An Investigation of Athlete Workload Monitoring and Injury in Professional Men's Basketball

Jasper Wong

BSR (Sport and Exercise Science)

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School of Sport and Recreation

Table of Contents

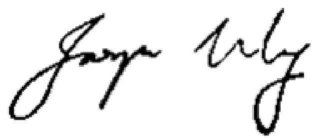
List of Figures

List of Tables

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made.

Chapters 2, 3 and 4 of this thesis represent three separate papers that have been submitted to peer-reviewed journals for consideration for publication. My contribution and the contribution by the various co-authors to each of these papers are outlined at the beginning of the thesis. All co-authors have approved the inclusion of the joint work in this Master's thesis.



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Candidate Contributions to Co-authored Papers

Chapter 2.	Wong, J., Whatman, C., Sheerin, K., Wells, D. The relationship between workload and injury risk in sport: A narrative review. To be submitted to *New Zealand Journal of Sports Medicine*.	Wong: 80% Whatman: 7.5% Sheerin: 7.5% Wells: 5%
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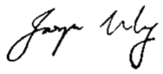
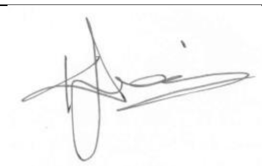
We, the undersigned, hereby agree to the percentages of participation to the chapters identified above:

		
Jasper Wong	Chris Whatman	Kelly Sheerin
		
Denny Wells	Robert Borotkanics	

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Ethical Approval

Ethical approval for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC). The AUTEC reference was 14/383.

Abstract

Basketball is an intermittent high intensity team sport requiring both technical skill and physical athleticism. Due to the need for repetitive absorption of high landing impact forces, the majority of injuries sustained in basketball occur in the lower extremities, most commonly in the lower back, knee and ankle. Additionally, a high frequency of overuse and inflammation injuries have been observed, which could reflect the cumulative effects of a high physical workload combined with travel, and short between-match recovery times. Appropriate load monitoring strategies should be implemented to allow for sufficient recovery while optimising performance. To date, there is limited literature that has investigated the relationship between workload and injury risk in professional basketball. The overall purpose of this thesis was to investigate athlete workload monitoring and injury in professional men's basketball.

A prospective cohort study was conducted to investigate the relationship between absolute and relative measures of workload and injury risk. Although it was observed that a higher proportion of injuries occurred when in the high acute to chronic workload ratio (ACWR) range, analysis using a frailty model showed no significant difference in injury risk between different ACWR categories, nor was there sufficient evidence to support the existence of an ACWR sweet spot as reported in previous studies. Additionally, there were no significant differences between injury risk and a number of different measures of absolute workload. These findings suggest that the ACWR may not be suitable for informing injury risk in professional basketball, and that workload should not be considered in isolation for informing injury risk in professional basketball. However, this study was limited by a small sample size, therefore further research using a larger sample size is needed to reduce the uncertainty of the findings.

Another important component of athlete monitoring is the periodization and distribution of training load. To better understand the training demands in professional basketball, a drill workload profile was established, relative to official in-season game workload. Results showed that game intensity (8.02 ±2.59 AU/min) was significantly higher than that of any drill type with moderate to very large differences. There was also a clear distinction between high intensity drills (fitness, offensive, defensive, scrimmage) and low intensity drills (shooting, tactical), with large to very large differences. These findings provide new information on the loading intensity of different drill types used in basketball relative to the intensity of a game, which may be used to aid workload prescription depending on the desired intensity or training outcome of a session.

Chapter 1: Introduction and Rationale

Background

Basketball is an intermittent high intensity team sport that requires a combination of physical athleticism and technical skill for individual and team success. It is characterized by repeated accelerations, decelerations, changes of directions, sprints and jumps (Schelling & Torres-Ronda, 2013). The frequency of competitive basketball games is higher compared to many field-based team sports, with teams in the Australia New Zealand Basketball League (NBL) playing one to two games each week, and teams in the American National Basketball League (NBA) playing up to four games each week. Developments in gameplay and strategy have led to increases in the pace, physicality and overall intensity of the game. As a result, players experience high external and internal workloads throughout the course of a competitive season, which may have contributed to increased injury rates in professional basketball players (Starkey, 2000). Due to the explosive nature of the game, players experience repetitive absorption of high landing impact forces on a regular basis. Injury data from the NBA indicates the majority of injuries in basketball occur in the lower quarter, most commonly in the lower back, knee and ankle (Deitch, Starkey, Walters & Moseley, 2006). Additional reports have indicated a high frequency of overuse and inflammatory conditions, which accounted for the greatest amount of game time lost (Deitch et al., 2006; Starkey, 2000). This could reflect the cumulative effects of a high physical workload combined with low recovery time. It has been suggested that athlete workload is a modifiable injury risk factor, and therefore appropriate load monitoring strategies should be implemented to ensure athletes are getting sufficient recovery while optimising performance (Halson, 2004).

Only limited research has investigated the relationship between workload and injury risk in professional basketball (Anderson et al., 2003; Weiss et al., 2017). The majority of research in other team sports has suggested that both low and high weekly workloads are associated with a greater injury risk, which has led to the suggestion that there may be a workload range within which injury risk is minimized without compromising performance (Anderson et al., 2003; Dennis et al., 2003; Dennis et al., 2004; Gabbett, 2004b; Gabbett & Domrow, 2007; Thornton et al., 2017). It has also been reported that sudden increases in acute workload, or weekly workload, are associated with a greater injury risk (Anderson et al., 2003; Gabbett, 2004a; Hulin et al., 2015). In contrast, high chronic workloads, or the rolling average acute workload over four weeks, have been associated with a lower injury risk compared to low chronic workloads (Hulin et al., 2014; Hulin et al., 2016). Exposure to high workloads over time is thought to improve an athlete’s fitness and tolerance for higher workloads, thereby offering a protective effect against any spikes in training load as athletes are more physically prepared for them (Malone et al., 2018). While high workloads may be beneficial, any increases to training load should be gradual rather than sudden, and workload prescription should follow proper periodization to ensure athletes are physically prepared for any changes in workload (Hulin et al., 2014). Additionally, both internal and external load measures have been observed to be informative of injury risk, with the exception of training duration, which was not thought to be specific enough to reflect workload intensity (Brooks et al., 2008; Gianoudis, Webster & Cook, 2008; Korkia, Tunstall-Pedoe & Maffulli, 1994). Currently, there is a lack of evidence as to which workload variable is most informative of injury risk in basketball.

Given the potential interaction between acute and chronic workload, recent research has examined the effects of monitoring acute workload relative to chronic workload, known as the acute to chronic workload ratio (ACWR). This metric is derived from the workload-performance model originally proposed by Banister et al. (1975), which estimated athletic performance based on the difference between a positive function (fitness) and a negative function (fatigue). The basis of the ACWR is that it provides a measure of athlete preparedness relative to their training history, where acute workload is analogous to a state of fatigue, and chronic workload is analogous to a state of fitness (Blanch & Gabbett, 2016; Gabbett, 2016). This suggests that when acute workload exceeds chronic workload, the athlete is in a fatigued state, and conversely when chronic workload exceeds acute workload, the athlete is in a better prepared state. The ACWR is thought to be more informative than monitoring acute and chronic workloads in isolation, as it also quantifies the magnitude of change in weekly workload, which may assist in periodizing workload prescription during different phases of a competitive season. Studies in field-based team sports including rugby league, Australian football and soccer have observed that both high and low ACWRs are associated with a greater injury risk (Bowen et al., 2019; Colby et al., 2017; Hulin et al., 2015; Malone et al., 2017; Stares et al., 2018). This has led to the suggestion that there is an ACWR range which is associated with a lower injury risk compared to ratio scores above and below this range, also known as the ACWR sweet spot (Colby et al., 2017; Hulin et al., 2015). Currently, there is no consensus on what this sweet spot is, with varying sweet spot scores being reported, even within the same sport (Carey et al., 2016; Colby et al., 2017; Stares et al., 2018). Regardless, this does suggest that workloads can be increased or decreased throughout the season without increasing injury risk, as long as the change is kept within a specific range. There has only been one study in professional basketball that has investigated the relationship between the ACWR and injury (Weiss et al., 2017).

While monitoring absolute and relative workloads provides an indication of athlete weekly training volume, the distribution of training load throughout the week is also another component of athlete load monitoring. This is especially important in basketball, given the high frequency of games, and short between-match recovery times. Coaches should prescribe sufficient physical stimuli to promote physical, tactical and technical development, while allowing sufficient recovery to avoid athlete overload. Therefore, an understanding of game and drill workloads may better inform the overall periodization and structuring of training sessions. Coaches may be able to use this information in conjunction with monitoring weekly workloads to structure higher or lower intensity sessions depending on the recovery status of the athlete, or desired training outcome of a session (Corbett et al., 2018; Loader et al., 2012). To date, the majority of research examining drill load in basketball has selectively examined different formats of small sided games (SSG), or scrimmages (Schelling & Torres, 2016; Svilar, Castellano, Jukic & Casamichana, 2018; Svilar, Castellano & Jukic, 2019; Torres-Ronda et al., 2016). SSGs are an effective drill for preparing athletes for competition, as they simulate game like intensities and scenarios (Corbett et al., 2018; Gamble, 2004; Loader et al., 2012). However, these studies have excluded other drill types that specifically focus on positional skills, shooting skills or tactical awareness, hence there is insufficient understanding of their physical demands, and how they might affect training prescription. Currently, there is a lack of research that has quantified the workload of different drill types and how drill loads relate to in-season game workload in professional basketball.

Structure of the thesis

In accordance with the Auckland University of Technology's Format Two, this thesis contains a literature review and two experimental chapters that are suitable for journal publication. The manuscripts are presented as they have been submitted to, or formatted for, the target journals, and as such the repetition of some information occurs. Each chapter begins with a preface, which serves to demonstrate the sequential progression and brings together the thesis as a cohesive whole. Finally, the thesis concludes with a general discussion integrating findings from the preceding chapters (Chapter 5), while also outlining the practical implications of this research, as well as study limitations and directions for further work. The referencing format has been standardised to the American Psychological Association 6th Edition, with a single reference list prepared for the thesis.

Purpose of the thesis

This thesis had three primary objectives, which were:

I. To explore current literature examining different measures of training load, to clarify the relationship between workload and injury risk in sport.
II. To investigate the relationship between different workload measures and injury risk in professional men's basketball.

III. To determine the relative intensity of different training drill types and how these compare to official in-season games.

Chapter 2 is a narrative review of the current literature surrounding the relationship between workload and injury risk in sport. Given the increasing attention the ACWR has received in recent research concerning the workload-injury relationship, the review specifically highlights the current evidence and limitations of this particular workload measure. Chapter 3 is a prospective cohort study investigating the relationship between different workload measures and injury risk in professional men's basketball, with a particular focus on the application of the ACWR. Chapter 4 examines the physical workload of different drill types in basketball relative to official in-season game load. This is followed by Chapter 5, which is a discussion on the key findings of the overall thesis, including any limitations and implications for future research.

Prelude to Chapter 2

In order to investigate athlete workload monitoring and injury in professional basketball, there must first be an understanding of the relationship between workload and injury risk. A narrative review was conducted to clarify the relationship between workload measures and injury risk, and to identify any gaps in the literature regarding the relationship between workload and injury risk in professional team sport.

Chapter 2: The Relationship Between Workload And Injury Risk In Sport. A Narrative Review

Introduction

Athlete monitoring has become an important process for coaches and athletes, both for performance enhancement, as well as injury prevention. It has received increased attention especially as the level and intensity of competition has increased in many sports worldwide. A large component of athlete monitoring involves measuring and tracking an athlete's training load, which is seen as a modifiable risk factor of overuse or fatigue related injury (Gabbett, 2016). It is thought that the manipulation of training load in conjunction with appropriate training periodization may minimize the risk of injury. This is particularly relevant for team sports such as basketball, where much of a team's performance and success can depend on player availability. Recent research suggests that there may be a training load sweet spot that minimizes injury risk without compromising competition readiness, however this research is mostly limited to team field sports such as Australian football (AFL), soccer and cricket (Hulin et al., 2014; Stares et al., 2018; Malone et al., 2018). Currently there is little research surrounding load monitoring strategies in basketball (Weiss, Allen, McGuigan & Whatman, 2017).

Basketball is a fast and dynamic sport that has seen an increase in physical contact between players and overall game intensity. This has resulted in higher physical workloads throughout a season, leading to increased injury rates among professional basketball players (Starkey, 2000). Data from the National Basketball Association (NBA) and National Collegiate Athletic Association (NCAA) indicates that 60-65% of injuries sustained occurred in the lower extremities, with the most common injury sites being the ankle, knee and lower back (Deitch, Starkey, Walters & Moseley, 2006; Dick et al., 2007). This is likely in part due to the repetitive absorption of high impact forces players often experience upon landing, as well as repetitive acceleration, deceleration and change of direction movements.

