population.

Hypothesis 2 – Variation of training load through the in-season period will be reflected in changes in RSI performance.

Hypothesis 3 – The RSI will be an effective diagnostic tool to gauge general fatigue and neuromuscular status amongst professional basketball athletes during the in-season period.

Chapter 2 - Literature Review

Introduction

Basketball is the second most popular sport in the world with 213 nations participating in international competitions and over 450 million regular participants [14]. Globally, the popularity of basketball on the international stage is demonstrated in the National Basketball Association (NBA) in 2006/07 season paying $US1.93 billion salaries [15]. In Australian basketball there are over a million players spread over 20,000 clubs [14] giving the sport the second highest participation rate for all team sports with in the country. Not only is the popularity of the sport changing, so too are the physical demands associated with playing the game. The modern basketball athlete requires highly developed muscular strength, power, aerobic and anaerobic capacity, speed, agility, mobility, and stability to complement their skill [15, 16]. The evolution of the game of basketball has placed a greater emphasis on physical, tactical, and technical preparation in order to meet the physical and performance demands required of the sport. This development is in line with modification to the rules made in 2000, as in Australia the game is divided by four 10 minute quarters with shorter attacking times, this has affected both the physical and tactical demands of the game. Furthermore in the Australian National Basketball League (NBL) in 2012/13 each team played 28 regular season fixtures (not including finals) [17] compared to 82 matches per team in the NBA in a very similar time period [18] (Oct-Apr/May) posing a unique situation when preparing for competition.

Generally, physical preparation in elite basketball involves progressive training of the muscular, metabolic, cardiovascular and neurological systems [19]. The main goal of this systematic approach to training focuses on stimulating the physiological adaptations that underpins the performance requirements associated with high-level basketball play. The principle of progressive performance adaptation can be explained as a “dose-response” relationship [19] where there is an interaction between the physiological ‘response’ to the prescribed “dose” of training. Conceptually, the “dose-response” is an extension of the fitness-fatigue paradigm [20] where the two after effects of training stress, fitness and fatigue have an opposing effect on performance. The fitness and fatigue after-effects are independent, the fatigue after-effects can be neural and metabolic and are both negative responses, whereas the fitness after-effects are generally positive physiological adaptations, the culmination of these after-effects is critical in performance improvement [21]. Of vital importance in performance training is the total negative physiological responses experienced

by the athlete as discussed by Chiu et al. [21], the magnitude and duration of these responses is related to the absolute load, training intensity and total work of a training bout. Ultimately, the ability to optimize preparedness is facilitated by structuring training interventions that maximize fitness and minimize fatigue [20, 21]. In order to increase the potential of successfully accomplishing this goal it is important that the athlete's physiological adaptations are assessed with specific performance based measures, whilst training load is monitored in order to optimize the training prescription. The ability to monitor both physiological and performance responses to training may be even more critical in the team sport environment where several athletes may respond differently to the training interventions [19].

In order to monitor the training process firstly the appropriate measures of "Training Load" needs to be established. The opposing physiological demands between sports suggest that using one method of quantifying training load for all sports is not ideal. The culmination of all training stress is termed "Training Load" [22] and can be quantified by internal (physiological), perceptual measures and/or external methods (time or distance ran) [19]. Internal training load is related to the physiological stress placed on the athlete from an imposed training stimulus [19]. For example, acute heart rate response to a training load would be indicative of an internal responses to a training bout, while the external load may be quantified as the volume of weight lifted during a strength training session [23, 24] or distances run in match play or during a training session [25, 26]. Fundamentally there exists a cause and effect relationship between the internal and external loads, as displayed in Figure 2.1.

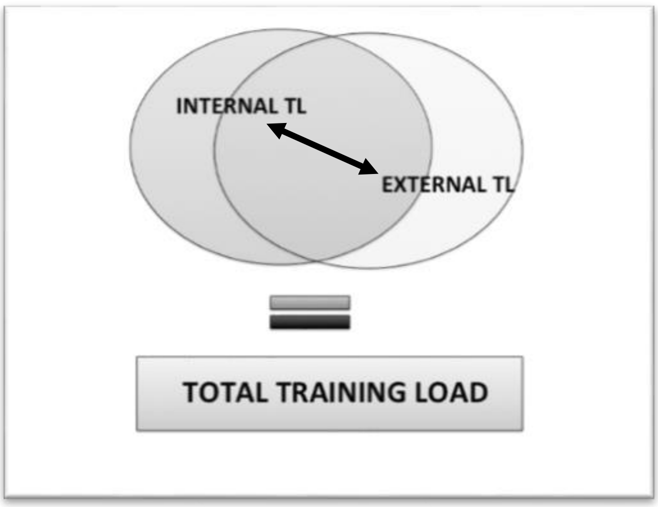

Figure 2.1: The relationship between internal and external factors that contribute to training load.

Ultimately the internal training load (outcome) is inextricably linked to the prescribed external training load (training process) [22]. In order to direct the training process strength and conditioning (S+C) professionals implement periodised training programs that modulate the external and internal training loads in order to enhance the performance and physiological adaptations required to achieve the goals of the athlete of team [8].

Internal Training Load

Internal training load has been quantified in a variety of team sport settings via measures such as heart rate, blood lactate, hormonal, and psychological markers as seen in Table 2.1.

Table 2.1: A snapshot of the current literature of the quantification of internal training load.

Reference	Physiological measure	Subjects	Training Load Indices /Performance Measure	Results
Borresen et al. [27]	HR	Physically active men (n=15) and women (n=18)	sRPE TRIMP SHRZ	TRIMP vs SHRZ (r= 0.98) TRIMP vs sRPE (r =0.76) SHRZ vs sRPE (r=0.84)
Chatzinikolaou et al. [28]	HR BLa Inflammatory markers Oxidative stress markers	Basketball (n=20 male, elite)	Vertical jump Leg strength Upper body strength Speed Agility and anaerobic performance Muscles soreness	Jump performance decreased during 48 h of recovery (ES = 0.6), Anaerobic perforamnce and agility declined (9% and 3%, p<0.05). Knee extensor DOMS increase for 24 h of recovery (ES = 8.8, p<0.05), knee flexor DOMS was greater in magnitude (2.5 – 5 fold, p<0.05) and duration (48 h, p<0.05). CK increased (50-97%, ES = 3.3, p<0.05), C increased (33%, ES = 4.7, p<0.05), oxidative stress variables demonstrated an F (7,133) = 48.27-1125.4 (p<0.05).
Coutts et al. [29]	HR BLa	Football (n=20, male, amateur)	Mean HR BLa sRPE	sRPE significantly correlated with BLa (r=0.63, p<0.05) and %HR peak (r=0.60, p< 0.05)
Foster et al. [8]	HR	Basketball (n=14, male, collegiate)	TRIMP SHRZS sRPE	Significant relationship between sRPE and SHRZ (p <0.05)
Gaviglio et al. [30]	Salivary T Salivary C	Rugby Union (n=22, male, professional)	Win/loss/draw	The teams pregame T concentrations were significantly higher when the outcome of the game was a win compared to losses ($P = 5.8 \times 10^{-5}$).
Haff et al. [31]	Blood T Blood C	Weightlifting (n=6 female, elite)	Isometric/dynamic mid-thigh pull. Peak force (PF) Peak rate of force development (PRFD)	Very strong correlation was found between percentage of T : C ratio, isometric maximal strength and VL from week 1-11.

Impellizzeri et al. [22]	Psychological measures. sRPE HR	Football (n=19, male, youth)	sRPE SHRZ TRIMP Lucia's TRIMP	Correlations between sRPE and HR based TL were all significant (p<0.01 to p<0.001)
Manzi et al. [7]	HR	Basketball (n=8 male, professional)	TRIMP sRPE	sRPE and HR methods significant relationship (r = 0.69 to 0.85, p< 0.05))
Martinez et al. [32]	Blood T Blood C	Basketball (n=12, male, professional)	Nil	The T/C ratio increased during the season first half of the season, followed by significant decrease in the later part of the season.
McLean et al. [33]	Salivary T Salivary C Psychological measures	Rugby League (n=12 male, professional)	CMJ flight time CMJ relative power Perceptual response	Most CMJ variables returned to near baseline following 4 days. Salivary T and C did not change in response to the match.
Mclellan et al. [34]	Salivary and blood markers Plasma creatine kinase (CK) Salivary cortisol concentratio n (sCort)	Rugby League (n=17 male, elite)	PRFD, PP PF	Significant (p<0.05) correlation between CK and PRFD (30mins and 24hours post) sCort significantly correlated (p<0.05) with PF (30 min post)
Moreira et al. [35]	sRPE Salivary C	Basketball (n=10 male, elite)	sRPE	Results show a significant difference between post-OM and pre-OM salivary cortisol (p < 0.05). sRPE was significantly higher for OM compared with SM
Nunes et al. [36]	Salivary T Salivary C Salivary IgA	Basketball (n=12, female, professional)	Maximal strength Vertical jump	Significant improvements in both strength and vertical jump performance (p<0.05). T/C ratio increased significantly with training at 0730 hours (p<0.05). Significant moderate correlations were observed between the

				changes in all strength tests and the changes in T concentrations at 0730 hours (p<0.05)
Nunes et al. [37]	sRPE Recovery stress state (RESTQ-76) Salivary IgA T C	Basketball (n=19, female, professional)	Strength Jumping Power Running endurance Agility	The salivary markers T, C and IgA were not impacted despite changes in sRPE (p>0.05). All performance measures improve from pre to post training program (p<0.05).
Perandini et al. [38]	HR Bla	Taekwondo (men n=7, women n=4, elite)	TRIMP (Banister + Edwards) sRPE	sRPE significantly correlated with TRIMP (Banister + Edwards) (r=0.52 p<0.02 and r=0.64 p< 0.01) and BLa (r=0.71 p<0.01)

Abbreviations**:** HR = heart rate, TRIMP = training impulse, SHRZS = summated heart rate zone score, sRPE = sessional rated perceived exertion, Bla = blood lactate, DOMS = delayed onset of muscles soreness, CK = creatine kinase, sCort = salivary cortisol, PRFD = peak rate force development, PP = peak power, PF = peak force, T = testosterone, C = cortisol, CMJ = countermovement jump, TL = training load, OM = official match, SM = simulated match, IgA = immunoglobulin A.

Changes in performance outcomes are assumed to occur as a result of the adaptive physiological response to the training load imposed on the athlete. Measuring subsequent performance improvement is a crucial component of athletic performance, though in recent times the need to accurately quantify the cumulative training process has become increasingly more important [1]. The quantification of the training process has led to the development of indices of training load such as Banisters training impulse (TRIMP) that uses heart rate HR (internal measure) to equate a single unit measurement of how the athlete is responding to training [27]. Examples methods of how internal measures are used in the monitoring process are examined below.

Heart Rate Monitoring: Heart rate (HR) monitoring is a very popular method to measure internal load [39] at the squad level because of the availability of team-based HR monitoring systems which allow training load to be easily administered in a large group settings. There are several methods for utilizing heart rate to evaluate internal training load (Table 2.1).

The first method of quantifying internal training load with HR was developed by Banister et al. [40] and is termed the TRIMP. The TRIMP score is used to produce an index of workload formulated by calculating resting, average and maximal HR levels and exercise duration (Equation 2.1).

Equation 2.1: Training Impulse Equation:

$$\boxed{\text{TRIMP} = \text{duration of training (min)} \times \Delta \text{ HR ratio} \times Y}$$

The equation is multiplied by a weighting factor “Y” which is based on the lactate-workload relationship of trained men and women [27]. The purpose of the weighting factor is to account for the intensity of the exercise in order to negate disproportionate values calculated between long/slow exercise compared with short/fast exercises [39]. The lactate response to training is affected by multiple external and internal factors, for example dehydration and the rate of change in exercise intensity raising debate about its inclusion in the TRIMP equation [27]. Furthermore, improvements in physical condition have been associated with decreased maximal and sub-maximal blood lactate concentration, therefore a generic weighting factor may not be suitable for all athlete populations. The TRIMP method, first described by Banister [40] has been successfully used in a variety of settings most of which rely on aerobic and anaerobic energy pathways [7, 8, 27, 38, 41].

A second method for utilizing HR as a marker of internal load is the summated heart rate zone score (SHRZS). The SHRZS relies on HR response to training to calculate a single index of training load [39]. The difference compared to the TRIMP method is the analysis of the time spent in each 5 HR zones attempting to better reflect interval-based training. Each zone is weighted individually i.e. 50-60% = 1, 60-70% = 2, 70-80% = 3, 80-90% = 4 and 90-100% = 5. The accumulated time spent in each zone is summated to provide an arbitrary unit of training load [39]. The SHRZS has been related with the subjective quantification of training load sessional rated perceived exertion (sRPE) in taekwondo and football [22, 38]. The accuracy of the SHRZS is questioned when comparing objective and subjective measures. Borresen et al. [27] suggest that due to the SHRZS weighting system during higher intensity exercise this system may over-estimate training load in comparison to sRPE and similarly with low intensity exercise the SHRZS may under-estimate the true load incurred.

A third method is Lucia's TRIMP method [42] is a modification of the SHRZS that are related to the 3 zones of the ventilatory threshold [39]. One limitation of this method of quantifying training load is that the linear fashion of the weighting system is not reflective of the physiological response to exercise above the anaerobic threshold [39]. This creates an important consideration when working with team based sports, such as basketball where the athletes will perform exercise at intensities above the anaerobic threshold. In addition each individual's response to stimuli above the anaerobic threshold may vary, this could be observed when comparing basketball forwards and guards considering the difference in nature of their positions and physical size.   In these scenarios the physiological cost will vary between individual athletes who are performing at the same percentage of HR max. These types of limitations could directly impact the overall accuracy of this index as a tool for quantifying the internal training load.

Overall, measures of internal load which are dependent on the collection of HR data are influenced by exercise intensity and duration, environmental conditions, daily variation, and hormonal status [39], which could result in limitations in the utility of HR as a reliable measure to quantify training load in elite team sport [39]. Practical limitations on the use of HR to quantify wrestling and grappling in Rugby League training are reported by Lovell et al. [4] likewise similar limitations have been reported with non-aerobic based training interventions such as strength and power training [39]. This can be attributed to the dissociation of HR and $V0_2$ in intermittent high intensity exercise [43]. In addition, HR monitors are likely to be dislodged or damaged with athletes who are engaging in physical contact. If this occurs there is the possibility of a disruption in HR data collection effectively creating a scenario in which the TRIMP method cannot be used. Ultimately, this may limit the ability of the TRIMP method to be used to accurately quantify the training session.

The natural extension of monitoring internal load via HR is to measure the subsequent effect that exercise has on the acute and longer term status of an athlete's biochemistry, this has been quantified by various blood and salivary markers in the scientific literature.

Blood Lactate: Studies by Coutts et al. [29] and Perandini et al. [38] have established a relationship between objective measures of internal load and subjective training load indices, such as sRPE. Internal training load quantified based upon the blood lactate response of amateur soccer players and taekwondo athletes appear to have a direct relationship with the sRPE. Coutts et al. [29] concluded that combining HR and blood lactate measures accurately predicts RPE in small-sided games in football. Likewise Perandini et al. [38] found the blood lactate response that occurs in response to high-intensity intermittent training observed in taekwondo correlates strongly with sRPE ($r=0.71$, $p<0.01$). There is a distinct relationship between the findings of the mentioned studies with the physical demands of basketball. These physical demands require a major contribution of energy production from anaerobic metabolism [44]. The high intensity intermittent fashion of basketball training and competition has been found to elicit high average blood lactate concentration [44]. The similar training conditions reported in the studies by Coutts et al. [29] and Perandini et al. [38] suggests that sRPE could be well suited for monitoring the internal training load in basketball because it can accurately reflect alterations in both blood lactate and heart rate responses. In contrast it may not be practical to perform daily blood lactate assessments as the sRPE may offer a more viable tool for the quantification of the internal training load [29, 38].

