Sleep, Recovery and Performance in Collision Sport Athletes

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ATTESTATION OF AUTHORSHIP

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

Richard Roy Swinbourne

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ABSTRACT

Sleep is considered an essential component of athlete health, post-exercise recovery and performance. Sleep in athletes is a novel and vital area of sports science. Despite the importance of sleep in athletes, relatively little is known in this field, both in New Zealand and globally. The overall aim of this PhD was to characterise sleep in elite collision sport athletes, develop and apply interventions to improve their sleep quantity and quality, and investigate resultant recovery and performance benefits.

Study one investigated indices of sleep and sleepiness using qualitative methodology (Chapter three) and revealed a high prevalence of poor sleep quality, sleepiness and obstructive sleep apnoea (OSA) risk factors in collision sport athletes. Indeed, one in two athletes scored as 'poor sleepers' with the Pittsburgh Sleep Quality Index (PSQI) and one in three athletes reported clinically significant daytime sleepiness. Furthermore, the prevalence of clinically suspicious OSA (8%) was twice that of the general population. With an understanding of sleep behaviour among elite collision sport athletes, and a growing appreciation that their risk of poor sleep is high, Chapter four expanded upon qualitative methodology to investigate the recovery-stress state within the same cohort of athletes. The Recovery-Stress-Questionnaire for Athletes (RESTQ-Sport) was used to establish relationships between validated measures of sleep quality and sleepiness and various RESTQ-Sport subscales, including sleep quality. Specifically, a moderate negative relationship between the PSQI score and RESTQ-Sport sub score of sleep quality was observed (-0.49; ± 0.10). Furthermore, there was a moderate relationship between the PSQI score and RESTQ-Sport sub score of lack of energy (0.36; ± 0.11) and a small relationship between the ESS score and RESTQ-Sport sub score of fatigue (0.11; ± 0.13). Results suggest that the RESTQ-Sport can adequately assess sleep quality in athletes, although the addition of validated sleep questionnaires such as the PSQI and ESS, alongside the RESTQ-Sport, may

provide coaches more thorough information about an athletes sleep based recovery. Furthermore, additional comprehensive sleep monitoring may be most pertinent during hard training phases.

Chapter five built upon the qualitative findings of the previous two studies. A six week pre-post control-trial intervention study was conducted with the aim of further characterising measures of sleep in professional rugby players using quantitative methodology (sleep monitors). Following a control phase, where baseline sleep, immune function and stress hormone data was observed, this study applied a three week sleep extension intervention during a pre-season training block. The efficacy of a sleep education programme and sleep extension in improving sleep quantity and quality and markers of physical stress, immune function and performance was evaluated. Results from the control phase further demonstrated that collision sport athletes experience poor sleep quality, which declined further during an intensive training phase, with a concomitant rise in stress hormone levels. The sleep extension intervention elicited a significant, moderate (-0.65; ± 0.99) improvement in the percentage change in sleep quality scores compared to the control (-24.8 %; ± 54.1 %) A greater time in bed (7.3 %; ± 3.6 %) and total sleep time (6.3 %; ± 6.3 %) was observed after sleep extension, with a moderate (0.84; ± 0.42) and small (0.46; ± 0.46) difference in the changes between groups, respectively. Sleep extension also mitigated a small (-0.40; ± 0.45) rise in cortisol levels (-18.7 %; ± 26.4 %) and small (-0.44; ± 0.31) resultant improvements in reaction times (-4.3 %; ± 3.1 %) were observed. These results suggest that implementing a sleep extension programme with elite athletes can be worthwhile and should be considered for inclusion by elite athletic programmes.

Finally, the efficacy of consuming a tart cherry juice concentrate (TC) for improving sleep and indices of recovery and performance during an off season training period were investigated (Chapter six). The effect of TC on measures of sleep and daytime sleepiness,

fatigue and muscle soreness were inconclusive. However, the TC intervention demonstrated a decrease in inflammation represented by C-Reactive Protein (C-RP) concentration (-8.5 % ± 97.3 %) compared to an increase in the placebo group (119 % ± 174 %), with a moderate difference in the change in C-RP between groups (-0.98; ± 1.16). Results suggest that TC may be applied to mitigate increases in inflammation in highly trained rugby players, and there may be a dose dependent relationship with sleep quality. Tart cherry juice supplementation may provide collision sport athletes in particular an adjunctive strategy to enhance recovery alongside sleep extension. Further research is required to establish both a minimal effective TC dose and to fully realise the potential of TC supplementation for sleep, recovery and performance benefits.

Chapter 1

PREFACE

1.1 Rationale and Significance of Research

It is accepted that sleep is critical for health, recovery, and optimal performance. Sleep based recovery is particularly relevant to the collision sport athlete, due to the physical and mental demands rugby players are subjected to from training and competition (McLellan & Lovell, 2012; Smart, Gill, Beaven, Cook & Blazevich, 2008; Takarada, 2003; Twist, Waldron, Highton & Daniels, 2012). Furthermore, it appears that sleep is integral to an athlete's adaptation to training stressors (Datillo et al., 2011). Thus sleep is a potential gateway to promoting a bigger, faster and more powerful athlete. Improving knowledge specific to the sleep elite rugby players experience and their associated sleep behaviours is a critical first step towards enhancing sleep. Augmenting athlete sleep may in turn promote athletic development and performance via a means that is currently under-utilised.

Historically, knowledge surrounding the function and importance of obtaining adequate sleep has been explored via a sleep deprivation paradigm. The negative impacts of poor sleep on human health and performance have been well documented (Fullager et al., 2015; Haack & Mullington, 2005; Halson, 2014; Motivala & Irwin, 2007; Poussel et al., 2014; Spiegal, Leproult & Van Cauter, 1999). With respect to athlete sleep quality, research has recently turned towards inverting the sleep research question, and asking instead 'what happens if we extend sleep in athletes rather than restricting it'? While there is a paucity of research in this field, a small body of work investigating athlete sleep extension has shown promise with college basketball players (Mah, Mah, Kezirian, & Dement, 2011). Whilst the study by Mah and colleagues (2011) had a small sample size and un-controlled design, it was suggestive that several weeks of sleep extension in college athletes is significantly beneficial for athletic performance. Conversely, the only other athlete specific study in this area found no significant benefit from one week of sleep extension in female runners (Famodu, 2014). However, to the author's knowledge there have been no controlled sleep performance studies

with elite athletes, in an applied training environment. Thus this PhD aimed to gain privileged access to elite rugby players and further investigate this promising area of sleep science. Moreover, should strategies to improve sleep in elite athletes be validated, sleep enhancement may be progressed as an important athlete development and performance pillar.

To the author's knowledge there is no research on the sleep behaviour, sleepiness, or prevalence of obstructive sleep apnoea risk factors in elite New Zealand collision sport athletes. Prior to engaging athletes with sleep improvement strategies, an essential first step is to characterise their sleep. From previous qualitative sleep research (Antic et al., 2013; George, Kab, Kab, Villa & Levy, 2003; Samuels, 2008) it is probable that collision sport athletes are a high risk population for poor sleep quality. Thus exploring habitual sleep and related morbidity in athletes via validated sleep questionnaires is of interest. Furthermore, evaluating the relationship between sleep and recovery-stress states in athletes may better inform the interaction between sleep and recovery, and how sensitive common recovery-stress monitoring tools are at detecting poor sleep. Together, this information may encourage regular monitoring of sleep among elite athletes in a robust and practical manner, and inform the need for further intervention.

Few studies have investigated sleep quality in elite athletes during intensive training phases, and to the author's knowledge none have focused on collision sport athletes. Actigraphy studies suggest that athletes, in general, sleep poorly (Mah et al., 2011; Fietze et al., 2009; Sargent, Halson & Roach, 2014; Leeder, Glaister, Pizzoferro, Dawson & Pedlar, 2012). Furthermore, sleep appears to deteriorate as intensive training phases progress (Hausswirth et al., 2014). It is unknown how sleep responds to intensive pre-season training in elite rugby players, or correlates with immune response and physiological markers of stress. The recuperative role of sleep extends to supporting immune function, which may become compromised after intense exercise (Walsh et al., 2011), whilst evidence links sleep loss to

alterations in inflammation (Faraut, Boudjeltia, Vanhamme & Kerkhofs, 2012) and hormonal markers of stress (Spiegel et al., 1999). Furthermore, a wide variety of learning processes in humans requires post-training sleep (Mednick, Nakayama & Stickgold, 2003) and sleep may be harnessed to improve skill acquisition and execution. Sleep extension has also been observed to positively influence neural performance in athletes, such as reaction times (Mah et al., 2011). Thus there are a myriad of potential physiological and performance benefits that may be gained from enhancing sleep in elite rugby players. No research has attempted to apply conventional methodology to examine the application and efficacy of a sleep education and extension programme in elite athletes, with the aim of exploiting these aforementioned benefits. The validation of such an intervention may provide an incentive for applying regular quantified sleep monitoring and implementing sleep enhancement strategies in elite environments. The application of such strategies may influence elite athlete health, recovery and performance.

Sleep-nutrient interactions offer the potential to enhance sleep following improvement by an education and behaviour change process. A plethora of nutrients have been explored in the literature within the context of improving sleep latency or efficiency (Halson, 2014; Peuhkuri, Sihvola & Korpela, 2012). Anecdotally, tart cherry juice is commonly prescribed for and consumed by collision sport athletes, but applied research in this population is limited. Tart cherry juice is a known source of exogenous melatonin and existing research suggests it to be an effective sleep aid (Howatson et al., 2011; Pigeon, Carr, Gorman & Perlis, 2010). Tart cherry juice is also a rich source of anti-oxidants, and its potential to mitigate inflammation has been suggested as an alternative mechanism of action. Despite anecdotal evidence suggesting widespread use among elite rugby players, questions surrounding effective dosage and timing remain. The effects of TC on the secondary inflammation cascade have also not been thoroughly investigated. Thus research findings

may better inform the application of this nutrient-sleep strategy for both practitioners and athletes. Such a strategy may be poignant, should TC improve indices of sleep, inflammation and soreness, or influence athlete adaptation and performance.

Considering the brevity of research that exists in the area of sleep, athletic recovery and performance in collision sport athletes, the outcomes of this PhD are of great importance. As such, a series of studies were designed as a 'ground up' investigation of sleep in elite rugby players, with the intent of evolving athlete sleep assessment methodology and enhancing athlete health, recovery and performance via novel sleep interventions.

1.2 Purpose of Research

The objectives of this thesis were to:

1. Characterise normative sleep quality among highly trained team sport athletes using validated qualitative methodology.
2. Establish whether relationships exist between validated measures of sleep quality and sleepiness and measures of recovery-stress balance.
3. Quantify indices of sleep quality in professional rugby players during an intensive pre-season training phase and observe parallel changes that may occur in immune function and stress hormone secretion.
4. Evaluate the efficacy of a sleep extension intervention in improving sleep quantity and quality and markers of physical stress, immune function and performance.
5. Examine the efficacy of consuming tart cherry juice concentrate on mitigating symptoms of inflammation and muscle damage, and improving muscle function, sleep and fatigue during an off-season resistance training and conditioning period.

The overall aim of this thesis was to comprehensively profile sleep in elite collision sport athletes and explore methods for improving sleep whilst observing subsequent recovery and performance benefits. This was achieved by applying a battery of validated qualitative and quantitative sleep monitoring tools and novel sleep enhancement interventions in highly trained rugby players in applied training environments.

1.3 Significance of Thesis

High quality sleep is implicitly linked to good health, complete post-exercise recovery and optimal human performance; viewed equally as important as nutrition (Mah et al., 2011; Venter, 2008). Elite athletes are regularly assessed and educated on nutrition and hydration to promote adaptation to training and execute game plans to a high standard. However, optimising athlete sleep quality has been relatively ignored. Thus a critical gap exists within the dynamics of recovery and performance in high performance rugby environments. Novel sleep research, clear sleep guidelines, and behaviour changes toward sleep are required in athletes and coaches. Such an evolution in sleep science is topical not only for professional players, but sub-elite and young development players alike.

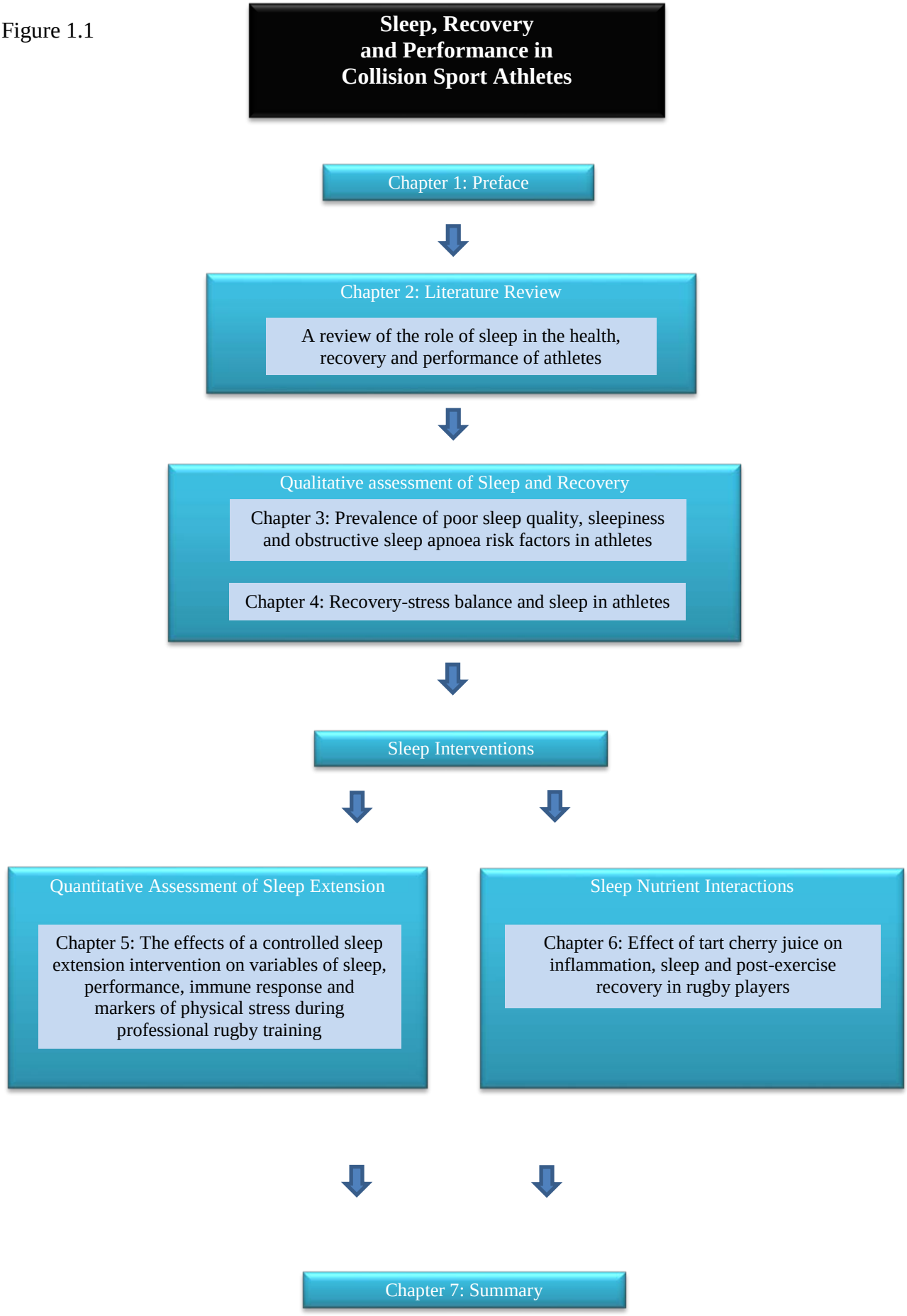
It has been acknowledged that collision sport athletes are at great risk of poor sleep (Shearer, Jones, Kilduff & Cook, 2015). The routine assessment and monitoring of sleep quantity, quality, and risk factors for organic sleep related morbidity needs to be established throughout the professional game. Undertaking rigorous but robust and practical sleep analysis in elite athletes will help raise athlete self-awareness of this fundamental performance pillar. Furthermore, routine sleep assessment may identify at risk players for additional clinical investigation or treatment, and set a strong foundation for health and performance driven sleep education and related interventions.

Finally, the novel information obtained from this PhD significantly adds to the limited body of knowledge specific to collision sport athletes. It is hoped these research findings will stimulate further applied investigation in this area. Furthermore, it is anticipated this PhD will provide a catalyst for prompt action from professional and non-professional teams to integrate sleep assessment and education into their programmes. To do so will greatly contribute towards the betterment of both athlete health and athletic performance.

1.4 Structure of Thesis

This thesis is comprised of four inter-linking sections (Figure 1). The first section is comprised of a literature review (Chapter 2) systematically reviewing the role of sleep in the health, recovery and performance of athletes, with a particular relevance to collision sports. The focus of the second section surrounds the qualitative assessment of sleep, sleepiness, sleep related morbidity and recovery-stress states in a large cohort of team sport athletes (Chapter 3 and 4). The third section assesses sleep in professional rugby players via quantitative means and investigates the efficacy of sleep extension and education interventions on variables of sleep, performance, immune response and markers of physical stress during professional rugby training (Chapter 5). The fourth and final section examines sleep-nutrient interactions by investigating the effects of tart cherry juice supplementation on inflammation, sleep and post-exercise recovery in rugby players (Chapter 6).