As well as the increasing intensity of individual games, the number of games played weekly may also affect injury risk. Given that games carried out at a higher intensity than training (Montgomery, Pyne & Minahan, 2010), the number of games played per week also has a large impact on athlete loading and subsequent risk of injury (Dellal et al., 2013; Dupont et al., 2010). In many field sports such as soccer or rugby league, games are usually played once a week, with regularly scheduled practices. In contrast, basketball teams usually play multiple games each week in addition to training. In the Australia and New Zealand National Basketball League (NBL), teams play 28 games in a season, alternating between one and two games per week. In comparison, the NBA season consists of 82 regular season games played over approximately 23 weeks; teams can play between two and four games per week. Therefore, compared to other single game per week sports, basketball players experience higher weekly loading that accumulates over the season, and may have a risk of injury without appropriate load monitoring and recovery strategies (Dupont et al., 2010; Montgomery, Pyne & Minahan, 2010). This paper will explore current literature examining different measures of training load, to clarify the relationship between workload and injury risk in sport, and to provide recommendations for use in athlete workload monitoring. This paper is organised into two sections: training load, including the relationship of both internal and external training load and injury; the acute to chronic workshop ratio, including its relationship to injury risk, sweet spot, measurement time periods, and possible limitations.

Training Load As A Concept

Athlete training load is the cumulative stress on an athlete's body from single or multiple training sessions over a period of time (Eckard et al., 2018). It can be quantified using either internal or external measures. Internal measures can be either objective or subjective, the most common of which include heart rate (HR) or rating of perceived exertion (RPE). These have been used extensively studies assessing player load, and seem to reliably reflect workload across a number of different sports (Bourdon et al., 2017; Drew & Finch, 2016). Conversely, all external load measures are objective, such as running speed or total distance run, which can be divided into different bands to quantify load intensity. The evolution of wearable technologies, such as Global Positioning System (GPS) units and accelerometers, has greatly expanded the types of external load variables that can be measured. Given the large number of external load measures available, it is important to select appropriate options that most accurately reflect the athlete workload for a given sport, as the specificity of the load measure to the sport may affect its ability to inform injury risk.

The majority of studies examining the relationship between training load and injury have found that higher training loads lead to increased injury risk (Anderson et al., 2003; Dennis et al., 2003; Dennis et al., 2004; Gabbett, 2004a; Thornton et al., 2017). It has been suggested that internal training load using RPE has a stronger relationship with injury risk compared to external training loads, but this is likely due to the choice of external training load used in some studies (Eckard et al., 2018). A common finding across multiple studies is that injury incidence increases following a sharp spike in training load, usually after the pre-season or following a prolonged break during the season (Anderson et al., 2003; Gabbett, 2004a). Therefore, it has been suggested that undertraining, or training at lower loads, may also contribute to injury risk as athletes are less prepared physically for any spikes in their workload during a competitive season (Drew & Finch, 2016; Gabbett et al., 2016).

Another common form of load quantification is absolute and relative loads. Absolute loads refer to the total load sustained over a given period, the most common being weekly periods (Anderson et al., 2003; Gianoudis, Webster & Cook, 2008). Relative loads, which are also commonly measured in weekly blocks, take into account the previous weeks' loading, providing an indication of the load variation between two successive time periods. The most prominent example of a relative load is the acute:chronic workload ratio (ACWR), which typically compares an athlete's most recent week of training load, to load experienced over the previous four weeks (Gabbett, 2016; Hulin et al., 2015). This ratio is thought to provide a better indication of the week-to-week variation in training load compared to monitoring absolute workloads in isolation. Recent research has argued that the ACWR as a more meaningful method of athlete load monitoring, however its application is currently limited to field sports such as rugby league and Australian football (Hulin et al., 2013; Gabbett, 2016).

Injury definition

A number of different injury definitions have been used in team sport injury surveillance, which can affect the scope of injury data collected. Rugby union and football consensus statements both define an injury as any physical complaint sustained by a player during a match or training, regardless of the need for medical attention or time lost from any matches or trainings (Fuller et al., 2006; Fuller et al., 2007). An injury requiring a player to receive medical attention is defined as a 'medical attention' injury, while an injury resulting in a player being unable to fully participate in matches or trainings is defined as a 'time loss' injury (Fuller et al., 2006; Fuller et al., 2007).

The time loss definition is the most commonly used in team sport injury surveillance, perhaps because it captures injuries that have a direct influence on a player's ability to participate in trainings and matches, and are therefore most relevant for coaching staff concerned with team performance (Bahr, 2009). The severity of time loss injuries is based on the number of days lost, and this definition does not require a medical professional to record the injury data, thus making it simple to implement while maintaining good reliability (Bahr, 2009; Clarsen, Myklebust & Bahr, 2013). However, this definition also likely captures the least amount of injuries. In many team sports, it is common for players to train and compete through injuries of a chronic or overuse nature while experiencing some degree of functional limitation or pain (Clarsen et al., 2015). Therefore, use of the time loss definition may not register these types of injuries until they get severe enough to cause missed trainings and or games. As a result, this definition may not provide a fair representation of true injury incidence (Bahr, 2009; Orchard & Hoskins, 2007). In contrast, the medical attention definition encompasses all types of injuries and provides a more complete representation of total injury incidence. However, the magnitude of an injury is not captured, hence there is no way to classify the severity of an injury. Additionally, variations in the amount of medical support available to a team, as well as individual player pain tolerance, may result in differences in the injury incidence reported between studies (Bahr, 2009; Fuller et al., 2006). Therefore, this definition is considered less reliable for multi-team injury surveillance and may be more suited to studies involving a small population or a single team (Orchard & Hoskins, 2007).

One of the limitations of these common injury definitions (medical attention and time loss) is that they do not accurately describe the magnitude of an injury. It is likely that studies using these definitions underestimate the true magnitude of the injury problem as players continue to play with injuries and/or fail to seek medical attention. This makes it difficult to detect injuries of an overuse or chronic nature, which are a prevalent injury type in many sports and can be contributing factors to some acute injuries. The Oslo Sports Trauma Research Centre (OSTRC) recently developed an overuse injury questionnaire, which was found to be effective in registering overuse injuries in a number of different sports including volleyball, floorball, handball, cycling, cross-country skiing and basketball (Clarsen et al., 2013; Clarsen et al., 2015; Weiss et al., 2017). The self-reported questionnaire grades the severity and impact of painful or problematic areas on athlete participation on a weekly basis (irrespective of medical attention or time loss), making it a simple and effective method of athlete monitoring (Clarsen et al., 2013). Additionally, it was shown to have greater sensitivity in registering overuse injuries compared to diagnosis by a medical professional, which suggests that it may be a more valid classification system for use in investigating the relationship between training load and injury (Weiss et al., 2017).

Internal training load and injury

The majority of studies measuring internal training load have suggested that the higher the training load, the more susceptible athletes were to injury (Anderson et al., 2003; Gabbett, 2004a; Gabbett, 2004b; Gabbett & Domrow, 2007; Gabbett & Jenkins, 2011). Each of these studies used session RPE (sRPE) as the internal training load measure, which was multiplied with session duration to calculate an overall session load.

Gabbett's 2004 prospective study examined the influence of training and match load on injury incidence in 79 semi-professional rugby league players over one competitive season (Gabbett, 2004a). Strong relationships were observed between training related injury incidence and training load ($r=0.86$; $p<0.05$), and training duration ($r=0.79$; $p<0.05$). Additionally, match-play injuries were strongly correlated with match load ($r=0.86$), and match duration ($r=0.86$). These findings indicated that in rugby league, injury incidence increased as training and match-play intensity increased. These findings are in agreement with an earlier study involving 12 female collegiate basketball players from the NCAA Division III team, where a moderate positive correlation between weekly training load and weekly injury incidence was found (r=0.68) (Anderson et al., 2003). Notably, injury incidence was observed to spike in parallel with spikes in training load. In both studies, training load was highest following periods of little or no training, both in the preseason, and following a week off training during the mid-season (Anderson et al., 2003; Gabbett, 2004a). It is possible that the injury incidences observed in these studies were exacerbated due to athletes not being physically ready to cope with the high training demands immediately after a break in training. This suggests that it may not have been the magnitude of the absolute loads that contributed to the higher number of injuries, but rather the timing of the increased training load.

Studies in rugby league have also found higher training loads were associated with higher injury incidence. It has been observed that in rugby league, training load is highest in the preseason phase, before tapering off during the competition phase (Gabbett, 2004a; Gabbett, 2004b; Gabbett & Domrow, 2007). Correspondingly, injury incidence was found to be highest in the preseason phase. It has been found that increased training load in the preseason has a greater effect on injury incidence compared to any relative increases in the early or late competition phase. Based on these findings, it would seem that a reduction in preseason training load may be prudent, or that a progressive increase in training load and intensity during the preseason would better protect athletes from injury. Indeed, it has been shown that reductions in preseason training load reduces preseason injury incidence (Gabbett, 2004b). Moreover, it was also revealed that the relative gains in physical fitness were equivalent despite a lowered training load in the latter two preseasons. It therefore seems possible to minimise training related injury risk by reducing either training intensity or duration, without losing any of the expected improvements in physical fitness in the preseason. It is unclear whether this extends to the competition phase in rugby league athletes, however it has been found that while increases in training load did not result in further increases in injury incidence during the early competition phase, agility performance was reduced (Gabbett & Domrow, 2007).

Further research in professional rugby league produced contrasting findings to those previously noted, and the authors noted that the players had completed a 6-week active offseason prior to the beginning of the study, which may have contributed to a higher base level of fitness at the beginning of the preseason compared to semi-professional players (Killen, Gabbett & Jenkins, 2010). While no relationship between internal training load and injury incidence was reported, a spike in injury rate was observed immediately after an 11 day break, which is consistent with earlier studies (Anderson et al., 2003; Gabbett, 2004a). Subsequent studies involving professional rugby league athletes concluded that higher internal training loads were associated with an increased risk of injury incidence (Gabbett & Jenkins, 2011; Thornton et al., 2017). One study considered both absolute and relative loads, acknowledging that considering relative loads is essential in understanding how an athlete's load fluctuates, providing a better understanding of their fatigue (Thornton et al., 2017). Furthermore, it was found that the impact of different training load measures on injury incidence varied depending on playing position. This highlights the need for an individualized or positional approach when considering injury surveillance in a team sport, however, this might be hard to implement in studies involving semi-professional or sub-elite athletes due to lesser resources compared to professional athletes.

External training load and injury

Evidence of a relationship between external training load and injury risk is less clear than that of internal training load. It appears that the ability of the external training load to reflect the demands of the sport is an important factor. Research that has used training duration as the primary measure of external training load has not demonstrated any association with injury risk (Brooks et al., 2008; Gianoudis, Webster & Cook, 2008; Korkia et al., 1994), while studies that have used other measures of external training load (e.g. number of fast balls bowled, high speed running distance, or total running distance) have found a clearer relationship between external training load and injury.

A study of 46 high school basketball players measured the time spent each week participating in different physical activities over 15-weeks, the majority of which were basketball related (Gianoudis, Webster & Cook, 2008). No significant differences were found in the weekly amount of physical activity between injured and non-injured athletes. Similar observations were made across 155 recreational to elite triathletes (Korkia et al., 1994). No significant associations were observed between weekly training duration, frequency or distance and injury incidence. A commonality between these studies were the lack of measures of training intensity. Considering that the most commonly used measure of internal training load, sRPE, is calculated using both training volume and intensity, it may be possible that capturing only training volume is not an accurate representation of training load. Also, both studies utilized a self-reporting of training volume, as well as injuries, potentially adding reporting error and bias to the results (Korkia et al., 1994). Injuries were defined as an event that required the athlete to stop a session or race, prevented them from returning, or required them to rest more than a day after an injury, hence it likely excluded minor injuries, or those that did not cause missed training. While it is not uncommon for athletes to train through minor injuries, these may develop into more substantial overuse injuries if not addressed.

Additional studies measuring the duration of training as the primary load measure have observed some relationships with injury incidence, despite the lack of an intensity measure . Brooks et al. (2008) measured weekly training volume (hours) from 502 rugby players over two competitive seasons. No statistically significant relationships were observed between injury incidence and weekly training volume, however training at a high volume (>9.1 hours) increased the average severity of injuries sustained, while training at intermediate volumes (6.2-9.1 hours) was associated with the lowest overall injury severity and training days missed. This suggests that while different training volumes did not affect injury incidence, there may be a certain training threshold which minimizes the injury severity and time lost. Another study did find a statistically significant relationship using training duration, but only with traumatic injury incidence (Brink et al., 2010). Players who had a higher weekly training duration were more at risk of traumatic injuries the following week, however, there was no significant difference in training duration between those who were uninjured and those who developed overuse injuries. A possible explanation for this is that overuse injuries are generally sustained after longer periods of repetitive training and insufficient recovery time, hence only using a one week period prior to the injury may not be enough time to find any relevant relationship between weekly training duration and overuse injury risk.

An apparent problem with using training duration is that there is no measure of training intensity (Gianoudis, Webster & Cook, 2008). Consequently, as a load measure it may not accurately reflect the demand of different sports; studies using different load variables that are more sport specific have found a much clearer relationship between external training load and injury (Dennis et al., 2003; Dennis et al., 2004; Thornton et al., 2017). In professional cricket fast bowlers, it has been found that the number of bowls delivered weekly has an impact on injury risk. While the number of deliveries per session was the same between injured and non-injured bowlers, injured bowlers delivered significantly more bowls per week, and had fewer rest between sessions (Dennis et al., 2003; Dennis et al., 2004). There was also evidence of increased injury risk when working below and above a certain threshold of bowls delivered each week, which supports the observation that training within a threshold may minimize injury risk (Brooks et al., 2008; Dennis et al., 2003). A later study involving professional rugby league players also found a relationship between injury risk and various external load measures, including total distance run over 7 days, and high intensity running load (Thornton et al., 2017). Evidently, a relationship between external training load and injury does exist, but is dependent on the load variable used.