Biochemical Measures: The physiological response to both competition and training are considered to be important factors underpinning the ability to understand the athletes ability to respond and adapt to training [19]. In order to better understand these relationships several studies have examined hormonal responses to quantify internal training load and to compare to the indices of global training load for example sRPE [29, 31, 34, 38, 45, 46]. Some hormonal markers that have been investigated include creatine kinase (CK), cortisol and testosterone amongst others. Creatine kinase has been reported to be an indirect measures of skeletal-muscle damage in humans whilst testosterone and cortisol provide markers of physiological stress [47]. This has been investigated before and after a professional male basketball match, the results discussed that the inflammatory response measured by blood markers coincide with a decrease in leg strength (Leg Press, $p < 0.05$; ES = 0.70), jumping ability ($p < 0.05$) and speed (5-7%, $p < 0.05$) up to 72 hours post match [28]. Specifically, the enzymatic and endocrine responses to high-intensity exercise and their effect on athletes' fatigue response, recovery status and readiness for training or competition has been the focus

of recent research in elite sport. For example, Haff et al. [31] measured the response of the testosterone to cortisol (T/C) ratio in female weightlifters over an 11 week training period and established a very strong correlation ($r = -0.83$; $r^2 = 0.69$) with an estimate of external load (i.e. the volume load (kg)). These findings suggest that the primary indicator of training stress is an alteration in basal cortisol levels, which exert a significant effect on the athletes T/C ratio. Thus the T/C ratio seems to be indicative of the athletes level of tolerance for the training stress and potentially indicate the athletes overall level of preparedness [31]. Support for the concept that the synergy between the T/C ratio and preparedness can be seen in the reduced ability to generate maximal forces when training volume is high and the T/C ratio is suppressed. This is supported by Martinez et al. [32] who suggest that monitoring T/C throughout a professional competitive season will provide accurate information to manage athlete stress levels and prevent overtraining syndrome. In addition to the T/C ratio, morning (0730 hours) levels of salivary testosterone have been found to have a significant moderate relationship ($p<0.05$) to improved strength performance in female basketball athletes [36]. A similar relationship to performance was observed in professional Rugby Union were the teams salivary testosterone levels pre-game were significantly higher before games won compared to losses ($P = 5.8 \times 10^{-5}$) [30]. The strong relationship between training volumes and physiological stress and the potential impact they can have on performance highlight the necessity for team sports such as basketball to monitor training loads. The information garnered from salivary and blood hormonal markers provide significant information on the physiological status of an athlete but may be limited by high costs and longer processing times. For these reasons coaches continue to invest time in to other measures that are more global in nature, training load indices that combine both physiological and psychological assessment.

Perceptual measures: Sessional-rating of perceived exertion (sRPE) as proposed by Foster et al. [8] is a simple perceptual method for measuring internal training load. In comparison to alternative indices of internal training load the sRPE is cost and time effective, easily administered and quickly analysed. Due to these factors the sRPE has increasingly become a foundational component of many training monitoring systems in team sport [48]. Like TRMIP and SHRZS a single unit of training load is calculated by multiplying an athlete's subjective perception of intensity (internal) with total training duration (external). Athletes chose from a rate of perceived exertion (RPE) scale that equates specific descriptors of physical exertion with a number value 30 minutes post-exercise and is used to create a global measure of the overall sRPE [8]. When utilising this scale athlete will choose a number value which is based upon their perception of their physical exertion and then this number is multiplied by to total duration of the training intervention in order to calculate the total training load [8]

(Equation 2.2). Additionally, the monotony and strain can determined through evaluating the sRPE over several days or training cycles [8] (see Table 2.3 and Figure 2.2).

Table 2.2: Modified perceived exertion scale.

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

Note: Adapted from Foster et al. [8]

Equation 2.2: Training load equation using the sRPE method.

Basketball Team/Tactical Session.

Duration = 90 mins;

Intensity = 5 (Hard);

Training Load (AU) = Duration (90) x Intensity (5)

Load = 90 x 5 = 450 AU

Table 2.3: Weekly breakdown of training load as per sRPE method.

	Mon	Tues	Wed	Thur	Fri	Sat	Sun	Week Total	Mean	Standard Deviation	Monotony	Strain
Athlete A	360	1100	1000	375	660	0	480	3975.0	567.86	384.92	1.48	5864.12
Athlete B	315	900	820	300	510	0	300	3145.0	449.29	318.52	1.41	4436.18
Athlete C	0	1040	970	337.5	420	0	240	3007.5	429.64	423.92	1.01	3048.09

Note: The week total is the summation of the sRPE figures (AU) of all training interventions. The mean and standard deviation is calculated from the weeks training, monotony is calculated by dividing the weekly mean by the standard deviation. Once this calculation is performed the monotony is multiplied by the week total to produce the strain value.

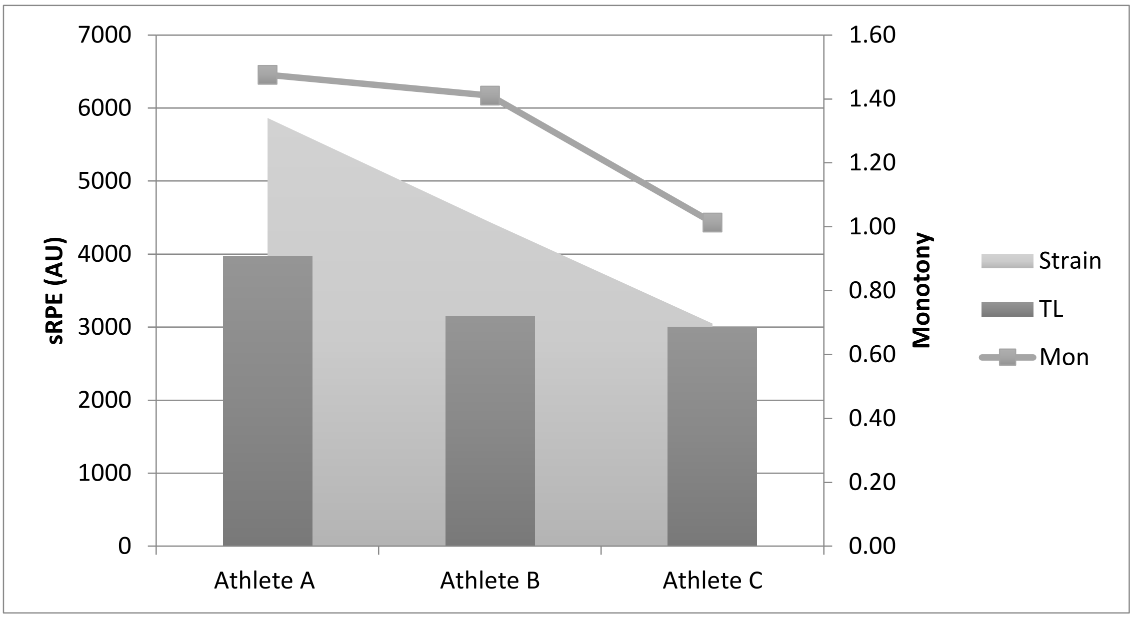

Figure 2.2: Weekly sRPE data from Table 2 graphed for athletes' A, B and C.

Notes: TL = training load, Mon = monotony

Multiple relationships have been reported sRPE with exercise intensity and the physiological response to training [49]. This relationship has been validated with heart rate, blood lactate and performance measures across numerous sports encompassing a large spectrum of athletic development (Table 2.1 and Table 2.4). However, when critically evaluating the scientific literature there is a paucity of research that directly examines the use of sRPE in elite level basketball. In one of the few studies investigating the topic Manzi et al. [7] examined the use of the sRPE to describe the periodisation of a portion of the in-season period in elite men's basketball and as a global indicator of training load. The results strengthen argument for the use of sRPE in elite basketball as the sRPE method of monitoring training load was strongly related ($r = 0.69$ to 0.85, $p < 0.001$) to Edwards and Banisters TRIMP load quantification method. This relationship is particularly important, as both indices are equated utilising HR measures which have been shown to be indicators of internal training loads. More recently in Australian basketball at the semi-professional level sRPE has been investigated and related to external measures of training load [9]. Interestingly the results of this study reported a moderate relationship ($r = 0.49$, $p < 0.001$) between sRPE and external load quantified by accelerometer technology but a large correlation to SHRZ ($r = 0.61$, $p < 0.001$). The results of this study strengthen the application of sRPE in basketball but also highlight the need to further investigate sRPE and establish any potential relationship to

external training load measures. Both investigations have particular significance to monitoring the training process in elite basketball, though to date to the authors' knowledge there is no research in elite Australian basketball of training load quantification.

Table 2.4: Literature investigating sessional ratings of perceived exertion.

Reference	Measures	Subjects	Results
Alexiou et al. [43]	sRPE, Banister's TRIMP, Edwards TRIMP, LT Zone	Football (soccer) (n = 15, female, women).	There was significant correlation between sRPE and Banisters TRIMP (r=0.67 – 0.95), LT zone (r=0.56 – 0.97), Edwards TRIMP (r=0.50 – 0.96).
Clarke et al. [48]	sRPE, Polar TRIMP, Edwards TRIMP	American Football (n = 20, male, collegiate)	sRPE was strongly correlated with Polar TRIMP (r = 0.69 – 0.91) and Edwards TRIMP (r = 0.69 – 0.91).
Coutts et al. [3]	sRPE	Rugby League (n = 25, male, professional)	Players perceived matches won to be significantly lower load than matches that were lost (479 ± 32 – 520 ±33 A.U., p<0.05). Match load was related to the number of tackles completed by the team each match (r=0.54, p <0.05).
Elloumi et al. [50]	sRPE, Wellness Survey	Rugby 7's (n=16, male, professional)	Training load, training strain and total score of fatigue were significantly correlated (r= 0.63 – 0.83).
Foster et al. [8]	sRPE, SHRZ	Basketball (n=14 male, collegiate)	Significant difference between sRPE and SHRZ (744± 84 - 652 ± 59, p = <0.05). Regression analysis revealed similar response between steady state and basketball practice.
Gabbett et al. [6]	sRPE	Rugby League (n=79 male, professional)	sRPE was significantly related (p=<0.05 to overall injury (r=0.82), non-contact field injury (r = 0.82), and contact field injury rates (r = 0.80).
Gallo et al. [51]	sRPE, GPS	Australian Football (n = 39 male, professional)	External TL (GPS) had moderate to very large associations with sRPE, average speed (r = 0.45), high-speed running distance (r = 0.51), player load slow (r = 0.80), player load (r = 0.86) and distance (r = 0.88).
Impellizzeri et al. [22]	sRPE, Banister, Edwards & Lucia TRIMP	Football (soccer) (n= 19, male, youth)	Correlation between sRPE and Banister's, Edward's and Lucia's TRIMP were strong (r = 0.50 – 0.85, p=<0.01).
Manzi et al. [7]	sRPE, Edwards TRIMP, Banister TRIMP	Basketball (n = 8, male, professional)	Significant relationships found between individual sRPE and Edwards and Banister TRIMP (r values from 0.69 to 0.85; p = <0.001)

Nunes et al. [37]	sRPE, immune-endocrine, RESTQ	Basketball (n = 19, female, professional)	Internal TL increased significantly across all weeks from 2- 11 ($p < 0.05$), in addition internal TL significantly decreased during the tapering weeks ($p < 0.05$)
Rogalski et al. [5]	sRPE	Australian Rules Football (n = 46 male, professional)	Larger 1 weekly (>1750 AU, OR = 2.44 – 3.38), 2 weekly (>4000, OR = 4.74) or previous to current week changes in load (>1250, OR = 2.58) significantly related to larger injury risk (p=<0.05).
Scanlan et al. [9]	sRPE, TRIMP, SHRZ, Accelerometer	Basketball (n = 8 male, semi-professional)	Significant moderate relationship observed between external TL and sRPE (r = 0.49, p = <0.001) and TRIMP (r = 0.38, p = <0.011). A large correlation was found between external TL and SHRZ (r = 0.61, p = <0.001).

Abbreviations: A.U = arbitrary unit, sRPE = sessional ratings of perceived exertion, TRIMP = training impulse, SHRZ = summated heart rate zone, LT Zone – lactate threshold zone, OT = odds ratio, TL = training load, RESTQ = recovery-stress state questionnaire

Once the sRPE is established it can be used to determine the monotony and strain of the training loads [52]. This is of particular importance in elite sport as these monitoring tools can be used as part of a global training load management system[53]. Findings of Manzi et al. [7] and Coutts et al.[3] suggest that the sRPE is a valid method for coaches to quantify internal TL and manage training loads. Additionally, sRPE can be us ed for future planning by estimating training intensities and duration to form the basis of the periodised training plan. Monitoring athletes daily can provide an indication of how they cope with the periodised training plan [53]. The individuals' weekly values can then be compared to their previous and current values, squad weekly averages and the coach estimated values as this can identify whether training loads have been managed in line with the goals of the overall training program. The benefit of this method of load monitoring analysis was shown by Rogalski et al. [5] in Australian Rules Football where athletes that reported consecutive weeks of sRPE values >4000AU (odds ratio = 4.73, 95% CI 1.14 – 19.76, p = 0.03) and week to week variations >1250AU (odds ratio = 2.58, 95% CI 1.43 – 4.66, p = 0.002) had a significantly increased injury risk [5]. A similar relationship has also been found in professional rugby league, where total training load was related to the overall incidence of injury (r = 0.82, $p < 0.01$) [6]. Furthermore, the pioneering work of Foster et al. [52] suggest that high monotony and strain values can result in negative training adaptations such as illness and infection in trained athletes. Taken collectively this information may enable coaches to periodise training plans that cycle through hard and easy days to ensure variability in the training prescription and minimize the occurrence of concurrent high monotony and strain values.

The many benefits of sRPE are attributed to the fact that it is a psychophysiological integrator [49], though there are some limitations with its use due to the subjective nature of its implementation. There is an assumption that the athlete is competent in understanding changes in intensity of exercise and can appropriately measure their own stress levels accordingly [48]. Furthermore athletes' must be adequately educated to understand the difference between the descriptors of the modified intensity scale used by Foster et al.[54]. Table 2.2 illustrates that some numbers on the 0-10 scale do not have a written descriptor, therefore the athlete must interpret whether their perceived exertion falls between two numbers for example the number 6 lies between 5 = Hard and 7 = Very Hard.

Furthermore, the utilisation of sRPE as a monitoring tool is limited as there is often a discrepancy between the coach or strength and conditioning professional's subjective planned intensity and the athletes' actual sRPE scores [55]. In a study by Wallace et al. [56] 12 well trained swimmers reported higher intensities when a lower intensity session was planned and the opposite, lower intensities reported during training bouts planned to be high in intensity in comparison to the coach predicted intensity. This difference as suggested by the authors could

be potentially harmful to the athlete; misjudgement of training intensities could lead to negative physiological responses and performance. However, if the sRPE method is appropriately monitored and analysed, the difference in reported intensities can prove valuable for improving the control of training variables [56] and help direct future training and physical recovery.

It is has been previously recommended that intensity ratings for each session be collected a standardized 30 minutes post exercise, to eliminate the athlete being swayed by events encountered during the last stages of training. Recent findings in professional boxing and soccer explain the impractical nature in the professional field employing this standardise data collection method [57, 58]. Both authors found that collecting sRPE ratings immediately after, 10 or 30 minutes post exercise resulted in no difference in the athlete's sRPE rating when comparing training sessions of the same or different intensities [57, 58]. It may appear that this minimal time difference is insignificant, the successful implementation of a training measure is directly influenced by the ease of the data collection process, this is even more apparent within team sports with a large number of athletes. The mentioned limitations require further research in order to establish whether sRPE is a valid tool to quantify training load in elite Australian basketball.

Another popular perceptual method utilised in athlete monitoring is the use of self-reported questionnaires and diaries [1]. Asking an athlete how they are 'feeling' is an effective and efficient means to quantify internal training load and monitor large groups of athletes. Questionnaires can be tailored specifically to gauge an athlete's physical and psychological wellness that can target illness symptoms, muscle soreness, stress and quality of sleep and recovery. This information can be analysed to identify trends developed over a longer term (4-6 weeks) or to observe day to day variance which can reflect how an athlete is coping to training, there is evidence to suggest that is an effective monitoring strategy in multiple sport settings [37, 50, 59-61]. Two example questionnaires are the daily analysis of life demands for athletes (DALDA) and the Wisconsin upper respiratory symptom survey (WURSS-21). These two surveys were shown to be positively related to measures of training load, respiratory infections and salivary markers of stress and immune function in collegiate male basketball players [61]. Specifically, when training loads were high for consecutive weeks there was an increased number of worse than normal responses on the DALDA and WURSS-21 surveys ($p < 0.05$) [61]. The authors conclude that inclusion of the DALDA and WURSS-21 can assist in monitoring training loads and to recognise the onset of illness symptoms. Another questionnaire used is the recovery-stress questionnaire for sport (RESTQ-Sport), this examination assesses 7 general stress and 5 general recovery subscales as well as 3 sport-

specific stress subscales and 4 sport-specific recovery scales on a Likert-type scale (0 (best) – 6 (worse)). The RESTQ-Sport was investigated with amateur male and female basketball players for the purpose of determining the gender specific responses to different training phases [62]. The results illustrate that men had higher scores on physical recovery ($F_{1, 26}$ = 6.22, p< 0.02), sleep quality ($F_{1, 26}$ = 6.76, p <0.02), and self-efficacy ($F_{1, 26}$ 6.56, p <0.02) than women. In addition, both male and females responses from the RESTQ-Sport were similar during pre-season and the competition phase. The higher training loads completed during the pre-season phase coincided with higher scores in emotional stress ($F_{1,26}$ = 3.29, p <0.02) and fatigue ($F_{1,26}$ = 6.12, p <0.02) in comparison to the competition phase for both males and females [62]. These findings suggest that the RESTQ-Sport is an effective tool at monitoring stress recovery balance for male and female athletes more specifically it aids the identification of psychological and physical under-recovery and assists in mitigating the risks associated with overtraining.