Figure 1.1


Sleep, Recovery and Performance in Collision Sport Athletes
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Qualitative assessment of Sleep and Recovery
Chapter 3: Prevalence of poor sleep quality, sleepiness and obstructive sleep apnoea risk factors in athletes
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Chapter 2

LITERATURE REVIEW: THE ROLE OF SLEEP IN THE HEALTH, RECOVERY AND PERFORMANCE OF COLLISION SPORT ATHLETES.

2.0 Overview

In an effort to develop better athletes and improve post exercise recovery, sport science has recently turned its attention to sleep. Despite sleep being essential for human health and performance, sleep science is a relatively unexplored area within elite sport. This is a literature review of sleep as it relates to collision sport athletes. In particular, sleep is defined, and the role of sleep in health and recovery is explored. Sleep has traditionally been understood through the mechanisms of complete or partial sleep deprivation, and this body of research is summarised with respect to physical performance. The small numbers of studies that have attempted to characterise sleep in elite athletes and explore the behaviours and issues influencing their sleep, have been reviewed. Furthermore, validated methods of assessing sleep in athletes are described, with the intention of informing subsequent research methodology in this project. Of particular relevance to the elite sporting environment are experimental methods of improving sleep, and related indices of physical and mental recovery and performance. Thus the areas of sleep hygiene, behavioural intervention, sleep extension and nutrient-sleep interactions are explored. Recommendations for elite athlete application are made. These may in turn benefit the health of athletes and offer a competitive edge that is being largely ignored.

2.1 Introduction

Rugby is an appealing global contact sport that is seeing Rugby 7s introduced to the 2016 Olympic Games. Rugby Union is a repetitive high intensity collision sport. Rugby players must train at high intensity to maintain or improve physical qualities such as speed, power and strength. Thus optimising recovery is vital. With weekly matches typical, the balance between training, physical stress and recovery is paramount to ensure optimal weekly performance. Sleep is likely to play a significant role in the recovery process for rugby players however there is limited literature in the area that solely addresses this important facet of the rugby performance equation.

Indeed, adequate sleep has been identified by athletes and coaches as an important aspect of the post-exercise recovery process, and anecdotally is thought to be a critical component for optimal performance (Samuels, 2008, Davenne, 2009). Physiological recovery from exercise encompasses a complex range of issues. Various non-training elements, including nutrition, have a major influence on training itself, and an athletes' performance. Of these, nutrition and sleep are viewed as two of the most crucial components for maintaining an optimum level of physical and mental health (Venter, 2008). When considering the importance of sleep, it is not elective, but rather is a basic human need equivalent to that of air, food, and water, however, the importance of sleep is largely ignored and/or underestimated (Rosekind, 2010).

There is strong evidence to suggest that significant proportions of both New Zealand adults and adolescents experience sleep disturbances (Dorofaeff & Denny, 2006; Gander, Fink & Paine, 2010). While it is unclear whether this trend extends to athletic populations and specifically rugby players, previous research suggests that the incidence of inadequate sleep in athletes is as high as 85% (Samuels, 2008). However, the prevalence of inadequate sleep and identification of 'poor' sleepers within athletic populations requires further

investigation. Furthermore, anecdotal evidence suggests that athlete's knowledge of how to improve sleep, and delivery of such education, is poor. There is potential to formerly apply basic principles of sleep science to rugby players and examine the efficacy of education and intervention on indices of sleep, recovery and performance.

Until recently, there has been little scientific evidence supporting the observation that sleep has a positive influence on athletic performance (Samuels, 2008). It has been reported that reductions in sleep may harm cognitive (Davenne, 2009; Kryger, Roth & Dement, 2011; Poussel et al., 2014; Venter, 2008) and physical performance (Reilly & Edwards, 2007) during sustained or repeat exercise bouts likely to occur during training sessions or team sport participation. There is, however, a paucity of research examining the benefits of sleep extension or improving the quality of sleep in athletes (Mah et al., 2011). Furthermore, enhancing sleep via these methods is likely to benefit the athlete at a number of adaptation and performance levels, including neural and muscle function (Datillo et al., 2011; Mah et al., 2011; Rupp, Wesenston, Bliese & Balkin, 2008). Improving sleep may also benefit various indices of post-exercise recovery and parameters of health, including the degree of inflammation (Imeri & Opp, 2009) immunity (Faraut et al., 2012) and endocrine responses (Halson, 2014) to both physical stress and sleep. To date, such research has not been conducted with rugby players throughout a pre-season or competition season and therefore warrants investigation.

The present review will detail the role of sleep in health, physical recovery and performance in athletes and specifically rugby players. The prevalence of poor sleep and sleep pathology (e.g. Obstructive Sleep Apnoea) in athletes will be considered, and the methodological assessment of sleep quality in athletes reviewed. The relationships between sleep, athletic recovery and performance will be examined. Additionally, potential sleep-nutrient interactions and interventions to improve sleep quality, athletic recovery and

performance, including sleep extension, will be discussed. This review may in turn benefit the health of athletes and inform a competitive edge that is being largely under-utilised.

2.2 Sleep

2.2.1 Function of Sleep

According to a simple behavioural definition, sleep is a reversible behavioural state of perceptual disengagement from and unresponsiveness to the environment (Kryger et al., 2011). Sleep comprises of two distinct physiological states, non-Rapid Eye Movement (non-REM) and Rapid Eye Movement (REM) sleep (Shapiro & Flannigan, 1993).

Non-REM sleep is conventionally subdivided into four stages, which roughly parallel a depth of sleep continuum, with arousal thresholds generally lowest in stage one, and highest in stage four (Kryger et al., 2011). Stages three and four are collectively known as 'slow wave sleep' or deep sleep (Shapiro & Flannigan, 1993). Slow wave sleep is reported to be the most recuperative form of sleep (Davies, Graham & Chow, 2010), and is associated with a release of growth hormone (GH) (Adam & Oswald, 1984; Davies et al., 2010; Shapiro & Flannigan, 1993; Smith, 1985). Rapid eye movement sleep is the stage during which the most dreaming occurs and is characterised by brainstem inhibition of spinal motor-neurons (Shapiro & Flannigan, 1993). Non-REM and REM sleep alternate throughout the night with an approximate 90 minute cycle (Shapiro & Flannigan, 1993; Kryger et al., 2011). The quantity of sleep an individual healthy adult obtains is determined by a number of factors, including volitional control, genetics, environmental and social factors. However, the variability of sleep length between participants and nights is high (Kryger et al., 2011).

Adults require approximately eight hours of overnight sleep to avoid deficits in daytime functioning (Van Dongen, Maislin, Mullington & Dinges, 2003). However, athletes may

be at an increased risk of achieving less than seven hours sleep per night, compared to the general adult population (Sargent, Lastella, Halson & Roach, 2014). Interestingly, when instructed to attempt ten hours sleep per night over five to seven weeks, Mah and colleagues found athletes were able to achieve an average of 8.46 hours of sleep per night, with associated improvements in sports specific performance (Mah et al., 2011). Therefore, increased sleep quantity may optimise chronic athletic performance, however further research is required.

Modern sleep research began in 1953, and over 60 years of research is yet to provide an unequivocal answer to the question 'why do we sleep?' (Imeri & Opp, 2009). Various theories have been proposed in an attempt to explain why humans need sleep, including energy preservation and creating metabolic resources to support the immune system (Shapiro & Flanigan, 1993; Motivala & Irwin, 2007). Indeed, total body restoration is strongly supported by the observation that anabolism peaks during sleep (Adam & Oswald, 1984; Shapiro & Flanigan, 2003; Smith, 1985). In support of the latter theory, during sleep there is an increase in growth hormone (GH) secretion and muscle protein synthesis, with a contrasting decrease in catabolic hormone expression (cortisol and catecholamines) and subsequent protein degradation (Adam & Oswald, 1984; Shapiro & Flannigan, 1993; Smith, 1985). This resulting anabolic environment attenuates normal biological growth and healing rates of damaged tissue (Adam & Oswald, 1984). In further support of the body restoration theory for athletes, a study comparing sleep before and after a 92 km marathon found that total sleep time increased during the four nights following the event, and in particular slow wave sleep was increased (Shapiro, Bortz, Mitchell, Bartel & Joost, 1981). However, whilst sleep is anabolic, muscle protein synthesis rates are limited by amino acid availability (Beelen et al., 2008). Muscle protein metabolism may be influenced overnight

via dietary strategies that ensure an adequate supply of amino acids during the nocturnal window (van Loon, 2013).

Contrary to the aforementioned body restoration theory, there is a body of thought that it is the brain, and not the body, that recuperates most during sleep (Shapiro & Flanigan, 1993). It has been suggested that sleep is vital for the development of skill and memory (Walker & Stickgold, 2005), as well as psychological restoration and recovery (Venter, 2008). Indeed it is well accepted that mood state is negatively affected by sleep deprivation (Fullager et al., 2015) and there is evidence that mood state can be enhanced in athletes by sleep extending beyond habitual (and sub-optimal) amounts of sleep (Mah et al., 2011). Whilst debate surrounds the exact function of sleep, there is no debate about its importance, owing to the fact humans spend approximately one third of their lives in a sleep state.

2.2.2 Effects of Poor or Insufficient Sleep

At its most severe, prolonged sleep deprivation is fatal in both vertebrates and invertebrates (Gally & Edelman, 2004). Sleep loss is associated with increased obesity, impaired glucose tolerance, diabetes, and cardiovascular disease, and may be causal due to the hormonal and metabolic disturbance inflicted by sleep loss (Imeri & Opp, 2009; Halson, 2014). A study by Spiegel and colleagues (1999) showed that sleep restriction of four hours per night for six nights resulted in a harmful effect on glucose tolerance and hormonal perturbations, including disturbed thyrotropin and cortisol concentrations. Elevated sympathetic nervous system activity was also observed (Spiegel et al., 1999). Chronic partial sleep deprivation in athletes may also result in altered glucose metabolism and neuroendocrine function. Dysfunctional glucose regulation, an increase in appetite and food intake, and impaired protein synthesis via over secretion of catabolic hormones and a decrease in anabolic hormones are serious sources of concern for an athlete (Halson, 2014). The relationship between sleep and appetite stimulation, with resulting negative effects on body composition and body weight

management is a pertinent issue for weight class athletes and athletes requiring a high power to weight ratio such as in Rugby 7s. Interestingly, inflammatory processes are present in obesity and diabetes pathologies (Imeri & Opp, 2009). Immune system impairment and increased pro inflammatory cytokine expression occurs with sleep loss, exacerbating inflammatory pathology, joint pain, and destruction of bone and cartilage in rheumatoid arthritis (Motivala & Irwin, 2007). Optimising sleep may play an important role in modifying the inflammatory state in athletes participating in collision sports.

With respect to cognition, modest reductions of sleep duration have been associated with cognitive deficiencies such as reduced reaction time, concentration, learning, memory and decision making ability (Davenne, 2009; Fullager et al., 2015; Kryger et al., 2011). In an adolescent athlete population, whereby 56 athletes rated their sleep quality as 'poor' or 'just sufficient', poor academic performance was correlated with poor sleep quality (Poussel et al., 2014). Disturbed sleep is also characteristic of patients with mood disorders (Kryger et al., 2011) and chronically sleep deprived participants have exhibited increased levels of depression, stress, anxiety, worry, frustration, irritability and difficulty coping with new environmental stressors (Venter, 2008). With even minimal sleep loss, perceived physical exertion has been shown to increase while pain tolerance is reduced (Hack & Mullington, 2005; Venter, 2008). Perhaps the clearest effect of sleep loss is sleepiness (Kryger et al., 2011). Sleepiness may be considered a state of fatigue, tiredness or a low level of alertness (Johns, 1993). Clinically significant daytime sleepiness was noted in a study of 302 professional American football players. Twenty two percent of athletes had an Epworth Sleepiness Scale score >10 and the study population were sleepier than controls (George et al., 2003). Daytime sleepiness was also more pronounced in those athletes who snored (George et al., 2003). Australian Rules Football players have also shown a similar trend to sleepiness (mean ESS 8.1; 34% ESS >10) (Antic et al., 2013). Similarly, college basketball

players have been reported to have on average very high ESS scores (9.64, s = 3.8) (Mah et al., 2011). Collision sport athletes are at high risk of traumatic brain injury (TBI), a large proportion of which go unreported (Daneshvar, Nowinski, Mckee & Cantu, 2011). Symptoms of TBI include drowsiness (Daneshvar at al., 2011) and athletes report poorer subjective sleep quality than controls without TBI, although objective measures do not support this observation (Gosselin et al., 2009). Nevertheless, the cognitive impact of TBI's in athletes remains a concern with regards to sleep, and further research is warranted (Venter, 2012).

Another consideration for the athlete is that of effective post-exercise recovery. Sleep is well accepted as a primary means of recovery and has been recognised as the most important recovery modality by a large number of elite team sport athletes, including rugby union (Venter, 2014). Thus the aim of improving poor sleep would be to benefit the health of athletes and offer a competitive edge via sleep mechanisms that are being largely ignored. In particular, rugby players may stand to gain better skill acquisition via improved learning efficiency, heightened immune function, reduced variables of physical stress, an improved neural function, heightened recovery from strength training and collisions, and a steeper adaptation curve to training. The possibility of improved sleep associated with the aforementioned outcomes are worthy of further investigation in athletes and more specifically rugby players.

2.2.3 Sleep Apnoea

Athletes appear vulnerable to poor sleep quality possibly due to poor sleep behaviours (Samuels, 2008). This could be related to early/late training sessions increasing sleep debt (the accumulated amount of sleep loss from insufficient sleep) and competitive pressures increasing sleeplessness. Obstructive sleep apnoea (OSA) is a significant and often

unrecognised issue (Emsellen & Murtagh, 2005). In contact sport athletes, including American football and rugby union, characteristics such as Pacifica and Maori ethnicity, a high lean body mass index (BMI>28) and large neck circumference (>40cm) are considered assets and attributes that enhance performance, and are often present in high achievers in these sports (Emsellen & Murtagh, 2005). However, these same physical traits also predispose an individual to an increased correlative risk of OSA (Emsellen & Murtagh, 2005). Furthermore, the incidence of OSA appears to be high among indigenous men (4.4 % Maori Men, 4.1 % non-Maori men) (Mihaere et al., 2009) and higher again (14 % and 19 %, respectively) in American football players with these physique traits (George et al., 2003; Rice et al., 2010). Indeed, several lines of evidence suggest that football players may have significantly increased cardiovascular risk, influenced by identified factors including hypertension and sleep disordered breathing (Dixit, Hecht & Concoff, 2011).

Characterised by partial or complete pharyngeal airflow obstruction during sleep, and often associated with snoring, OSA results in oxygen desaturations and increased sympathetic tone and arousals, thus increasing non restorative sleep, daytime sleepiness and sleep fragmentation (Emsellen & Murtagh, 2005). With regards to general health, OSA is strongly associated with the development of hypertension, cardiovascular disease, stroke, cognitive impairment, mood disorder and sexual dysfunction (Emsellen & Murtagh, 2005; Kryger et al., 2011).

Professional American Football players (n=302) from eight teams in the National Football League were assessed for risk of OSA. Players completed a sleep self-assessment and were stratified into low and high risk of OSA by the Multivariable Apnoea Prediction (MAP) Index (Maislin et al., 1995). Subjective sleepiness was assessed by an Epworth sleepiness scale (ESS) and players undertook anthropometric and medical assessments, including body mass, BMI, neck circumference and airway size. Overnight polysomnography (PSG) was

completed on 52 randomly selected players. Primary outcome measures included ESS and an apnoea-hypopnea index (AHI), calculated from PSG, ≥ 10. More than 20 % of players recorded an ESS > 10, with ESS highest in habitual snorers, indicating clinically significant daytime sleepiness. The prevalence of OSA was 34 % in the high risk group and 7 % in the low risk group, whilst linemen accounted for the majority of positive cases. The overall prevalence of OSA in this athletic population was estimated to be 14 % (George et al., 2003). Similarly, the prevalence of at least mild disordered respiration during sleep has been observed as high as 19 %, although there was no difference in risk between linemen and non-linemen (Rice et al., 2010). Observations from the American football literature contrast with respect to Australian football players, who whilst found to be excessively sleepy, had a comparatively lower, yet still significant, prevalence of OSA (AHI>10) of 5 % (Antic et al., 2013).

Findings from George et al. (2003) indicate that daytime sleepiness is present in a large percentage of professional American football players, and the presence of OSA in this group is substantially higher than the general population. Clinical suspicion should now be raised in these and other athletes who are of the same age and size (George et al., 2003), including rugby union and rugby league. Doing so may minimise potential negative health sequelae and optimise athletic performance in at-risk athletes. Appropriate screening, prompt diagnosis, including PSG in any athlete who has risk factors predictive of SDB, and non-invasive treatment interventions including CPAP airway therapy and oral appliances are recommended (Emsellem & Murtagh, 2005).

In summary, OSA appears to be more prevalent in certain athletic populations, in particular strength-power athletes with predisposing risk factors. Existing literature on OSA in athletes is minimal. The consequences of undiagnosed and untreated OSA are severe at a health level, but little is known about the impact on athletic performance. Further investigation is

required to determine which athletes suffer OSA. Such information may impact not only performance outcomes but also the future health of professional athletes (George et al., 2003).