In some sports it is not uncommon for athletes to play in multiple matches per week. Studies have consistently found that match frequency as a variable is linked to increased injury incidence. Given that match intensity and duration are often higher than in training, it would be reasonable to think that playing multiple games per week places the athlete under a higher weekly load compared to only playing in one game per week, which could be detrimental without adequate recovery (Montgomery, Pyne & Minahan, 2010). Professional soccer players who play two games per week have been shown to have a significantly higher injury risk compared to players only participating in one game per week (Dellal et al., 2013; Dupont et al., 2010; Vilamitjana, Lentini & Masabeu, 2013). An increase in injury severity was also been observed in players participating in two games each week, as well as a greater proportion of overuse injuries (Dupont et al., 2010; Vilamitjana et al., 2013). It is also important to note that players still participate in practice sessions of varying intensity between matches, which contributes to the overall weekly player load (Dupont et al., 2010; Vilamitjana et al., 2013). This highlights the need for appropriate planning around rest and recovery methods, as well as appropriate load monitoring guidelines, especially when playing multiple games per week. This is particularly relevant to basketball, where teams usually play one-to-two games per week in the NBL and up to three to four games per week in the NBA.

The Acute to Chronic Workload Ratio

More recently, studies have proposed that load management should consider monitoring relative loads, as this is thought to be more informative on how the training load is achieved compared to monitoring weekly workloads in isolation. One of the more common forms of relative load monitoring is the acute to chronic workload ratio (ACWR), which compares the absolute workload completed in the most recent week (acute workload), to the average weekly workload of the most recent four weeks (chronic workload) (Gabbett, 2016; Hulin et al., 2015). The ACWR was derived from a workload-performance statistical model proposed by Banister et al. (1975), which estimated performance based on the difference between a negative function (fatigue) and a positive function (fitness). The premise of the ACWR is that it provides an indication of athlete preparedness relative to their training history, where acute workload is equivalent to a state of fatigue, and chronic workload is equivalent to a state of fitness (Blanch & Gabbett, 2016; Gabbett, 2016). It has been argued that when acute workload exceeds chronic workload (ACWR >1.0), an athlete is in a fatigued state relative to what they have prepared for. Conversely, when chronic workload is greater than or equal to acute workload (ACWR≤1.0) an athlete is in a better prepared state (Gabbett, 2016). Subsequently, the ACWR also provides a measure of the magnitude of change in weekly workload. Due to the periodization of training load throughout a competitive season, it is not unrealistic to see the ACWR fluctuate below and above 1.0 (Blanch & Gabbett, 2016; Hulin et al., 2015; Hulin et al., 2016). A ratio score too far below or above 1.0 could represent a spike in training load, and could indicate that the athlete over- or under-trained in relation to what they were physically prepared for.

The characteristics and participant information from studies investigating the use of the ACWR in informing injury risk in professional team sports are summarized in Table 1. A total of 12 studies have been published in a number of different sports, including Australian football (n=4), rugby league (n=2), soccer (n=3), cricket (n=1), Gaelic football (n=1), and basketball (n=1). This encompassed 529 athletes across all 12 studies. The largest study included 70 athletes, while the smallest study included only 13. Data was collected over varied periods, from a single season, to 5 continuous seasons.

Table 1: Participant and study characteristics for studies investigating the use of the ACWR in informing injury risk in professional team sport.

Reference	Design	Sport	Participants	Research Aim
Hulin, B. T., Gabbett, T. J., Blanch, P., Chapman, P., Bailey, D., & Orchard, J. W. (2014)	Prospective Cohort	Cricket	28 elite fast bowlers over 5 Australian domestic cricket seasons	To investigate the relationship between acute and chronic workload and injury risk in elite cricket fast bowlers.
Hulin, B. T., Gabbett, T. J., Lawson, D. W., Caputi, P., & Sampson, J. A. (2015)	Prospective Cohort	Rugby league	53 players from one NRL club over 2 seasons (preseason and competition).	To investigate whether acute and chronic workloads predict injury in elite rugby league players.
Hulin, B. T., Gabbett, T. J., Caputi, P., Lawson, D. W., & Sampson, J. A. (2016)	Prospective Cohort	Rugby league	28 players from one NRL club over 2 seasons (competition phase only).	To investigate the relationship between acute and chronic workload and injury risk following short and long between-match recovery times in elite rugby league players.
Carey, D. L., Blanch, P., Ong, K-L., Crossley, K. M., Crow, J., & Morris, M. E. (2016)	Prospective Cohort	Australian football	53 players from one professional AFL team over 2 season, total of 90 individual player seasons.	To identify whether daily ACWR inform injury risk, and to identify which combination of workload variable and acute:chronic time windows best explain variation in injury risk.
Murray, N. B., Gabbett, T. J., Townshend, A. D., & Blanch, P. (2017)	Prospective Cohort	Australian football	59 elite players competing in the AFL over 2 seasons, total of 92 individual player seasons.	To determine the difference between the ACWR as calculated using rolling averages versus exponentially weighted moving averages, and their association with injury risk.
Colby, M. J., Dawson, B., Peeling, P., Heasman, J., Rogalski, B., Drew, M. K., Stares, J., Zouhal, H., & Lester L. (2017)	Prospective Cohort	Australian football	70 players from one AFL club over 4 seasons.	To identify injury risk factors in Australian Football, and to establish a multivariate model combining different injury risk measures to aid individualised workload management.

Stares, J., Dawson, B., Peeling, P., Heasman, J., Rogalski, B., Drew, M., Colby, M., Dupont, G., & Lester L (2018)	Prospective Cohort	Australian football	70 elite players from one AFL club over 4 seasons, total of 179 individual player seasons.	To examine the effects of different acute:chronic timeframes for calculating ACWR, and whether this is associated with injury risk in Australian Football players.
Malone, S., Owen, A., Newton, M., Mendes, B., Collins, K. D., & Gabbett, T. J. (2017)	Observational Cohort	Soccer	48 elite soccer players from two teams at the highest level of European competition, over one season.	To investigate the relationship between workload measures and injury risk in elite soccer players.
Malone, S., Owen, A., Mendes, B., Hughes, B., Collins, K., & Gabbett, T. J. (2018)	Prospective Cohort	Soccer	37 elite soccer players, over one season.	To investigate whether high speed running and sprinting increases injury risk in elite soccer players, and whether aerobic fitness would affect injury risk.
Bowen, L., Gross, A. S., Gimpel, M., Bruce-Low, S., & Li, F-X. (2019)	Prospective Cohort	Soccer	33 professional soccer players from one English Premier League club over 3 seasons, total of 61 individual player seasons.	To examine the relationship between GPS-derived workloads and injury risk in English Premier League football players.
Malone, S., Roe, M., Doran, D. A., Gabbett, T. J., Collins, K. D. (2017)	Prospective Cohort	Gaelic football	37 elite Gaelic football players over one season.	To examine the relationship between sRPE workload measures and injury risk in elite Gaelic footballers.
Weiss, K. J., Allen, S. V., McGuigan, M. R., & Whatman, C. S. (2017)	Prospective Cohort	Basketball	13 professional basketball players from a the Australian New Zealand Basketball League, over one season.	To establish the relationship between training load and lower limb overuse injury in professional basketball players.

The Acute to Chronic Workload Ratio and Injury Risk

A novel finding that has emerged from literature investigating the use of the ACWR in informing injury risk is that spikes in acute workload are associated with a greater risk of injury (Hulin et al., 2015; Malone et al., 2018). A total of 12 studies investigating the use of the ACWR in informing injury risk in professional team sports have been published. Further detail on the load measures used and findings related to absolute and relative workloads are summarized in Table 2.

It was observed that elite soccer players who performed moderate high speed running (HSR) distances had a lower injury risk compared to those who performed low and high HSR distances (Malone et al., 2018). Considering that acute workload is analogous to a state of fatigue (Gabbett, 2016), this suggests that increases in workload greater than what the athlete has physically prepared for could increase injury risk, which supports earlier observations that injury incidence increased in parallel to spikes in training load (Anderson et al., 2003; Gabbett, 2004a). In contrast, high chronic workloads have been associated with a decreased injury risk, while lower chronic workloads have been associated with a greater injury risk (Colby et al., 2017; Hulin et al., 2014; Hulin et al., 2016; Malone et al., 2018; Stares et al., 2018). Exposure to high workloads is thought to improve tolerance for higher workloads as a result of musculoskeletal and cardiovascular adaptations, or a higher state of physical fitness (Malone et al., 2018). This is thought to offer a protective effect against spikes in acute workload, as it is much more difficult for acute workload (fatigue) to exceed chronic workload (fitness) when chronic workload is high (Malone et al., 2018). It is unlikely that there will always be a perfect balance between fitness and fatigue throughout a competitive season, however when one state exceeds the other past a certain threshold, athletes could be at a higher risk of injury. A possible benefit of using the ACWR is that this change in workload can be quantified relative to training history, such that safe increases or decreases in workload can be calculated and implemented when necessary.

The first study to investigate the relationship between relative loads and injury risk was conducted in cricket fast bowlers, where it was observed that when acute workload exceeded chronic workload, referred to in this study as a negative training-stress balance, injury risk in the subsequent week was doubled (relative risk = 2.1 [1.81-2.44], $p = 0.01$) (Hulin et al., 2014). Furthermore, the greater the acute workload relative to chronic workload, the higher the injury risk observed. This was supported by a study in rugby league, which reported that high (1.2-1.6) and very high (>1.6) ACWRs combined with short between-match recovery times were associated with an injury risk 2.8 and 5.8 times greater than when the ACWR was between 1.0 and 1.2 (Hulin et al., 2015). Similar findings have been corroborated by subsequent studies, which reported that high and very high ACWR were associated with greater injury risk compared to lower ACWRs in Australian football (Carey et al., 2016; Colby et al., 2017; Murray et al., 2017; Stares et al., 2018), soccer (Bowen et al., 2019; Malone et al., 2017; Malone et al., 2018), and basketball (Weiss et al., 2017). Given that a high ACWR represents a spike in acute workload relative to chronic workload, this suggests that when there is a sudden increase in workload greater than what the athlete has prepared for, injury risk also increases. It has also been reported that low ACWR is associated with increased injury risk (Colby et al., 2017; Stares et al., 2018; Weiss et al., 2017). This suggests that lower training loads may have a negative effect on fitness and athlete preparedness, which has led to the suggestion an ACWR 'sweet spot' exists, which refers to an ACWR range associated with a lower injury risk compared to ratio scores above and below it (Colby et al., 2017; Malone et al., 2017; Weiss et al., 2017).

Multiple studies have also observed that a low chronic workload coupled with a high or very high ACWR is associated with a greater risk of injury (Bowen et al., 2019; Colby et al., 2017; Hulin et al., 2015; Stares et al., 2018). In contrast, a high chronic workload coupled with a high ACWR was not associated with an increased injury risk (Colby et al., 2017; Stares et al., 2018). This suggests that monitoring the ACWR, relative to the chronic load it was derived from, may be more informative of injury risk compared to monitoring the ACWR alone. Athletes with a low chronic workload are more likely to reach a high ACWR, as the amount of acute workload needed to produce a high ACWR is much lower than the amount of acute workload needed to produce a corresponding increase in ACWR when chronic workload is high (Stares et al., 2018). Put differently, athletes with a higher chronic workload are less likely to reach an increase in ACWR of the same magnitude compared to athletes with a low chronic workload base (Colby et al., 2017). Stares et al. (2018) also noted that the athletes they studied rarely reached a high ACWR when chronic workload was high or very high, given the amount of acute workload would be needed to elicit the same degree of increase in ACWR using a high chronic workload. Similarly, another study noted there was a lack of injury observations when chronic workloads were high (Bowen et al., 2019), which further illustrates the possible protective effects of high chronic workloads.

It should be noted that while the majority of researchers agree that both high and low ACWRs are associated with an increased injury risk, the actual ACWR values and ranges reported differ between studies. For example, Hulin et al. (2015) reported a high ACWR as 1.75-2.10 and a very high ACWR as ≥2.11 in professional rugby league players, but in a later study assessing a similar cohort and using the same external load variable, an ACWR between 1.23-1.61 was described as high, and above 1.62 as very high (Hulin et al., 2016). It appears that the ACWR values reported are specific to the sample population used, and generalization of results should be done so with caution. It is likely that teams considering implementing the

ACWR will need to establish their own ranges using data collected over at least one full season. It is also possible that individuals within a team will have different low-to-high ACWR thresholds, as each individual responds to workload differently. One of the possible limitations of the current literature is that the ACWR has been used as a team average, when it may be more practical to use it as an individual measure to better account for the variation in workload between different players or playing positions. Currently, there is no literature that has investigated the use of the ACWR as an individual measure for informing injury risk.

Table 2: Summary of key findings from studies investigating ACWR and injury risk in professional team sport.