It is discussed by Halson [2] that self-directed questionnaires and diaries are best used in conjunction with objective measures of training load to be most effective as a monitoring tool. Due to the subjective nature of questionnaires and diaries they can be influenced by the length, timing and frequency of administration, therefore examining the results of these surveys in conjunction with a more objective measure such as an external training load measure could provide a more complete picture [2]. For example, comparing an athletes perceived muscle soreness to the cumulative running loads completed in training, this helps to identify specific areas that may have experienced ill-effects or gauge the level of physical and psychological recovery which can in-turn help aid future decisions for that athlete.

External Training Load

The acute physiological responses and chronic adaptations of an athlete are determined by the frequency, duration, and intensity of the training exposure [39]. These acute training variables are often defined as external measures of the training load. The quantification of these external measures provides a valuable description of the training process. Examples of methods that have been used the scientific literature to define the external training load can be seen in Table 2.5. When assessed in combination with indices of the internal training load these measures yield a comprehensive account of the athlete's response to the training stimuli. Conversely a single load monitoring method will not yield enough information about the overall response to the training stimuli [4]. Specifically, external load measures provide an indication on the amount of 'work' completed, while the internal load measurements yield evidence about the physiological cost of the work completed.

Therefore, it is common practice in elite sport to combined measures of internal and external load when evaluating athletes. For example, an external training load measure such as volume load in resistance training may be combined with the athlete's sessional rating of perceived exertion (sRPE) to quantify their internal load. By combining measures of both internal and external training load a comprehensive a global team-training load monitoring program can be established.

Coaches historically have prescribed training for performance improvement intuitively based upon external measures [19]. This method of training load prescription has been strengthened as a result of the improvement in micro-technologies such as global positional systems (GPS) and accelerometers, which can produce accurate data on various running variables and the ground and body impacts experienced during training and matches [4, 19, 25, 26, 63, 64] . This technology has enabled a more detailed understanding of the interaction between internal and external training loads in athletic populations. Numerous investigations [4, 19, 25, 26, 63, 64] primarily in the football codes have looked at specific GPS measure in order to determine their impact on performance and incidence of injury. This growing body of scientific literature is relevant for the strength and conditioning (S+C) professional working in the team environment because it can give then added information about the training loads encountered by the athlete. Specifically, this type of data can contribute to the justification of external load monitoring, though there are numerous limitations that need to be considered. Indoor sports such as Basketball have started to implement the use of GPS and accelerometers [64, 65], though they are yet to be validated in the literature possibly due to complex set-up, high running costs, and functional issues related to being in an indoor environment. In addition to the concerns around the ecological validity there is a lack of evidence that supports the reliability of the data of GPS systems in court based sports [66]. Total distance and mean and peak speed's reliability is severely impacted due to the confined and repetitive nature of the movements in court based sports (CV 4-25%), it was reported that measurement error increased when movement speeds increased and movements occurred repetitively over a similar area [67]. Before this advancement in technology a number of alternative external load measures were used in professional sports. For example, time motion analysis is often used as well as analysis of the total time spent in each specific basketball-training component (team/tactical, individual skill development, strength/power, conditioning). Additionally, resistance training can be evaluated in term of the total Volume Load (kg) (VL) undertaken [68].

Table 2.5: Examples of external load quantification within the literature.

Reference	External load measure	Subjects	Results
Gabbett et al. [25]	Global Positioning System (GPS)	Rugby League (n=30 male, professional)	Positional difference was compared. Measures absolute distance, total distance, number of collisions, frequency of collisions. Game vs training.
Haff et al. [31]	Volume Load (VL) kilograms	Weightlifting (n=6 female)	Percentage change in VL (-77.8%) from Week 1-11 showed large correlation (r= -0.83; r^2 = 0.69). Decrease in VL results in increase in t:c ratio.
Lovell et al. [4]	Global Positioning System (GPS)	Rugby League (n=32 male, professional)	Measures of distance and HSR provided very large (r - .82) and large (r = .62) correlations, respectively, with sRPE
McBride et al. [23]	Volume Load (VL) kilograms	Physically active (n=10 male)	VL is simple to equate in hypertrohpy and strength protocol.
McLellan et al. [26]	Global Positioning System (GPS)	Rugby League (n=22 male, professional)	Difference exists between movement demands of forwards and backs during competitive match play, especially in the frequency, duration, and distances ran.
Montogomery et al. [64]	Triaxial accelerometer	Basketball (n=11 male, elite junior)	Physical demand of live play is substantially more demanding than 5on5 or offensive and defensive drills.
Peterson et al. [24]	Volume Load (VL) kilograms	83 subjects (n = 43 males, n=40 females, age = 25.13 ± 5.5 years)	VL was strongly associated with 1RM improvement, males (β = 0.66, p<0.01) females (β = 0.26, p=0.02)
Scanlan et al. [9]	Triaxial accelerometer	Basketball (n = 8 males, semi-professional)	Moderate relationship was found between sRPE and external training load (r = 0.49)

Abbreviations: VL = Volume load in kilograms, GPS = Global positioning system, 1RM = One repetition maximum, t:c = testosterone to cortisol ratio, HSR = High speed running, sRPE = sessional rated perceived exertion, 5on5 = five players versus five players.

Volume Load (kg): External load quantification is particularly important in resistance training [23]. Specifically, the ability to estimate the work completed by an athlete enables the coach to strategically plan, monitor and modify the training prescription in relation to the established goals of the training session/cycle. One commonly used method to estimate the work completed during resistance training is Volume load (VL) [68]. Volume load determination is based upon the calculation of the total number of repetitions performed multiplied by the external load (kg) lifted of a nominated exercise [68] (Table 2.6). This workload estimate should be considered to be a gross measurement of multiple modifiable variables (number of sets, repetitions, exercises, intensity, load lifted) acknowledging that it is a simplistic method to periodise and monitor training and for the quantification of external training load [23, 24, 31]. Limitations are apparent with this method of calculation as it does neglect particular variables of resistance training that could impact the accuracy of the amount of work being completed. There are alternative equations that take in to consideration the distance and range of motion required when performing certain exercises and also the intensity at which the exercise is completed in respect to an individual's one repetition maximum [68]. Theoretically the addition of displacement or range of motion could provide a more accurate depiction of the work completed, though it is not without its own limitations including the availability, cost and time required to use specialised equipment (for example, linear positional transducers), furthermore not all exercises intensities are prescribed as a percentage of a maximal lift particularly in regards to supplementary type exercises.

Table 2.6: Volume Load calculation.

Exercise	Sets	Reps	Load (kg)	Volume Load (kg)
Back Squat	4	6	120	2880
Bench Press	4	5	90	1800
Dumbbell Row *	3	5ea. side	30	900
Total session volume load				5,580

Note: Volume load (VL) is calculated by the following equation (sets x reps x load). * = The VL calculation for unilateral exercises such as dumbbell row need to account for both limbs performing the action, therefore the number of reps performed in total is 10 in this instance (5 on each side).

Even though VL is simple in its methodology, manipulation of VL in resistance training has been related to metabolic and hormonal responses, as well as neural adaptations [24]. Collectively the volume load of training has the potential to affect both the athletes overall preparedness and performance capacity. A study by Peterson et al. [24] established a relationship between VL and maximal strength improvement in untrained men over a 12 week period ($b = 0.14$; $p = 0.04$). Similarly, Haff et al. [31] suggest that VL is related to the T/C ratio and maximal force capabilities in elite female weightlifters who were undertaking an 11 week training period. In contrast, increases in VL have been reported to exert a negative impact on performance. Specifically, Haff et al. [31] report a very large negative correlation between weeks 1 to 11 between VL and T/C ratio ($r = –0.83$; $r^2 = 0.69$) was determined with elite weightlifters. These findings highlight the importance of monitoring external training load, such as volume load in weightlifting, as it appears that these loads directly impact the internal (physiological) training load.

When examining elite Australian Basketball it is evident that resistance training plays a significant role in the basketball athlete's preparation. Anecdotally, basketball athletes will perform on average 2-3 resistance training sessions per week during the in-season, totalling 25-40% of the total training prescription during this period of training. Therefore, a justified need to quantify such a significant component of the total training process is required. It is also fair to assume that the variance in VL experienced by basketball athletes could alter performance outcomes that may be evident in results from tests of maximal power production, which may support the findings found by Haff et al. [31] in elite women weightlifters. Of particular interest to the current investigation is to address whether the reactive strength index (RSI) is sensitive to changes in VL in basketball athletes. To the authors knowledge there is no literature on this specific topic, the presented review suggests that the volume and intensity of resistance training will change in line with the periodised training plan, the subsequent physiological effect this has on the athlete may be able to be measured by maximal neuromuscular performance such as the RSI assessment.

<u>GPS and Accelerometers:</u> Technological advancements of player tracking via GPS, accelerometers and gyroscopes have allowed team sports to accurately quantify player movements and contact loads [4, 19, 25, 26, 63, 64]. The improvement of micro-technology has allowed for a more detailed analysis of the 'dose-response' type relationship between internal and external training load [4, 19, 25, 26, 63, 64]. Studies by Gabbett et al. [25] and McLellan et al. [26] have analysed Rugby League match-play conditions to quantify positional specific physical demands of these athletes. Both authors suggest that this technology has

provided a resource to improve the ability of S+C coaches to prescribe training that is closer to simulating the physical demands of actual match play. As previously mentioned this technology presents a detailed picture of the external training load, which may be related to the athletes overall internal training load. In support of this contention, Lovell et al. [4] report strong relationships between GPS and accelerometers training load measurements and the athletes internal training load measure (sRPE) in rugby league. The results revealed that 62.4% of the variance in sRPE could be explained by GPS measures of distance covered, impacts and HR response.

There is evidence to suggest that GPS technology is considered to be the gold standard of external load quantification in outdoor field based sports [69]. However, there is a paucity of data exploring the use of this technology within indoor sports such as basketball. Due to the requirements of satellite technology when using portable GPS units outdoors, the application to the indoor setting has severe limitations and the technologies use in these scenarios has not been completely developed. Therefore to quantify player movements in indoor court based sports, such as basketball and netball, the use of tri-axial accelerometers have been implemented and investigated in order to assess their validity and relationship to other training load indices. Specifically, Montgomery et al [64] were able to quantify the physical load per minute between offensive and defensive drills and 5on5 and scrimmage in elite junior basketball athletes with the use of triaxial accelerometers. Physical load calculated from the accelerometers was moderately different between 5on5 scrimmage and live play (505 scrimmage = 171 ± 84 AU/min, live play 279 ± 58 AU/min; ES 1.17±0.65 AU). A potential issue that complicates external load monitoring in basketball via micro technology is the non-linear movements that involve short durations and moderate-to-high speeds performed during training and match conditions for example lateral defensive shuffling [9]. It has been reported within the literature that there is strong relationship between internal load and external measures in field sports (Table 2.4), this was not observed in basketball at the semi-professional level measured by accelerometer data [9]. This particular investigation reported a moderate relationship between sRPE and accelerometer external load ($r = 0.49$) in comparison to the reported strong relationships observed in football codes ($r = 0.74$-0.84) [9]. These findings are significant and there is potential for its application in the elite setting, however further investigations are needed to ensure the ecological validity and reliability of this method of load monitoring in court based sports. In addition, it is yet to be demonstrated whether this type of data collection can be analysed and interpreted in a time efficient fashion in order to have a meaningful impact on future planning and training load management within the team

environment. This is particularly relevant in the Australian professional league (NBL) where training load quantification is paramount as the majority of time is spent training in comparison to the NBA which features a considerable more amount of matches [18].

Time spent in training components: The total time duration spent training in each training component produces a reflection of the variability of the prescribed training. The in-season period poses considerable challenges for elite sporting teams as it often contains changing preparation times/days in order to accommodate match play [3], travel and cumulative fatigue associated with training. As previously mentioned coaches will often plan training based on external measures with frequency and duration (mins) of training being the most frequently modulated training factors, as they can have the greatest impact on the total training load. The addition or removal of a training session, the reduction or increase of time-spent training a particular component can have a subsequent physiological impact on an athlete, which could lead to alterations in the internal training load. As duration is present in the calculation of sRPE it is likely that similar relationships will be established between the total time-spent training and other training load measures. Specifically, quantification of the time spent in each mode/component of training can provide an insight in to how each component contributes to the total training load. A study by Coutts et al. [3] analysed the mean daily training load (sRPE) of 5-9 day breaks between matches and found that there were significant difference in internal training loads between a 5 to 6,7,8 and 9 day turn-around. The findings of this study suggest that the time spent in each training component was most likely modified to impact the total training load to account for the altered preparation times between matches. Furthermore, it is reasonable to suggest that varying the duration of a training session would impact training load (sRPE) the greatest as it is this one variable that the coach has complete control over when prescribing training loads. To the authors knowledge no study has reported on the use of quantifying external training load via the cumulated time spent in each training component for example team tactical, strength, and power session through a complete in season period of competition in elite basketball.

Overall, to the author's knowledge there is no agreed best practice in training load quantification for elite basketball presented within the scientific or coaching literature. Like other team-based sports there is a distinct relationship between the athlete's internal response and the external work completed by the athlete [4]. Future research exploring training loads in basketball should aim to quantify internal and external training loads during both off- and in-season periods. Increasing the overall understanding of the physiological cost

of elite basketball training will enable S+C coaches to improve training prescription, ability to monitor athletes and in turn affect athletic performance.

Performance Tests

Strength and conditioning coaches have long conducted performance tests to assess physical qualities, monitor performance improvements and evaluate an athlete's level of preparedness for competition or training [70]. The assessment of strength and power qualities can provide objective information that can be used to guide the athletes training process [71]. Sport specific, valid and reliable tests that reflect the physical demands of the sport can enable efficient data interpretation and information transfer which can be extremely useful when preparing athletes for elite sport. Conceptually, elite basketball can benefit from regular strength and power testing as successful basketball performance relies on highly developed muscular strength and power [15, 16], which is best represented by vertical jumping ability. Using specialised equipment such as force platforms, linear positional transducers and contact mats, different jump tasks (e.g. counter-movement, static and drop jumps) can produce accurate data on the performance of targeted lower body power qualities [72]. Of interest to this current investigation is whether drop jump performance is a valid testing method for the monitoring of fatigue and assessment of reactive strength abilities. Collectively, the relationship of jumping performance to measures of external and internal training load are also of particular interest to those who work in elite basketball environments.

Various vertical jump tests have been used to assess performance in athletic populations [10, 73-77]. It has been suggested that jumping tasks allow for the functional assessment of the stretch shortening cycle (SSC). The SSC is the basic muscle function observed in movements such as running, jumping or hopping, and is defined by a series of muscle actions, pre-activation, lengthening (eccentric) followed lastly by a concentric (shortening) action [78]. These movements when repeated place significant mechanical stress on the muscular system, quite frequently fatigue of the SSC is observed, the severity of which is related to the duration and intensity of the SSC activity [78]. Fatigue of the SSC is a complex mechanism and negatively effects performance, Figure 2.3 represents the theoretical framework presented by Komi et al. [13] which suggests a basic sequence of SSC fatigue induced performance reductions. In summary, there is an initial induced muscle damage and deterioration of muscle function that leads to a reduction in tolerance to impact load. There is then a loss of potential elastic energy production that results in an increase in the amount of work performed to push off during SSC activities such as jumping [13]. The physical and

perceptual side-affects associated with SSC fatigue may include delayed-onset muscle soreness, reduced muscular coordination and power production that has the potential to remain for several days [13, 78]

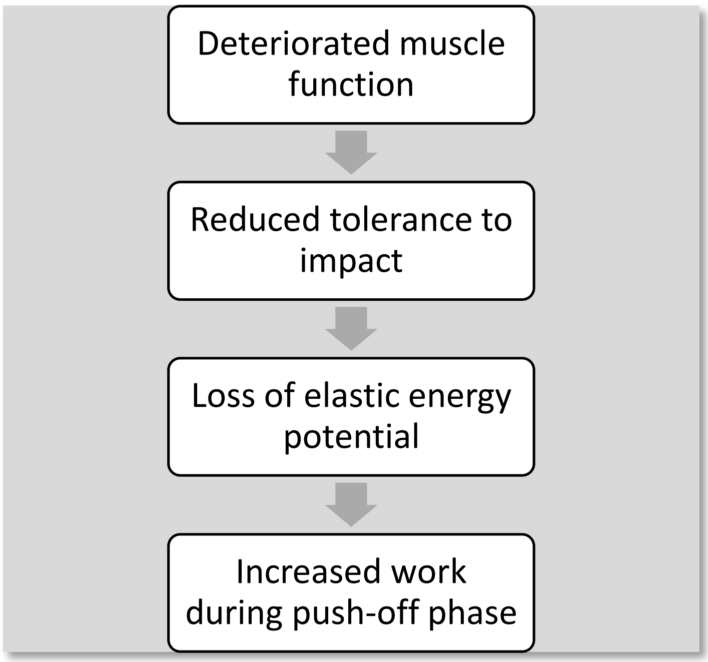

Figure 2.3: Proposed summary of SSC fatigue and relationship to performance reduction.