2.3 Sleep Deprivation and Performance

In the area of sleep and exercise performance, the majority of current literature has focussed on the effects of complete sleep deprivation, or chronic sleep loss, on physical performance (Reilly & Edwards, 2007). Table one summarises the effects of complete sleep loss on both cognitive and physical variables of performance.

Table 2.1. Performance effects of complete sleep deprivation

Study	Sleep deprivation	Variables	Results
Blumert et al., 2007	24 hrs	Weight lifting; Snatch, clean and jerk, front squat, total volume load, training intensity, mood (POMS questionnaire)	N=9 males. Weight lifting performance unaffected after 24 hrs of no sleep. Mood was negatively affected (P=0.002).
Bredahl, 2010	32 hrs	Anaerobic performance; Wingate test, max grip strength, heart rate, blood pressure	N=5 males & 2 females. Adverse effects to anaerobic performance and heart rate response to anaerobic exercise. Decrease in peak anaerobic power (P<0.000), relative peak anaerobic power (P<0.005), mean anaerobic power (P<0.005), and heart rate (P<0.009).
Hill et al., 1994	25-30 hrs	Total work Aerobic and anaerobic contributions to exercise during incremental cycling test to exhaustion	N=7 males, 7 females. Sleep deprivation did not affect total work, or contribution of aerobic and anaerobic work. Trend towards reduced VO_2 after the sleepless night (P = 0.13).
Lucas et al., 2009	96-125 hrs	Strength and strength endurance of knee extensor and elbow flexor, vertical jump, 30s-wingate performance, cognitive performance after an ultra-endurance adventure race	N=9. Reduction of strength (P<0.05) of the legs (17%), and arms (11%), was equivalent (P=0.17). Reductions in strength endurance was inconsistent (legs 18%, P=0.09); arms 13%, P=0.40) but equivalent between limbs (P=0.80). Vertical jump (n=24) (-8% ± 9%, P<0.01), 30s-wingate (n=27) peak (-7% ± 15%, P=0.04), mean power (-7% ± 11%, P=0.01) and end power (-10% ± 11%, P<0.01) performance negatively affected. Cognitive performance (n=9) (complex response times) slower (16%) after 100hrs of no sleep and sustained exercise (P=0.18).
Martin & Chen, 1984	50 hrs	Time to exhaustion while walking	N=8. Sleep loss reduced time to exhaustion by 20 % (P<0.01).
Meney et al., 1998	40 hrs	Stationary cycle ergometer; mood (POMS questionnaire), muscle strength, self- chosen work rate, perceived rate of exertion, heart rate.	N=11 males. Mood deteriorated day 1 (depression (P=0.07), vigour (P=0.00), fatigue (P=0.00), friendliness (P=0.02), TMD (P=0.01)), but recovered on day 2 of sleep deprivation. Back muscle strength (P=0.01) and rate of perceived exertion (P=0.09) was negatively affected after no sleep. Self-chosen work rate and heart rate was not affected.
Oliver et al., 2009	24 hrs	Endurance running performance; 30 min pre load treadmill run followed by a 30min self-paced distance run.	N=11 males. Less distance (P=0.016, d = 0.23) was covered in the distance test after sleep deprivation (6037 (759) 95%CI; 5527 to 6547 m) compared with control (6224 (818) 95%CI; 5674 to 6773 m) (likely an increase in self-perception of effort).

Racinais et al., 2004	38 hrs	Leger and Gadoury shuttle run test score.	N=22. No significant difference in shuttle score after sleep deprivation.
Skein et al., 2011	30 hrs	Repeat sprint performance; mean and total sprint time, repeat sprint pace strategy, muscle glycogen, voluntary peak force and muscle activation, perceptual strain. Two consecutive day trials.	N=10 males. Mean sprint times were slower on sleep deprivation trial 2 (2.78 ± 0.17 s) compared with sleep deprivation trial 1 (2.70 ± 0.16 s) and control 2 (2.74 ± 0.15 s, P< 0.05). Distance covered during self-paced exercise was reduced during sleep deprivation trial 2 during the initial 10 min compared with sleep deprivation trial 1 and during the final 10 min compared with control 2 (P<0.05). Muscle glycogen concentration was lower before exercise on sleep deprivation trial 2 (209 ± 60 mmol/kg^{-1} dry weight) compared with control 2 (274 ± 54 mmol/kg^{-1} dry weight, P=0.05). Voluntary force and activation were reduced on day 2 of both conditions but were lower in sleep deprivation 2 compared with control 2 (P<0.05). Sleep loss did not affect RPE but negatively affected POMS ratings (P<0.05).
Souissi et al., 2003	24 & 36 hrs	Cycling; maximal power, peak power, mean power	N=13 males. Anaerobic power variables intact after 24 hrs but peak power (P = 0.01), mean power (P=0.03) and maximal power (P=0.001) were all impaired after 36hrs of no sleep.
Symons, et al., 1988	60 hrs	Maximal isokinetic and isometric muscle strength and endurance, Wingate anaerobic test, reaction time	N=11 males. No significant effects of sleep deprivation were observed on variables of strength, endurance or on the Wingate anaerobic power test.
Taheri et al., 2012	24 hrs	Peak and mean power and reaction times	N=18 males. Peak and mean power were not significantly different after sleep extension compared to baseline. Mean reaction times were significantly slower after sleep deprivation (P<0.005).
Takeuchi et al., 1985	64 hrs	Vertical jump performance and isokinetic knee extension strength, isometric strength, 40m sprint performance	N=12 males. Vertical jump performance (P=0.02) and isokinetic knee extension strength (P=0.01) reduced after 64hrs of no sleep. Isometric strength and 40m sprint performance was unaffected.
Temesi et al., 2013	32 hrs	Subjective Sleepiness Cognitive test Rate of perceived exertion Heart rate Cycling time to task failure Neuro-muscular response	N=12 males. Subjective sleepiness was greater at all time points during day 2 than day 1 during sleep deprivation compared to control (P<0.001). After sleep deprivation, there was no difference in heart rate between conditions. After sleep deprivation, exercise time to task failure was shorter (1137 ± 253 vs 1236 ± 282 s, P=0.013) and RPE during 40 min submaximal cycling was greater (P=0.009) than that in control. Maximal peripheral voluntary activation decreased by 7 % (P=0.003) and cortical voluntary activation tended

			to decrease by 5 % (P=0.059) with exercise. No other differences in neuromuscular function or cognitive control were observed between conditions. After sleep deprivation, mean reaction time was 8 % longer (P=0.011) and cognitive response omission rate before cycling was higher (P<0.05) than that in control.
Vardar et al., 2007	30 hrs	State anxiety inventory and Wingate anaerobic test	N=13 males. State anxiety level was higher after sleep deprivation (P=0.002). Anaerobic performance remained unchanged.

Of more relevance to the athletic population is a focus on partially reduced sleep in the day or days before or after sporting competition (Reilly & Edwards, 2007), or during heavy training periods (Reilly & Piercy, 1994), when physical adaptation needs to be optimised. Previous findings with regards to the effects of partial sleep deprivation on athletic performance are inconsistent. Significant negative effects of partial sleep deprivation (several hours of sleep restriction over 1-3 nights prior to performance) have been observed on variables of power in football players (Abedelmalek et al., 2012), Judo competitors (HajSalem, Chtourou, Aloui, Hammouda & Souissi, 2013; Soussi et al, 2013) and serving accuracy in tennis players (Reyner & Horne, 2013). Conversely, no significant effects of partial sleep deprivation have been observed on intermittent running test scores in Taekwondo athletes (Mejri et al., 2014), maximal sustained exercise intensity in cyclists (Mougin et al., 1996) or variables of power in highly trained participants (Mougin et al., 1991). However, few studies have examined the prevalence of sleep problems and the resultant effects on elite athletes. Lastella and colleagues (2014) examined pre-competition sleep behaviour and how it relates to pre-competitive mood and subsequent behaviour (Lastella, Lovell & Sargent, 2014). Almost 70 % of athletes experienced poorer sleep than usual and poor sleep quality negatively related to pre-competitive mood state. Nonetheless, there was no significant effect of disrupted sleep on relative sporting performance (Lastella et al., 2014). The poor pre-competitive sleep observed by Lastella and colleagues (2014) agrees with quantitative findings on cyclists, who received less sleep the night before competition (6.5 ± 0.9 h) and during the first night of competition (6.8 ± 0.8 h) than at baseline (7.4 ± 0.6) (Lastella et al., 2015). Similarly, a large study including 632 elite athletes from both individual and team sports reported that 62 % of athletes questioned had experienced poor sleep in the night/s prior to competition (Erlacher, Ehrlenspiel, Adegbesan & Galal El-Din, 2011). Furthermore, athletes competing in individual sports reported more sleep issues than those from team sports (Erlacher et al.,

2011). Whilst the majority of participants (57 %) indicated that poor sleep had no bearing on competition performance (with 14 % reporting poorer performance), athletes also reported effects such as increased daytime sleepiness (27 %), and a bad mood the following day (19 %) (Erlacher et al., 2011). The authors note that the general sleep behaviour of the athletes was not obtained, and it is unclear whether sleep problems were extended into their out of competition lives. The application of a standardised sleep questionnaire such as the Pittsburgh Sleep Quality Index would be helpful in future studies, as well as exploring further the interaction between measures of sleep quality and anxiety state (Erlacher et al., 2011), pre-competition sleep, or indeed wider markers of stress and non-restorative sleep.

The impact of an athlete's regular training time on partial sleep loss is another important consideration. Rowing and swimming in particular are two sports that require athletes to train early, which may affect total sleep time. The impact of early morning training on the amount of sleep obtained by elite swimmers was investigated and early morning training sessions were found to severely restrict the amount of sleep obtained (Sargent, Halson et al., 2014). On nights that preceded training days, swimmers obtained an average 5.4 ± 1.3 hours sleep, with a rising time of 5:48 am. Conversely, on nights that preceded rest days, swimmers arose at 9:47 am and obtained 7.1 ± 1.2 hours of sleep. Sargent and colleagues (2014) observed a similar trend between early morning trainings, total sleep and fatigue in elite athletes from seven different sports (Sargent, Lastella et al., 2014). Moreover, total sleep time decreased as training times advanced. Athletes received less than five hours sleep prior to training sessions that began between 5 and 6 am, whereas later starts allowed athletes to sleep for more than seven hours. A significant effect of sleep duration on pre-training fatigue levels was also observed (Sargent, Lastella et al., 2014). Given that chronic sleep restriction of <6 hours can impair physical and cognitive functioning, and possibly adaptation

to training, early morning schedules may be counter-productive to training (Sargent, Lastella et al., 2014).

Evening training is also a common scenario for athletes, particularly among the sub-elite or youth athletes, and could potentially disrupt pre-bed routines or negatively impact total sleep time. However, a recent report by Buman (2014), showed that 97 % of adult non-elite respondents reported they slept well after vigorous night time activity (Buman, Phillips, Youngstedt, Kline & Hirshkowitz, 2014). Similarly, a study examining the effect of early evening high intensity training on sleep in elite youth soccer players found no effect on sleep quantity or quality, other than feeling significantly more sleepy prior to bed, compared to their home environment condition when not training. Athletes woke one hour later after the evening high intensity training (07:45 ± 1:09 h, $p<0.01$), compared to their rested home condition (06:44 ± 0:41h) (Robey et al., 2014). A later waking time after high intensity evening exercise may indicate that the athlete desired or required more sleep to recuperate. Work or school commitments may be a barrier to obtaining additional restorative sleep, resulting in accrued sleep debt throughout the week.

With respect to partial sleep loss, males and females appear to be affected equally, and more pronounced declines are observed in mood, cognition, speed and psychomotor function rather than performance measures, which appear to follow a circadian rhythm (Reilly & Edwards, 2007). The decrease in mood and cognition experienced following partial sleep deprivation has been well described (Bonnet & Arand, 2003; Fullager et al., 2015; Reilly & Piercy, 1994). However, a review of 56 studies found that neuropsychological functions relating to attention were affected in only 22.8 % of studies (Fulda & Shultz, 2001). Similarly, Bonnet and Arand (1996) did not observe any significant psychomotor performance decrements when experimental sleep disturbance was induced. This may be explained by insufficient

sensitivity in assessment methodology, or perhaps regular insomniacs amplify the adverse effects of disturbed sleep, such as those observed in chronic sleep loss studies. Alternatively, under mild sleep deprivation, most individuals may be able to sustain performance under a time-limited testing situation (Sateia, Doghramji, Hauri & Morin, C, 2000). With regard to sleepiness and cognitive performance lapses, the speed at which sleep loss occurs is important to consider, as gradual sleep loss of one or two hours per night can be adapted to, with a subsequently longer period of recovery. Sleep extension beyond seven to eight hours in young healthy adults who are excessively sleepy improves alertness, and it is well reported that recovery from continuous wakefulness of 40-110 hours can be achieved after a single night of sleep (usually eight hours) (Kryger et al., 2011). Whether these cognitive trends extend to chronically sleep deprived athletes or athletes with excessive daytime sleepiness remains unknown. However, reversing inadequate sleep via sleep extension over five to seven weeks does appear to improve cognitive markers of neuropsychological function in athletes (Mah et al., 2011).

With regards to performance, Reilly and Deyken (1983) (as cited in Halson, 2008) observed no reduction of gross motor functions following sleep loss, including muscle strength, lung power and endurance running, after eight trained men slept for only 2.5 hours per night for three days. Swimmers with restricted sleep (2.5 hours per night for four nights), showed no decrement in 50 m and 400 m swimming performance, along with back and grip strength and lung function, although mood state was negatively affected (Sinnerton & Reilly, 1992) (as cited in Halson, 2008). Additionally, both men and women appear to be resistant to muscle strength depreciation with partial sleep. A strong time of day influence has been observed on gross motor function, and is therefore an important consideration for future research investigating athlete sleep and performance (Bambaeichi, Reilly, Cable & Giacomoni, 2005).

While performance measures are relatively robust with respect to partial sleep deprivation, sleep may play a role in sustaining exercise intensity over several days. This could be important when considering performance in multi-day tournaments such as rugby 7s, or when optimising training quality during an intensive training block. This theme was explored by Reilly and Piercy (1994), who examined sustained exercise performance at both sub-maximal and maximal intensity using weight lifting tasks and subjective states of exertion after three nights of partial sleep. While maximal bicep strength remained unaffected following acute sleep deprivation, there was a decline in maximal leg press and dead lift performance with each successive day of sleep loss. Maximal bench press differed between groups on the final day of the experiment (Reilly & Piercy, 1994). Sub-maximal performance of all four exercises was more affected by sleep loss than maximal efforts. Furthermore, perceived exertion was negatively affected by sleep deprivation after one night of sleep loss (Reilly & Piercy, 1994).

Motivation appeared crucial to the successful performance of maximal lifts, and performance declined as mood states deteriorated, implying that sleep loss mediated central nervous system fatigue affecting maximal weight-lifting performance (Reilly & Piercy, 1994). This could be explained by a decline in vigour and fatigue after just one night of sleep loss. While maximal strength testing in itself may be stressful on the central nervous system, particularly exercises that recruit large amounts of muscle mass such as leg press and dead lifts, these results suggest that accrued sleep deprivation is harmful to both maximal and sub-maximal weightlifting efforts over consecutive days (Reilly & Piercy, 1994). Strategies to dissolve sleep debt could be helpful to the strength-power athlete to optimise longitudinal training intensity.

Interestingly, a more rapid recovery from sleep loss may be facilitated by habitual physical activity, and thus heightened physical fitness in athletes (Meney et al., 1998). However, the potential benefit to athletes is far from established. Furthermore, while some variables are susceptible to the immediate effects of sleep deprivation and others are resistant, general advice regarding likely responses to sleep deprivation is difficult to provide. This highlights the importance of individualising an athlete's education and plan when considering ability to train in a circumstance when sleep loss has occurred (Meney et al., 1998). In addition, it is important to reassure athletes that should sleep be compromised by environmental factors or competition pressure, physical performance may be maintained (Fullager et al., 2015) and any impairment in cognitive performance and mood can be easily dissolved by obtaining a full night of (Kryger et al., 2011).

Important considerations have been highlighted with respect to methodology when studying sleep in athletes (Reilly & Edwards, 2007). This includes the importance of satisfying research conditions such as isolating circadian from homeostatic components or including a competitive event to reduce motivational confounds. The distortion associated with simulating real competition, and reducing other confounds such as home advantage, climate, and changes in fitness and individual circumstances should be considered, but are rarely adjusted for and are difficult to control (Reilly & Edwards, 2007). Furthermore, the requirement of elite athletes to undertake an experimental protocol that has the potential to impair performance may be unethical, and blinding participants or administering placebos is difficult. Precision in study design and data collection may also be compromised in field studies of competing athletes (Reilly & Edwards, 2007). However, methodological considerations must be balanced against the unique opportunity that studying athletic groups or events presents within an applied research design (Reilly & Edwards, 2007).