Reference	Workload Measure	Main Findings - Absolute Load	Main Findings - Relative Load
Hulin, B. T., Gabbett, T. J., Blanch, P., Chapman, P., Bailey, D., & Orchard, J. W. (2014)	ETL - total number of balls bowled per week, including training and competition. ITL - sRPE 7 day acute period, 28 day chronic period.	↑ chronic ETL associated with lower injury risk in both the current and subsequent weeks. No relationship between acute or chronic ITL load and injury in the current or subsequent weeks.	Negative ETL and ITL training-stress balances associated with an increased injury risk in subsequent week. No relationship with injury risk in the current week.
Hulin, B. T., Gabbett, T. J., Lawson, D. W., Caputi, P., & Sampson, J. A. (2015)	ETL - Absolute total distance (m) covered during all training sessions and matches, measured using GPS. 7 day acute period, 28 day chronic period.	↑ acute load associated with a greater injury risk in the current week. No difference in injury risk among different chronic workloads.	High ACWR (≥2.11) associated with greatest injury risk in the current week. ACWR between 0.85-1.35 associated with lowest injury risk in the subsequent week.
Hulin, B. T., Gabbett, T. J., Caputi, P., Lawson, D. W., & Sampson, J. A. (2016)	ETL - Absolute total distance (m) covered during all training sessions and matches. Between-match recovery times - short (<7 days) and long (≥7 days). 7 day acute period, 28 day chronic period.	↑ chronic workload associated with lower match injury risk during short between-match recovery times. Higher chronic workloads protected against spikes in acute workload.	High ACWR (>1.23) during short recovery periods associated with higher match injury risk. High ACWR (≥1.50) during long recovery periods associated with higher match injury risk.
Carey, D. L., Blanch, P., Ong, K-L., Crossley, K. M., Crow, J., & Morris, M. E. (2016)	ETL - total distance (m), player load (arbitrary units), high speed running, moderate speed running, average speed. ITL - sRPE. Acute periods of 2,3,4,5,6,7,8,9 days. Chronic periods of 14, 18, 21, 24, 28, 32,35 days.	Did not report findings related to absolute load.	Different workload variables had different "optimal" acute and chronic windows. 3:21 acute:chronic periods generated better performing injury models. ↓ match injury risk when approaching match with ACWR between 0.8-1.0.

Murray, N. B., Gabbett, T. J., Townshend, A. D., & Blanch, P. (2017)	ETL - total distance covered (m), low-speed distance, moderate-speed distance, high-speed distance, very high-speed distance, player load (au). 7 day acute period, 28 day chronic period. EWMA ACWR calculated.	Did not report findings related to absolute load.	Lower ACWR values calculated using EWMA model at moderate to very high ACWR ranges compared to rolling average model. EWMA model more sensitive to spikes in TL. ↑ ACWR associated with ↑ injury risk for both models.
Colby, M. J., Dawson, B., Peeling, P., Heasman, J., Rogalski, B., Drew, M. K., Stares, J., Zouhal, H., & Lester L. (2017)	ETL - total distance covered (m), sprint distance (m) ITL - sRPE 7 day acute period, 28 day chronic period	↑ chronic loads protect against spikes in acute loading	↓ chronic ETL (total distance) combined with ↑ ACWR associated with greater injury risk than moderate ACWR. ↓ chronic ITL load combined with ↓ ACWR associated with greater injury risk than moderate ACWR ACWR outside the 0.8-1.2 range considered as potential injury risk factor.
Stares, J., Dawson, B., Peeling, P., Heasman, J., Rogalski, B., Drew, M., Colby, M., Dupont, G., & Lester L (2018)	ETL - total distance covered (m), sprint distance (m) ITL - sRPE 1-2 weeks acute period, 3-8 weeks chronic period	Most injuries occurred when there was ↓ chronic load	No acute:chronic timeframe was better than another for injury prediction in AFL players. ↑ ACWR accounted for a significant number of injuries. ↑ injury risk when ACWR is outside the 0.6-1.5 range. ACWR should be monitored in conjunction with chronic loads.
Malone, S., Owen, A., Newton, M., Mendes, B., Collins, K. D., & Gabbett, T. J. (2017)	ITL - sRPE 7 day acute period, 28 day chronic period	↑ injury risk during the pre-season than the in-season at similar acute and chronic workloads. ↑ acute loads associated with ↑ injury risk	↓ injury risk when ACWR between 1.0-1.25 ↑ intermittent-aerobic capactiy protected against spikes in acute load.
Malone, S., Owen, A., Mendes, B., Hughes, B., Collins, K., & Gabbett, T. J. (2018)	ETL - high speed running distance (m), sprint running distance (m), training load (AU) ITL - sRPE 3 day acute period, 21 day chronic period	↑ chronic ETL associated with lower injury risk for both HSR and SR, protects against spikes in acute TL. ↓ chronic ETL associated with higher injury risk at similar HSR and SR distances. ↑ acute ETL associated with greater lower limb injury risk.	↑ risk of subsequent injury associated with a 3:21 ACWR of >1.25 (HSR) and >1.35 (SR). ↑ aerobic fitness better protected players against spikes in acute TL.

Bowen, L., Gross, A. S., Gimpel, M., Bruce-Low, S., & Li, F-X. (2019)	ETL - total distance (m), low-intensity distance (m), high-speed running distance (m), sprint distance (m), number of accelerations, number of decelerations 7 day acute period, 28 day chronic period	Did not report findings related to absolute load.	↓ chronic TL combined with ↑ ACWR associated with greatest overall injury risk and non-contact injury risk. Moderate to high ACWR (1.1-1.5) associated with greatest contact injury risk. Different workload variables more predictive of injury risk.
Malone, S., Roe, M., Doran, D. A., Gabbett, T. J., Collins, K. D. (2017)	ITL - sRPE 7 day acute period, 28 day chronic period	↑ acute loads associated with ↑ injury risk. ↑ 2-weekly and 3-weekly loads associated with ↑ injury risk. ↑ injury risk during late-season compared to preseason.	High ACWR (>2.0) associated with ↑ injury risk during preseason and early season. ↓ injury risk when ACWR is between 1.35-1.50 during preseason and early season. ↑ aerobic fitness associated with ↓ injury risk at similar workloads.
Weiss, K. J., Allen, S. V., McGuigan, M. R., & Whatman, C. S. (2017)	ITL - sRPE 7 day acute period, 28 day chronic period	Did not report findings related to absolute load.	ACWR between 1.0-1.49 associated with lowest proportion of team injured. ACWR ≤ 0.5 1.5 times more likely to get injured. ACWR between 0.5-0.99 1.4 times more likely to get injured. ACWR ≥ 1.5 1.7 times more likely to get injured.

The Acute to Chronic Workload Ratio Sweet Spot

A quadratic relationship between ACWR and injury risk has been noted by a number of studies, indicating an ACWR range associated with a lower injury risk compared to ratio scores above and below this range (termed the sweet spot) (Carey et al., 2016; Stares et al., 2018; Weiss et al., 2017) (Table 2). However, the actual sweet spot range suggested varied between studies. Studies in Australian football have reported different ranges of 0.8-1.0 (Carey et al., 2016), 0.8-1.2 (Colby et al., 2017), and 0.6-1.5 (Stares et al., 2018) as potential ACWR sweet spot ranges. Comparatively higher ACWR sweet spot ranges have been proposed in soccer (1.0-1.25) and professional men's basketball (1.0-1.5) (Malone et al., 2017; Weiss et al., 2017). It is possible that increases and decreases in workload occur without increased injury risk, where changes in workload fall within this proposed sweet spot range. In contrast, a recent study in soccer observed that a moderate to high ACWR between 1.1-1.5 was associated with the greatest contact injury risk for a number of workload variables (Bowen et al., 2019). Furthermore, there was no clear quadratic relationship between AWCR and injury risk observed. These inconsistencies could suggest that the ACWR ranges reported are specific to the sport or specific sample, reflecting the different physical demands and competitive schedules.

Acute and Chronic Time Periods

A commonly cited limitation of the current acute and chronic time periods is that the ACWR cannot be used until there is sufficient chronic load data (Carey et al., 2016; Stares et al., 2018). With the most widely used chronic time period being 28 days, it is not possible to calculate the ACWR without four weeks of data (Colby et al., 2017; Hulin et al., 2014; Murry et al., 2017; Weiss et al., 2017). In some situations this could coincide with the start of a season, which is not ideal as it has been reported as a time of high injury occurrence where athletes may be physically under prepared for competition and the sudden increases in physical load (Anderson et al., 2003; Gabbett, 2004a; Gabbett & Domrow, 2007). Changing the acute and chronic windows could allow the use of the ACWR earlier in the season without compromising its ability to inform injury risk. It is also possible that different acute and chronic time periods are more appropriate for informing injury risk depending on the sport and the frequency of training and competitive games.

Two studies have manipulated the acute and chronic time windows and examined the effect on the ACWR's ability to inform injury risk in Australian football (Carey et al., 2016; Stares et al., 2018). The first study reported that a 6-day acute period paired with a 14-day chronic produced better performing models for explaining the variation in injury likelihood for matches and trainings combined (Carey et al., 2016). However, when injury data was divided into match injuries only, the best performing ratio was calculated using a 3-day acute period and a 21-

day chronic period. Furthermore, it was noted that the optimal acute and chronic time window differed depending on the workload variable, suggesting that a single optimal acute and chronic period does not exist, and is instead dependent on the workload variable used. It is also likely that the acute and chronic periods were specific to this study population, and therefore generalization of these findings may not be possible.

In contrast, the second study found that using different acute and chronic periods did not improve the ability of the ACWR in informing injury risk any more than using the standard 7-day acute and 28-chronic periods (Stares et al., 2018). It should be noted that this study calculated ACWR weekly, whereas Carey et al. (2016) calculated a daily ACWR, though it is still unclear how this might affect the choice of acute and chronic periods used. It is suggested that daily calculations may be more appropriate to account for the varying periods between games, as a weekly calculation may misrepresent the ACWR when calculated at the beginning of the week (Stares et al., 2018). Both studies suggest that it may be possible to manipulate the acute and chronic time windows to improve ACWR model performance. Therefore, it may be possible to shorten the chronic period without compromising the capacity of the ACWR to inform injury risk, allowing its use earlier on in the season. Despite these findings, the statistical analyses used were not particularly comprehensive and potentially inappropriate. Re-analysis of these data, as well as additional research, using more robust statistical analyses is needed to support these preliminary findings. Additionally, with both studies assessing Australian football athletes, further research, especially on sports with different competition schedules, such as basketball, is warranted. It is possible that different sports will have different acute and chronic time periods that are more appropriate for reflecting workload and injury risk relative to the specific training and competition schedule of the athlete, however there is currently insufficient evidence to support this.

Limitations

Given the varied ways in which the ACWR can be calculated, there are a few methodological limitations associated with the calculation of the ACWR itself. Currently, the majority of studies calculate the ACWR based on the coupled method, where acute workload is included in the calculation of the chronic workload. As a result, the acute workload is included in both the numerator and denominator when calculating the ACWR, which leads to possible mathematical coupling (Griffin et al., 2020; Lolli et al., 2019). It was shown that when the acute workload is included in the calculation of chronic workload, there was a moderate to large positive correlation between the two variables (r=0.52; 95% CI: 0.47-0.56). Conversely, when acute workload was excluded from the calculation of chronic workload, the association was significantly weaker (r=0.01; 95% CI: -0.05-0.07) (Lolli et al., 2019). This suggests that mathematic coupling results in a spurious, or false, correlation between the acute and chronic workload regardless of whether there is any true biological or physiological association between the two variables (Lolli et al., 2019). Subsequently, this leads to a bias inference and could affect the accuracy and validity of the resultant ACWR. This limitation may be resolved by excluding the acute workload period in the calculation of chronic workloads, however, limited research has shown that high ACWRs are still associated with greater injury risk, regardless of whether the ACWR was calculated using coupled or uncoupled workloads (Gabbett et al., 2019). It is currently unclear whether calculation of the ACWR using the uncoupled method is a more valid representation of athlete workload, and further research is needed to examine this.

Another concern with the ACWR calculation is that using a rolling average chronic workload does not account for decaying effects of fitness and fatigue over time on injury risk (Murray et al., 2017; Williams et al, 2017). Additionally, a rolling average does not account for the variation in daily workload, or how workload is distributed, over the chronic time period. It has been suggested that an exponentially weighted moving average (EWMA) be used to calculate acute and chronic workloads instead of the standard rolling average, where older workload values are assigned a decreased weighting to account for the decaying effect (Williams et al., 2017). While the majority of studies examining the ACWR have used rolling averages in their calculation, some studies have observed ACWR models calculated using an EWMA were more sensitive for predicting injury risk compared to ACWR models using the rolling average, which underestimated the risk of injury at higher ACWRs in Australian Football players (Esmaeili et al., 2018; Murray et al., 2017). This was supported by observations that a high EWMA ACWR was associated with a greater injury risk in American Football players (Sampson et al., 2018). However, it is acknowledged that although the EWMA model does seem to have more sensitivity compared to the rolling averages model, any sudden increases in workload are associated with an increased injury risk, regardless of whether the ACWR is calculated using rolling averages or the EWMA (Esmaeili et al., 2018; Murray et al., 2017).

Conclusion

Spikes in acute workload have been associated with an increased injury risk in professional rugby league, soccer and Gaelic football. In contrast, high chronic workloads have been associated with a decreased injury risk in Australian football, cricket and rugby league. It is thought that high chronic workloads promote enhanced physiological developments and ultimately a higher state of physical fitness, thus improving tolerance for higher workloads. Both high and low ACWRs have been associated with an increased injury risk, leading to suggestions that an ACWR sweet spot exists. However, there is still limited evidence to support this proposition, and a lack of clarity as to what the sweet spot range might be.