Note: Adapted from Komi et al. [13]

Jumping tasks or plyometric exercises are often categorized by their intensity rating, evaluation of the intensity rating can be gauged by the sum of peak powers measured through the ankle, knee and hip joints [79]. Jumping tasks that are classified as high intensity usually are more advanced techniques and require maximal effort to perform; an example is the drop jump. The 'drop jump', is an explosive vertical jump task where an athlete drops from a designated height and jumps as high and as fast as possible. This is considered a test of leg extensor muscle function and when performed with fast contact times (<250 ms) elicits a fast SSC response [80]. Drop jumps are extensively practiced in athletic development [81, 82], prescribed to improve muscular power and jumping ability [80], and require high levels of muscular strength, coordination and skill [82]. The common practice of drop jumps in testing and training programs are due to the underlying mechanisms involved when performed. Compared to alternative jumping styles for example counter-movement jumps (slow SSC, >250ms ground contact time) there is a high stretch load placed on the muscle therefore there

is a significant overload placed on the mechanical output of the muscles, hence higher power and force outputs are experienced [82]. The higher magnitude of force and power outputs can be influenced by biomechanical, technique factors and performing jumps from greater drop heights [82]. The typical technique used to perform a drop jump test involves the athlete performing a bounce like movement, where the athlete is cued to ‘jump as high and as fast as possible’ [80, 82].

It has been established that measuring drop jump performance will provide an indication of SSC function of particular relevance to the present investigation is the notion that fatigue of the SSC appears to peak 48 to 72 hours post exercise [10, 78]. Suggesting that a drop jump test may be an effective tool for monitoring the SSC response to training and the athletes overall response to the training process. Using jump mat technology, the variables of contact time (ms) and jump height (mm) can be recorded and analysed to provide a representation of an athlete’s reactive strength capabilities, which is often referred to as the reactive strength index (RSI) [83] . Recently, the RSI has been assessed with athletic populations to monitor the performance of the SSC [11, 73, 74, 76, 77, 84, 85]. Effectively, this test is typically used to assess an athlete’s capability to produce maximal force in minimal time [11, 73]. Fundamentally, this test involves a drop jump task from a nominated height on to a force platform or contact mat, from which the RSI is then calculated based upon the jump height achieved and the ground contact time (Equation 2.3) [86].

Equation 2.3: Reactive Strength Index Equation:

RSI = jump height (millimetres) / ground contact time (milliseconds)

The RSI has been demonstrated to be an effective index to evaluate plyometric conditions [11], as previously mentioned the definition of fast and slow SSC performance is dependent on the ground contact time of the task being performed. The physical and neuromuscular requirements of fast versus slow SSC activities differ significantly; the use of a drop jump provides conditions most appropriate for the analysis of fast SSC performance as previously mentioned. Since the RSI test can be automated with computer technology this method of evaluating the SSC performance provides a reliable, valid and time efficient test when working with large groups [87, 88]. A further benefit of the RSI is the ability to create a

jump profile of an athlete's SSC capacity or tolerance to increasing stretch-loads [73]. Performing drop jumps incrementally for example from 20-50cm and recording the respective RSI will produce a reflection of an individual's SSC capabilities [72]. This profile in turn identifies the critical threshold when the drop height and downward velocity is too great there is a subsequent performance decline [11, 73]. This can be observed as an increased contact time (>250 ms), the inability to maintain correct jumping technique and most obviously a decreased RSI value. Newton et al. [72] suggest that the optimal box jump height for an individual can be identified as the box height that corresponds with the highest RSI value. An example RSI profile is presented in Figure 2.4. Specifically, this example curve is based upon an incremental box jump assessment and illustrates the difference between two athletes' reactive strength abilities. In this example, athlete 1 demonstrates a superior tolerance to higher drop heights, as the RSI values increase as the drop height increased up to 40cm (optimal height), in contrast Athlete 2 has poor reactive strength ability as seen with the RSI values decreasing with the increase in box height (optimal drop height is 20cm). This individualised approach to athletic profiling has been suggested to be a good tool for guiding future training prescription that could allow for maximal performance adaptation, the minimisation of injury risk [73] or the monitoring of individual athlete progress.

Whilst the profiling of reactive strength capabilities has been practiced for years only recently has the reliability of this protocol been assessed in an athletic population. The higher the drop height the greater the physical demand required for the optimal drop jump performance suggesting that the changing conditions should express varying levels of reliability. Previous investigation established that the 30cm drop height expresses high reliability (ICC ≥ 0.90) [87], though it is currently unknown whether the same level of reliability is observed when the RSI is performed from higher or lower drop heights with basketball players.

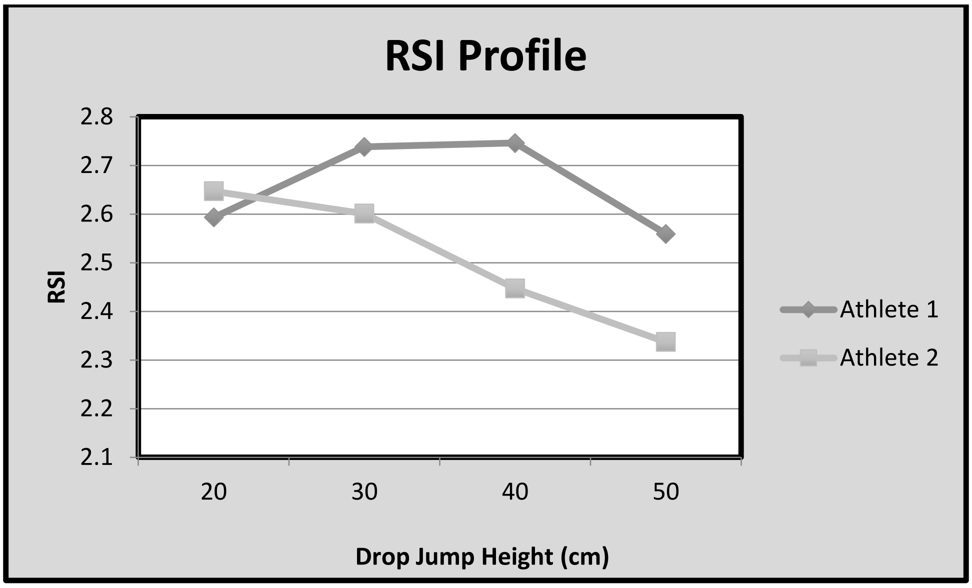

Figure 2.4: Profile of an incremental drop jump assessment.

The RSI has been demonstrated to be a reliable test to assess the functional capacity of the SSC, has demonstrated overall high level of reliability [87], and may be a useful neuromuscular fatigue monitoring tool. Theoretically, RSI performance could be influenced by the cumulative fatigue incurred from the prescribed training load and with appropriate analysis relationships between RSI performance and internal and external training load measures could be apparent. This theory has been successfully tested in Olympic level female field hockey, where the RSI has been used as a component of a comprehensive monitoring program designed to track how effectively a squad of athletes tolerate the prescribed training and matches played [84]. The authors established that the RSI, through the time course of preparation for international competition, is related to internal (sRPE, wellness questionnaires, hormonal response, menstrual cycle) and external training load measures (volume load (kg))[84]. At the squad level the average RSI performance identified the effectiveness of the different loading strategies employed during the individual micro and mesocycles. Additionally, the RSI values were related to an overall index of performance (win/loss) and the athlete's perceived recovery status. Monitoring of these variables may allow for the manipulation of future preparation for improved team performance or to better monitor and manage the training stress encountered by individuals within the team. At the individual level, the authors utilised two statistical approaches, to analyse whether a significant change in performance was experienced. First, the RSI was performed 3 days per week, for monitoring purposes with the current score being assessed in relation to the individuals rolling average.

Secondly, difference of more or less than one standard deviation from the mean determined whether the athlete was okay, stable or bad [84]. Poor performance was considered to be reflective of inadequate recovery and individual training modifications were made based upon the individual athletes RSI profile. Collectively, this example demonstrates that the information garnered from this type of testing may be utilized to guide the training process as well as balance the training load and recovery interventions [84].

There is potential for the RSI to be used in the monitoring process in basketball, given the involvement of the SSC on jumping performance, which is an important aspect of the sport. However, to the authors' knowledge the use of the RSI as a preparedness-monitoring tool has not been investigated with elite level basketball players. To the author's knowledge the only one study has examined the use of the RSI with basketball players (Division I Collegiate Female athletes). This study used the drop jump test to determine the relationship between drop jump performance (RSI) and the athletes perception of recovery as indicated by a stress and recovery questionnaire [77]. Across the season testing was conducted in the pre-season (3 testing points) and in-season period (4 testing points) to analyse various measures from a drop jump task including the RSI. The findings of this investigation reported a decrease in RSI performance from T1 0.651 ± 0.25 – T5 0.599 ± 0.18, ($p=0.027$) coinciding with a significant difference in total recovery stress score ($p = 0.001$), global recovery ($p= 0.001$) and global stress score ($p= 0.01$). The authors' findings support the implementation of objective and subjective monitoring techniques to manage basketball athletes' in-season. This investigation forms a strong foundation for the development of a training load monitoring program for basketball athletes, to further develop on this approach future investigations should established between changes in drop jump performance and alternative training load measures. Of interest to this particular investigation is to establish the potential relationship between sRPE values and performance of a drop jump task expressed by the RSI.

The need for training load monitoring in Basketball

Quantification of training load is suggested to be a central component in fatigue monitoring in professional sports in Australia [1]. Within Australia, the monitoring process is considered a crucial aspect necessary to optimize the athlete's performance capacity in professional sport. Recently, results from a survey of current trends in high performance sport published by Taylor et al. [1] highlighted that while 70% of respondents place equal focus between training load quantification and fatigue/recovery monitoring, 20% of participants solely focused on training load quantification alone. These results are supportive of developing a monitoring program that is multi-dimensional to manage training loads, sole focus on one element i.e. recovery could be detrimental to the athlete. Commonly elite sport programs in Australia will incorporate the use of subjective and objective measures to manage training load holistically [89]. Self-reporting questionnaires, physical screenings and sRPE combined with markers of hormonal and neuromuscular status are commonly used strategies [2, 89]. Table 2.6 provides an example of training-load management in elite Australian Rules Football (AFL).

Table 2.6: Load and fatigue monitoring program in elite Australian Football.

Frequency	Monitoring/Measuring Tool
Annually	Agreed Training Philosophy Load selection, interventions Periodisation
Monthly	Multi-Component Training Distress Questionnaire
Weekly	Neuromuscular Fatigue (1/week) Hormonal Status (1day/week) Load, monotony and strain (calculated from sRPE)
Sessional	Pre-training Wellness Questionnaire (3/week) Screening – Physiotherapist, Dietician, Sleep assessment Rated Perceived Exertion.

Notes: Adapted from Cormack et al. [89].

Professionals in Australian high performance sports implement training load monitoring to prevent overtraining and injury, to assess the efficacy of training interventions, and to maintain performance in-season [1]. In professional rugby league a distinct relationship between training load and injury incidence is apparent. Specifically, during the preseason period the odds of an athlete experiencing an injury is increased (1.50 – 2.85) for each arbitrary unit increase in training loads (155 and 590 AU, $p < 0.01$) [90]. Arguably the opposite scenario can also exist, if an athlete has not completed the necessary training negative physical side-affects such as delayed recovery times and potentially injury can occur [21, 90]. This highlights the importance of quantifying and monitoring training loads effectively [6]. Such information can then be used to prevent injury by developing an understanding of individual's tolerance to the prescribed training load and serve as a tool to assess their ability to recover from the imposed training stress. Support for this contention can be seen in basketball and rugby league where this type of information is used to plan the training cycles contained in the periodised training plan [3, 7]. The planned training load can be analysed comparatively to the actual training load perceived by the athlete, not only can better decisions be made in the best interest of the athletes health and wellness but this information can be useful for determining team selections and gauging an athlete's level of readiness to perform [2]. These are amongst a host of reasons of why the quantification of training load in professional sport is paramount.

There is no agreed upon best practice for training load quantification in elite basketball. The most applicable work to date in the area has been presented by Manzi et al. [7] where a significant relationship ($p<0.001$) between individual sRPE and HR based measures of training load have been established. More recently internal load parameters of perceived exertion and the salivary hormone response have been quantified in relation to official and simulated match play [35]. These findings have significant standing for the quantification of elite men's basketball in the future, but neither study adequately account for the complete training load experienced by these athletes. For example, the load experienced during strength and power training was not included in the overall training load quantification in these studies. There have been further developments in elite female basketball in identifying a more complete training load management approach. Over a 12 week preparatory period training load was quantified via internal measures of sRPE, recovery-stress questionnaires and immune-endocrine response as well as various performance markers [37]. The results show that sRPE method is a favourable approach to measure ITL and that the recovery-stress and immune-endocrine responses reflected a successful periodisation strategy leading in to a competition [37]. Another investigation looked at the short-term inflammatory and

performance effects of a professional basketball match [28]. Analysis of blood markers demonstrate that a basketball match evokes a moderate inflammatory response, which has a negative effect on performance between 24-48 hours post match for example jump performance (ES = 0.6, $p < 0.05$) [28]. The mentioned studies both illustrate the effectiveness of training load monitoring in elite basketball, the limitations of these studies are the short time frames they have investigated, future research should investigate the time-course of a professional basketball season. It is acceptable to conclude that both internal and external measures are able to represent an athlete's training load, incorporating both in a monitoring program has been suggested to improve a programs scope and overall functionality [2].

Consideration must be given to the physiological and movement demands of a sport before implementing measures to quantify training load with the aim of forming a monitoring program. At the elite level training load monitoring programs must be effective at efficiently capturing relevant data, that can be reported quickly and that can distinguish between team and individual responses [2]. When examining the scientific literature there is evidence to suggest that HR and sRPE [7, 8, 64, 91, 92] both of which have been assessed at elite, sub-elite and youth basketball populations, are reliable measures for the quantification of the internal load.

Conversely, there is a paucity of research on external load monitoring in basketball. For example, one study has assessed the external load of junior basketball players using tri-axial accelerometers, and this technology enabled the measurement of the difference in physical load between training drills and live play [64]. More recently at the semi-professional level in Australian basketball the relationship between the internal response to external measures of training load were only moderate ($r = 0.49$, $p < 0.001$) potentially due to the unique movement demands of basketball [9]. The lack of consensus on the best methods of training load monitoring in elite basketball necessitates further research to better understand the demands placed on these athletes in all facets of basketball performance training. In particular in Australian basketball the demands on the athlete are vastly different to the well establish leagues of USA and Europe. Australian basketball is characterized by less official matches and a greater time spent training for competition. Therefore, the present study aims to quantify internal measures of sRPE and to external measures of the time spent in each training component to represent the total training load experienced by professional Australian basketball athletes. In addition, the RSI will be employed as an indicator of fatigue status and the performance of this test will be assessed with the aforementioned internal and external measures to establish any relationship (Figure 2.5).