Whilst gross motor function may be resistant to the effects of sleep loss during time-limited maximal efforts, it does appear to deteriorate during sustained exercise or repeat exercise bouts, as may occur during extended training sessions or team sports (Reilly & Edwards, 2007). The issue of accumulated fatigue resulting from accrued sleep debt may indeed be more pertinent to athletes than the effect of acute sleep loss on maximal efforts. While the physical effect of sleep loss on competition involving maximal efforts is minimal, athletes need to support a rigorous training schedule to optimise adaptation and performance enhancement, particularly those involved in longer sub-maximal exercise, multiple exercise tasks or team sports. The relationship between early morning or late training times, sleep quantity and quality and fatigue status is deserving of future research. Further investigation into the effect of accumulated fatigue resulting from sleep debt on training quality, adaptation and methods to mitigate such fatigue is also required. Additional research with regards to the neuropsychological benefits of sleep extension will also add to a limited body of evidence that suggests these exist. Unique research opportunities with athletic groups in both training and competition environments are present in elite sport, and should be embraced to expand knowledge of how sleep interacts with neuropsychological functioning, physical training quality, adaptation, and subsequent performance.

2.4 Sleep and Recovery

Post-exercise recovery is an important consideration for all athletes. Furthermore, sleep is an important aspect of the recovery process for athletes (Venter, 2012) to allow specific adaptations to occur (Datillo et al., 2011). If the balance between training stress and physical recovery is inadequate then adaptation from, and performance in, subsequent training sessions or competition may not be optimal (Datillo et al., 2011; Hausswirth et al., 2014; Venter, 2014). Importantly, inadequate sleep ($\leq$ 6 h and $<$ 8 h sleep, respectively) has also been linked with an increased incidence of fatigue related injury in youth athletes

(Luke et al., 2011; Milewski et al., 2014). Specifically, collision sports can result in a large amount of physical damage via blunt trauma and exercise stress. This manifests in neuromuscular, biochemical and endocrine changes, which have been well documented (McLellan & Lovell, 2012; Smart et al., 2008; Takarada, 2003; Twist et al., 2012).

Sleep issues have been identified in over reached and under recovered athletes in qualitative studies using a survey or questionnaire (Filho et al., 2013; Maestu, Jurimae, Kreegipuu & Jurimae, 2006; Matos, Winsley & Williams, 2011). The Recovery-Stress Questionnaire for Athletes (REST-Q Sport) measures the complex effects of stress and recovery, including sleep (Purge, Jurimae & Jurimae, 2005). Jurimae, Maestu, Purge and Jurimae (2004) assessed the recovery-stress state of competitive male rowers during a high volume training phase and observed poor sleep quality to coincide with poor recovery and increased fatigue. Whilst qualitative monitoring tools for fatigue and sleep perturbations are useful, alterations in actigraphic markers of sleep quality have also been observed during intense training whereby the athlete was likely over reached or under recovered (Hausswirth et al., 2014; Fietze et al., 1997).

During intense training the aetiology of sleep disturbances is unclear. It is unknown whether poor sleep is a symptom of over-training, or intense training exerts a negative effect on sleep and recovery (Hausswirth et al., 2014). In support of the latter hypothesis, muscle fatigue or soreness may be a cause of nocturnal restlessness (Hausswirth et al., 2014) with pro-inflammatory cytokines being linked to the disruption of normal sleep (Imeri & Opp, 2009). Inadequate recovery can also lead to lower autonomic nervous system (ANS) resources, with a concomitant decrease in heart rate variability (HRV) and increase in heart rate (Hynynen, Uusitalo, Konttinen, & Rusko, 2006). Heart rate variability is altered in response to a change in training load (Kaikonnen, Hynynen, Mann,

Rusko, & Nummela, 2010) and is negatively affected by reduced sleep (Zhong et al., 2005). With adequate physical recovery, however, HRV values increase, reflecting a slower heart rate and reduced ANS excitability. Thus sleep and nervous system recovery are intricately entwined.

An alternative marker of physical stress that is being increasingly utilised is that of salivary alpha amylase (sAA). In a review of the literature, Nater and Rholeder, (2009) describe how sAA is increased in states of stress when autonomic activation is increased (Nater & Rholeder, 2009). Increases in sAA may therefore reflect changes in ANS function and can be considered a sound marker for sympathetic activity (Fletcher & Bishop, 2011; Nater & Rholeder, 2009). The application of sAA as a surrogate marker of ANS function in relation to sleep and sleep extension appears to be novel, and there is sound scientific rationale to suggest this could be a relatively robust and effective variable to use in future sleep research.

The quality of sleep that athletes experience has been reported as significantly poor (Samuels, 2008). Sleep quality in athletes is therefore a deserving focus for future research at both a performance and recovery level. If physiological stress from exercise and competitive sport elevates pro-inflammatory cytokines, and these in turn disrupt or are affected by sleep quality, then it would seem that interventions aimed at optimising sleep and therefore recovery in athletes is vital.

2.5 Qualitative Assessment of Sleep

Qualitative methods have been used to assess the prevalence of poor sleep quality, circadian sleep phase preference, sleepiness, possible sleep disorders and mood profiles in a range of competitive athletes (Antic et al., 2013; Erlacher et al., 2011; Fallon, 2007; George et al., 2003; Mah, Mah & Dement 2007, 2008, 2009, 2010; Mah et al., 2011; Richmond et al.,

2007; Samuels, 2008; Venter, 2014). To date, qualitative data suggests the incidence of poor sleep in athletes to be high (Antic et al., 2013; Fallon, 2007; Samuels, 2008). Samuels (2008) observed that 85 % of adolescent athletes (n=46) who completed a Pittsburgh Sleep Quality Index (PSQI) questionnaire reported poor sleep quality and the majority of the athletes were getting < 8 h sleep per night. Similarly, 24 athletes from the Bobsleigh Canada Skeleton squad followed a similar trend with approximately 78 % of athletes reporting poor sleep quality (Samuels, 2008).

Due to the apparent high risk of inadequate sleep, monitoring an athlete's sleep quality would seem an important consideration within an athletic programme. The efficacy of sleep questionnaires in accurately assessing athlete sleep patterns has been previously challenged (Leeder et al., 2012). Athletes and non-athletes alike may find it difficult to describe their sleep for a variety of reasons, and a discrepancy between an individual athlete's subjective estimate of their sleep and actual sleep quantified by actigraphy has been noted in elite Australian rules players (Richmond et al., 2007). However, two qualitative tools that may prove useful to future research are the PSQI and ESS as global markers of sleep quality and daytime sleepiness. The PSQI provides a subscale rating of subjective sleep quality, as well as subscale measures of sleep latency, sleep duration, and habitual sleep efficiency. Some components relate to sleep disturbances, use of sleeping medication, and daytime dysfunction. The sum of the scores for these seven components yields a global score that is a composite of sleep quantity and quality (Kryger et al., 2011). Acceptable measures of internal homogeneity, reliability and validity have been obtained for the PSQI (Buysse, Reynolds, Monk, Berman & Kupfer, 1989). Furthermore, a global PSQI score >5 has resulted in a diagnostic sensitivity of 89.6 % and specificity of 86.5 % in distinguishing 'good' and 'poor' sleepers (Buysse et al., 1989). Indeed, good correlations have been observed between the subjective evaluation of sleep timing and duration and

actigraphy in adults (Lockley, Skene & Arendt, 1999). Furthermore, self-reported PSQI global scores have been shown to correlate significantly with objective measures of sleep as determined by polysomnography (Backhaus, Junghanns, Broocks, Riemann & Hohagen, 2002). As such, the PSQI may present the sleep scientist with an assessment tool to differentiate between 'good' and 'poor' sleepers, and provide an insight into particular areas of sleep behaviour. Therefore, sleep improvement strategies can be better applied to athletes for whom poor sleep is an issue.

Daytime sleepiness has been specifically evaluated in athletes by use of the Epworth Sleepiness Scale (ESS) (Antic et al., 2013; George et al., 2003; Mah et al., 2007, 2008, 2009, 2010, 2011). The ESS is a simple questionnaire measuring the general level of daytime sleepiness, or average sleep propensity, experienced by an individual (Johns, 1993). This measure is comparable to tests such as the multiple sleep latency test, is a valid and reliable measure of objective sleepiness (Johns, 1993) and is a practical evaluative tool that has been applied to athletes (Antic et al., 2013; George et al., 2003; Mah et al., 2007, 2008, 2009, 2010, 2011,). Furthermore, ESS scores have been shown to change with sleep extension in athletes compared to baseline (Mah et al., 2011), and following OSA therapy (Johns, 1993), indicating reductions in daytime sleepiness. The ESS may compliment the PSQI and provide information on whether the athlete is experiencing a daytime functional disturbance from sleep problems, which may impact concentration, skill acquisition and training quality.

Sleep logs are widely implemented and useful to observe habitual sleep, and specifically time in bed, rising time, sleep latency, number and duration of awakenings, and napping episodes (Leger, Metlaine & Choudat, 2005). Visual analogue scales that enquire about sleep quality, energy upon waking and daytime functioning may also be incorporated into

sleep logs. Sleep logs may accompany and compliment objective actigraphic sleep data, as participants tend to overestimate sleep latency and underestimate total sleep time, and provide an easy and convenient tool to assess sleep (Leger et al., 2005). Sleep diaries have also been used to record sleep-wake activity in competitive athletes (Mah et al., 2011; Richmond et al., 2007). Adequate instructions should be given to ensure compliance and accuracy in completing the sleep diary.

Compared to other areas of sports science relatively little is known about sleep behaviour and sleep quality in elite athletes involved in collision sports. The application of questionnaires and sleep screening tools is a promising area of research to determine the prevalence and incidence of inadequate sleep quantity and quality in elite collision sport athletes. A comprehensive understanding of current athlete sleep quality is critical before a sleep optimisation programme can be implemented.

2.6 Quantitative Assessment of Sleep

Whilst numerous questionnaires have been implemented to qualitatively assess athlete sleep behaviour, there is also a need to employ quantitative assessment methods to better investigate sleep quantity/quality. One method which shows much promise in the physiological monitoring of sleep is actigraphy.

2.6.1 Actigraphy

Sleep may be quantitatively assessed using either polysomnography (PSG) or actigraphy. Polysomnography is traditionally a laboratory or clinic based sleep study which measures brain activity, eye movement, muscle and cardiac activity and provides information on sleep staging (Halson, 2014). While PSG is considered the gold standard for sleep assessment, it is largely impractical for the majority of applied or field based sleep studies.

Actigraphy appears to be a practical and effective method to monitor athletes in their daily training environments.

Actigraphy measures limb movement, usually with the participant wearing a monitoring watch on their non-dominant wrist, or on a waist holster. Movement is recorded as 'awake', whilst a contrasting lack of movement below a pre-determined activity count threshold coinciding with data entry in a sleep diary is interpreted as being asleep (Halson, 2014). Actigraphy has been validated as a tool to measure sleep patterns in healthy adults, is indicated for characterising sleep patterns in young people, including adolescents, and is a useful outcome measure to evaluate the response to a given treatment, education programme or nutritional intervention (Garrido et al., 2009; Howatson et al., 2011; Morgenthaler et al., 2007). Many studies have used actigraphy data to estimate laboratory based polysomnography measures such as duration of sleep onset, total sleep, wake time, and wake time during the night (i.e. sleep quality or sleep efficiency), assumed sleep and immobility (Garrido et al, 2009; Garrido et al., 2010; Mah et al., 2011; Fietz et al., 2009; Morgenthaler et al., 2007; Shearer et al., 2015). The American Academy of Sleep Medicine (2007) lists actigraphy as a diagnostic tool primarily when sleep patterns are assessed over time (Morgenthaler et al., 2007) and can be applied to longitudinal monitoring of athletes. Assessments may occur in home and competition environments, as opposed to a sleep clinic, and have been applied to basketball players (Mah et al., 2011), national ballet dancers (Fietz et al., 2009), swimmers (Sargent, Halson et al., 2014), Olympic athletes (Leeder et al., 2012), nationally ranked athletes from a variety of sports (Sargent, Lastella et al., 2014) and professional rugby players (Shearer et al., 2015). Therefore, actigraphy is a well-accepted research tool that may be implemented in the field to assess measures of sleep/wakefulness, and to provide sleep quality feedback to athletes for educational purposes.

A study by Leeder et al. (2012), aimed to quantify sleep in elite Olympic athletes from a variety of sports (n=47) using wrist actigraphy, and compared sleep to non-athletic controls (n=20). There were significant differences in all measures between the athlete and control groups, except for 'time asleep'. There was a significant effect of gender on 'time awake', with males spending more total time in bed. On average male athletes also slept for longer per night (7:06 ± 0:28 hr:min) compared to female athletes (6:56 ± 0:44 hr:min) (Ledder et al., 2012). Overall sleep quality in the athlete group was observed to be within the range of what is considered normal sleep, but sleep characteristics were poorer than an age and gender matched control group of non-athletes. Specifically, athlete sleep efficiency was reduced compared to non-athletes (80.6 ± 6.4 % and 88.7 ± 3.6 % respectively) and sleep was more fragmented. Total sleep time and sleep efficiency was also remarkably similar to a group of professional ballet dancers whose sleep was monitored by actigraphy for 67 days prior to a premier performance (6:58 ± 0:43 hr:min and 81 ± 4 % respectively) (Fietze et al., 2009) a group of basketball players (6:68 ± 1:03 hrs:min) prior to intervention (Mah et al., 2011), and nationally ranked athletes from seven different sports (6:30 ± 01.24 hrs:min) (Sargent, Lastella et al., 2014). Sleep patterns of elite rugby union players have also been observed prior to and following match play. Sleep latency and efficiency were considered abnormal compared to that expected in non-athlete populations (Shearer et al., 2015).

Actigraphic studies on athletes to date suggest that athletes obtain a similar total amount of sleep as non-athletes. However, total sleep time was less than the eight hours required for good health and human function (Van Dongen et al., 2003) and significantly less than a suggested target for athletes of nine to ten hours per night (Mah et al., 2011), which may be required to optimise athletic recovery and performance. Moreover, observations suggest sleep quality in athletes is poorer, with more awakenings and less sleep efficiency. These results agree with anecdotal reports from athletes, although comparisons between contact

and non-contact sports would be of interest, due to heightened muscle damage and soreness possibly disrupting sleep more in contact sport athletes. Future research should aim to further characterise sleep quality in a broad range of athletes, including contact sports like rugby union, using quantitative measures, and focus on interventions to both extend total sleep time and improve sleep efficiency. Furthermore, actigraphy offers a data collection method that is practical, portable and validated for the assessment of sleep quantity and quality in humans. There is a paucity of qualitative and actigraphic evidence characterising sleep in collision sport athletes, particularly during heavy training phases. As such, little is known with regards to athletic sleep quality in a day-to-day training environment or under experimental conditions in the elite sporting environment, including rugby union. Further quantitative sleep research would provide a valuable contribution to the current body of literature in this area, and the exploration of contact sport athlete sleep patterns would indeed be valuable at a global level.

2.7 Sleep Extension and Performance

Whilst the resultant effects of sleep loss have attracted much attention, the area of sleep extension has not been as thoroughly examined (Mah et al., 2007). Furthermore, the impact of sleep extension on athletic function and performance has, until recently, been unknown. It appears that partial sleep deprivation impairs neuropsychological functioning (Bambaeichi et al., 2005; Reilly & Piercy, 1994) and sub-maximal exercise performance (Reilly & Piercy, 1994), but the effect of recovering sleep debt by sleep extension requires further investigation.

The phenomenon of ‘binge sleeping’, or catching up on lost sleep has been observed in shift workers, students, and employees (Oginska & Pokorski, 2006). Extending sleep in school age children by an average of 35 minutes has been shown to positively affect a child’s

perceived fatigue and sleepiness (Sadeh, Gruber & Raviv, 2003). Furthermore, sleep extension has been found to significantly improve reaction times and memory function, suggesting that moderate changes in sleep duration have detectable effects on children's neuropsychological functioning (Sadeh et al., 2003). Research investigating extended nightly sleep time in adults are relatively scarce and inconsistent (Kamdar, Kaplan, Kezirian & Dement, 2004). Sleep extension has not proven beneficial in performance on a pinball task (Taub, Globus, Phoebus & Drury, 1977). In addition, sleep extension has not been found to improve self-reported mood or sleepiness, auditory vigilance or Multiple Sleep Latency Test (MSLT) scores (Harrison & Horne, 1996). Compared to baseline, performance measures were not improved following sleep extension (Belenky et al., 2003), nor was sleep extension more effective in reducing sleepiness compared to a short mid-afternoon nap or caffeine (Horne, Anderson & Platen, 2008). Conversely, sleep extension has been observed to have a beneficial effect on energy and mood, decrease sleepiness and improve reaction time (Carskaden & Dement, 1979; Kamdar et al., 2004; Mah et al., 2011; Roehrs, Tims, Ardith & Roth, 1989). Short increases in sleep time through the use of naps have also shown improvements in mood, sleepiness, vigilance and sprint performance (Horne, Anderson & Platen, 2008; Hayashi, Wantanabe & Hori, 1999; Dinges, Orne, Whitehouse & Orne, 1987; Waterhouse, Atkinson, Edwards & Reilly, 2007).

An experiment by Barbato and colleagues (1994) highlighted that individuals may enter sleep studies with sizeable sleep debts (Barbato, Barker, Bender, Giesen & Wehr, 1994). It was noted that after a baseline week of eight hours sleep per night, participants slept for 12 hours or more per night during the first four nights of sleep extension opportunity. Sleep time slowly declined over the pursuing three weeks and levelled off at a mean of 8:15 hours following 21 nights, once they had recovered from initial sleep debt (Barbato et al., 1994). Similarly, if athletes were provided the opportunity to sleep more, existing sleep debt may

cause an increase in total sleep time, be it via either night time sleep or daytime napping or both. The health and performance benefits available to athletes by reducing sleep debt seem considerable (Mah et al., 2011).