Prelude to Chapter 3

The narrative review has identified that both high and low absolute workloads are associated with an increased risk of injury. Additionally, the acute to chronic workload ratio (ACWR), a relative load measure, has been shown to inform injury risk in a number of different team sports. Furthermore, evidence suggests that an ACWR sweet spot exists, which represents an ACWR range associated with a lower injury risk compared to ACWR scores above and below this range. However, there is currently a lack of literature that has examined this workload-injury relationship in basketball. Therefore, a prospective cohort study was conducted to further investigate whether absolute and relative workload measures were associated with injury risk in professional men's basketball. This may better inform which workload measures should be included when monitoring athlete workload and injury risk in basketball.

Chapter 3: The relationship between training and game workload and injury risk in basketball: A prospective cohort study

Introduction

Basketball is an intermittent high intensity team sport requiring a combination of technical skill and physical athleticism, involving repeated accelerations, decelerations, changes of directions and jumping movements (Schelling & Torres-Ronda, 2013). Within professional basketball, the frequency of competitive games is high. Teams in the Australia New Zealand National Basketball League (NBL) play between one to two games each week in addition to regular training sessions, whereas teams in the American National Basketball Association (NBA) play up to four games each week. Consequently, players are exposed to high physical workloads over the course of a season, with short between-game recovery times. While it is accepted that a certain workload level is required to improve performance, coaches need to allow sufficient recovery to prevent overtraining, a deficit of which could increase the risk of training related injury (Halson, 2014). Data from the NBA has indicated a high frequency of overuse and inflammatory conditions, which account for the greatest amount of time lost from games and trainings (Deitch et al., 2006; Starkey, 2000). Such injuries can have a negative effect on team success, and while there are many factors that may contribute to injury risk, athlete workload is considered an important modifiable risk factor (Gabbett, 2016). Therefore, appropriate athlete monitoring strategies need to be implemented to allow for sufficient recovery, potentially reducing the risk of workload related injury.

Understanding the relationship between workload and injury risk may be beneficial for load prescription and management during the season. Currently, there is limited research investigating the workload-injury relationship in basketball (Anderson et al., 2003 Weiss et al., 2017). Research from other team sports has found that both high and low weekly workloads (termed acute workload) are associated with a greater injury risk (Dennis et al., 2003; Hulin et al., 2016; Malone et al., 2017; Malone et al., 2018). This has led to the suggestion that working within a certain workload range could minimize injury risk, while maximizing performance (Brooks et al., 2008; Dennis et al., 2003). In contrast, higher average weekly workload over four weeks (termed chronic workload) has been associated with decreased injury risk compared to low chronic loads. This supports the idea that a certain level of physical stimulation is required to ensure athletes are physically prepared for competition (Hulin et al., 2014; Hulin et al., 2016). Exposure to higher workloads is thought to improve an athlete's tolerance for higher workloads, as a result of multiple adaptations to the musculoskeletal and cardiovascular systems (Malone et al., 2018). This is thought to offer a protective effect against sudden increases in weekly workload, which have been associated with increases in injury risk (Anderson et al., 2003; Malone et al., 2018). Therefore, consideration of proper training load periodization is important to ensure athletes are physically prepared for changes in workload, especially following periods of inactivity such as breaks in the season or when returning from injury.

Research surrounding the workload-injury relationship has focused on the use of the acute to chronic workload ratio (ACWR) as a metric to inform injury risk and aid workload prescription (Hulin et al., 2016; Colby et al., 2017). The ACWR assesses the acute workload relative to the average workload performed in the previous four weeks (chronic workload). The resulting workload index provides an indication of whether the athlete's weekly acute workload is greater than, equal to, or less than that which they had prepared for in the previous chronic period, and thus provides a measure of the magnitude of change in weekly workload (Hulin et al., 2015). Although this measure originated from a workload-performance perspective, studies in Australian football, soccer and rugby league have suggested that spikes in ACWR are associated with a greater injury risk (Bowen et al., 2019; Colby et al., 2017; Hulin et al., 2015; Malone et al., 2017; Stares et al., 2018). There have also been reports of an ACWR sweet spot, where injury risk is lower compared to ACWRs above and below this range (Colby et al., 2017; Hulin et al., 2015). Only one study has investigated the relationship between workload and injury risk in basketball using the ACWR (Weiss et al., 2017). This study observed that an ACWR range of 1.0-1.49 was associated with the lowest injury risk compared to ACWR ranges above and below this threshold, however further statistical analysis did not reveal clear differences between injury risk for different ACWR categories. Further research is needed to determine whether the ACWR is useful as a load monitoring strategy in informing injury risk in professional basketball, hence allowing potential reduction in injury rates, minimising time loss from trainings and games, and maximising potential team performance. Therefore, the aim of this study was to investigate the relationship between different workload measures and injury risk in professional men's basketball.

Methods

Participants

In-season data (excluding pre-season and post-season) were collected from male professional basketball players (n=16; 26.3 ±4.9 yrs) from a single NBL team over the 20 weeks of the 2017-2018 season (28 games and 41 training sessions). Four players were excluded from the final analysis due to being in the development squad and not participating in any matches. A further three players were excluded as they were on temporary contracts and were not with the team for the entire season. Following exclusion there was a total of 597 individual player sessions available for analysis. Ethical approval was obtained from the

Auckland University of Technology Ethics Committee (#14/383), and all players provided written consent.

Quantifying workload

Player workload data were collected for all team training sessions and matches using wearable sensors (ClearSky T6, Catapult Innovations, Australia) incorporating global positioning system (GPS) tracking, in addition to tri-axial accelerometer, gyroscope and magnetometer sensors. The sensors were placed between the scapulae, held in place using a tight fitting vest. Real-time tracking of GPS data were unavailable due to the indoor setting, therefore only accelerometer based data (sampled at 100 Hz) was used to quantify workload. External workload was quantified as an arbitrary player load (PL), calculated based on the formula:

$$\text{Load} = \sqrt{((Ac1n - Ac1n{-}1)^2 + (Ac2n - Ac2n{-}1)^2 + (Ac3n - Ac3n{-}1)^2)}$$

Ac1, Ac2 and Ac3 represent the instantaneous rate of change in acceleration in the three planes of body movement (Montgomery, Pyne & Minahan, 2010). This metric has been shown to be a valid and reliable measure of workload in basketball compared to session rating of perceived exertion (sRPE) (Montgomery, Pyne & Minahan, 2010; Svilar, Castellano & Jukic, 2018).

For match data that was incomplete or recorded incorrectly (n=65 of 252 player sessions; 26%), estimations were made based on matches with complete data recordings over four quarters of play. An average player load per minute was calculated according to individual game time and multiplied against playing time for matches with incomplete data in a manner similar to that reported previously (Bowen et al., 2019).

Injury definition

Injury information, including location and diagnosis, were recorded by the team physiotherapist. An injury was defined as any physical complaint sustained during training or match-play that required assessment from the physiotherapist, regardless of any time lost from team activities (Fuller et al., 2007).

Data analysis

Workload data were grouped into weekly blocks from Monday to Sunday. Acute workload was calculated as the absolute workload performed in one week, and chronic workload was calculated as the four-week rolling average of acute workload. The ACWR was calculated by dividing the acute workload by the chronic workload. Based on recently highlighted limitations of the ACWR and suggestions regarding alternative load measures in recent studies (Lolli et al., 2018; O'Keeffe, O'Conner & Ni Cheilleachair, 2019), additional load measures included cumulative workload (2-4 weeks) and the absolute difference in workload from the previous week (Bowen et al., 2019; Colby et al., 2017; Malone et al., 2017). Each workload measure was split into four quartile categories (very low, low, moderate, high) which were used in the subsequent analysis.

Overall injury incidence was calculated by dividing the total number of injuries by the total number of training and match hours. Injury incidence for individual workload categories were taken to be the number of injuries relative to the number of exposures in each category.

Statistical analysis

The relative risk of injury in the subsequent week, for each workload variable, was estimated via a frailty model. The frailty model is an extension of the Cox proportional hazards model dealing with time to event analysis, and has been suggested as a more appropriate method of statistical analysis when dealing with sports injury recurrent events (Ullah, Gabbett & Finch, 2014). For each workload variable the frailty model calculated the hazard ratio (HR), with 95% confidence intervals, associated with each category of the workload variable. Separate univariate models were run for each workload variable, with the 'low' category used as the reference group, in order to gain a preliminary understanding of how workloads are associated with injury risk in basketball players (Malone et al., 2018).The frailty model could not be run successfully with quartiles when ACWR was the independent variable due to a low number of cases. Therefore the ACWR was dichotomised using the median value to reduce the likelihood of excessive data cells with small counts in the model (Gabbett, Ullah & Finch, 2012). An additional frailty model was run where ACWR was categorized into three groups (<1.0, 1.0-1.5, >1.5), using an ACWR range of 1.0-1.5 as the reference group, as previous research has suggested that this is the ACWR 'sweet spot' in professional basketball (Weiss et al., 2017). Resulting HRs below 1.0 indicated a lower injury risk relative to the reference group, whereas a HR above 1.0 indicated a higher injury risk relative to the reference group, and a HR of 1 indicated no difference. All data was analysed using Stata v15 (StataCorp, Texas, USA) with statistical significance set at $p<0.05$ throughout.

Results

A total of 27 injuries were recorded over the season, at an incidence rate of 0.81 injuries per 1,000 hours of training/matches. The majority of injuries occurred in the lower limb (ankle n=7, 26%; Achilles n=4, 15%; calf, n=2, 7%; hamstring, n=2, 7%).

The results of the frailty model for accumulated workload (2 to 4 weeks) and absolute difference in acute workload are presented in Table 3. There were no statistically significant differences between any of the four workload categories and injury risk in the subsequent week for either of these workload measures.

Table 3 Injury risk in the subsequent week for accumulated workload (2-4 weeks) and absolute difference in acute workload.

Model Variable	Hazard Ratio (HR) (95% CI)	p	Standard Error (SE)	z
Accumulated workload (2 weeks)				
Low (≤2332AU)	-	-	-	-
Mod (2333-2950AU)	1.02 (0.28-3.74)	0.98	0.68	0.02
High (2951-3419AU)	1.83 (0.43-6.90)	0.44	1.22	0.77
Very High (>3419AU)	2.02 (0.39-10.47)	0.40	1.70	0.84
Accumulated Workload (3 weeks)				
Low (≤3636AU)	-	-	-	-
Mod (3637-4350AU)	0.55 (0.12-2.50)	0.44	0.43	0.77
High (4351-5063AU)	1.21 (0.33-4.43)	0.78	0.80	0.28
Very High (>5063AU)	0.22 (0.03-1.67)	0.14	0.23	1.47
Accumulated Workload (4 weeks)				
Low (≤4777AU)	-	-	-	-
Mod (4778-5906AU)	0.56 (0.13-2.50)	0.45	0.43	0.76
High (5907-6805AU)	0.71 (0.19-2.66)	0.62	0.48	0.50
Very High (>6805AU)	0.35 (0.06-2.09)	0.25	0.32	1.15
Absolute difference in acute workload(±)				
Low (≤234AU)	-	-	-	-
Mod (235-480AU)	0.64 (0.11-3.62)	0.61	0.56	0.51
High (481-834AU)	1.75 (0.39-7.79)	0.46	1.33	0.73
Very High (>834AU)	0.78 (0.08-7.65)	0.83	0.91	0.21

AU=Arbitrary units; Mod=moderate

No statistically significant differences in injury risk were observed between different workload categories for the acute workload, chronic workload or the ACWR (Table 4). However, visual inspection of descriptive statistics presented in Table 5 suggested that a higher proportion of injuries occurred in the very high ACWR category. It was also observed that a higher proportion of injuries occurred when the absolute difference in acute workload was high and very high. There were no such observable patterns for accumulated workload, chronic workload or acute workload.

Table 4 Injury risk in the subsequent week for acute workload, chronic workload and ACWR.

Model Variable	Hazard Ratio (HR) (95% CI)	p	Standard Error (SE)	z
Acute workload				
Low (<1073AU)	-	-	-	-
Moderate (1073-1480AU)	1.20 (0.15-9.29)	0.86	1.25	0.17
High (1481-1807AU)	1.09 (0.11-10.74)	0.94	1.27	0.07
Very High (>1807AU)	0.92 (0.09-10.00)	0.95	1.12	-0.07
Chronic workload				
Low (<1194AU)	-	-	-	-
Moderate (1194-1475AU)	0.56 (0.13-2.50)	0.45	0.43	-0.76
High (1476-1701AU)	0.71 (0.19-2.66)	0.62	0.48	-0.50
Very High (>1701AU)	0.35 (0.06-2.09)	0.25	0.32	-1.15
ACWR				
Low (≤1.05)	-	-	-	-
High (>1.05)	1.98 (0.23-17.13)	0.54	2.18	0.62

ACWR=acute chronic workload ratio

Table 5 Count of players injured/uninjured in the subsequent week in each category for (A) Absolute difference in acute workload (±) and (B) ACWR.

(A) Absolute difference in acute workload (±)				
	Low	Moderate	High	Very High
No Injury	32	35	32	40
Injury	5	2	6	10
Total	37	37	38	50
Proportion injured	0.14	0.05	0.16	0.20
(B) ACWR category				
	Low	Moderate	High	Very High
No Injury	30	34	27	48
Injury	4	2	3	14
Total	34	36	30	62
Proportion Injured	0.12	0.06	0.10	0.23

Risk of injury in a proposed sweet spot

The results from the frailty model using an ACWR range of 1.0-1.5 as the reference group are presented in Table 6. There was no statistically significant increase in risk of injury for workload ratios above this reference category. A HR was unable to be calculated for the low group (<1) due to a small number of cases in this ACWR range.