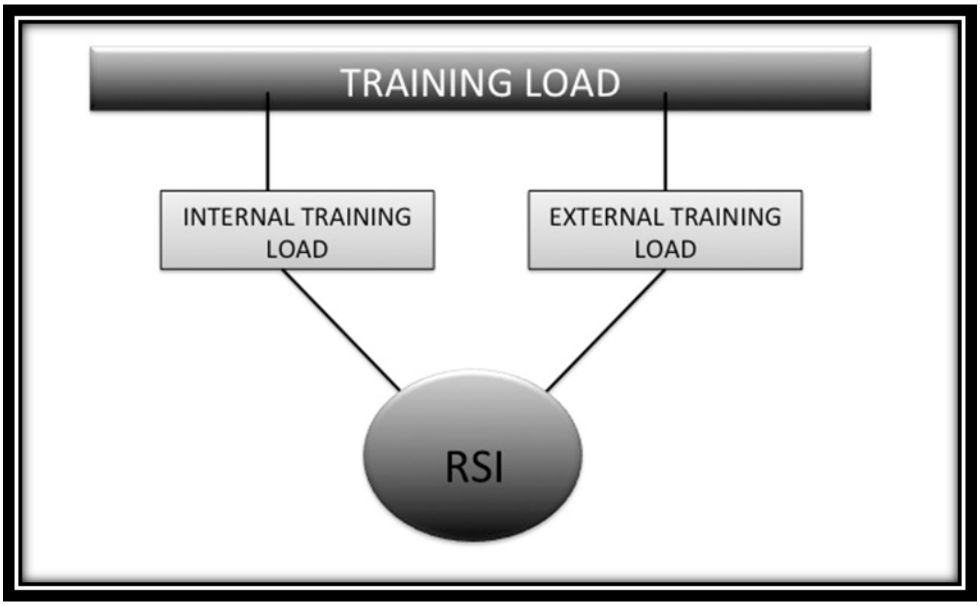

Figure 2.5: Theoretical framework to present investigation.

Chapter 3 – Experimental Study 1

Title: The intraday reliability of the reactive strength index (RSI) calculated from a drop jump in professional men's basketball.

Markwick WJ, Bird SP, Tufano JJ, Seitz LB, and Haff GG. The intraday reliability of the reactive strength index (RSI) calculated from a drop jump in professional men's basketball. *International Journal of Sports Physiology and Performance.* 10: 482-488, 2015.

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Introduction

Strength and conditioning professionals have long conducted performance tests to assess physical qualities, performance improvement and evaluate an athlete's level of preparedness for competition or training[70]. The assessment of strength and power qualities provide objective information that has the potential to impact training or competitive performance[71]. Conceptually, elite basketball players can benefit from regular strength and power testing as successful basketball performance relies on highly developed muscular strength and power [15]. Specifically, jumping tasks rely on the ability to express high levels of strength and power. When examined from a movement perspective the ability to jump plays a large role in dictating basketball performance. As such, tests that target vertical jumping capacities are of paramount importance in a basketball-monitoring or testing program.

Various vertical jump tests can be used to assess performance capacities in athletic populations and give insight into the ability to engage the stretch shortening cycle (SSC) [10, 12, 73-77]. There are two distinctly different SSC responses that are defined by the rate at which they are engaged [80]. The slow SSC response (sSSC) requires a longer contact time (>250ms) to produce a powerful muscular action, while fast SSC (fSSC) responses occur in <250ms [93]. The countermovement jump (CMJ) is a sSSC activity that has been determined to be a reliable assessment of jumping ability and neuromuscular performance in a plethora of athletic settings [12, 33, 74, 94, 95]. One type of jumping test that examines the fSSC is the drop jump test [80]. These tests require the athlete to drop from a designated height and then immediately perform an explosive vertical jump [96]. Typically, drop jumps are performed onto either a jump mat or force platform in order to determine contact and flight time, as well as estimate vertical jump displacement [87]. Manipulation of the drop height enables different jump characteristics to be observed, with drop heights from 12 to 90 cm reported in the literature [96] Previous drop jump investigations have examined the SSC response by measuring contact time at different drop heights, specifically at drop heights that elicited the greatest jump displacement [80, 96].

In addition to determining the type of SSC, the flight and contact times collected during a drop jump can be used to calculate the reactive strength index (RSI) [73, 87]. The RSI is typically used to profile stretch-load tolerance and to identify optimal drop heights for the performance of drop jump training [11, 73, 74, 76, 77, 84, 85]. The RSI is calculated with the following equation:[86]

RSI = flight time (ms) / contact time (ms)

More recently, the RSI has been reported as an athlete-monitoring tool in order to evaluate the athlete preparedness [72, 84]. While the assessment of the RSI from a drop jump test is easy to conduct, the ability to reliably perform the test may be predicated by the drop heights and more importantly the commands given to the athletes during the test [80]. A previous investigation reported that jumping technique can significantly impact the results of the drop jump assessment [96]. The use of standardised commands such as “jump as high and as fast as possible” are recommended to ensure consistent jumping performance [80].

While the assessment of the RSI from a drop jump test has increased in popularity, there is a paucity of research examining its reliability, especially with various drop heights. This is an important consideration because if the RSI is to be used as an athlete monitoring tool, a high level of reliability is necessary in order to determine meaningful changes in performance [94]. This becomes even more critical in the context of drop jump heights as a variety of heights are used when assessing athletes [96]. Additionally, one of the practical applications of the drop jump test is to create a ‘drop jump profile’, which can be used to produce a graphical representation of the RSI or JH performance at the different drop heights [72]. When the JH is used to create this profile it is often compared to the CMJ height giving insight into the athlete’s reactive strength capabilities. While using various drop jump heights is becoming more common, it is possible that different drop heights may demonstrate diverse reliabilities.

When examining the literature, the RSI has been reported to have a high intraday reliability (ICCα ≥0.90) when performed from a 30 cm drop height [87]. Whilst this information is valuable, to our knowledge there have been no comprehensive investigations examining the within session reliability of the RSI calculated from a drop jump performed from incremental drop heights with team sport athletes such as professional basketball players. Therefore, it is beneficial for practitioners and researchers alike to determine the reliability of the RSI calculation in order to maximise its diagnostic capacities.

Performance tests in the elite environment must display high levels of reliability in order to be used to monitor athletic performance. It is critical testing protocols and procedures reflect best practice to ensure the results are reliable and allow for appropriate analysis. This involves determining the correct preparation routine and most importantly the minimum number of trials required to achieve appropriate standards of reliability. A previous investigation suggests that a drop jump from a 30 cm drop height requires only one trial to be

performed as the results between trial-to-trial demonstrated extremely high reliability [87]. The present study aims to expand on this finding by analysing the reliability of a variety of drop heights including 20, 30, 40 and 50 cm and determine the minimum number of trials. This is important as it is has been established that performing drop jumps from higher drop heights (40-60 cm) places greater stress on the joints of lower extremities, which contributes to an increased demand on neuromuscular system for successful performance and therefore could influence the reliability the results of the test [79, 80, 96]. Establishing the reliability of a variety of drop heights could strengthen the application of the drop jump profile used to analyse an elite athlete's reactive strength capabilities.

Therefore, the present study aimed to evaluate the intraday reliability of the RSI and JH performance from multiple drop heights in an elite basketball population.

Methods

Participants

Thirteen professional male athletes competing in the National Basketball League (mean ±SD: age 25.8 ± 3.5 y, height 1.96 ± 0.07 m, mass 94.8 ± 8.2 kg) were recruited to be participants in the present study. All participants were free from any lower body injuries that could impact their jumping performance at the time of testing and had completed a comprehensive medical screening as a part of their professional team's medical protocols. All participants had a minimum of 2 years experience in strength and power training and provided written consent for this University Research Ethics Committee approved project prior to the commencement of testing.

Design

The present study employed a quasi-experimental design to examine the reliability of the RSI measurement calculated from a drop jump performed from various drop heights (i.e. 20, 30, 40, and 50 cm) and a CMJ test that were performed in a randomized order. All subjects were familiarised with the testing protocols prior to the testing session. All testing was conducted in the morning (0800-0900) on the first day of the training week 48 hours after the participant's last training exposure.

Methodology

Two familiarisation sessions were completed prior to the testing session in order to insure that the athletes were familiar with the appropriate performance of the drop jump and CMJ tasks. During these sessions all participants were instructed in the specific technique requirements of the drop jump and CMJ and were given a sufficient number of attempts to ensure that they were able to perform the test correctly. The technical criteria involved initiating the drop jump by stepping one foot off the box at a time, on ground contact keeping the heels from hitting the ground, not tucking the feet whilst in the air and remaining on the jump mat when they had completed the jump.

Prior to the commencement of the testing session, the participants followed a structured dynamic warm-up protocol consisting of, movement preparation (squatting, lunging and hinging), stationary cycling (5 min), dynamic stretching (leg swings), various running drills (A skips, B skips, side skips), CMJ, CMJ with bounce and ankle jumps. This dynamic warm-up was chosen based upon previous published literature that suggests greater jumping performance can be stimulated with this type of warm-up.[12]

Drop Jump Test

The participants held a carbon fibre pole across their shoulders in order to restrict arm movement.[80] Each participant performed 3 maximal jumps on an electronic jump mat (kinematic measuring system, Fitness Technology, South Australia) at each of the 4 randomly assigned drop jump heights (20, 30, 40 and 50 cm box; 12 jumps in total). Each jump was separated by 1 minute of rest and 3 minutes of recovery was given between each drop jump height. To initiate the drop action, participants were instructed to 'step out' from the box one foot at a time and to not jump from the box. They were also instructed to "jump as high and as fast as possible" upon landing [80]. In order for a trial to be deemed acceptable, the participants were required to remain on the jump mat after landing. Each jump was carefully scrutinised and was deemed unacceptable if the participant lifted their feet (tuck) during the flight of the jump or jumped forward off the jump mat. Based upon previous investigations, instructional feedback was provided after each jump trial in order to provide motivation to the participant [80, 96]. Successful trials had to meet the contact time cut off of <250ms to standardise jumping technique and to ensure utilisation of fSSC [93]. Specifically, participants were continually instructed to "jump as high and as fast as possible" and to "try and beat" their previous attempt. The electronic jump mat interfaced with the computerised software kinematic measuring system (KMS) (Fitness Technology, South Australia) was used to collect all

drop jump data. Measurements of flight time and contact time were recorded in milliseconds (ms) and the flight time to contact time ratio (RSI) was determined.

Countermovement Jump Test

Each participant performed 3 maximal CMJ attempts separated by a 1-minute of recovery period. CMJs were performed on a force plate (400 series force plate – Fitness Technology, SA, Australia) connected to computer software (Ballistic Measurement System – Fitness Technology, SA, Australia) that sampled at 600 Hz. Participants held a carbon fibre pole across their shoulders to standardise arm movement. The participants were instructed to use a self-selected depth and to jump as high as possible, in accordance with previously established jump assessment methods [12].

Figure 3.1: Participant performing a drop jump on to an electronic jump mat.

Statistical Analysis:

The means and standard deviations (SD) were calculated for each drop height and CMJ. A one-way ANOVA was performed to compare the JH and RSI achieved during each drop jump assessment. When significant differences were noted, pair wise comparisons were performed in conjunction with a Holm's sequential Bonferroni to control for type I error [97]. Finally a 1x4 (RSI) and 1x5 (JH) repeated measures ANOVA was performed to determine the difference between the performance at each drop height.

Reliability analyses were performed using a pre-designed Excel spread sheet [98]. Trial to trial reliability analysis was calculated for each jump height and RSI measurement. Reliability was assessed with the use of the coefficient of variation (CV) and the ICC coupled with 90% confidence intervals (CI). Typically the first criteria for determining if a test is reliable is to set the CV ≤ 10% [12]. In the present study the upper CI was set at a CV ≤ 8% based upon previously published reliability studies on jumping tasks and to maximise the potential usefulness of the measurement [99]. The second reliability criteria was that the lower CI cannot be ICCα < 0.80 [100]. The test/variable was only deemed to be reliable when both reliability criteria were met.

The typical error (TE) was calculated by dividing the standard deviation by the square root of 2 (SD/√2) in order to provide a reflection of the noise within the test caused by biological or technical aspects [100].

Results

There was no significant difference ($p \leq 0.05$) between the 3 trials completed at either the 20 cm, 30 cm, 40 cm and 50 cm drop heights for the RSI calculation (Figure 3.2). Similarly there was no statistical difference between the 3 trials at all drop heights for the JH (Figure 3.3) and CMJ variable.

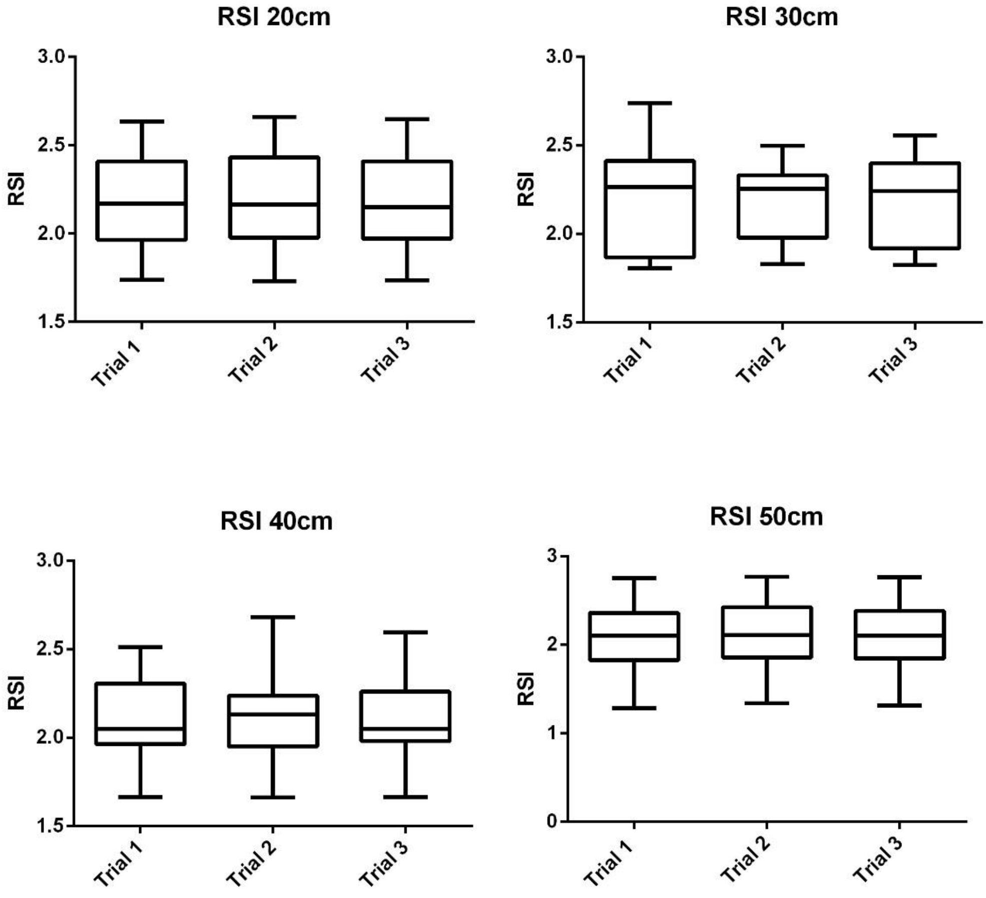


Figure 3.2: The mean and range for all 3 trials performed at the 20cm, 30cm, 40cm and 50 cm drop heights for the reactive strength index.

Notes: There was no significant difference in the means (p ≤0.05) between the trials at all drop heights.