The concept of banking sleep may also be applicable to athletes before periods where poor quality or restricted sleep is anticipated. Rupp et al. (2008) established a habitual sleep group (mean sleep time 7:09 hours) and a sleep extension group (10 hours in bed) prior to a seven night sleep restriction phase of three hours per night. When comparing performance and sleep behaviour during the sleep restriction phase, psychomotor vigilance task lapses were more frequent and sleep latency shorter in the habitual sleep group, indicating increased fatigue (Rupp et al., 2008). The habitual sleep group showed continuing improvement across five recovery days; however performance in this group failed to improve to the same extent as that of the sleep extension group, even following five nights of recovery sleep (Rupp et al., 2008). Moreover, in the sleep extension group, performance deficits recovered after one night of recovery sleep (eight hours). For athletes, accumulating sleep prior to competition may help maintain performance while under competitive duress, and enhance recovery from competition or travel.

Adding further value to the strategy of overnight sleep extension and napping, increased sleep may alter immune and inflammatory status (Faraut et al., 2012). Experimental data indicates that there is a non-specific activation of immune parameters and a state of low level systemic inflammation following sleep loss. Coupled with the fact that strenuous exercise may result in immune suppression and reduction in lymphocytes immediately post-exercise (Faraut et al., 2012), sleep extension could play a key role in fortifying an athlete's immune function. It has been suggested that sleep improves the formation of antigen specific immune defence as reflected by antibody production in humans and that sleep mediated factors play an important

role in humoral and cell mediated immunity and inflammatory systems (Faraut et al., 2012). Furthermore, fatigue countermeasures such as napping and sleep extension may improve the systemic recovery process regarding immune and inflammatory parameters (Faraut et al., 2012). While adequate sleep quality and quantity may reduce inflammatory processes and immune dysfunction from aging and inflammatory diseases (Faraut et al., 2012), there is a plausible scientific rationale that sleep mediated countermeasures may also reduce inflammation and mitigate immune dysfunction in athletes not only from sleep debt but also the stress and trauma of training and competition (Majde & Kreuger, 2005).

Mucosal immune function has been monitored in swimmers, rugby union players and Americas cup yacht athletes, via saliva Immunoglobulin A (s-IgA) concentrations (Gleeson et al., 1999; Cunniffe et al., 2011, 2010; Neville, Gleeson & Folland, 2008). A decline in s-IgA was observed over a three week period preceding an upper respiratory tract infection in a group of professional yachtsmen over 50 weeks of training, and provides some evidence of a link between depressed immune function and illness in athletes (Cunniffe et al., 2011). Upper respiratory tract infection has also been associated with changes in s-IgA and alterations in training load in elite rugby union players (Neville et al., 2008). Furthermore, it has been proposed that stress induced increases in cortisol release may contribute to reductions in mucosal immunity, which, when lowered, predispose rugby players to an increased risk of illness (Neville et al., 2008). Considering the relationship between sleep, stress hormone secretion and immune function, it is plausible that sleep extension may mitigate stress induced alterations in immune function in athletes. Further investigation into the area of sleep extension influencing both s-IgA as a marker of immune function, and inflammatory status in athletes, is required.

To examine the specific relationship between sleep extension and athletic performance, a small body of research has emerged from the Sleep Disorders Clinic and Research Laboratory at Stanford University. Significant improvements in athletic performance were observed in those athletes who achieved extended night time sleep, compared to baseline. Following a two week baseline recording period, athletes competing at collegiate level swimming, basketball, tennis, and American football were required to extend night time sleep as much as possible, aiming for 10 hours per night. Athletes who extended sleep reported improved sport specific skill performance, increased energy, improved mood and vigour, decreased fatigue and decreased daytime sleepiness at the completion of the extended sleep period (Mah et al., 2007, 2008, 2009, 2010). Conversely, following a one week baseline recording period, one additional hour of sleep extension in female track runners showed no significant effects on variables of power, fatigue or reaction times, although mood scores improved significantly ($P = 0.01$) (Famodu, 2014). Sleep extension participants demonstrated a trend towards improvements in peak power compared to the control (692.9 ± 213.2 watts and 713.5 ± 214.6 watts, $P = 0.07$ respectively). One week of sleep extension may have been inadequate to optimise physical performance improvements, and an increased sleep extension dosage may be required to observe significant benefits.

The most recent study conducted by Mah and colleagues (2011) investigated the effects of sleep extension over multiple weeks on specific measures of athletic performance, as well as reaction time, mood, and daytime sleepiness in eleven basketballers (Mah et al., 2011). Sleep patterns were measured via actigraphy, and a sleep diary. Prior to sleep extension athletes were achieving, on average, 6.68 hours of sleep per night. Following sleep extension of 110.9 minutes per night, compared to baseline, participants achieved an average of 8.46 hours of sleep per night. The sleep extension group demonstrated faster sprint times and a 9 % improvement in shooting accuracy. Mean reaction times improved, measured by a

Psychomotor Vigilance Task (PVT), and together these indices reflected a positive change in athlete performance. Daytime sleepiness scores decreased, determined by the ESS. Increased vigour and decreased fatigue was noted with improved Profile of Mood State (POMS) scores. Participants also reported improved overall ratings of physical and mental well-being during training and competition (Mah et al., 2011). Study design limitations were identified by the author, including small subject numbers and non-randomised subject selection (Mah et al., 2011). The addition of a control such as a habitual sleep group would undoubtedly strengthen future study designs.

A consistent pattern of change was observed by Mah et al. (2011) across all measures of performance and mood in competitive athletes who extended habitual sleep times. These results suggest extended sleep to have a meaningful effect on athletic performance and mood variables. Such a change in performance may be explained by increased sleep positively influencing adaptation to exercise, sport specific skill acquisition and neural functioning. With respect to training adaptation, power development and power change over time may be used as a measure of the effectiveness of a training programme or intervention (Black, 2010). Power variables including distance, peak and mean velocity can be measured with accuracy using a Linear Position Transducer (LPT). The GymAware Optical Encoder (Kinetic, Canberra ACT) is one system gaining popularity due to it being affordable, transportable and practical for use in the field, and has been validated for power assessment against a calibration rig (Black, 2010). Monitoring power changes with a LPT in sleep extended strength power athletes such as rugby union players would make a valuable contribution to existing literature suggesting athletes adapt faster to a training programme when sleep is optimised.

Sport skill acquisition too appears to be more acute with basketball players improving their shooting accuracy following sleep extension (Mah et al., 2011). A wide variety of learning processes in humans require post-training sleep (Mednick et al., 2003). It is believed that after initial training, the human brain continues to learn, and that this delayed improvement develops during both overnight sleep and short daytime naps of 60-90 minutes (Walker & Stickgold, 2005). Whilst it is evident that a wide range of environmental factors are important to sport skill development, including coaching, practice quality and social influences, further research is required (Baker, Horton, Robertson-Wilson and Hall, 2003). Such research should include core sport specific skill development in response to sleep extension, such as passing a ball off the ground in rugby union and at a target to assess passing speed and accuracy, which involves both gross motor function and acute hand eye coordination. Furthermore, athletic sleep extension research should involve comprehensive indices of sleep quality, physical health, recovery and performance with more traditional research methodology to further investigate the effect improving sleep quality on the elite athlete.

2.8 Strategies to Improve Sleep Quality

2.8.1 Psychological and Behavioural Treatments for Insomnia

2.8.1.1 Sleep Education Programmes

Sleep education programmes have been shown to be highly effective in the treatment of insomnia and poor sleep quality (Jacobs, Benson, & Friedman, 1996). From the current body of evidence, it appears that increasing sleep knowledge within individual athletes can be a valuable and likely performance enhancing strategy in all sports at all levels (Mah et al., 2011). One particular sleep education programme, the Multifactor Insomnia Behaviour Intervention, built education around the components of general sleep education, medication

withdrawal and sleep hygiene (including caffeine management), sleep scheduling, modified stimulus control and relaxation response, cognitive restructuring to manage stress, and maintaining therapeutic gains. Of these, patients considered sleep education and sleep scheduling most important. One hundred percent of patients enrolled stated their sleep had improved to a certain degree, and 58 % reported significant improvement (Jacobs et al., 1996). Sleep education programmes are relatively simple and yet highly effective, enabling them to be routinely applied to athletes to achieve adequate sleep.

2.8.1.2 Sleep Hygiene

Sleep hygiene refers to behaviours that are believed to promote improved quality and quantity of sleep (Halson, 2008). The intention of sleep hygiene education is to provide information regarding lifestyle (diet, exercise, substance abuse) and environmental factors (light, noise, temperature) that may either interfere with or enhance sleep (Kryger et al., 2011). Although poor sleep hygiene is rarely the primary cause of insomnia (Kryger et al., 2011), it can potentiate sleep difficulties caused by other factors, or interfere with treatment progress. Thus sleep hygiene education may be helpful for mild insomnia (Kryger et al., 2011). Sleep hygiene education may also assist an athlete in properly extending total sleep time, to nap effectively, and optimise sleep based recovery post-exercise and following late night competition or to better adapt to a new time zone following travel. Therefore, it is important to address sleep hygiene strategies with athletes, and revisit them regularly when consulting athletes to ensure behavioural compliance. Below is a list of sleep hygiene recommendations for athletes.

Non-pharmacological strategies to improve sleep quality and /or quantity in athletes

General

- Ensure appropriate recovery from training, competition and travel. Follow prescribed and best practice recovery across disciplines, including nutrition, physical, psychological and social recovery.

- Consume high protein tryptophan containing foods such as milk, meat, fish, chicken, eggs, beans, peanuts, cheese and leafy green vegetables in the evening meal to increase melatonin production. Consuming milk or other dairy proteins before bed may also help (Peuhkuri, Sihvola & Korpela, 2012).

- Include an adequate carbohydrate load in the meal four hours before bedtime.

- Consider consuming tart cherry juice in the evening, with the evening meal or one hour prior to bed to increase exogenous melatonin and anthocyanin intake (Howatson, Bell, Tallent, Middleton, McHugh & Ellis, 2011).

- Consider using magnesium or zinc or ZMA one hour before bed to potentially increase melatonin production (Peuhkuri et al., 2012).

- Consume a balanced, healthy diet ensuring all food groups and colours are represented. The addition of two kiwifruit one hour before bed may improve sleep via anti-inflammatory and serotonin actions (Hsiao-Han, Pei-Shan, Su-Chen & Jen-Fang, 2011). Achieving recommended intakes of omega-3 fatty acids (fish or flaxseed oil) or consuming a quality fish oil supplement may improve sleep quality via melatonin and / or anti-inflammatory actions (Calder, 2006; Montgomery, Burton, Sewell, Spreckelsen & Richardson, 2014).

- For all above points, consult a sports nutritionist before using nutritional strategies or supplements, ensure supplements are WADA anti-doping compliant and periodise use.

- Lowering core body temperature in the evening to induce drowsiness and sleep:

    - Skin-warming (in cool environmental conditions) – this can be achieved through warm baths/shower/spa, hot foot baths, warm blankets or dressing gowns, wearing warm socks and woollen boots/slippers

    - Skin cooling (in warm environmental conditions) – this can be achieved through cool showers, cold water immersion, appropriate use of air conditioning, light bed covers

Sleep hygiene measures

- Maintain a regular bed and waking time each day (0-30 minute fluctuation - entrains circadian rhythm).

- Allow one hour, 'the de-power hour', to unwind before bed and prepare physiology for sleep.

- De-stress and unclutter the mind. Use a journal to write down worries/thoughts before bed. Write a 'to do' list for the next day to help relax the mind of next day responsibilities.

- Minimise screen time - avoid computer screens, texting, bright lights for 1-2 hours before bed (blue light stimulates the eye and suppresses melatonin production). Some people may find a dimmer TV screen from a distance helps them relax. However, keep the TV out of the bedroom. Blue light blocker apps on smart phones and i-devices / computers may be helpful.

- Lower ambient light levels two hours prior to bedtime – switch off inside / over-head lights, use low level lamps

- Keep the bedroom for sleep activities only, and ensure it is quiet, dark, cool and comfortable. In hotel / training camp situations, a TV may be present, but dim overhead lights. If sharing a room / bed with another person, the use of ear plugs and eye masks may preserve the sleeping environment and manage sleep wreckers. Set air conditioning to 18 °C to optimise sleeping temperature. Use light bedding as appropriate. Travel with your usual pillow for comfort. The use of a fan for cooling and white noise may be helpful.

- Minimise alcohol intake prior to bedtime (fragments sleep later in the night)

- Minimise caffeine and nicotine stimulants intake prior to bedtime (individual tolerances do exist). This includes coffee, tea, energy drinks, cola and chocolate.

- Be cautious of fluid intake prior to bedtime. Consume fluids with evening meal to increase absorption, then taper intake. Individual fluid prescriptions may be necessary following late night training/competition to ensure rehydration practices are optimised. Aim for no more than one visit to the bathroom during the night to minimise sleep fragmentation.

- Be conscious of food (eating can raise core body temperature and make it difficult to fall asleep) and fluid intake prior to bed (to minimise need to go to the bathroom).

- If you cannot sleep within 15 minutes of going to bed, get up again and try a different strategy. Reading a book under a lamp for 10-20 minutes may help. Eliminate the bedroom clock (avoids stress of 'losing valuable sleep time/clock watching'). Set an

alarm on cell phone.

- Nap appropriately
    - If insomnia is a problem, do not nap in the day. Otherwise time naps to be 8 hours after rising time (i.e. nap zone between 1-4pm) and keep these no longer than 30 minutes.
    - Individuals who are trying to increase their total sleep during heavy training or prior to competition, who are having short or fragmented nights, or the day after competition, may experiment with a 90 minute nap mid-afternoon (one full sleep cycle).
    - Naps times between 30-90 minutes or longer than 90 minutes may results in temporary sleep inertia and performance impairments. Napping 10-12 hours after morning waking time will likely disturb subsequent nocturnal sleep.
    - Set an alarm to wake at the right time post nap. Nap timing is critical.
- Explore the use of cognitive behavioural therapy and relaxation

Adapted from Halson, 2008

In addition to sleep hygiene, multi-component therapies are becoming the preferred approach to treating insomnia (Kryger et al., 2011), and may be applied to athletes in an attempt to improve sleep quality. Morin et al. (2006) completed a systematic review of the literature and evaluated 37 psychological and behavioural insomnia treatment studies published between 1998 and 2004. Findings from this review provided evidence for the efficacy of psychological and behavioural treatment of persistent insomnia. Furthermore, 26 of the 37 clinical studies reviewed had evaluated a multi-component approach to treatment of insomnia (Morin et al., 2006). Such an approach typically includes a behavioural (stimulus control, sleep restriction and sometimes relaxation), a cognitive (cognitive restructuring therapy), and an educational component (sleep hygiene), hence the term cognitive behaviour therapy (Kryger et al., 2011).

2.8.1.3 Stimulus Control

Stimulus control is a set of instructions designed to reinforce the association between the bed and bedroom with sleep to re-establish a consistent sleep-wake schedule:

- Go to bed only when sleepy
- Get out of bed when unable to sleep
- Use the bedroom for sleep only (no reading, watching TV etc)

- Arise at the same time every morning, regardless of what time one went to bed
- No napping

(Kryger et al., 2011)

2.8.1.4 Sleep Restriction

Sleep restriction is designed to restrict time spent in bed to as close as possible to actual sleep time, thereby strengthening the homeostatic drive to sleep. Once this is achieved, the sleep window is gradually increased over a period of a few days to weeks until optimal sleep duration is achieved (Kryger et al., 2011).

2.8.1.5 Relaxation Training

Clinical procedures (e.g. progressive muscle relaxation, meditation) aimed at reducing autonomic arousal, muscle tension, and intrusive thoughts interfering with sleep. Most relaxation procedures require some professional guidance initially and regular practice thereafter (Kryger et al., 2011).