Table 6 Injury risk in the subsequent week using ACWR 1.0-1.5 as the reference.

ACWR Category	Hazard Ratio (HR)	Confidence Intervals (95%) Lower	Upper	p	Standard Error (SE)	z
1-1.5	-	-	-	-	-	-
<1	NC	NC	NC	NC	NC	NC
>1.5	1.41	0.26	7.68	0.69	1.22	0.40

NC=not calculable

Discussion

The objective of this study was to explore the relationship between different workload measures and injury risk in men's professional basketball. The present findings showed no statistically significant differences in injury risk between different workload categories for acute workload, chronic workload or the ACWR. Additionally, no significant associations were detected between injury risk in the subsequent week and accumulated workload or absolute difference in acute workload. This is one of the few studies to investigate the relationship between injury and workload in professional basketball, and the first study to analyse this relationship using a frailty model.

The main finding from the present study was that the ACWR was not informative of injury risk in professional men's basketball. To date, only one other study has investigated the relationship between the ACWR and injury risk in basketball (Weiss et al., 2017). Based on measures of perceived exertion, this study reported a small-to-moderate reduction in the proportion of injured players at an ACWR between 1.0-1.49 compared to all other workload ratios outside of this range (Weiss et al., 2017). However, this was based on a very small sample of six athletes, and further statistical analysis using a form of binary logistic regression actually showed unclear differences in injury risk between different workload ratio ranges (Weiss et al., 2017). Based on these findings, the current study used the suggested 1.0-1.49 ACWR range as the reference category to further investigate the existence of the proposed sweet spot using a more robust method of statistical analysis. While our findings suggested there may have been a greater injury risk associated with an ACWR greater than 1.50 (HR=1.41), this association was not significant and therefore there was insufficient evidence to support the use of the proposed ACWR sweet spot in basketball. It should be noted that the current study used an external load variable, while Weiss et al. (2017) used an internal load variable which likely reflected workload differently. Additionally, the injury definition used in the present study could have impacted on the scope of injuries observed, and thus the relationship between load and injury. A separate study by Weiss, McGuigan, Besier & Whatman (2017) identified that injury definition based on diagnosis by the team physiotherapist was less sensitive in detecting overuse injuries in professional basketball compared to injury classification based on a self-reported overuse injury symptom questionnaire. Therefore, to get a true indication of the relationship between workload and injury it may be more appropriate to expand the injury definition to include overuse injury symptoms when monitoring injury risk in basketball. Given the small team size, players often continue to train or compete despite the presence of injury problems, which may not otherwise be diagnosed by medical staff until the injury increases in severity and results in time loss.

The results from the present study also differ to previous findings regarding the relationship between workload and injury risk in team sports. It has generally been reported that an ACWR sweet spot exists, and working at an ACWR higher or lower than this range is associated with a higher injury risk (Bowen et al., 2019; Colby et al., 2017; Hulin et al., 2016; Malone et al., 2017; Malone et al., 2018; Stares et al., 2018). Previous research has also reported that higher acute loads and accumulated loads were associated with an increased injury risk (Hulin et al., 2015; Malone et al., 2017; Malone et al., 2018), and that higher chronic loads were associated with a decreased injury risk (Colby et al., 2017; Hulin et al., 2014; Hulin et al., 2016; Malone et al., 2018). It should be noted that while many studies have observed this positive link between workload and injury risk, the actual workload category values differ between studies, even when it has been conducted in the same sport. For example, studies in Australian football have all reported different sweet spot values of 0.8-1.0 (Carey et al., 2016), 0.8-1.2 (Colby et al., 2017) and 0.6-1.5 (Stares et al., 2018). This could have been due to differences in the number of players and seasons that data was collected from, which would have affected the spread of the data and subsequently the categorization of workload. There were also differences in acute and chronic time periods used in the calculation of the ACWR. Therefore, it is likely that previously reported findings are highly specific to the sample population used in different studies, and therefore generalization of results should be made with caution.

The lack of any significant observations in the present study could also be due to the low number of injuries observed in the sample population, particularly given the injury incidence of 0.81 injuries/1000hr was much lower than that reported in previous studies (Colby et al., 2017; Stares et al., 2018). However, this was similar to another study that used an injury definition based on diagnosis by the team physiotherapist (0.97 injuries/1000hr) (Weiss et al., 2017). Additionally, the choice of acute and chronic time periods used in the calculation of the ACWR may not have been specific to the basketball competition schedule. The present study used one-week acute and four-week chronic time periods, based on previous research that has applied the ACWR in field sports such as rugby league or Australian football, where games are played weekly (Hulin et al., 2015; Murray et al., 2017). To date, there is no clear consensus on the most appropriate acute and chronic periods for use in the ACWR calculation, with one study suggesting a 3:21 acute:chronic period generated better performing injury models (Carey et al., 2016), while another study found no difference when using different acute and chronic time periods (Stares et al., 2018). This inconsistency suggests that the choice of time periods may be specific to the sample population, and caution should be applied when generalizing the results. It is possible that different acute and chronic time windows may better reflect workload in basketball, where multiple games are played each week, however there is currently no research to support this theory. Additionally, when monitoring workload and injury risk, it should be considered that fitness and fatigue have a decaying nature, in that older workload exposures will have less of an impact on injury risk compared to more recent workloads performed by an athlete. It has been suggested that this could be accounted for by using an exponentially weighted moving average, which would give a higher weighting for more recent workloads, however there is currently insufficient research to support this approach (Murray et al., 2017). Future research should also be careful of manipulating the data without any reasonable rationale to force the observation of an association that may not actually exist.

One of the major limitations of previous studies is that the statistical analyses used may not have been the most appropriate for analysing recurrent or repeated injury data. In team sports, it is common for an athlete to suffer multiple injuries within a season, and it is likely that a player's injury history will have an influence on the risk of subsequent injuries, regardless of injury type. Additionally, depending on the severity of the initial injury, players may continue to train and compete before fully recovering through the modification of movement patterns or biomechanics, further altering their injury risk. As a result, the risk of subsequent injury should not be considered the same as it was for the initial injury. To date, studies investigating the relationship between the ACWR and injury risk have generally used binary logistic regression or Poisson regression models (Bowen et al., 2019; Colby et al., 2017; Hulin et al., 2016; Stares et al., 2018). These statistical models assume that each injury is a statistically independent event, which leads to the assumption that the risk of each subsequent injury is equal, potentially leading to inappropriate findings (Ullah, Gabbett & Finch, 2014). The frailty model is more appropriate for analysing recurrent sports injuries as it includes a random effect that accounts for the within-player injury dependency (Ullah, Gabbett & Finch, 2014). Using this method of statistical analyses, the present study did not find any of the previously mentioned findings regarding player workload and injury risk, suggesting that the ACWR is not a useful measure for informing injury risk. It has also been suggested that mathematical coupling exists in the calculation of ACWR, which may result in a false correlation between acute and chronic load (Lolli et al., 2018). Therefore, the ACWR itself may be misrepresenting the change in workload and could be an unreliable metric for measuring workload.

Limitations

One of the main limitations of this study is that the sample size was relatively small, although this is an acknowledged limitation when working with elite athletes, especially in a sport such as basketball where team size is small to begin with. Furthermore, a single team was studied over a single season, which inherently limits the amount of workload and injury data available for analysis, as well as the generalizability of these findings. Future research should consider using a larger sample size over multiple seasons. Another limitation is the incomplete match data, which accounted for 26% of all match data. While estimations were made based on previous methods (Bowen et al., 2019), these are only estimations resulting in some uncertainty in actual payer load. Only one external load variable was used in this study, and it is possible that other sport specific external load variables are more informative of injury risk. Internal training load could also be considered in conjunction with external loads as this may provide a more complete assessment of workload related injury risk. Sensor placement could have affected the specificity of load measures collected. Given that the majority of injuries in basketball occur in the lower limb, it may be more appropriate to place the sensors on the lower leg to more accurately capture lower limb loading, as much of the landing forces will have been attenuated by the time they reach the trunk (Weiss et al., 2017). Future research should utilise a greater range of external and internal load measures and consider sensor placement to better measure lower limb loading.

Conclusion

The results of the present study suggest that there is a lack of evidence supporting the use of the ACWR to predict or inform injury risk in professional men's basketball. The lack of significant association between different absolute workload measures also suggests that workload should not be considered in isolation for informing injury risk. This was the first study to investigate the relationship between workload measures and injury risk using a frailty model. There were observations that a higher proportion of injuries occurred when ACWR was high, however this association was not significant. While this study provides an initial insight into the relationship between workload measures and injury risk in basketball, further research using a larger sample size or data collected over multiple seasons is needed to give these findings statistical power, and to further validate whether the ACWR is informative of injury risk in basketball.

Prelude to Chapter 4

The relationship between absolute and relative measures of workload and injury risk in professional men's basketball has been reported. While monitoring workload provides an indication of how much athletes should be training each week, the distribution of training load throughout the week is also an important component of athlete workload monitoring. Coaching staff should prescribe a sufficient level of physical stimuli to maintain or improve performance, while allowing sufficient recovery to avoid overloading the athlete. To date, the majority of studies that have investigated drill workload in professional basketball have selectively focused on different formats of scrimmages, or small-sided games, hence there is a lack of understanding of the workload profiles of other types of drills used in basketball relative to official in-season games. A more inclusive drill workload profile can be used to aid workload prescription depending on the recovery status of the athlete and/or desired training outcome.

Chapter 4: Physical workload of games and training drills in professional men's basketball

Introduction

Basketball is an intermittent high intensity sport characterized by repeated accelerations, decelerations, sprints, changes of direction and jumps (McInnes et al., 1995; Schelling & Torres-Ronda, 2013). Developments in players' athleticism and explosiveness, as well as gameplay and strategy, has led to increases in the physicality, intensity and overall pace of the game. As a result, players are experiencing higher workloads throughout the competitive season, which could partly explain reports of increased injury rates among professional basketball players (Starkey, 2000). There is evidence to suggest that high training loads in team sports are associated with an increased injury risk, and that there may be certain training load ranges within which injury risk is minimized (Brooks et al., 2008; Dennis et al., 2003; Thornton et al., 2017). Therefore, careful manipulation of training load and periodization of training sessions throughout the season may contribute to minimizing injury risk while maintaining or enhancing performance.

Developments in wearable microtechnology such as global positioning system (GPS) and accelerometers have introduced a wider range of external load variables that contribute to more comprehensive load quantification, providing coaches with more sport specific load variables that can assist in the planning and periodization of training sessions (Svilar et al., 2018). The monitoring of athlete workload is important, not only for minimization of training related injury risk, but also in understanding and tracking the physiological and physical responses to training (Halson, 2014). When designing training sessions in team sports, coaching staff need to prescribe sufficient physical stimulus to prepare individual athletes for competition, while also factoring in post-match recovery to avoid overloading an athlete. They also need to balance physical, tactical and technical development. Therefore, understanding drill loads may better inform coaching staff during the planning and structuring of training sessions, as they will be able to prescribe higher or lower intensity drills depending on the desired training outcome of the session, or the recovery status of an individual athlete (Corbett et al., 2018; Loader et al., 2012). Much of the relevant workload research to date is limited to field sports such as Australian football or rugby, as the use of wearable microtechnology in official basketball competition is still restricted in many basketball leagues.

It has been well documented that training should simulate game intensity and demands for effective translations of skills and conditioning (Aguiar et al., 2012; Gamble, 2004; Loader et al., 2012). In order to achieve this there must first be an understanding of the different physical demands of games and different types of training drills. Currently, research quantifying load profiles of different drill types in basketball is limited. Previous studies examining drill load in basketball have primarily focused on small sided games (SSG) or scrimmages, classifying drills based on confrontation format in terms of number of players involved (Schelling & Torres, 2016; Svilar et al., 2018; Svilar, Castellano & Jukic, 2019; Torres-Ronda et al, 2016). Acceleration load, or player load, was observed to be highest in 3v3 and 5v5 full court formats (Schelling & Torres, 2016), and 5v5 scrimmages have been shown to produce similar workload and intensity compared to games (Torres-Ronda et al., 2016). However, the game data used for comparison in these previous studies were obtained from pre-season games, therefore the reported intensities may be different than that of an in-season game. As there are restrictions with using wearable microtechnology in official competition, there is a lack of research using in-game data quantifying external game load. Additionally, these studies have only analysed SSGs, which are only one type of basketball drill. Other types of drills that specifically target positional skills, shooting or tactical awareness have been excluded in these studies, resulting in a limited understanding of the physical demands of other basketball drills. In order to provide more comprehensive information about the workload demands of each drill type, we propose that a more inclusive method of drill classification may be to base the categories on the primary focus of the drill similar to that used by Montgomery, Pyne & Minahan (2010).

The primary aim of this study was to quantify the physical workload of in-season games and different training drill types, in order to determine the relative intensity of different training drill types compared to official in-season games. This would lead to a better understanding of training load application, which could assist in the planning of periodized training sessions throughout a competitive season.

Methods

Participants

Sixteen professional male basketball players (26.3 ±4.9 yrs) from a single team competing in the Australia New Zealand National Basketball League (NBL) agreed to participate in the study. Seven players were excluded from the study due to being in the development squad or being on temporary contracts with the team. Ethical approval was obtained from the Auckland University of Technology Ethics Committee (#14/383), and all players provided written consent.