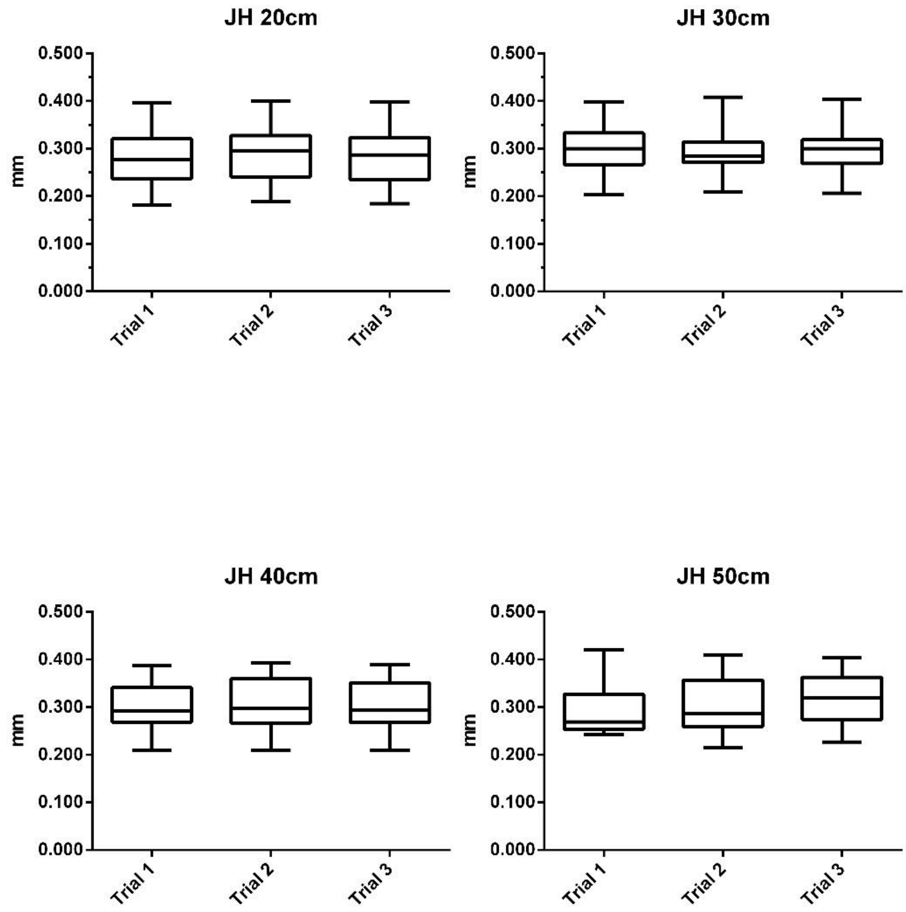


Figure 3.3: The mean and range for all 3 trials performed at the 20cm, 30cm, 40cm and 50cm drop heights for the jump height variable.

Notes: There was no significant difference in the means ($p \leq 0.05$) between the trials at all drop heights.

A summary of the reliability statistics for the RSI is displayed in Figure 3.4 and Table 3.1. The 20, 40 and 50 cm drop heights resulted in the most reliable measures for the RSI. Specifically, the 20cm drop height resulted in a CV = 3.1% and an ICCα= 0.96 the 40 cm drop height resulted in a CV= 3.0% and an ICCα= 0.95, while the 50 cm drop jump height resulted in a CV= 2.1% and an ICCα= 0.99. Additionally, the 20, 40, and 50 cm drop heights displayed a high (>0.90) single-measure and average measure ICC for the RSI (Table 3.2).

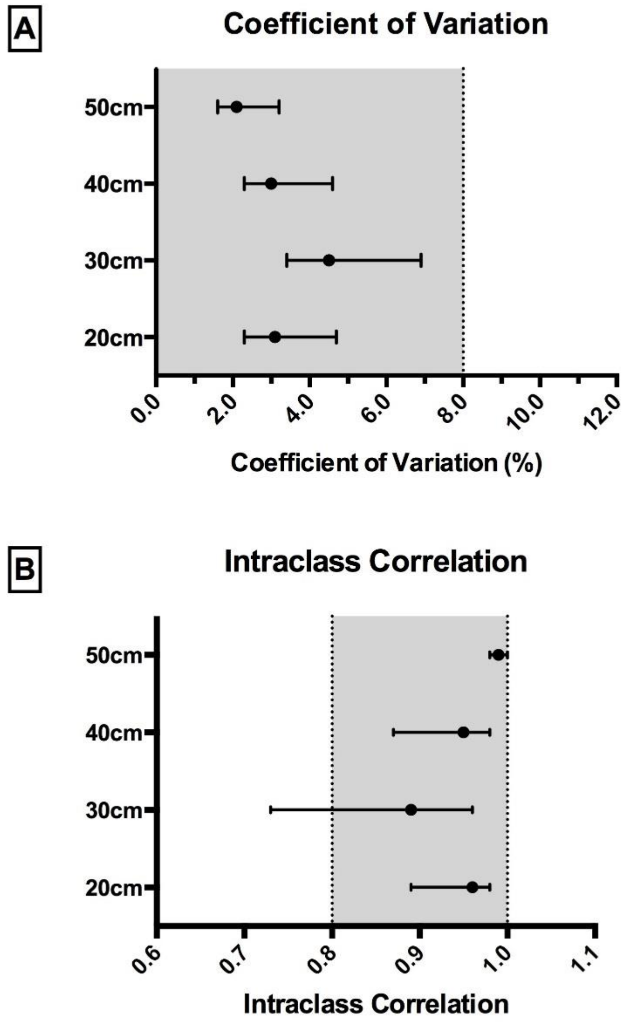


Figure 3.4: Coefficient of variation (A) and intraclass correlation (B) for the reactive strength index.

Notes: Graph A - the shaded area represents the set range for CV% (≤ 8%) as the minimum criteria to determine reliability.

Graph B – the shaded area represents the ICCα ≥ 0.80 cut off value to determine the reliability of the test.

Table 3.1: Reliability statistics for the reactive strength index.

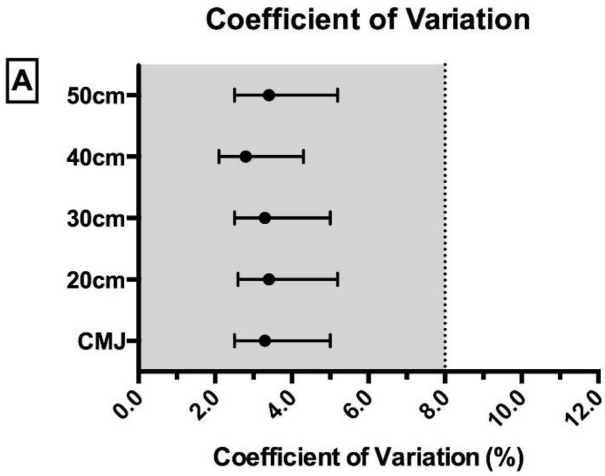
	Mean	SD	TE	Lower 90% CI	Upper 90% CI
20cm	2.189	0.29	0.07	0.05	0.11
30cm	2.208	0.26	0.39	0.30	0.59
40cm	2.126	0.26	0.07	0.05	0.10
50cm	2.083	0.41	0.09	0.07	0.14

Notes: Values are reported as mean, standard deviation (SD), typical error (TE) and 90% confidence intervals (CI). There was no significant difference in the means ($p \leq 0.05$) of all the drop heights.

Table 3.2: Reliability – Single and Average Intraclass Correlations

Variables		Intraclass Correlation					
		Single Measures			Average Measures		
Reactive Strength Index	20 cm	0.942	0.821	0.982	0.970	0.901	0.991
	30 cm	0.847	0.574	0.951	0.917	0.729	0.975
	40 cm	0.933	0.797	0.979	0.965	0.887	0.989
	50 cm	0.991	0.972	0.997	0.996	0.986	0.999
Jump Height	20 cm	0.979	0.934	0.994	0.990	0.966	0.997
	30 cm	0.960	0.874	0.988	0.979	0.933	0.994
	40 cm	0.972	0.911	0.991	0.986	0.954	0.996
	50 cm	0.969	0.900	0.990	0.984	0.948	0.995

When the JH variable was assessed for reliability, the 40 cm drop jump height resulted in the highest reliability as indicated by a CV= 2.8% and an ICCα= 0.98. All other drop heights produced ICC values >0.90, and met the CV% criteria (≤ 8%). A summary of the reliability statistics for JH is displayed in Figure 3.5 and Table 3.3. Additionally, all drop heights displayed a high (>0.90) single-measure and average measure ICC for JH (Table 3.2).



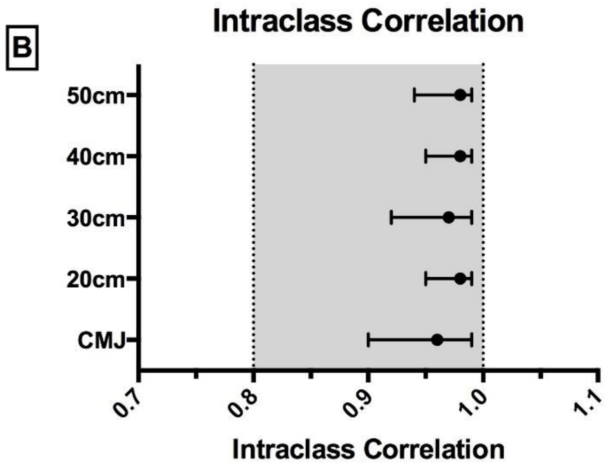


Figure 3.5: Coefficient of variation (A) and intraclass correlation (B) for jump height.

Notes: Graph A - the shaded area represents the set range for CV% (≤ 8%) as the minimum criteria to determine reliability.

Graph B – the shaded area represents the ICCα ≥ 0.80 cut off value to determine the reliability of the test.

Table 3.3: Reliability statistics for the jump height variable.

	Mean	SD	TE	Lower 90% CI	Upper 90% CI
CMJ	0.360*	0.05	0.18	0.13	0.27
20cm	0.286	0.06	0.14	0.11	0.22
30cm	0.297	0.05	0.20	0.15	0.30
40cm	0.304	0.06	0.02	0.13	0.25
50cm	0.304	0.06	0.16	0.12	0.25

Notes: Values are reported as mean, standard deviation (SD), typical error (TE) and 90% confidence intervals (CI).

*= Significantly different ($p \leq 0.05$) than 20, 30, 40 and 50 cm.

Discussion

The primary finding of the present study was that both the RSI and JH variables determined from all drop heights expressed acceptable reliability as indicated by a CV (≤ 8.0) and ICCα (>0.80). Secondarily, there were no significant trial-to-trial differences ($p>0.05$) between each of the three trials used to determine the RSI or JH measurement at each individual drop jump height assessed (Figures 3.2 & 3.3).

The results of the RSI are in line with a previous study assessing RSI performance of collegiate track and field athletes [87]. Slightly lower ICCα values (30 cm; ICCα= 0.89) were found in the present study when compared to the work of Flanagan et al. [87] who reported an ICCα of 0.99 for a 30 cm drop jump height. Importantly, the 30 cm drop jump height met the pre-determined criteria for acceptable reliability (ICCα >0.80) in the Flanagan et al. [87] and the present study. However, in the present study, the ICC lower 90% CI of the 30 cm drop jump height (ICCα= 0.73) was below the acceptable cut-off for the ICCα (ICC >0.80) suggesting that it may be more appropriate to utilise either higher or lower drop heights when monitoring the RSI with professional basketball players. Indeed, the 20 cm, 40 cm and 50 cm drop heights displayed excellent reliability for the RSI in the present study as the mean and 90% CI were both above (ICCα) or below (CV) the threshold criteria for acceptable reliability (Figure 3.4).

This is an important finding for coaches and researchers who intend to use the RSI with professional basketball athletes. In order to ensure reliable testing, the present results suggest that drop jump heights at 20cm, 40 cm and 50 cm will result in a more reliable method for determination of the RSI.

Regarding JH during the drop jump test, all drop heights used were reliable based upon both criterions for reliability established in the present study. The JH achieved from all the various jump heights exceed the criteria established for reliability with the ICCα >0.90 (ICCα = 0.97 - 0.98) and the CV < 8.0% (CV= 2.80-2.60%). These findings support the work of Flanagan et al.[87] who reported that JH from a 30 cm drop height was very reliable (ICCα >0.99).[87] Based upon the present data and the reliability criteria established for this study, the 40 cm drop jump resulted in the highest reliability (ICCα = 0.98; CV= 2.8%). Collectively the JH data is in line with the results of the RSI data in the present study with the higher drop heights resulting in marginally higher levels of reliability, specifically at the 40 cm level. Additionally, the CMJ test had higher levels of reliability (CV = 3.3%, ICCα = 0.96), in comparison to similar published data on professional Australian football athletes (CV =5.2%) [12].

The high levels of overall reliability of both the RSI and JH data may be attributed to the standardisation of the jumping technique and the coaching cues given to the participants. Previous research has shown that both of these factors influence jumping performance greater than the height of the drop [80, 96]. For example, instruction provided about ground contact time produced clear differences in the jumping characteristics. Additionally, the feedback provided to the participants between trials may have improved the performance outcome [80, 96]. Therefore, based upon the current body of scientific knowledge and the results of the present study, it is critical that a protocol including standardised instructions is needed in order to ensure the highest testing reliability is achieved during drop jump assessments.

Finally, analysis of the trial-to-trial performance of all the drop heights for both the RSI and JH measures recorded no statistical difference (Figure 3.2 & 3.3). These results support the findings of Flanagan et al.[87] who reported that only one trial may be necessary when calculating the RSI from the 30 cm drop height. The results of this investigation expand and further strengthen the contention of Flanagan et al. [87] that one trial would be acceptable when assessing the RSI at the 20,40 and 50cm level (30cm did not display appropriate reliability) and JH with drop heights from 20-50 cm with this population. Ultimately, the ability to assess the RSI and JH from drop jumps with one trial has the potential to improve time

efficiency and injury minimisation when using a drop jump assessment with large groups. Future research needs to assess the inter-day reliability of both the RSI and JH in order to address whether these measures are able to detect the smallest worthwhile change.

Another potential use of the drop jump test is the development of a player's reactive strength profile. Specifically, Newton et al.[72] suggests that the most effective way to assess an athlete's reactive strength capacity is to profile the JH or RSI achieved from an incremental drop height protocol [72]. Although drop heights from 30 cm to 75 cm is a common prescription for the drop jump test, to our knowledge there has been no investigation on the reliability of this particular methodology. In addition, a CMJ is performed and the JH is analysed comparatively to the jump displacement recorded from each of the drop heights. An athlete who is considered to have excellent reactive strength capabilities will elicit greater jump heights from a drop jump task in comparison to a CMJ [72]. Well-trained athletes have highly developed SSC responses compared to untrained populations and are able to absorb higher eccentric velocities and quickly produce powerful concentric muscle actions resulting in superior jump performances in drop jumps compared to CMJ. The present study implemented a randomised protocol that tested drop jumps from 20 to 50 cm in 10 cm increments. All drop heights and the CMJ demonstrated extremely high reliability when assessing the JH variable. These results strengthen the argument for the use of this testing protocol as a tool to profile the reactive strength capabilities of professional basketball athletes. Specifically, ensuring appropriate contact times (<250ms) the JH variable appears to be the most appropriate variable to use when creating a drop jump profile considering it is reliable at all drop heights, only one trial is required and can be related to the CMJ height. Additionally, the comparison between the JH of the CMJ and drop jumps provides a reflection of reactive strength ability.

Practical Application

The results of the present study provide evidence that the 20, 40 and 50 cm drop height are the most appropriate for the assessment of the RSI calculated from a drop jump test. Ensuring appropriate familiarisation and the implementation of a standardised warm-up and testing protocols only one trial appears to be necessary when assessing either RSI or JH from 20-50 cm drop heights. If time permits two to three trials could be performed with the assessment of maximal drop jump performance. Further research is warranted to determine if

the RSI measurement is reliable on an inter-day basis with the scope to monitor athlete preparedness.

The JH measure appears to be the most useful variable for creating a reactive strength profile as it can be easily related to CMJ performance. Additionally, when creating this profile the present data suggests that only one-drop jump is need at each of the box heights tested when creating an athlete's profile. However, further research is needed to determine how this profile may change in response to structured training during preparatory and competitive periods associated with the sport of basketball.

Chapter 4 – Experimental Study 2

Title: Title Does session RPE relate with reactive strength qualities? A case study investigation within the National Basketball League

Journal of Strength & Conditioning Research (In Review)

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Introduction

The quantification of training load is essential when monitoring an athlete’s response to a training stimulus. Additionally, it ensures that positive training adaptations are translated into an advantageous performance in competition [2, 3]. According to Impellizzeri et al. [101], the quantification process can occur either internally (i.e. physiological constituents) or externally (i.e. movement production/outcome constituents). Thus, to gain a comprehensive profile an athlete’s training load, professional sporting organizations commonly incorporate both internal and external assessments.

A successful performance in team sporting contexts is often attributed to the interaction with multi-factorial skill qualities. Within basketball, for example, players are often required to possess proficient technical skills that broadly encapsulate different aspects of ball disposal; physical attributes inclusive of jumping and landing; and tactical qualities that encapsulate decision-making and pattern recall skills. Given this diversity, difficulties can be encountered when prescribing a training dosage that facilitates a positive multi-factorial development, but does not place an athlete at risk of injury or illness due to non-functional overtraining [3]. Fortunately, a simplistic, yet effective, technique for quantifying an athlete’s internal training dosage could be to monitor their rate of perceived exertion (RPE) during specific training modalities and/or sessions [49]. More directly, obtaining an athlete’s session-RPE (sRPE) following the conclusion of a training stimulus has been shown to provide a valid measure of exercise intensity within team sporting contexts [3, 5, 7]. Consequently, an athlete’s sRPE is often used to calculate an arbitrary training load value; where it is multiplied by the session duration (in minutes) to provide a coach with a measure of an athlete’s internal training load.