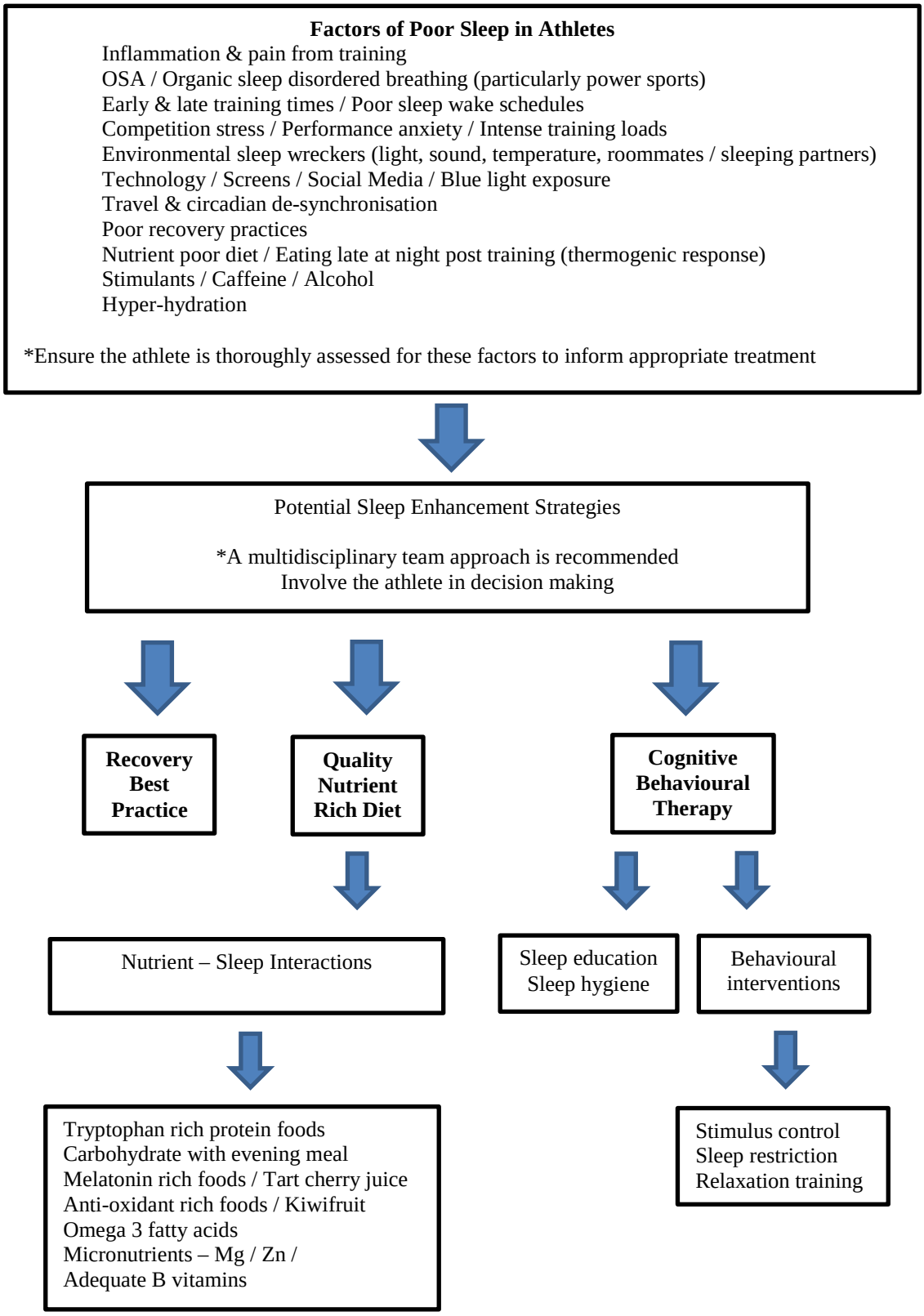
2.8.1.6 Cognitive Therapy

Cognitive therapy is a psychological approach using Socratic questioning and behavioural experiments to reduce excessive worrying about sleep and to reframe faulty beliefs regarding insomnia and the perceived resulting daytime consequences (including athletic performance detriments). Additional cognitive strategies may involve paradoxical intention techniques to alleviate performance anxiety associated with the attempt to fall asleep. This usually requires a trained and skilled clinician (Kryger et al., 2011). Athletes should approach a relevant mental skills practitioner to facilitate these strategies.

Based on the available empirical evidence and current clinical paradigm of insomnia treatment (Morin et al., 2006; Kryger et al., 2011), a multimodal approach to treating

insomnia in athletes may be recommended, as this addresses different causes of insomnia that may be relevant to the athlete. Furthermore, this approach may be combined with nutritional sleep interventions to optimise the sleep window (Figure 1).

Figure 1. Factors of poor sleep in athletes and potential strategies to improve sleep.



George et al., 2003; Halson, 2008; Hausswirth et al., 2014; Howatson et al., 2011; Kryger et al., 2011; Lastella et al., 2014; Montgomery, Burton, Sewell, Spreckelsen & Richardson, 2014; Peuhkuri et al., 2012; Sargent, Halson et al., 2014; Venter, 2012

2.9 Sleep-Nutrient Interactions

The importance of adequate sleep quality is acknowledged for optimal health and athletic performance, and while there are a number of medications to address sleeplessness, there is also a demand for natural alternatives to address insomnia, or improve overall sleep (D'Anci, 2011). Natural alternatives may be perceived as having less potential for harm or additional health and performance benefits inherent in nature, which may or may not have been identified. Natural alternatives include tart cherry juice (melatonin), alpha-lactoalbumin (tryptophan), serotonin/5-HTP (kiwifruit), herbs such as valerian and passionflower, theanine, minerals like magnesium, and manipulating tryptophan levels via consumption of high glycaemic carbohydrates before bed (Table 2.2). Of these natural alternatives, those that raise melatonin levels are a growing area of interest in sleep research (D'Anci, 2011). However, due to the number of natural alternatives identified, a review of the literature will help evaluate their efficacy and identify which are likely to be of benefit to athletes.

2.9.1 Macronutrients

2.9.1.1 Protein

Anecdotal evidence suggests protein is commonly consumed by athletes prior to sleep. In Western countries, cow milk has traditionally been regarded as a sedating drink with sleep inducing capacity (Peuhkuri et al., 2012). Researchers have found improved sleep duration and reduced sleep fragmentation in people who consumed milk fortified with malted barley and wheat Horlicks powder (Brezinova & Oswald, 1972). Consumption of *Lactobacillus-helveticus* fermented milk has demonstrated beneficial effects on sleep efficiency and fragmentation, as measured by actigraphy and sleep questionnaires, in a double blinded study (Yamamura et al., 2009). Melatonin is present in cow milk, and the concentration can be increased by milking cows in darkness, with improved sleep in study participants subsequent to consumption before bed (Valtonin, Niskanen, Kangas & Koskinen, 2005). However, as

well as the melatonin in milk, it is perhaps the effect of milk, or more specifically the effect of tryptophan protein in milk, on the serotonin-melatonin pathway that may also explain milk's efficacy in improving sleep (Brezinova & Oswald, 1972; Griffiths, Lester, Coulter & Williams, 1972; Peuhkuri et al., 2012).

2.9.1.2 Tryptophan

Tryptophan is an essential amino acid precursor of serotonin and melatonin. Tryptophan crosses the blood-brain barrier by competing for transport with a number of other large neutral amino acids. Conversion to serotonin (5-hydroxytryptamine:5-HTP) is thus dependent on sufficient precursor availability in the brain (Halson, 2008). Specifically, an increase in brain tryptophan results when the ratio of free tryptophan to branched chain amino acids increases. Following a degree of tryptophan converting to serotonin, melatonin is then produced (Halson, 2008). In an early review of the literature on the effect of tryptophan on sleep, Hartmann (1983) concluded that there was overwhelming evidence that tryptophan has a positive effect on sleep, particularly improved sleep latency, with tryptophan doses of 1 g or more (Hartmann, 1983). Doses below 1 g have produced trends towards a similar direction, and doses greater than 5 g are required to modulate sleep stages (Silber & Schmitt, 2010).

The effect on sleep of muesli bars enriched with a small amount of dietary tryptophan from de-oiled gourd seed, a rich source of tryptophan (22 mg/1 g protein), coupled with glucose has been compared with bars containing 250 mg pharmaceutical tryptophan plus glucose and glucose alone (Hudson, Hudson, Hecht & Mackenzie, 2005). The de-oiled gourd seed bars produced a similar trend towards increased total sleep time as the pharmaceutical tryptophan bars (5.5 % and 6.5 % respectively, $p<0.10$), similar significant effects on parameters of sleep efficiency, time awake at night and sleep quality index, and outperformed pharmaceutical tryptophan with respect to time awake due to sleep interruption (Hudson et al., 2005). Such

profound effects on sleep from such a small dose of melatonin are notable. A combination amino acid formula containing GABA, tryptophan and choline (Gabadone) has influenced significant changes in sleep latency, nocturnal awakenings, morning alertness and improved parasympathetic function assessed by HRV compared to placebo (Shell, Bullias, Charuvastra, May & Silver, 2010). However, a natural source of tryptophan may be preferred for consumption. Pharmaceutical grade tryptophan has been associated with eosinophilia myalgia syndrome (EMS), a serious medical condition that can result in fatality, and has thus been withdrawn from sale in a number of countries (Hudson et al., 2005). Sources of tryptophan from natural foods include milk, meat, chicken, fish, eggs, beans, peanuts, cheese and leafy green vegetables (Halson, 2008).

A particular primary milk protein, α-lactalbumin, (Peuhkuri et al., 2012), is reported to be the richest natural source of tryptophan from all food protein sources (Heine, Radke, Wutzke, Peters & Kundt, 1996). Markus et al. (2000) have shown that ingesting α-lactalbumin enriched whey protein increases tryptophan to the sum of other large neutral amino acids (LNAA) ratio by 48 % compared to a casein enriched diet (Markus et al., 2000). Furthermore, in stress vulnerable participants, a decrease in cortisol and reduced depressive feelings under stress (Markus et al., 2000) and improved cognitive performance (Markus, Olivier & de Haan, 2002) was observed following the consummation of α-lactalbumin enriched diets. These results suggest consuming dietary rich sources of tryptophan elevate brain tryptophan levels and in turn serotonin activity (Markus et al., 2000; Markus et al., 2002). In a further study by Markus et al. (2005), 14 healthy participants with mild sleep complaints consumed two evening milkshakes containing 20 g of α-lactalbumin. Compared with a casein placebo, evening α-lactalbumin intake resulted in a 130 % increase in tryptophan:LNAA before bed and modestly but significantly reduced sleepiness and improved alertness early the next morning, most likely attributed to improved sleep (Markus

et al., 2005). In addition, tryptophan depletion studies have demonstrated decreased plasma tryptophan levels, followed by sleep alterations, including increased sleep fragmentation, REM sleep latency and REM density compared to baseline or placebo (Arnulf et al., 2002; Bhatti et al., 1998). Furthermore, there is increasing attention on milk based bioactive peptides, such as α-s1-Casein, some of which have opioid and opioid antagonist activities, and have been associated with beneficial effects on sleep (Peuhkari et al., 2012). The consumption of casein may also offer additional muscle recovery benefits by making essential amino acids available overnight for muscle protein synthesis (van Loon, 2013). Thus the consumption of tryptophan rich foods, including milk, by athletes in the evening, may be a prudent strategy to enhance sleep, and the development of an α-lactalbumin enriched casein protein to consume nocturnally may warrant further attention.

2.9.1.3 Carbohydrates

Dietary carbohydrates are known to affect the plasma tryptophan:LNAA ratio, and the addition of a high carbohydrate food to the evening meal may compliment the positive sleep enhancing effect of consuming tryptophan rich proteins (Peuhkuri et al., 2012). Upon consumption of carbohydrates, insulin is released from the pancreas. Insulin mediates the uptake of LNAAs into the muscle but not tryptophan, although the role of insulin per se in affecting drowsiness is not fully understood (Peuhkari et al., 2012). Consequently, the tryptophan:LNAA ratio remains high, and the concentration of other competing LNAAs is reduced (Peuhkuri et al., 2012). Thus a high carbohydrate load in the evening meal may enhance sleep by increasing tryptophan concentration in the brain. This hypothesis was tested by Afaghi and colleagues (2007), who investigated the effects on sleep of consuming an evening meal with a high glycaemic load (GL) (Jasmine rice) and low GL (Mahatma rice) four hours prior to bed time. The high GL meal promoted significantly shortened sleep onset latency compared to the low GL meal, with no other effects on sleep measures (Afaghi,

O'Connor and Moi Chow, 2007). Carbohydrate accounted for 90 % of total calories in the high GL meal, which would however be considered unbalanced and too low in protein for most athletes.

Herrera et al. (2011) re-examined the high GL-tryptophan relationship, but included a more balanced macronutrient meal (66.5% CHO, 17% Pro, 16.5% fat), with both high and low GI carbohydrate portions, compared to a high carbohydrate, high GL meal with less protein (90% CHO, 8% Pro, 2% fat). The percentage increase of tryptophan:LNAA from baseline after the high carbohydrate, high GL meal was marginally but not significantly higher compared to the mixed high GI meal, but almost three fold and significantly higher than the mixed low GI meal (Herrera et al., 2011). Therefore it appears that the amount and type of carbohydrate has a strong bearing on the post prandial tryptophan concentration. Interestingly, a high GI milk drink consumed one hour before bed induced a poorer sleep in children compared to a low GI milk, with increased sleep fragmentation during the first half of the night (Jalilolghadr, Afaghi, O'Connor & Chow, 2011). These findings would suggest that athletes can take advantage of the effect of including adequate high GI carbohydrates in an evening meal, four hours before bedtime, to increase evening sleepiness.

2.9.1.4 Omega-3 Polyunsaturated Fatty Acids

Omega 3 polyunsaturated fatty acids (PUFAs) are considered essential fatty acids which cannot be fully synthesised in the body and play a critical role in good health (Spector, 1999). Omega 3 polyunsaturated fatty acids consist of two fatty acid sub-fractions, eicosopentanoic acid (EPA) and docosahexanoic acid (DHA). Docosahexanoic acid is considered to be possibly the more essential sub-fraction owing to its role in neural development (Spector, 1999). Thus PUFAs must be sourced from the diet and traditional sources include seafood and plant foods. Anecdotal evidence suggests fish oil supplementation in the form of

capsules are regularly taken by collision sport athletes, as PUFAs down regulate expression of pro-inflammatory eicosanoids and may be ingested for therapeutic use (Calder, 2006). A relationship between high blood concentrations of Omega 3 PUFA and less sleep problems has been suggested in infants (Cheruku, Montgomery-Downs, Farkas, Thoman & Lammi-Keefe, 2002), children (Burgess, Stevens, Zhang, & Peck, 2000) and adults (Papandreou, 2013). A randomised placebo controlled trial involving 362 healthy children with a reading difficulty has recently found that taking 600 mg of supplemental Omega 3 PUFA from algae sources for 16 weeks significantly improved sleep quantity and quality (Montgomery et al., 2014). Specifically, children taking supplemental omega 3 PUFA obtained almost one hour more sleep and seven less awakenings per night compared to placebo (Montgomery et al., 2014). The authors postulated that children with higher DHA levels slept better due to the involvement of DHA in melatonin production. Considering pro-inflammatory cytokines disrupt normal sleep (Imeri & Opp, 2009), the anti-inflammatory effect of omega 3 oil is another possible mechanism of action to improve sleep. Further investigation is required in adults and athletes to establish a therapeutic effect in these populations.

2.9.2 Micronutrients

2.9.2.1 B Vitamins & Magnesium

Self-help advice to improve sleep often features vegetables and wholegrains, as a source of B vitamins, and Magnesium (Halson, 2008). There is a physiological rationale to this recommendation. Vitamin B12 contributes to melatonin secretion, vitamin B6 is needed in the synthesis of serotonin from tryptophan, and Niacin may have a tryptophan sparing effect. Sparing tryptophan thus increases the availability of tryptophan for conversion to serotonin and melatonin (Peuhkuri et al., 2012). Treatment with varying amounts of vitamin B12 has had mixed effects on the sleep-wake rhythm and in delayed sleep phase syndrome, and no effects on sleep duration (Peuhkuri et al., 2012). Consuming Niacin increased REM sleep in

six participants with normal sleep and improved sleep efficiency in those with moderate to severe insomnia (Robinson, Pegram, Hyde, Beaton & Smythies, 1977) (as cited in Peuhkuri et al., 2012). Magnesium is also thought to enhance melatonin secretion and act as a GABA agonist, which is the main inhibitory neurotransmitter of the central nervous system (Peuhkuri et al., 2012). Held et al. (2002) found oral magnesium supplementation to increase slow wave sleep duration compared to placebo in older adults (16.5 ± 20.4 min compared to. 10.1 ± 15.4 min, p< or =0.05 respectively) (Held et al., 2002). Similarly, a placebo controlled double blinded study on older adults using a food based supplement of pear pulp enriched with 5mg melatonin, 225mg magnesium and 11.25mg zinc improved subjective sleep measures and total sleep time measured via actigraphy (Rondanelli et al., 2011). The strength of the dietary supplement was aligned to the crucial roles both magnesium and zinc have in the endogenous production of melatonin, and the resulting synergy of these three nutrients (Rondanelli et al., 2011). Recovering alcoholics also experienced improved subjective sleep quality determined by a PSQI questionnaire, and reduced sleep onset latency by almost 20 minutes in a pilot study of magnesium supplementation (Hornyak, Haas, Veit, Gann & Riemann, 2004).

There is modest, but still insufficient evidence to establish firm conclusions or recommendations concerning B vitamin and magnesium therapy to improve sleep. It is also important to note that deficiencies in B vitamins and magnesium may disrupt sleep (Peuhkuri et al., 2012). A nutritional goal in the first instance should be to include a balanced diet containing an array of fruit and vegetables and whole grains, as well as milk, to avoid deficiencies of these micronutrients. Further research is required in the area of micronutrients and their influence over serotonin and melatonin synthesis.