Procedures

External workload data was collected using wearable GPS units (ClearSky T6, Catapult Innovations, Australia) that included a tri-axial accelerometer, gyroscope and magnetometer. Only accelerometer data was used in this study. The units were attached to tight fitting vests and positioned between the scapulae. Players were assigned the same sensor for the season. A workload/arbitrary player load variable was calculated using accelerometer data based on the equation:

$$Load = \sqrt{(Ac1n - Ac1n{-}1)^2 + (Ac2n - Ac2n{-}1)^2 + (Ac3n - Ac3n{-}1)^2}$$

Ac1, Ac2 and Ac3 represent the instantaneous rate of change in acceleration in the three planes of body movement (Montgomery, Pyne & Minahan, 2010). This variable has been shown to be a valid and reliable measure of workload in basketball compared to session rating of perceived exertion (sRPE) (Montgomery, Pyne & Minahan, 2010; Svilar, Castellano & Jukic, 2018).

Player workload data were collected from all in-season training sessions (n=41) and games (n=28) during the 2017-2018 NBL season. Preseason and postseason data were not included in this study. The team alternated between playing one or two games per week during the 20 week season. Team practices varied between two to four sessions per week depending on the number of games scheduled in a particular week, travel and stage of season. Sessions where players were returning from injury were excluded, as these particular players would likely have been training at reduced intensities.

Each training session was comprised of a number of different drills. Due to the differences in length of drills and games, player load was expressed per minute of activity to provide a standardized measure of intensity similar to that reported previously (Schelling & Torres, 2016; Svilar, Castellano & Jukic, 2019). Each drill was assigned to one of six categories, based on the primary focus of the drill as shown in Table 7. Only one previous study has reported player workload during an official match. In this study dead ball situations were excluded from the recording period (Svilar, Castellano & Jukic, 2019), which could have overestimated actual player workload. Therefore, for this study game intensity was calculated from player load recorded during each quarter during which a given player was active. This data included time outs and other dead ball situations, such as foul shooting and inbounding, as these contribute to a player's load on court, and therefore better reflect the actual player load during a match.

Table 7 Description of different drill categories.

Drill Type	Description
Scrimmage	Small sided games
Offensive	Contact drills with an offensive focus (defensive team rotates out)
Defensive	Contact drills with a defensive focus (offensive team rotates out)
Fitness	Non-contact drills targeting aerobic and anaerobic fitness

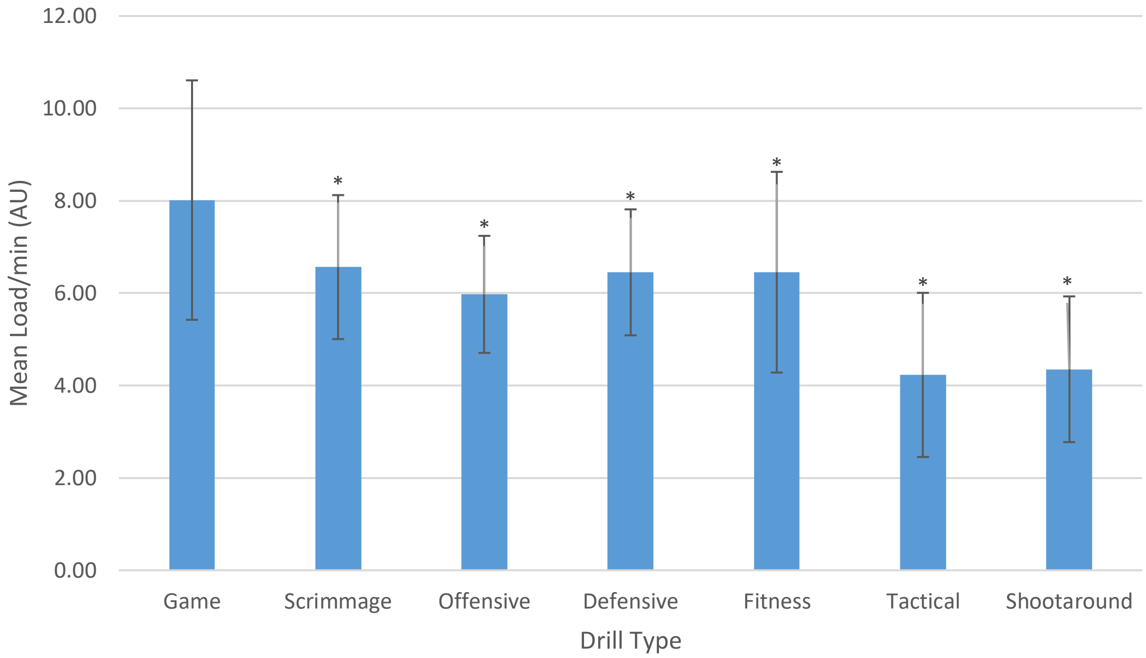
Tactical	Non-contact walk-through of plays and strategy
Shooting	Non-contact shooting practice in pairs (one shooter, one rebounder)

Statistical Analysis

Descriptive statistics to describe training intensity for each drill category are presented using mean and standard deviation (SD). Differences in the mean player load per minute between each drill category and game load was assessed using a one-way analysis of variance (ANOVA) with post-hoc multiple comparisons using the Tukey HSD test. Statistical significance was set at $p<0.05$, with 95% confidence intervals. Standardized mean differences (Cohen's d) were used to gain a better understanding of the magnitude of any differences found between each drill type, using the following thresholds: 0.2 = small, 0.5 = medium, 0.8 = large, 1.2 = very large, 2.0 = extremely large (Cohen, 1988; Sawilowsky, 2009). All statistical analyses were performed using SPSS 25.0 (SPSS Inc., Chicago, IL, USA).

Results

Figure 1 shows the mean load per minute for games and each of the training drills. Game load intensity (8.02 ±2.59 AU/min) was higher than that of any other drill types (scrimmage = 6.56 ±1.56AU/min; offensive = 5.97 ±1.27 AU/min; defensive = 6.45 ±1.36 AU/min; fitness = 6.45 ±2.17 AU/min; tactical = 4.23 ±1.78 AU/min; shooting = 4.35 ±1.58 AU/min).



AU = Arbitrary units; * = significantly different from game load ($p<0.05$)

Figure 1 Mean player load per minute for each drill type and game.

The mean differences in load per minute between game and individual drill types are presented in Table 8, with corresponding effect sizes (ES) shown in Table 9. Again, game intensity was higher than the intensity of any other drill type, and based on ESs these differences were moderate to extremely large (0.7 to 1.7). There were no differences in intensity between scrimmages, defensive and fitness drills. Intensity during scrimmages were higher than offensive drills, although based on ESs this difference was small (0.42). Tactical and shooting drill intensities were similar and both were lower than all other drill types and game intensity (ES = 1.11 to 1.71).

Table 8 Mean difference (95% confidence intervals) in player load (AU) per minute between game and each drill type.

	Game	Scrimmage	Offensive	Defensive	Fitness	Tactical	Shooting
Game		1.5 (1.1-1.8)*	2.0 (1.6-2.5)*	1.6 (0.9-2.2)*	1.6 (1.2-2.0)*	3.8 (3.4-4.2)*	3.7 (3.2-4.1)*
Scrimmage			0.6 (0.1-1.1)*	0.1 (-0.6-0.8)	0.1 (-0.3-0.5)	2.3 (2.0-2.7)*	2.2 (1.7-2.7)*
Offensive				-0.5 (-1.2-0.3)	-0.5 (-1.0-0.4)	1.7 (1.2-2.3)*	1.6 (1.1-2.2)*
Defensive					-0.0 (-0.7-0.7)	2.2 (1.5-2.9)*	2.1 (1.4-2.8)*
Fitness						2.2 (1.8-2.7)*	2.1 (1.6-2.6)*
Tactical							-0.1 (-0.6-0.4)
Shooting							

* = significant difference (p<0.05), AU = arbitrary units

Table 9 Mean difference between game and drills expressed as an effect size.

	Game	Scrimmage	Offensive	Defensive	Fitness	Tactical	Shooting
Game		0.7	1.0*	0.8*	0.7*	1.7*	1.7*
Scrimmage			0.4*	0.1	0.1	1.4*	1.4*
Offensive				0.4	0.3	1.1*	1.1*
Defensive					0.0	1.4*	1.4*
Fitness						1.1*	1.1*
Tactical							0.1

Shooting	

* = significant difference ($p<0.05$)

Discussion

The objective of this observational study was to quantify the physical workload of in-season games and different training drill types, in order to determine the relative intensity of different drill types compared to official in-season games. This is the first study investigating the physical demand of elite basketball activities that has recorded training and in-season game data across an entire competitive season. Results showed that the physical demand of a game was higher than that of any drill type. There also appeared to be two distinct categories of drills, low intensity and high intensity, relative to game intensity. These results provide a better understanding of the physical demands of in-season games and different drill types, which can be used by coaches to aid the planning of periodized training sessions throughout the competitive season.

There is a scarcity of research that has compared training load to game load in basketball using competitive in-season games due to restrictions on the use of wearable microtechnology during competition. Only a few studies have been able to use this technology to measure physical demand in games, however these have either been simulated or pre-season games, which likely differ from actual in-season games (Montgomery, Pyne & Minahan, 2010; Svilar, Castellano & Jukic, 2019). Therefore, a novel finding of this study was the measure of in-season game workload (8.02 ±2.59 AU/min), which was shown to be higher than that of all drill types with moderate to very large differences depending on drill type. Our estimate of game workload is lower than that reported previously (11.13 ±2.00 AU/min), however this higher workload was calculated using pre-season game data (Svilar, Castellano & Jukic, 2019). Additionally, time outs were excluded in the game load calculation, which could have led to an overestimation of game load given that only periods of activity were included in the calculation. We argue that stoppage time should be considered part of a player's overall time on the court, as this time is part of basketball gameplay commonly used for strategic and recovery purposes. Therefore, its inclusion in the calculation of player game load may contribute to a more complete reflection of game load. Previous studies in Australian football have also reported that physical workload in games was higher than that found during training (Henderson et al., 2015; Ritchie et al., 2015). The difference in workload could be due to a number of factors, such as match duration, game pace, or differences in tactics. It is important to understand the different demands of games and trainings, as it has been accepted that the most effective method of preparing athletes for competition is to simulate game like intensities and scenarios during training (Corbett et al., 2018; Gamble, 2004; Loader et al., 2012).

Previous studies investigating drill workload have specifically focused on SSGs or scrimmages of different confrontation formats (Castagna et al., 2011; Schelling & Torres, 2016; Svilar Castellano & Jukic, 2019; Torres-Ronda et al., 2016). However, while SSGs are widely used in team sports for concurrently improving game specific fitness, skill and tactical proficiency, they are only one type of drill used in basketball. Drills that specifically address positional skills, shooting or tactics have generally been excluded from previous studies, hence there is little understanding of their physical demands and how this might affect training prescription. The drill classification system used in this study was based on the primary aim of the drill, and included all drills used by the team. The present findings indicated a clear separation between high intensity and low intensity drill types. Shooting (4.35 ±1.58 AU/min) and tactical drills (4.23 ±1.78 AU/min) had lower workload than any other drill type with large to very large differences, and were thus considered low intensity drills. Conversely, there were little differences in workload between scrimmages (6.56 ±1.56 AU/min), fitness (6.45 ±2.17 AU/min), defensive (6.45 ±1.36 AU/min) and offensive (5.97 ±1.27 AU/min) drills, hence these were all considered high intensity drills. These results differed somewhat to those reported by Montgomery, Pyne & Minahan (2010), who found that scrimmages had a greater physical workload compared to offensive or defensive drills in junior elite basketball players. This could be due to differences in drill specific definitions used in this study, as the offensive and defensive drills had a similar design to a small-sided game in the half court, albeit with a greater emphasis on offensive or defensive execution. It could also be reflective of training specificity, as drills targeting game specific components, such as offensive and defensive schemes, should be performed at intensities similar to games in order for the skills to translate effectively to live game situations (Corbett et al., 2018; Gamble, 2004).

The results from the current study provide general information on the loading intensity of different drill types used in basketball. This could assist coaches in the planning of training sessions, allowing them to consider both desired training outcomes and workload implications. Considering the game schedule in the NBL, where teams usually alternate between one to two games per week, coaching staff need to periodize training to allow for sufficient post-match recovery and pre-game preparation. Using sRPE measures, it has been reported that the weekly training load for professional basketball players during a single game week is higher than when they have a week with two games (Manzi et al., 2010). Therefore, coaches need to plan and structure training sessions effectively to avoid overloading players, potentially increasing the risk of reduced performance and/or overtraining related injuries, especially during weeks with multiple games. Lower intensity drills, such as shooting and tactical walkthrough of plays, may be more suitable for light or recovery sessions where the aim is to refine skill without overloading athletes (Loader et al., 2012). High intensity drills are more game specific, and may be more suitable when the aim is to improve game conditioning or prepare players for games. Scrimmages remain the most relevant drill type when the aim is to improve game specific skill and conditioning, however the current findings suggest that on average, scrimmage intensity is lower than game intensity. In order to increase the specificity of training, coaches should consider replicating game situations as closely as possible, in terms of number of players, court size and inclusion of dead ball situations. Previous research suggests that 5v5 full court scrimmages has the closest physiological and physical demand to games, and therefore may be the most suitable confrontation format for this drill type compared to reducing the number of players or court size (Svilar, Castellano & Jukic, 2019; Torres-Ronda et al. 2016). It has also been suggested that scrimmage intensity can be increased by removing dead ball situations such as free throw shooting, inbounding and time outs (Svilar, Castellano & Jukic, 2019). This increases the active time of players and reduces active recovery time and should be taken into consideration when the goal of the session is to overload athletes and improve game conditioning.