The advantage of the sRPE method lies within its diverse application. For example, sRPE appears to be a valid method for quantifying sport specific training interventions [3] as well as auxiliary training methods such as resistance training [102]. As such, it is often considered to provide a ‘global measure’ of an athlete’s internal training load [102]. This facilitates longitudinal analyses, as data can be quantified, and interpreted, over the course of an entire competitive season to provide an illustration of the periodized training plan [3, 7]. The use of the sRPE to measure global training load has been previously investigated at the college [8], semi-professional [9] and professional level [7] in basketball. However, despite this

research interest, there has been limited attention directed toward the establishment of its relationship with external training load derivatives in basketball.

As previously stated, elite sporting organizations often implement both internal and external methods of quantifying training load. Whilst there are multiple methods for quantifying external training load [1, 2], metrics stemming from the drop jump appear to be psychometrically comprehensive [11, 84, 85]. Additionally, the drop jump yields a better representation of reactive strength capabilities in comparison to the countermovement jump, as athletes are required to produce faster contact times. The primary criterion of the drop jump, the reactive strength index (RSI), may be indicative of neuromuscular performance, which could hold implications for injury prevention and functional athletic performance monitoring [76, 77]. Moreover, as the drop jump performance is somewhat transferable to the physical elements commonly encountered by basketball players whilst in game-play, it could be presumed that it is often used by basketball practitioners as a means of external training load quantification.

Given the aforementioned, this study aims to investigate the relationship between sRPE derived training load and the RSI measured using a drop jump task throughout the course of an Australian National Basketball League (NBL) season. It is hypothesized that the RSI will be sensitive to changes in the total training load given the presumption that variation in training loads will influence general levels of fatigue.

Methods

Participants

Data was obtained on 14 professional male basketball players from one Australian NBL team (age: 26 ± 3.6 y; body mass: 95.8 ± 9.0 kg; height: 197.3 ± 7.3 cm; professional basketball experience: 3.1 ± 3.0 y) throughout a 27-week competitive season. The NBL team finished the regular season with a win/loss record of 21/7 and final position 1st (Championship winner). The relevant Human Research Ethics Committee provided ethical approval, and informed consent was obtained from all participants in accordance with the University Ethics Committee Guidelines.

Procedures

Internal training load was quantified using the sRPE method, which has been described in greater detail elsewhere [7]. Briefly however, sRPE was collected approximately 30 minutes after each training session using a copy of Borg's Category Ratio 10 (CR-10) scale [8]. Thereafter, sRPE was multiplied by the duration of the training session (measured in minutes). Internal training load data were collected after every training session that included tactical team sessions, individual skill sessions, strength and conditioning sessions and competitive matches. This data was summated to create a weekly training load value during each week of the 27-week season, which was then used as the criterion variable for analysis.

Each player performed a drop jump test twice-per-week during the study period, with this test being performed at the same time and location each week. One day separated each drop jump testing sessions. The jump drop protocol was performed in accordance with previous research [86, 88] and was initiated by players performing a standardized warm up consisting of dynamic stretches and mobility exercises. Following this, each player performed three individual drop jumps stepping off from a 40 cm box, being provided with verbal cues regarding how to perform the jump prior to initiation. The 40 cm box jump height was selected for all athletes based upon a pervious study performed with these athletes examining the reliability of the RSI [88]. All drop jumps were performed onto an electronic jump mat interfaced with kinematic measuring system (KMS, Fitness Technology, South Australia), with data being exported to an Excel spreadsheet (Microsoft, Redmond, USA) for analysis. Specifically, flight time (ms) and contact time (ms) were extracted from the kinematic measurement system, and used to calculate a RSI by dividing the flight time (ms) by contact time (ms) [86]. This RSI was then used as the criterion variable for analysis.

Statistical Analysis

All modeling was conducted using a linear mixed model in *lme* package (Pinheiro & Bates, 2003) in the R statistical computing software (*R* Core Development Team, Austria, Vienna). Data were first modeled to examine the change in total training load (dependent variable) for each microcycle (independent variable). Thereafter, the relationship between RSI (dependent variable) and total training load (independent variable) was examined for each microcycle. Finally, the intercept was allowed to vary to account for within-athlete variation in total training load and RSI, and significance was set at $\alpha < 0.05$.

Results

The variation in total training load and RSI for each microcycle is presented in Figure 4.1. Total training load followed a non-linear pattern over the 27-week in-season, highlighted by weekly peaks and troughs. Multiple weeks within the season were found to be statistically different (*p* <0.05) from the baseline level (Week 1) as seen in Figure 4.1a. The variation of RSI performance also followed a similar response pattern but the magnitude of deviation was noticeably less in comparison to the sRPE values. Specifically, the RSI performance remained stable with only a few weeks within the season being statistically different from baseline measures (Figure 4.1b).

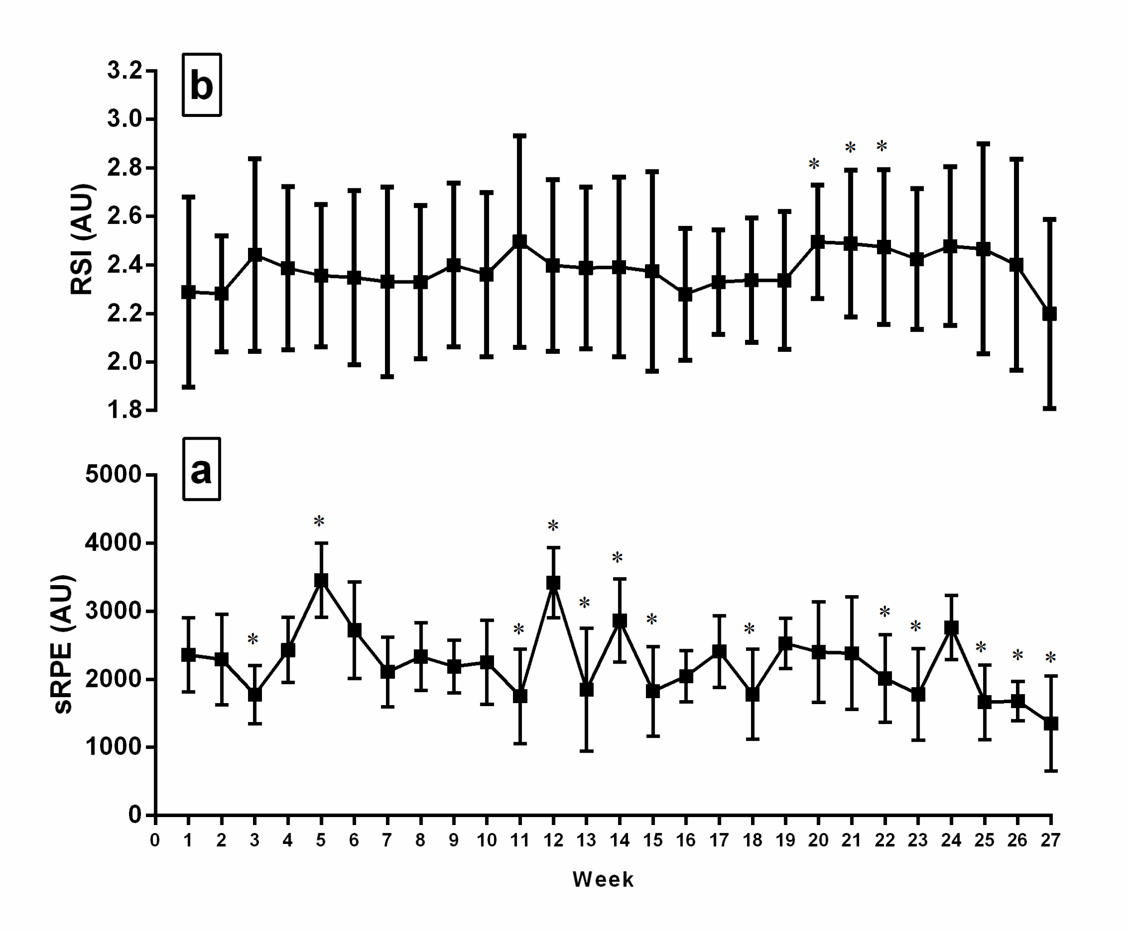

Figure 4.1: a) Training load data collected across the 27-week season. b) RSI data collected across the 27-week season.

Note: * significant difference to baseline measure (Week 1) (p <0.05)

AU = Arbitrary unit.

The relationship between RSI and total training load was significantly different from baseline at Week 24 ($p < 0.05$) and Week 26 ($p < 0.01$). The relationship between total training load and RSI was not different from baseline at any other microcycle ($p > 0.05$).

Discussion

This study aimed to investigate the relationship between sRPE training load and the RSI throughout an Australian NBL season. Results indicated that the total training load measured via sRPE across a 27-week competitive season varied in accordance to the training and competition schedule. Moreover, multiple microcycles were found the significantly differ from baseline values. These findings are consistent with what was reported by Manzi et al. [7] who modelled training load data over a comparatively shorter time period (12 weeks) However, it is noteworthy that Manzi et al. [7] did not report significant differences between microcycles irrespective of whether one or two competitive matches were played per week. These findings are interesting given that the literature on periodisation in team sports suggests that the variation in training loads through the in-season period is essential to ensure positive performance outcomes [103]. The challenge for strength and conditioning coaches in team sports like basketball is to devise and deliver a periodized training plan that encapsulates the entirety of the training process which involves tactical, technical and physical training and competition. Fundamentally, if the total training load is expected to follow a non-linear pattern through the in-season, it is reasonable to postulate that RSI performance may be sensitive to changes in training load seen from week to week across the season [84].

Despite the aforementioned, analysis of each individual microcycle during the in-season suggested that for the majority of the season, an athlete's RSI performance did not accurately reflect the changes noted in the total training load. In fact, the total training load determined from sRPE and the RSI were only significantly related during two weeks out of the 27-week in-season period. As such, it may be suggested that the relationship between these variables is questionable, as it appears that the RSI does not accurately reflect changes in training load as indicated by the sRPE. One explanation for this may be found in the common periodization practices utilized during the in-season in order to optimize performance and facilitate recovery via the use of non-linear training load applications [104]. For example, it is possible that the variation in training load seen stemmed from the maintenance of both

strength and power performance, resulting in an inability of the RSI measure to be sensitive to variations in training load.

Ultimately, the RSI variable has been suggested to be reflective of the neuromuscular systems performance capacity in plyometric activities [73]. As such, the premise of the present study was based upon the assumption that the RSI would reflect changes neuromuscular systems performance capacity in response to variations in total training load determined from the sRPE [84]. However, careful inspection of the RSI data collected across the 27-week in-season time period in the present study reveals that it was rather stable and exhibited minimal variation. The RSI was only significantly different from baseline during three of 27 microcycles. These findings suggest that the training load variations did not negatively impact upon an athlete's capability to perform demanding neuromuscular tasks, such as the drop jump test utilized in this study.

Ultimately, the current findings coupled with the questionable relationship between the total training load (sRPE) and the RSI seem to suggest that when planned periodization models are employed, there is an optimization of performance capacity, which may result in the maintenance of the RSI performance. Although speculative, when these results are viewed in relation to the team's on-court performance, it could be suggested that the periodized training plan followed by the NBL team contributed to their success (i.e., winning the championship). Consequently, when the data collected in the present study are considered in totality, the maintenance of the RSI across the 27-weekperiod may largely be a reflection of the non-linear periodization model employed to optimize the athlete's basketball performance capacity.

Conclusion

This study demonstrated that basketball players RSI might not be sensitive to detect changes in training load determined by the sRPE method during a competitive NBL season. Conversely, it can be presumed that the in-season periodization plan followed by the professional basketball team described in the present study resulted in the maintenance of the RSI performance across the season. Although speculative, this maintenance could have incurred a positive effect on the team's on-court performance (i.e., winning). Thus, to confirm

the aforementioned, further study is required to investigate if RSI fluctuations have a direct influence on a basketball team's game-play performance.

Chapter 5 – Conclusions

Collectively, the experimental studies of this thesis performed in a professional sport environment aimed at 1) examining training load monitoring in basketball; and 2) provide practical recommendations for strength and conditioning professionals. The primary goal of this thesis was to investigate the reliability of the RSI and then attempt to scientifically justify the implementation of the RSI in the training load management of elite basketball athletes.

Experimental study one investigated the intraday reliability of the RSI assessment from a drop jump from multiple drop heights. The main findings of this investigation were that the RSI assessed with drop heights of 20, 40 and 50 cm expressed the highest reliability and that only 1 trial is required when using the RSI to assess large groups. These results do not completely support the studies hypothesis though they do have important practical significance for the strength and conditioning coach. Drop jumps are implemented for both training and testing purposes and are a common testing method used to assess reactive strength capabilities, with the use of the RSI, from a variety of drop heights in order to create an individual profile. The present study suggests that not all drop heights express the same levels of reliability, highlighting that the selection of a drop jump height must be carefully considered. In the case of professional basketball athletes, after following an appropriate familiarisation protocol as detailed in this investigation, it is acceptable when testing large groups to complete only 1 trial at the 20, 40 and 50cm drop heights. This may allow for more regular use of the test as a monitoring tool as the time required to perform the test is minimal and data can be collected more efficiently than when performing multiple trials with a whole squad of athletes.

Experimental study two focussed on investigating the relationship between the RSI and training load derived via sRPE. Data was collected over the entire competitive season of a professional basketball team; the main finding showed that RSI was only related 2 weeks out of the 27-week season ($p < 0.05$). A closer investigation of the data shows that the training load varied throughout the season consistent with following the planned periodisation model employed by the staff of the team. Conversely, RSI performance remained relatively stable in comparison to sRPE with only 3 weeks resulted in a significant difference to baseline measures. Collectively the results of experimental study two illustrate that basketball players RSI may not be sensitive to changes in training loads, which does not support the hypotheses' of this thesis. It is fair to theorise that RSI performance was subsequently maintained throughout the 27-

week in-season and influenced by the periodisation model employed by the team's strength and conditioning coach.

In summary, this thesis is one of the first to investigate professional basketball within the Australian National Basketball League (NBL). Taken collectively both investigations have improved the understanding of this cohort and have provided a platform for future investigations specifically around training load monitoring. This thesis has identified the RSI form a drop box to express high levels of reliability at specific drop heights. The results of experimental study one suggest that practically the RSI is well suited to assess large groups of athletes in an efficient manner. This provides a strong rationale to implement the RSI in training load monitoring program specifically in the assessment of neuromuscular performance with professional basketball athletes. The results the experimental study two show that no significant relationship was established between RSI and training load future research may be able to identify other internal and external factors that affect RSI performance and how that differs between individual athletes.

Practical Applications

- When measuring the RSI drop heights of 20, 40 and 50cm are recommended as they express the highest reliability.
- The 20, 30, 40 and 50cm drop heights expressed high levels of reliability when measuring JH.
- When assessing the RSI in large group settings only one trial may be required.
- When assessing maximal performance of the RSI three trials are recommended.
- RSI performance can be maintained throughout a professional basketball season when following a periodised training plan.
- Strength and conditioning coaches are recommended to incorporate a variety of internal and external load measures to monitor training loads more accurately in professional basketball.

Chapter 6 – Future Research

The results and conclusion from this thesis has resulted in many practical findings and has highlighted specific areas of focus for future research.

In respect to experiment study one future investigations should assess the inter-day reliability of the RSI, controlling for all training and recovery variables during the quantification time period could provide information about fluctuations in the RSI within a training week. Therefore it may be most appropriate to complete this assessment in a non-training week. If the RSI expresses high reliability from day to day and the detection the smallest worthwhile change in performance is apparent this could enable the accuracy of the RSI in respect to measuring athlete preparedness or neuromuscular fatigue. Future investigations could focus on determining the sensitivity of the RSI measure to an acute training load bout for example high and low load sessions. In addition, exploring changes in drop jump performance from multiple drop heights during the preparatory and competitive periods to assess the impact of structured training and the competition schedule on reactive strength capabilities. This information could provide practical information of design of periodisation strategies, influence short-term and future training directions and assess the effectiveness of the current training strategy.

Despite the inability to establish a strong relationship between RSI and training load in experimental study two, it was speculated that maintaining RSI performance could be a factor in positive on court performances. Though there is no literature to support this contention future research is warranted to determine associations between RSI and game-play performance in professional basketball. In addition, considering the RSI as an external training load measure, future investigations may be warranted to investigate associations with alternative internal training load measures for example self-reported questionnaires or biochemical markers of fatigue. Identifying whether the RSI is related to subjective and objective markers could strengthen its use as a diagnostic tool to quantify fatigue in athletic populations.