2.9.2.2 L-theanine

L-theanine is an amino acid sourced naturally from both black and green tea leaves (Lyon, Kapoor & Juneja, 2011; Keenan, Finnie, Jones, Rogers & Priestly, 2011), and is also available in supplemental form (Suntheanine, Taiyo KagakuYokkaichi, Japan) (Lyon et al., 2011). Positive effects on sleep from L-theanine supplementation have been reported (Ozeki, Juneja & Shirakawa, 2004). Lyon et al., (2011) observed similar findings when they investigated the efficacy and safety of L-theanine supplementation (400mg/day) to improve objectively measured sleep quality in 98 male children with formally diagnosed attention-deficit hyperactivity disorder (ADHA). The children who consumed L-theanine obtained significantly higher sleep percentage and sleep efficiency scores, along with a non-significant trend towards less activity during sleep, compared to the placebo (Lyon et al., 2011). It should be noted that tea as a beverage is not a good source of L-theanine, and that tea with higher concentrations of L-theanine may also contain higher levels of caffeine. Thus consuming L-theanine from a tea source is not practical for athletes, and to date, there is insufficient evidence to recommend L-theanine supplementation to enhance sleep.

2.9.3 Melatonin

Nutritional interventions that may manipulate sleep patterns in athletes offer a relatively unexplored method of enhancing sleep related recovery. In the modern world of elite sport, athletes are often required to disrupt natural circadian rhythms and sleep quality. Sleep-nutrient interactions, including melatonin containing foods, hold the potential to enhance sleep quality (Brzezinski, 1997; Garrido et al., 2009; Garrido et al., 2010; Howatson et al., 2011). In humans, endogenous melatonin is the final product in the metabolism of the protein tryptophan, and is released from the pineal gland at the onset of darkness, triggering sleep via its hypothermic effect (Brzezinski, 1997; Halson, 2008). Pharmacological melatonin is commonly used to manipulate sleep patterns in athletes (Bartle, 2008).

Ingestion of melatonin affects sleep propensity and has hypnotic effects enhancing sleep duration and quality (Brzezinski, 1997).

The hypnotic effects of melatonin appears to be dependent on the time of administration, with larger doses that far exceed natural physiological melatonin levels, evoking soporific effects during the day when endogenous melatonin is low (van den Heuval, Fergusen, Macchi & Dawson, 2005). Smaller doses have improved sleep onset when administered later in the day (Attenburrow, Cowen & Sharpley, 1996). Pires et al. (2001) observed a positive effect of 0.3mg and 1mg exogenous melatonin on sleep latency when administered at 1800 hrs and 2000 hrs. However, there was no effect on sleep variables when 1mg was administered at 2100 hrs, and interestingly 0.3mg increased sleep onset latency when given at this later time. A dose dependent relationship with sleep onset was not observed; the smaller physiological dose, which more closely resembled natural endogenous melatonin concentrations, was as effective as the larger dose at promoting sleep when given at 1800 and 2000 hrs. The authors suggest this may be due to early melatonin administration attenuating a hypothetical alerting signal that emanates from the suprachiasmatic nucleus (Pires et al., 2001). Furthermore, the observed lack of a dose response effect may indicate that melatonin receptors, or other mechanisms responsible for its effects on sleep, are saturated at physiological levels (Pires et al., 2001). Thus larger doses of melatonin to induce sleep appear to not be more effective, and indeed may not be necessary. Furthermore, small physiological doses of 300 micrograms have been observed to entrain free running circadian rhythms in blind subjects (Lewy, Emens, Lefler, Yuhas & Jackman, 2005). This is of significance if blind individuals are to take melatonin for a lifetime to remain entrained to the 24 hour day (Lewy et al., 2005), or for anyone considering long term melatonin use. The issue of fast versus slow release melatonin has also been discussed in the literature (Arendt, Skene, Middleton, Lockley & Deacon, 1997). If

maintained night time levels of melatonin are important for sleep maintenance, then a slow release source of melatonin given in the evening may prove of greater benefit to sleep duration than a rapidly metabolized dose (Arendt et al., 1997).

2.9.4 Tart Cherries

Exogenous melatonin has been identified in a variety of edible plants and seeds in high concentrations, including tart cherries (Burkhardt, Tan, Manchester, Hardeland & Reiter, 2001; Garrido et al., 2009; Garido et al., 2010; Pigeon et al., 2010). Compared to pharmaceutical melatonin, the melatonin content of tart cherries is low, which may be significant as the risks of long term melatonin supplementation remain unknown (Kryger et al., 2011). Melatonin is readily absorbed when consumed orally, and thus tart cherries could be an important source of dietary melatonin to trigger sleep. (Burkhardt et al., 2001; Garrido et al, 2009; Garrido et al, 2010). The consumption of tart cherries as whole fruit and as a nutraceutical product has produced beneficial effects on actual sleep time, total nocturnal activity, assumed sleep, as well as total melatonin levels and antioxidant activity (Garrido et al., 2009; Garrido et al., 2010). While both of these studies were small, non-randomised, uncontrolled and unblinded, and nutraceutical absorption kinetics and resulting blood concentrations may potentially differ to pharmaceutical formulations, they are suggestive that tart cherries may have the potential to influence sleep architecture, and may be a useful tool available to athletes to enhance sleep quality.

Pigeon and colleagues (2010) examined whether a proprietary tart cherry juice blend improved subjective reports of insomnia compared to a placebo beverage in older adults with insomnia. Participants were randomised, within a double blind, crossover design, and consumed a tart cherry juice blend or placebo. Compared to placebo, tart cherry juice consumption was associated with a significant reduction on the insomnia severity index

($P < .05$) and in wake after sleep onset time ($P < .01$), with no such findings for sleep latency, total sleep time or sleep efficiency. Effect sizes were moderate. The authors concluded that tart cherry juice supplementation had modest beneficial effects on sleep in older adults with insomnia, equal to or exceeding those observed in studies on Valerian and some but not all studies on Melatonin (Pigeon et al., 2010). Furthermore, supplementation was not as effective as results achieved in pharmacotherapy or behavioural trials (Pigeon et al., 2010).

To identify if melatonin is the mechanism of tart cherry juice derived sleep enhancement, a study by Howatson et al. (2011) examined Montmorrency tart cherry consumption in 20 healthy adults using a randomised, double blind, placebo controlled cross over design. Measures of sleep quality were recorded using actigraphy, subjective sleep questionnaires were completed and total urinary melatonin levels were determined by testing urinary 6-sulphatoxymelatonin. Total melatonin content was significantly elevated in the cherry juice group, and there were significant increases in time in bed, total sleep time, and sleep efficiency following cherry juice supplementation. The authors concluded that tart cherry juice supplementation provided an increase in exogenous melatonin that is beneficial in increasing sleep duration and improving sleep quality in healthy men and women and might be of benefit in managing disturbed sleep (Howatson et al., 2011). Moreover, the range of phenolic compounds in cherries which have anti-inflammatory and antioxidant actions may provide athletes with additional post-exercise recovery benefits, as well as provide another possible mechanism of action for sleep enhancement (McHugh, 2011).

The consumption of tart cherry juice to prevent the symptoms of muscle damage has received some focus in the literature (Bell, Walshe, Davison, Stevenson & Howatson, 2015; Connolly, McHugh & Padilla-Zakour, 2006; Howatson et al., 2010; Kuehl, Perrier, Elliot &

Chestnut 2010). Aside from melatonin, flavonoids and anthocyanins have been identified in tart cherries. These compounds have high anti-oxidant and anti-inflammatory activities and may be effective in alleviating inflammation, as well as the strength loss and pain associated with exercise induced muscle damage (Bell, McHugh, Stevenson & Howatson, 2014; Connolly et al., 2006; Howatson et al., 2010; Kuehl et al., 2010). However, pro-inflammatory cytokines have also been explicitly linked to the physiological control and disruption of normal sleep architecture (Imeri & Opp, 2009). Experimental sleep deprivation is associated with increased circulating levels of Inter-leukin-6 (IL-6) and Tumour Necrosis Factor (TNF), with pronounced increases in sleep deprived populations (Motivala & Irwin, 2007).

In a placebo controlled, pseudo randomised trial involving tart cherry juice consumption, Howatson and colleagues (2010) examined markers of muscle damage and inflammation before and after 20 recreational runners completed a marathon. Inflammatory markers were significantly reduced following consumption of tart cherry juice for five days before, the day of and two days after running the marathon. At a muscle damage level, isometric strength recovered significantly faster following the consumption of tart cherry juice, whilst creatine kinase levels were reduced but not significantly different between groups (Howatson et al., 2010). Beneficial effects of tart cherry juice on post-exercise functional strength and / or pain have also been noted elsewhere in the literature (Connolly et al., 2006, Kuehl et al., 2010).

Whilst the sleep enhancing effect of tart cherry consumption has been attributed to both natural polyphenolic compounds called proanthocyanidins increasing tryptophan availability ("Tart cherry juice may help insomnia," 2014) and elevated circulating melatonin levels, the interaction of other anti-inflammatory phyto-chemicals cannot be

discounted (Howatson et al., 2011). Thus regular tart cherry ingestion may, via the mechanisms of pro-oxidant and cytokine suppression, reduce inflammation and muscle damage, in turn improving sleep quality that may be disrupted by pain or inflammation. Future research should address questions associated with dose and nutrient timing. The effects of tart cherry juice on indices of inflammation, muscle damage, soreness and recovery from sport induced trauma and fatigue needs to be examined further. Such research questions are particularly relevant to collision sports like rugby union and rugby 7s, whereby the recovery of muscle function during competition may be considered important. The aforementioned indices of muscle damage and recovery may be monitored alongside sleep quantity and quality in athletes, to enhance knowledge with regards to this interactive relationship.

2.9.5 Kiwifruit

Kiwifruit are a nutritionally dense fruit, containing a plethora of nutrients which may promote sleep promoting, including Vitamin C and Vitamin E, folate, other antioxidants including flavonoids, anthocyanins and carotenoids, as well as the sleep hormone serotonin (Lin, Tsai, Fang & Liu, 2011). In 24 participants with self-reported sleep disturbances the consumption of two kiwifruit one hour before bedtime for four weeks was found to significantly decrease subjective ratings of sleep quality, sleep onset latency and waking time after sleep onset by 42.4 %, 35.4 % and 28.9 % respectively, compared to baseline. Total sleep time and sleep efficiency were significantly increased (13.4 % and 5.4 %, respectively) as measured by actigraphy (Lin et al., 2011). Whilst the mechanism of action remains to be elucidated, the author's hypothesised that serotonin in Kiwifruit may contribute to the sleep promoting effects of endogenous serotonin. The rich antioxidant content may also suppress free radical expression and inflammatory cytokines, which are known to negatively affect sleep quality (Imeri & Opp, 2009). Lastly, folate deficiency may result in insomnia (Lin et al., 2011), and

the folate in kiwifruit might ameliorate a folate deficiency and consequently improve sleep. Although consuming kiwifruit in the evening is prudent from a nutritional perspective, the specific role of kiwifruit in promoting sleep requires further research.

2.9.6 Herbals

2.9.6.1Valerian

Herbal medications are frequently used for the treatment of insomnia. Valerian (*Valeriana officinalis*) is one of the most common herbal insomnia therapies. However, there is much uncertainty as to the active ingredients in Valerian, and its pharmacokinetics and route of metabolism remains unknown (Kryger et al., 2011). Overall, there is a lack of evidence to support the use of Valerian for the treatment of insomnia. Whilst a review of 16 randomised, placebo controlled trials by Bent et al. (2006) suggested valerian might improve sleep quality with no side effects, they did acknowledge that most studies were methodologically poor, and the valerian doses, preparations, and length of treatment varied considerably (Bent, Padula, Moore, Patterson & Mehling, 2006). Wheatley (2005) suggested Valerian to not be suitable as an acute sleep aid, but rather is a sleep maintainer, and more effective for managing chronic insomnia (Wheatley, 2005). A subsequent systematic review of 29 studies investigating the use of valerian as an effective and safe sleep aid found no significant differences between valerian and placebo (Taibi, Landis, Petry & Vitiello, 2007). Furthermore, studies which appear the most methodologically rigorous, found no significant effects of valerian on sleep (Taibi et al., 2007). Whilst the efficacy of valerian in the treatment of insomnia is not yet established, use with athletes should be reserved for those who wish to only treat insomnia with natural herbs (Kryger et al., 2011).

2.9.6.2 Other Herbs

Several other herbs have been traditionally linked to treating sleeplessness, including kava kava, Melissa officinalis, passionflower and hops (Halson, 2008; Wheatley, 2005). Kava kava is commonly used by Pacific Island rugby union and league players following games, and is anecdotally associated with improved sleep and recovery. Kava kava has proven anxiolytic properties, but cases of hepatotoxicity have seen it withdrawn from market in many countries worldwide (Wheatley, 2005). As such, there is no research examining use in athletes to date, and a formal prescription of kava kava for athletes is not recommended. However, use among Pacific Island athletes will no doubt continue, and individual case studies would contribute to this area of research, specifically investigating the effects on sleep quality and recovery.

There is a lack of evidence to support the use of passionflower and hops as sleep aids (Wheatley, 2005). Melissa (Lemon balm) leaf preparations contain volatile oils, and in a placebo controlled, randomised double blind clinical trial, the compound was found to be capable of inducing a mood state compatible with sleep following mild psychological stress (Kennedy, Little and Scholey, 2004). A review by the Natural Standard Research Collaboration (2005) reported that evidence for efficacy of Melissa in improving sleep quality was unclear (Ulbricht et al., 2005).

In summary, numerous nutrients have been examined in varying detail with respect to their efficacy in improving sleep quality. Of these, tart cherry juice as a natural source of melatonin appears to have the most sleep enhancing potential, as well as anti-inflammatory and anti-oxidant properties, which may also assist post-exercise recovery. Moreover, mitigating inflammation may further improve sleep quality. Further investigation of this novel area is needed to better define both dose and timing dependent effects on sleep and

recovery parameters. Other nutrients such as α-lactalbumin in milk, serotonin found in kiwifruit, omega 3 fatty acids and DHA in particular, and magnesium may hold potential sleep benefits for athletes, via effects on the serotonin-melatonin pathway. Further research is required to better define and explore these interactions.

Table 2.2. Summary of nutritional factors that may enhance sleep in athletes.

Nutrient / Food	Purpose	Efficacy / Support
Macronutrients		
Tryptophan rich protein foods e.g. α-lactalbumin in milk, meat, chicken, fish, eggs, beans, peanuts, cheese, green leafy vegetables.	Free tryptophan is converted to serotonin, and then to melatonin. Positive effect on sleep, particularly sleep latency.	Strong support to make firm recommendations regarding strategic use.
Carbohydrate	Affect the plasma tryptophan:LNAA ratio. Mediated by insulin. Carbohydrate amount, type and timing is important (moderate-high carbohydrate load, high GI, 4 hours prior to bed).	Strong support to make firm recommendations regarding strategic use. Body composition goals should also be considered prior to high carbohydrate prescriptions.
Micronutrients		
Magnesium & Zn	Mg & Zn involved in endogenous production of melatonin. Mg also acts as a GABA agonist, the main inhibitory neurotransmitter of the central nervous system.	Modest but insufficient evidence to make firm recommendations regarding supplementation. May be of benefit, thorough pre-post supplementation evaluation is prudent.
B vitamins	Involved as coenzymes in the	Modest but insufficient

	Trp – serotonin -melatonin pathway.	evidence to make firm recommendations regarding supplementation. May be of benefit, thorough evaluation pre-post supplementation is prudent.
L-Theanine	An amino acid sourced naturally from both black and green tea leaves. Purported to have positive effects on sleep.	Poor and insufficient evidence to make any recommendations regarding supplementation. N.b. drinking tea is a poor source of theanine.
Melatonin	Pharmacological melatonin is commonly used to manipulate sleep patterns in athletes. Ingestion affects sleep propensity (the speed of falling asleep), as well as the duration and quality of sleep, and has hypnotic effects.	Strong support to make firm recommendations regarding strategic use. Should be used under medical supervision. Dose and timing are important considerations. Reserve for treatment of de-synchronosis following trans-meridian travel.
Tart cherry juice	A rich source of exogenous melatonin which has sleep promoting effects. Also rich in anthocyanin anti-oxidants which have an anti-inflammatory effect. Polyphenolic compounds may also enhance tryptophan availability.	Modest support to make recommendations regarding strategic use. Athlete total anti-oxidant status should also be considered prior to use.
Kiwifruit	A source of anti-oxidants, vitamin C and serotonin. May have sleep promoting	Small but insufficient evidence to make firm recommendations regarding

	benefits.	supplementation. May be of benefit, thorough evaluation pre-post consumption is prudent.
Omega 3 fatty acids	A source of DHA fatty acid which is involved in pineal gland regulation of melatonin production.	Small but insufficient evidence to make firm recommendations regarding supplementation. May be of benefit, thorough evaluation pre-post consumption is prudent.
Herbals		
Valerian	Purported to have positive effects on sleep. Mechanism unknown. A common herbal treatment of insomnia.	Poor and insufficient evidence to make any recommendations regarding supplementation. Use should only be reserved for athletes who only wish to use a natural herbal remedy for insomnia.
Other herbs – Kava, Melissa, Passionflower, Hops	Herbals commonly associated with treating sleeplessness.	Poor and insufficient evidence to make any recommendations regarding supplementation.