Limitations

A potential limitation of this study is that only one external load variable was used. Consideration of a wider range of sport specific variables such as the number of accelerations, decelerations, jumps and change of directions, would provide more information on the physical demands of training and games. Internal training load, such as heart rate, should also be considered in conjunction with external training loads. Another potential limitation of this study is the relatively small sample size, however this is an acknowledged limitation that is often unavoidable when working with elite athletes. Due to the small number of players we were not able to analyse any positional differences in training and game physical demands. Despite this, future research should aim to involve a larger number of players or teams, as well as use a wider range of load variables, to increase understanding of differences in drill and game demand between different playing positions.

Conclusion

Game load in professional male basketball is higher than in training drills, irrespective of the drill type and this needs to be considered when preparing players for game demands. Shooting and tactical drills are lower intensity relative to higher intensity scrimmages, offensive, defensive and fitness specific drills. This information may assist coaching staff in the periodization and structuring of low, moderate and high intensity training sessions depending on the desired training outcome.

Chapter 5: Discussion and Conclusion

Discussion

Basketball has been identified as an intermittent high intensity team sport with high physical demands, requiring repeated accelerations, decelerations, changes of directions, jumping and sprinting. Due to the repetitive absorption of high landing impact forces, the majority of injuries in professional basketball occur in the lower quarter, most commonly in the lower back, knee and ankle. Additionally, the competitive schedule in basketball requires teams to play multiple games each week in addition to training sessions, hence players experience high physical workloads during a competitive season with short between-game recovery times. Appropriate load monitoring strategies should be considered to avoid overloading the athlete, and to minimize the risk of workload related injuries. Currently, research investigating the relationship between workload and injury risk in basketball is limited (Anderson et al., 2003; Weiss et al., 2017), therefore this thesis sought to investigate athlete workload monitoring and injury risk in professional men's basketball.

The majority of the literature has reported that both high and low workloads have been associated with a greater injury risk across a range of sports, when the load variable used is specific enough to reflect intensity and workload (Chapter 2). Additionally, spikes in acute workload have been associated with a higher injury risk, whereas high chronic workload has been associated with a lower injury risk, and potentially offers a protective effect against spikes in acute workload. Furthermore, both high and low ACWRs have been associated with an increase in injury risk in a variety of sports. This has led to suggestions that an ACWR sweet spot exists, which represents an ACWR range where injury risk is lower compared to ACWRs above and below this range (Carey et al., 2016; Colby et al., 2017; Malone et al., 2017; Stares et al., 2018). However, the majority of these studies were conducted in field sports such as rugby league, soccer and Australian football, which operate under a different competitive schedule compared to basketball. Only one other study has investigated the use of the ACWR for informing injury risk in basketball (Weiss et al., 2017).

This thesis provides novel insights into the relationship between workload and injury risk in professional men's basketball, based on a prospective cohort study conducted using data collected from a single team competing in the NBL over one full season (Chapter 3). Although it was observed that a higher proportion of injuries occurred in the high ACWR range, novel analysis using a frailty model showed there were no significant differences in injury risk in the subsequent week between different ACWR categories. An additional model using a previously suggested ACWR sweet spot range of 1.0-1.5 also found no significant differences in injury risk between different ACWR categories. These results suggest that there is limited evidence to support the use of the ACWR as a load monitoring metric for informing injury risk in basketball. Furthermore, there were no significant associations between injury risk and different measures of absolute workload, suggesting that workload should not be considered in isolation for informing injury risk. While this study provided an initial insight into the relationship between workload and injury risk in basketball, further research, ideally with larger sample sizes, is needed to reduce the uncertainty in findings. It is acknowledged this is difficult to achieve given the small playing numbers in a professional basketball team, and would likely require collaboration across multiple teams.

Finally, the main aim of Chapter 4 was to determine the relative intensity of different drill types used in basketball, and how these compare to official in-season games. To date, the majority of studies that have examined drill load profiles in professional basketball have selectively focused on different formats of small-sided games, or scrimmages (Castagna et al., 2011; Schelling & Torres, 2016; Svilar Castellano & Jukic, 2019; Torres-Ronda et al., 2016). As a result, literature detailing the workload profiles of other drills used in basketball is lacking. Results from this study provide novel insights suggesting that game load (8.02 ±2.59 AU/min) was significantly higher than that of any drill type, with moderate to very large differences. This should be taken into consideration if the aim of a particular drill is to prepare athletes for competition. There was also a clear distinction between low intensity drills (shooting and tactical) and high intensity drills (fitness, offensive, defensive and scrimmage), with large to very large differences. These results provide new information on the loading intensity of different types of drills used in basketball and can be used to aid prescription of workload depending on the desired training outcome of a particular session.

Limitations and future research recommendations

There were some limitations to this research which should be taken into consideration when interpreting the results. Based on these limitations and the outcomes of the thesis, suggestions for future research have also been provided:

- The primary limitation for both studies was the relatively small sample size, however this is an acknowledged limitation that is often unavoidable when working with elite athletes, especially in basketball where the team size is small. The small sample size may have limited the statistical power of associations observed between workload and injury (Chapter 3). Future research should aim to use a larger sample size, as increasing the number of injury observations would result in clearer associations between workload and injury risk.
- Additionally the small sample size did not allow for analysis of positional differences in injury risk or drill workloads (Chapter 3 and 4). This warrants further investigation as it

may be possible that different playing positions are associated with different workloads and injury risks, based on the differences in position specific demands. This is likely only achievable with collaboration across multiple teams in the same study and/or across multiple seasons.

- The small sample size also reduces the generalizability of the findings, as it is possible that the results presented in this thesis are specific to this team from this particular season (Chapter 3 and 4). Future research should consider collecting data over multiple seasons to improve the generalizability of the findings.
- A large amount of match data was incomplete or did not record correctly (26%) due to sensor related issues (Chapter 3). Match player load for these sessions was estimated using complete game data based on previous methods, however this could potentially have resulted in inaccurate assumptions of actual match player load and therefore affected the observations between workload and injury risk. In this study the sensors were switched on for data collection prior to the beginning of the match and switched off at the end of the match. Future research could consider more thorough monitoring of the sensors throughout the data collection period, such as manually starting and stopping the sensors each playing quarter to reduce the risk of incomplete data associated with sensor related issues.
- Only one external load variable was considered in this study (Chapter 3 and 4). It is possible that other load variables, both external and internal, are more specific for measuring workload intensity, or informing injury risk in basketball, therefore future research should include a wider range of basketball specific workload variables for analysis.
- The default sensor position in both studies was between the scapulae, using specially designed vests by Catapult. However, given that much of the landing impact force will have been attenuated by the time it reaches the trunk, this placement may not have been appropriate for capturing lower limb loading, which would have been more specific for basketball. Future research should consider sensor placement closer to the lower limb for a more sport specific load measure.
- The current study calculated the ACWR using standard acute and chronic time periods based on previous research in field sports, and did not consider the use of different acute and chronic time periods or a weighted moving average that may have better informed injury risk in basketball (Chapter 3). Currently, there is no clear consensus that using different acute and chronic time periods or a weighted moving average affects the ACWR's ability to inform injury risk, however, future research should

consider this given the difference in frequency of competitive games in basketball compared to many field sports.

Practical Applications

- There is limited evidence to support the use of the ACWR for informing injury risk in men's professional basketball.
- A lack of significant association between different workload measures and injury risk suggests that workload should not be used in isolation for informing injury risk in basketball.
- A drill workload profile for basketball has been established, with clear distinctions between low and high intensity types of drills relative to game intensity. This can be used to aid coaching staff in planning and structuring training sessions of varying intensities depending on the recovery status of the team and desired training outcome.
- Game load in men's professional basketball is significantly higher than training load, regardless of the drill type, and this needs to be taken into consideration when preparing athletes to meet game demands.

Conclusion

This thesis consisted of a review of literature and two studies with the overall aim of investigating athlete monitoring and injury in professional men's basketball. This was the first study to analyze the workload and injury relationship in a team sport using a frailty model, which is suggested to be more suitable for analysis involving repeated injury data. Contrary to previous findings, there were no significant associations between injury risk in the subsequent week and measures of workload, including the ACWR. There is currently limited evidence to support the use of the ACWR for informing injury risk in professional basketball, which also suggests that workload should not be monitored in isolation when considering injury risk. Future research addressing the limitations and expanding on the ideas presented in this thesis are needed to further our understanding of the relationship between workload and injury, in order to develop appropriate athlete monitoring strategies in professional men's basketball.

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Appendix A: Ethics Approval

AUTEC Secretariat

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

15 September 2016

Chris Whatman
Faculty of Health and Environmental Sciences
Dear Chris

Re: Ethics Application: **14/383 The quantification of cumulative knee loading in top-level netball and basketball.**

Thank you for your request for approval of amendments to your ethics application.

I have approved minor amendments to your ethics application allowing further data collection and for the placement of an additional sensor to be placed on the body. The addition of another team member has also been noted.

I remind you that as part of the ethics approval process, you are required to submit the following to the Auckland University of Technology Ethics Committee (AUTEC):

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 15 December 2017;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 15 December 2017 or on completion of the project.

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

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

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

All the very best with your research,

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

Cc: Mike McGuigan; Simeon Cairns; Kelly Sherrin

Appendix B: Participant Information Sheet

Participant Information Sheet

Date Information Sheet Produced:

September 2016

Project Title

The quantification of cumulative loading in top level basketball.

An Invitation

My name is Kelly Sheerin and I am a researcher at SPRINZ (Sports Performance Research Institute New Zealand) at the AUT Millennium Campus of the Auckland University of Technology. I am currently conducting a study on loading with basketball athletes and would like to invite you to participate in the research. This study is a continuation of the study conducted by Kaitlyn Wiess last season. Your participation would be greatly valued, but is entirely voluntary and you may withdraw at any time prior to the completion of the data collection.

What is the purpose of this research?

This research will be a collaborative effort with a group of scientists, athletes, coaches, and administrators involved with the New Zealand Breakers. The aim is to assess if inertial sensors can be used to monitor load related training and injury risk factors and an additional season of data will improve our understanding of these relationships. This will facilitate better training/injury prevention programs for both top level and recreational basketball players. The results of this research will be published in a scientific journal and presented at conferences.

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

You are being invited to take part in this research because you are a competitive basketball player with a minimum of one year of competitive experience, between the ages of 16 and 42, who is free from any current lower extremity injuries or neurological conditions that would prevent you from participating in practices and games. If you decide to participate, you will be one of approximately 8-50 people participating in the study.

What will happen in this research?

Participants will wear sensors positioned between their shoulder blades, held in place by a tight vest. The sensor software will then be set to collect and the participant will wear the sensors over the course of the entire training and or game. At the end of the game, the sensor software will be turned off and the sensors will be removed. Data from the sensors will be analysed by staff at SPRINZ and also by staff at Catapult (the maker of the sensors) to assist us with providing useful feedback to players.

What are the discomforts and risks?

Risks and discomfort from the movements you will be performing will be the same as you would experience during a match or practice. All data generated from the study will be confidential.

How will these discomforts and risks be alleviated?

Appropriate warm up and instruction will be given prior to all tasks.

What are the benefits?

Any information collected regarding your testing results will also be made available to you upon request. The information gathered from this study will also have broader benefits in that it is a step towards understanding potential mechanical risk factors and prevention strategies for basketball injuries. No direct incentives of compensations will be offered for your time.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

All information collected will be used for research purposes only. Consent forms and contact details will be securely stored on the AUT campus and destroyed after a standard 6 year time period. Data will be completely anonymous to researchers and participants will not be identifiable in any published documents. Due to the small number of participants, there is a chance that you may be identified, however, you individual test results will not be made available to anyone without your written consent.

What are the costs of participating in this research?

There will be no expenses incurred by the individuals associated with participation in this research project.

What opportunity do I have to consider this invitation?

The potential participants will be given ~2 weeks to consider the invitation.

How do I agree to participate in this research?

Potential participants are welcome to respond to the invitation via email, telephone, or in person. A consent form will be provided to interested potential participants at training.

Will I receive feedback on the results of this research?

Following the completion of data collection, each participant will be provided a summary report illustrating their individual outcomes as compared with overall group means and standard deviations for each of the variables tested in the research.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr. Chris Whatman, cwhatman@aut.ac.nz, 09 921 9999 x7037.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz* , 921 9999 ext 6038.

Whom do I contact for further information about this research?

Researcher Contact Details:

Kelly Sheerin, Kelly.sheerin@aut.ac.nz 09 921 9999.

Project Supervisor Contact Details:

Dr. Chris Whatman, cwhatman@aut.ac.nz, 09 921 9999 x7037.

Approved by the Auckland University of Technology Ethics Committee on *15 December 2014*, AUTEC Reference number *14/383*.

Appendix C: Participant Consent Forms

Consent Form	AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: The quantification of cumulative loading in top level basketball.

Project Supervisor: Dr. Chris Whatman

Researcher: Kelly Sheerin

- ○ I have read and understood the information provided about this research project in the Information Sheet dated September 2016.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ○ I am not suffering from any current lower extremity injuries or neurological conditions that prevent me from participating in practices or games.
- ○ I agree to take part in this research.
- ○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○

Participant's signature:

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Participant's name:

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Participant's Contact Details (if appropriate):

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Date:

Approved by the Auckland University of Technology Ethics Committee on 15 December 2014 AUTEC Reference number 14/383.

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