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Appendix

Appendix A: Ethics Approval

Will Markwick

From: Research Ethics <research.ethics@ecu.edu.au>
Sent: Wednesday, 4 September 2013 10:06 AM
To: 'wmarkwic@our.ecu.edu.au'; 'will@wildcats.com.au'
Cc: Greg HAFF; 'sbird@csu.edu.au'; FHES Student Information Office; Research Assessments
Subject: 10065 MARKWICK ethics approval
Attachments: Conditions of approval.pdf

Dear Will

Project Number: 10065 MARKWICK
Project Name: Training load quantification in elite Australian basketball and the use of the reactive strength index as a monitoring tool.
Student Number: 10324201

The ECU Human Research Ethics Committee (HREC) has reviewed your application and has granted ethics approval for your research project. In granting approval, the HREC has determined that the research project meets the requirements of the *National Statement on Ethical Conduct in Human Research*.

The approval period is from 4 September 2013 to 24 April 2015.

The Research Assessments Team has been informed and they will issue formal notification of approval. Please note that the submission and approval of your research proposal is a separate process to obtaining ethics approval and that no recruitment of participants and/or data collection can commence until formal notification of both ethics approval and approval of your research proposal has been received.

All research projects are approved subject to general conditions of approval. Please see the attached document for details of these conditions, which include monitoring requirements, changes to the project and extension of ethics approval.

Please feel free to contact me if you require any further information.

Regards
Kim

Kim Gifkins, Research Ethics Officer, Office of Research & Innovation, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027
Email: **research.ethics@ecu.edu.au** Tel: +61 08 6304 2170 | Fax: +61 08 6304 5044 | CRICOS IPC 00279B

Appendix B: Participant Information Letter

Information Letter to Participants

Thank you for expressing your interest in this research. The purpose of this document is to explain the study that you may choose to participate in as a subject. Please read this document carefully, and do not hesitate to ask any questions.

Project Title

Training load quantification in elite Australian basketball and the use of the reactive strength index as a monitoring tool.

Researchers

This research project is being undertaken as part of the requirements of a Masters of Science candidature (Sport and Exercise Sciences) at Edith Cowan University (ECU).

Masters Candidate: Will Markwick (will@wildcats.com.au) 0439 457 087

Supervisor: Dr Guy Gregory Haff (g.haff@ecu.edu.au) 08 6304 5416

Co-supervisor: Dr Stephen Bird (s.bird@csu.edu.au) 02 6338 4155

Purpose of the study

The primary aim of this study is to measure the internal and external factors that contribute to basketball performance training. To assess whether the reactive strength index can be used as a monitoring tool in professional basketball.

Research Outline

To participate in this study you will be asked to perform 3 separate testing sessions that will align with the playing schedule of your team. The testing sessions require maximal efforts on numerous tasks including 3 repetition maximum strength testing, speed and agility testing, jump testing and aerobic capacity testing. You will also be required to undergo body composition testing in the form of a 7 site skinfold measurement.

On a daily basis you will be asked to wear a heart rate monitor at each court training session you complete for the duration of the season. You will also be asked to assess your training session by providing a rating of perceived exertion.

You will also be required to perform a drop jump task 3 days/week for the duration of the in-season, this will be completed at your scheduled strength training sessions with one more test to be completed pre-game shoot around session.

Eligibility

You will be eligible for this study if:

- You are between 18 and 35 years old
- You have no physical injuries
- You are a professional basketball player

Risks

The intensity will be maximal at times and replicate your normal training and testing experiences. There are no inherent risks involved with this research. However, as with all physical training, there is the risk of;

- Muscle pulls or strains
- Joint sprains
- Delayed onset of muscle soreness
- Minor physical exhaustion
- Although very unusual in young and/or trained individuals the possibility of abnormal blood pressure, fainting or slow heart rhythm.
- In extremely rare instances heart attack, stroke or death.

All participants will be thoroughly instructed and familiarised with the correct technique by trained professionals. The listed risks will be minimised by adequate warm-up and cool down procedures supervised by qualified strength and conditioning personnel. In addition, qualified personnel with first aid and CPR certification will be monitoring testing. Standardised procedures for physical activity testing will be followed as previously performed in the Rugby WA training facility.

Benefits

You will be provided with instant feedback on your individual performance through the duration of the in-season. Recommendations will be provided on methods to improve your performance and aid your recovery.

Data collected will assist to reduce the potential for injuries through the in-season period.

Data collected will assist in the prescription of more effective strength and power training interventions through out the in-season period.

Confidentiality of Information

Your anonymity is ensured as much as possible during the investigation by assigning number codes to your data by the investigator. All information provided by you will be treated with full confidentiality. Your contact information will only be accessible by the chief researcher during the period of the study and only the researcher and supervisors will have access to the raw information for this study. The information and data gathered from you during the study will be used to answer the research question of this study. Data will be displayed to the coaching staff of the Perth Wildcats (your employer) though they will not have access to the raw data. Data will be stored in a password-protected computer and is only available to the researchers. Hard copy data will only be kept in the researcher's office and locked in a specific drawer/filling cabinet. All data will be stored according to ECU policy and regulations following the completion of the study.

Results of the Research Study

The results of this study are intended for completion of a Masters by research thesis and may be presented at conferences/seminars and published in peer-reviewed journals, as magazine articles, as an online article or part of a book section or report. Published results will not contain information that can be used to identify participants unless specific consent for this has been obtained. A copy of published results can be obtained from the investigator upon request.

Voluntary Participation

Your participation in this study is voluntary. No monetary reward will be provided. No explanation or justification is needed if you choose to not participate. Your decision if you not want to participate or continue to participate will not disadvantage you or involve any penalty.

Withdrawing Consent to Participate

You are free to withdraw your consent to further involvement in this project at any time. You also have the right to withdraw any personal information that has been collected during the research.

Questions and/or Further Information

If you have any questions or require any further information about the research project, please do not hesitate to contact:

Will Markwick (Masters Student – Researcher)

School of Exercise and Health Sciences, Edith Cowan University

270 Joondalup Drive, Joondalup, WA 6027, Australia -

Ph: 0439 457 087

E-mail: will@wildcats.com.au

If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact:

Research Ethics Officer

Edith Cowan University

270 Joondalup Drive

JOONDALUP WA 6027

Phone: (08) 6304 2170

Email: research.ethics@ecu.edu.au

This project has been approved by the ECU Human Research Ethics Committee.

Signature Date

Appendix C: Email to participants

Dear Participant,

You are invited to participate in a project involving the quantification of training load in elite Australian basketball. The proposed project is a Master's by research project (Edith Cowan University) for Will Markwick (chief investigator) and entails measuring certain components of training that you are exposed to as an elite basketball athlete.

Purpose:

The primary aim of this study is to measure the internal and external factors that contribute to basketball performance training. To assess whether the reactive strength index can be used as a monitoring tool in professional basketball.

Requirements:

- To participate in this study you will be asked to perform 3 separate testing sessions that will align with the playing schedule of your team. The testing sessions require maximal efforts on numerous tasks including 3 repetition maximum strength testing, speed and agility testing, jump testing and aerobic capacity testing. You will also be required to undergo body composition testing in the form of a 7 site skinfold measurement.
- On a daily basis you will be asked to wear a heart rate monitor at each court training session you complete for the duration of the season. You will also be asked to assess your training session by providing a rating of perceived exertion.
- You will also be required to perform a drop jump task 3 days/week for the duration of the in-season, this will be completed at your scheduled strength training sessions with one more test to be completed pre-game shoot around session.

Risks and Benefits.

- The intensity will be maximal at times and replicate your normal training and testing experiences. There are no inherent risks involved with this research. However, as with all physical training, there is the risk of muscle pulls or strains.
- You will be provided with instant feedback on your individual performance through the duration of the in-season. Recommendations will be provided on methods to improve your performance and aid your recovery.
- Data collected will assist to reduce the potential for injuries through the in-season period.
- Data collected will assist in the prescription of more effective strength and power training interventions through out the in-season period.

All information provided by you will be treated with full confidentiality. The information and data gathered from you during the study will be used to answer the research

question of this study. The results of this study are intended for completion of a Masters by research thesis and may be presented at conferences/seminars and published in peer-reviewed journals, as magazine articles, as an online article or part of a book section or report

Finally, Your participation in this study is voluntary. No monetary reward will be provided. No explanation or justification is needed if you choose to not participate. Your decision if you not want to participate or continue to participate will not disadvantage you or involve any penalty.

I look forward to hearing your response to this invitation. If you have any questions about the project I would be more than happy to answer them.

Kind Regards

Will Markwick

(Edith Cowan University, WA – Masters candidate)

will@wildcats.com.au

0439 457 087

Appendix D: Participant Checklist

PARTICIPANT CHECKLIST

Training load quantification in elite Australian basketball and the use of the reactive strength index as a monitoring tool.

Once you had read the information letter you should have a clear understanding of what you will be asked to do upon your consent. Please carefully read the bullet points below and initial next to each item that you clearly understand. If there is a point that is unclear please consult the investigator for further clarification. Once each point is explained to your satisfaction you will be asked to sign the informed consent form.

_________ I understand that I am freely consenting to participate in this study designed to look at the quantification of training load in elite basketball.

_________ I understand that I will complete 3 performance-testing sessions at the pre/mid and post the in-season period.

_________ I understand that data will be collected over the entire course of the in-season period.

_________ I understand that testing weeks will include anthropometric measures, strength testing, speed and agility testing, aerobic fitness testing and power testing.

_________ I understand that all testing and training sessions will be in alignment with the normal day to day training at your place of employment.

_________ I understand that my anonymity is assured throughout the project and all personal information will be treated with full confidentiality.

_________ I understand that I will not receive any compensation and/or reimbursement as a result of participating in this study.

Appendix E: Informed Consent

Informed Consent

Training load quantification in elite Australian basketball and the use of the reactive strength index as a monitoring tool

---

I have carefully read and clearly understand all the content of the information sheet and participant checklist and consent to being a participant in the research project titled "Training load quantification in elite Australian basketball and the use of the reactive strength index as a monitoring tool".

Declaration

- I have had all questions relating to the study answered to my satisfaction.
- I agree to participate in this project and give my consent freely. .
- I understand that I am free to withdraw at any time, for any reason without prejudice.
- I understand that the procedures will be carried out as detailed in the i nformation sheet, a copy of which I have retained.
- I agree that the research data obtained from this study may be published, provided that I am not identifiable in any way.
- I understand all the risks associated with being a participant in this study.

Participant: ______________________ ____________________ **Date:**
Printed name Signature

The researcher certifies that the participant has a full understanding of the procedures and their involvement as outlined in this form. The participant has given verbal confirmation of their understanding, which meets the research's satisfaction prior to signing this form.

Investigator: ______________________ ____________________ **Date:**
Printed name Signature

Witness: ______________________ ____________________ **Date:**
Printed name Signature

If you have any questions or require further information about the research project, please contact Mr Will Markwick at 0439 457 087, e-mail w.markwic@ecu.edu.au. If you have any concerns of complaints regarding the research project and wish to talk to an independent person, you may contact:

Human Research Ethics,
Edith Cowan University,
100 Joondalup Drive,
Joondalup, WA 6027.

Phone (08)-6304-2170 Email: research.ethics@ecu.edu.au

Appendix F: Sessional Rating of Perceived Exertion

Sessional Rating of Perceived Exertion

Subject #: ___________________ Date: __________

0	Rest
1	Really Easy
2	Easy
3	Moderate
4	Sort of Hard
5	Hard
6	
7	Really Hard
8	
9	Really, Really, Hard
10	Maximal: Extremely Hard

Instructions: Please check the box below that corresponds to the session you have undertaken. Please indicate the duration of the session and then using the above scale please rate the session.

Session Type:

☐ Strength Training Duration: ________ 1 2 3 4 5 6 7 8 9 10

☐ Team Practice Duration: ________ 1 2 3 4 5 6 7 8 9 10

☐ Individual Skills Duration: ________ 1 2 3 4 5 6 7 8 9 10

☐ Speed/Agility Duration: ________ 1 2 3 4 5 6 7 8 9 10

☐ Match Competition Duration: ________ 1 2 3 4 5 6 7 8 9 10

Appendix G: Copyright

I warrant that I have obtained, where necessary, permission from the copyright owners to use any third party copyright material reproduced in the thesis (e.g. questionnaires, artwork, unpublished letters), or to use any of my own published work (e.g. journal articles) in which the copyright is held by another party (e.g. publisher, co-author).

W. Markwick.

William Markwick

Appendix H: Co-authors signature

To Whom It May Concern,

I, *William Markwick*, contributed *to greater than 70% the data collection and writing process of the* paper/publications listed; with Greg Haff providing 20% contribution and the remaining 10% by the other listed co-authors.

Markwick WJ, Bird SP, Tufano JJ, Seitz LB, and Haff GG. The Intraday Reliability of the Reactive Strength Index (RSI) Calculated From a Drop Jump in Professional Men's Basketball. *International Journal of Sports Physiology and Performance* 10: 482-488, 2015.

W. Markwick.

William Markwick

I, as a Co-Author, endorse that this level of contribution by the Candidate indicated above is appropriate.

(Guy G. Haff) (Signature of Co-Author 1) (Edith Cowan University) (29/06/2015)

Stephen Bird

Stephen P. Bird (Signature of Co-Author 2)

Affiliation: Charles Sturt University, Bathurst NSW 2795 Australia

Date: 27/06/2015

(Laurent B. Seitz) (Signature of Co-Author 5) (Edith Cowan University) (29/06/2015)

James Tufano

(James J. Tufano) (Signature of Co-Author 6) Edith Cowan University, 26/06/2015

To Whom It May Concern,

I, *William Markwick*, contributed *to greater than 70% the data collection and writing process of the* paper/publications listed; with Greg Haff providing 20% contribution and the remaining 10% by the other listed co-authors.

Markwick, W. J, Govus, A. D, Woods C. T, Seitz. L. B, Tufano, J. J, Bird, S. P, Haff, G. G. Does session RPE relate with reactive strength qualities? A case study investigation within the National Basketball League. *Journal of Strength and Conditioning Research (In Review)*

William Markwick

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Stephen Bird

Stephen P. Bird (Signature of Co-Author 2)

Affiliation: Charles Sturt University, Bathurst NSW 2795 Australia

Date: 27/06/2015

(Carl T. Woods) (Signature of Co-Author 3) (James Cook University) (27/06/2015)

(Andrew D. Govus) (Signature of Co-Author 4) (Edith Cowan University) (27/06/2015)

(Laurent B. Seitz) (Signature of Co-Author 5) (Edith Cowan University) (29/06/2015)

James Tufano

(James J. Tufano) (Signature of Co-Author 6) Edith Cowan University, 26/06/2015

Appendix I: Experimental Study One - Acceptance Letter

Decision Letter (IJSPP.2014-0265.R2)

From:

ralph.beneke@staff.uni-marburg.d

e To: g.haff@ecu.edu.au,

gh10644@hotmail.com CC:

Subject: International Journal of Sports Physiology and Performance - Decision on Manuscript ID IJSPP.2014-0265.R2 Body: 16-Oct-2014

Dear Dr. Haff,

It is a pleasure to accept your manuscript entitled "The intraday reliability of the reactive strength index (RSI) calculated from a drop jump in professional men's basketball." in its current form for publication in the International Journal of Sports Physiology and Performance.

The In Press and MedLine listings should be available approximately 4 weeks from now. To facilitate that process, please fill out the attached form transferring copyright to Human Kinetics and send to the journal's Managing Editor, Julia Glahn, at juliag@hkusa.com.

Thank you for your fine contribution. On behalf of the Editors of the International Journal of Sports Physiology and Performance, we look forward to your continued contributions to the Journal.

Yours sincerely,

Prof. Ralph Beneke MD PhD FACSM
Editor, International Journal of Sports Physiology and Performance

Date Sent: 16-Oct-2014

File 1: * IJSPPcopyright.pdf

Appendix J: Experimental Study Two – Submission Letter

Jun 25, 2015

Dear Mr Markwick,

We have received your new manuscript entitled "Does session RPE relate with reactive strength qualities? A case study investigation within the National Basketball League".

You will be able to check on the progress of your paper by logging on to Editorial Manager as an author.

Additionally, you may view the Additional Information questions to obtain the copyright information by clicking here: 1. William Markwick, BHMS

Your manuscript will be given a reference number once an Editor has been assigned.

Thank you for submitting your work to this journal.

Kind Regards,

Journal of Strength and Conditioning Research