Halson, 2008; Howatson et al., 2011; Montgomery et al., 2014; Peuhkuri et al., 2012; Wheatley, 2005

2.10 Nutritional Factors that Negatively Affect Sleep Quality

Whilst much can be done to improve sleep quality, a brief review of nutritional factors that may negatively affect sleep is important to appreciate for both athletes and sports scientists. Caffeine and alcohol are two substances that are both often present in competitive sporting environments. Caffeine may be enjoyed socially by athletes and is a known ergogenic aid, exerting a stimulatory effect on the central nervous system (Burke & Deakin, 2006). Major sources for athletes include tea, coffee, cola, energy drinks, pre-exercise 'primers', chocolate and non-prescription medications (Burke & Deakin, 2006). Caffeine has a half-life of 4-6 hours and individuals can maintain peak levels for 3-4 hours (Graham, 2001). While the effects of caffeine differ between individuals, some may experience negative side effects, including impaired sleep (Burke & Deakin, 2006). It has been suggested that caffeine administered within two hours of bedtime can increase sleep latency, decrease slow wave sleep, and decrease total sleep time (Bonnet & Arrand, 1992). There also appears to be a dose-dependent relationship between caffeine consumption over a day and sleep onset, sleep time and sleep quality (Hindmarch et al., 2000). It is important for athletes to consider the acute and compounding effects of caffeine on sleep during both training and competition days. Furthermore, athletes should be cognisant of their performance responsiveness or lack thereof from caffeine, and evaluate this against their side effect sensitivity. This is particularly relevant when athletes are competing in multi-day sports, and need to optimise recovery between days to enhance performance (Burke & Deakin, 2006). Strategies to manage this include timing training and caffeine use during the morning, or avoiding caffeine during routine training and reserving it for major competition. During multi-day events, caffeine may be avoided or used in small amounts (1mg/kg) for heats, and taken in larger doses (2-3mg/kg) for finals (Halson, 2008).

Alcohol is often enjoyed by athletes after competition, and may also be consumed socially. Alcohol consumption before bed is considered detrimental to sleep quality and quantity (Venter, 2012). In high doses, alcohol exerts a hypnotic effect before sleep, but disrupts sleep during the second half of the night (Feige et al., 2006). Whilst alcohol is often used to 'unwind' or socialise after participating in sport, it should not be consumed in excess to enhance the onset of sleep, particularly if recovery is important to the athlete. Aggressive hydration / rehydration after sport may increase the need to wake and urinate during the night (Halson, 2008). Large dinner portions or excessive snacking during the night may also negatively affect sleep, possibly due to the thermogenic effect of digestion. This has been evidenced in the Muslim community during Ramadan (Roky, Chapotot, Hakkou, Benchekroun & Buguet, 2001), and may also affect athletes with poor eating patterns, who miss breakfast and calorically load in the evening to compensate. Energy restriction also has a negative influence on sleep and athletes in weight restricted sports or who are undertaking physique trait remodelling with a hypo-caloric diet may require support to address a loss in sleep quantity or quality (Halson, 2008).

2.11 Other Factors That May Negatively Affect Sleep Quality

There are multiple factors that may interfere with an athlete's ability to sleep well. Training may induce inflammation and pain, possibly disturbing sleep (Hausswirth et al., 2014). Training times can greatly interfere with total sleep time and disturb sleep wake scheduling. Furthermore, intensive training periods can be a source of anxiety, keeping an athlete awake (Sargent, Halson et al., 2014). Travel may disrupt circadian rhythms and affect sleep quantity and quality (Richmond et al., 2007). Pre-competition thoughts and nervousness commonly keep athletes awake at night (Erlacher et al., 2011). Obstructive sleep apnoea is prevalent in athletes with a high Body Mass Index, organically disturbing restorative sleep quality (George et al., 2003). Sleep saboteurs such as light, noise, temperature and room-mates in a

hotel or training camp situation, or bed partners are all possible sources of nocturnal disturbance. The prevalence of social media and technology use is emerging as a primary cause of concern with regards to sleep quality, both domestically around training and at pinnacle events. All of these factors should be addressed during a sleep hygiene education session, and following a thorough assessment to identify pertinent issues for the athlete.

2.12 Conclusion

Sleep is of vital importance to human health and function, considering humans spend approximately one third of their lives asleep and the potential ill effects of poor sleep. Athletes have arguably higher than average needs for sleep, and appear to suffer from inadequate sleep quantity and quality. Whilst sleep deprivation can have profound effects on performance, limited sleep extension research suggests that the future of athletic sleep investigations should hinge around methods to enhance sleep, and the effects of improving sleep in athletes. Multiple methods of enhancing sleep are available to athletes, including sleep education, sleep hygiene and pre-sleep behaviours, and nutritional interventions, of which tart cherry juice consumption is popular but under researched. Potential benefits of improving sleep for athletes are many, including improved psychological and physical health, immune function, post-exercise recovery at a muscle, neural and endocrine level, skill acquisition, exercise adaptation and performance. Future research may better characterise sleep specific to collision sport athletes, explore ways to optimise sleep, and provide powerful incentives for athletes, coaches and sport scientists to prioritise sleep. Indeed, future sleep research may illuminate the multiple benefits and competitive advantage that literally lies on an athlete’s pillow.

Chapter 3

PREVALENCE OF POOR SLEEP QUALITY, SLEEPINESS AND OBSTRUCTIVE SLEEP APNOEA RISK FACTORS IN TEAM SPORT ATHLETES

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3.0 Prelude

Prior to applying interventions to enhance sleep, it is essential to firstly understand or characterise the quantity and quality of sleep that athletes achieve. The review of literature in chapter two examined research to date that has characterised sleep in athletes. A significant finding within this review was that athletes appear to obtain a similar amount of total sleep as non-athletes, but sleep quality is poorer. Athletes appear to also experience a significant amount of daytime sleepiness, suggesting that the sleep they do obtain is inadequate for their requirements. Collision sport athletes also appear to be predisposed to an increased risk of obstructive sleep apnoea. Together these findings suggest that collision sport athletes in New Zealand may be a high risk population with regards to sleep, and investigation is warranted. Thus the aim of this study was to characterise normative sleep quantity and quality among highly trained team sport athletes, with a particular focus on collision sports.

3.1 Introduction

Sleep is well accepted as a primary means of recovery and has been recognised as the most important recovery modality by a large number of elite team sport athletes, including rugby union (Venter, 2014) as well as being an important consideration for cricket (Reddan, 2010). Sleep may also play an important role in physical adaptation from a training stimulus with resultant improvements in skill acquisition, physical performance and mood variables Mah et al., 2011). The consequences of inadequate sleep are many and have been well documented. Those pertinent to the athlete include negative mood and cognitive impacts (Poussel et al., 2014; Venter, 2008) immune system impairment and increased levels of inflammation (Motivala & Irwin, 2007); metabolic dysfunction (Halson, 2014; Spiegal et al., 1999) and an increase in perceived physical exertion and decrease in pain tolerance (Haack & Mullington, 2005; Venter, 2008). Physical performance during sustained exercise or repeat exercise bouts may also be reduced with inadequate sleep (Reilly & Edwards, 2007) and fatigue related injury risk for athletes may be increased (Luke et al., 2011).

Despite the consequences of inadequate sleep and the apparent advantages of improving sleep, globally little is known about athlete sleep habits or sleep quality. Actigraphy studies have characterised sleep in athletes from a range of sports, including basketball (Mah et al., 2011), national ballet dancers (Fietze et al., 2009), swimmers (Sargent, Halson et al, 2014) and Olympic athletes (Leeder et al., 2012. These findings suggest that athletes obtain a similar total amount of sleep as non-athletes (approximately seven hours per night), but athlete sleep quality is poorer, with more awakenings and less sleep efficiency. Seven hours of sleep per night is inadequate to prevent deficits in neuro-behavioural performance (Van Dongen et al., 2003) and is less than the minimum sleep time recommended by the Harvard Medical School Division of Sleep Medicine (2015).

Sleep surveys indicate that approximately one in four adults and adolescents within the general population appear to be experiencing inadequate sleep (Dorofaeff & Denny, 2006; Gander et al., 2010; Paine, Gander, Harris, & Reid, 2004). While there is strong evidence that significant proportions of the general population report sleep problems, a dearth of evidence exists on athletic populations. Questionnaires have been used to investigate athlete sleep quality, with results demonstrating that the incidence of poor sleep in athletes is high (Antic et al., 2013; Samuels, 2008). Furthermore, obstructive sleep apnoea (OSA) or sleep disordered breathing (SDB) is a significant and often unrecognised sleep issue (Emsellen & Murtagh, 2005) and the prevalence of OSA appears to be much higher in strength power athletes than the general population, possibly due to a large body mass and neck circumference.

A comprehensive understanding of sleep quality, using validated questionnaires in a large number of elite athletes, is a critical first step in obtaining a competitive edge that is currently under-prescribed. Thus the aims of the present study were to (i) characterise normative sleep quality among highly trained team sport athletes; (ii) explore sleep associated issues among this population, including degree and prevalence of daytime sleepiness and prevalence of OSA symptoms; (iii) compare sleep quality between various groups, such as between rugby union, rugby sevens and cricket players, early versus daytime and evening trainers, training phases; (iv) evaluate if there is a relationship between validated sleep quality and self-perceived sleep quality, quality of life (QOL), and daytime sleepiness.

3.2 Methods

3.2.1 Participants

Following approval from the University Ethics Committee, 175 highly trained male and female athletes from Rugby Union, Rugby Sevens and Cricket, volunteered to participate in the present study. Participants were members of regional training squads and national teams aged 18 years or older and provided written informed consent to participate in the study. Athletes were recruited from Super Rugby, National men's and women's sevens rugby teams, the national Under 20 rugby union squad, two regional rugby union academy squads and a regional cricket squad (Table 1).

Table 3.1 Participant demographics by sport (Mean ± SD) (n=175)

	Cricket n=15	Rugby Academy 1 n=34	Rugby Academy 2 n=9	National U 20 Rugby n=48	Super Rugby n=28	Men's Sevens Rugby n=21	Women's Sevens Rugby n=20
Age (Yrs)	24.3 ± 5.0	19.6 ± 1.7	19.4 ± 1.3	18.9 ± 0.2	24.2 ± 3.0	23.2 ± 3.4	23.7 ± 3.4
Height (cm)	181.1 ± 9.9	187.6 ± 8.2	189 ± 3.7	186.8 ± 7.9	187.2 ± 8.7	185.2 ± 7.2	170 ± 5.5
Weight (kg)	82.9 ± 9.0	97.8 ± 11.8	101.8 ± 5.4	100.5 ± 14.2	105.1 ± 10.3	92.2 ± 8.7	71.8 ± 9.8

3.2.2 Research Design

A qualitative questionnaire based research design was used to collect daytime sleepiness ratings, sleep quality, OSA, quality of life data, and player training phase information from different athletes during either off season, pre-season or in-season phases for rugby union, rugby sevens and cricket in 2012 and 2013. Measures of sleep quality were determined by the Pittsburgh Sleep Quality Index (PSQI) questionnaire Buysse et al., 1989). Daytime sleepiness was evaluated using the Epworth Sleepiness Score (ESS) questionnaire (Johns, 1991). Participants answered questions pertaining to their self-perceived sleep quality,

including difficulties with sleep latency, sleep fragmentation and feeling refreshed upon waking in the morning, as well as questions relating to their quality of life (QOL) (Paine et al., 2004). Questions were asked relating to obstructive sleep apnoea (snoring history and witnessed apnoea's) and recent travel and jet lag history. Training phases, training load and demographic data was recorded in a weekly training history diary. The questionnaires were administered together, with athletes in a group setting, in national training camps or team assemblies and took approximately 15 minutes to complete.

3.2.3 Procedures

Epworth Sleepiness Scale Questionnaire. The ESS is a simple questionnaire measuring the general level of daytime sleepiness, or average sleep propensity, experienced by an individual (Johns, 1993). The questionnaire yields a global score with a range of 0-24. The ESS measure is comparable to all day tests such as the multiple sleep latency test, is a valid and reliable measure of objective sleepiness (Johns, 1993) and is a practical evaluative tool that has been applied to athletes (Antic et al., 2013; George et al., 2003; Mah et al., 2011).

Pittsburgh Sleep Quality Index Questionnaire. The PSQI provides a subscale rating of subjective sleep quality, as well as subscale measures of sleep latency, sleep duration, and habitual sleep efficiency. Some components relate to sleep disturbances, use of sleeping medication, and daytime dysfunction. The sum of the scores for these seven components yields a global score with a range of 0-21 that is a composite of sleep quantity and quality (Kryger et al., 2011). Acceptable measures of internal homogeneity, reliability and validity have been obtained for the PSQI (Buysse et al., 1989). Furthermore, a global PSQI score >5 has resulted in a diagnostic sensitivity of 89.6% and specificity of 86.5 % in distinguishing 'good' and 'poor' sleepers (Buysse et al., 1989).

Quality of Life Questionnaire. The QOL questionnaire enquires about the participant's ability to concentrate and get things done, how they view their relationships with family and

friends, and wellness. Sub-scale measures range between 0 (poor) and 3 (excellent). The sum of the subscale measures generates a global score (Paine et al., 2004).

3.2.4 Statistical Analysis

Means and standard deviations were calculated for total sleep hours, ESS score and PSQI score with respect to gender, sport, ethnicity and phase of season. A percentage distribution was calculated from the resultant values for each PSQI category to indicate the spread and most common behaviour/outcome for the population.

Relationships between PSQI and self-rated sleep quality, quality of life and ESS score were determined with Pearson correlation co-efficient calculated using an Excel spreadsheet for analysis of linear validity (Hopkins, 2000). Cohen effect sizes after log transformation were calculated for differences between age groups, ESS and PSQI scores.

3.3 Results

3.3.1 Total Sleep Time

On average, athletes reported 7.9 ± 1.3 hours of sleep per night (Table 3.2) and all athletes reported a similar total sleep time, regardless of gender or sport surveyed.

3.3.2 Sleep Quality

Half of the athletes were classified as poor sleepers (PSQI >5), with an average PSQI score of 5.9 ± 2.6 (Table 3.2). The effect size of age on sleep quality was clear and moderate with participants >25 years of age experiencing poorer sleep quality (PSQI 6.9 ± 2.9) than athletes <20 years of age (5.4 ± 2.3). The relationship between self-rated sleep quality and actual PSQI score resulted in a Pearson correlation of 0.4 ± 0.1 (90% confidence limits). There was no relationship between self-perceived quality of life and PSQI score (-0.1 ± 0.1) nor a relationship between ESS and PSQI score (0.1 ± 0.1).

3.3.3 Daytime Sleepiness

A high prevalence of clinically borderline excessive daytime sleepiness was observed (Table 3.2; average global score 8.5). In total, 28% of participants were found to be excessively sleepy during the day (ESS >10). The effect size of age on daytime sleepiness was clear but small, with athletes <20 years of age reporting a higher ESS score (9.0 ± 4.1) than athletes older than 25 years of age (7.1 ± 4.3).

3.3.4 Phase of Season

Athletes reported longer sleep times during the off-season (8.2 ± 1.1 h) compared to athletes during the pre-season (7.8 ± 1.8 h) or in-competition (7.7 ± 1.1 h) phases (Table 3.2). Similarly PSQI sleep quality scores were best during the off season (5.3 ± 2.2) and poorest during the competition phase (6.2 ± 2.9). Athletes appeared to be most sleepy during the day in the pre-season training phase (ESS score 9.5 ± 4.4).

3.3.5 Time of Day of Training

Training before 8am was associated with a reduction in total sleep, higher daytime sleepiness and poorer sleep quality (higher PSQI score). Training during the day (8am-5pm) corresponded with enhanced sleep (Table 3.2).

3.3.6 Obstructive Sleep Apnoea

Thirty eight percent of athletes identified themselves as snorers with 19% unsure. The total percentage of athletes who reported having a witnessed apnoeic event was 8%, raising clinical suspicion of OSA in 14 athletes within the group.

Table 3.2 Total sleep hours, daytime sleepiness (ESS) and sleep quality (PSQI) questionnaire global scores by gender, sport, phase of season, ethnicity and training times for athletes (n=175) (Mean ± SD)

	N	Total Sleep Hours	ESS Score*	PSQI Score**
Female	23	7.1 ± 1.1	9.0 ± 4.2	8.2 ± 3.3
Male	152	8.0 ± 1.3	8.5 ± 4.4	5.6 ± 2.3
ALL	175	7.9 ± 1.3	8.5 ± 4.4	5.9 ± 2.6
Cricket	15	7.8 ± 0.8	6.1 ± 4.1	6.0 ± 2.1
Female	3	7.8 ± 1.3	6.3 ± 4.0	6.3 ± 3.1
Male	12	7.8 ± 0.7	6.1 ± 4.3	5.9 ± 2.0
Rugby Union	119	8.1 ± 1.4	8.7 ± 4.3	5.6 ± 2.2
Rugby Academy 1	34	7.8 ± 1.9	9.9 ± 4.5	6.1 ± 2.1
Rugby Academy 2	9	8.3 ± 0.5	8.3 ± 5.0	5.3 ± 2.1
NZ Under 20	48	8.2 ± 1.3	8.9 ± 3.9	5.0 ± 2.7
Super 15	28	8.2 ± 0.8	7.0 ± 4.2	4.8 ± 2.5
Rugby 7s	41	7.3 ± 1.0	9.0 ± 4.4	7.1 ± 3.3
Mens 7s	21	7.6 ± 0.9	8.6 ± 4.6	5.8 ± 2.8
Women's 7s	20	7.0 ± 1.1	9.4 ± 4.2	8.5 ± 3.4
In Comp	75	7.7 ± 1.0	8.2 ± 4.5	6.2 ± 2.9
Off Season	56	8.2 ± 1.1	8.5 ± 4.0	5.3 ± 2.2
Pre-Comp	2	8.5 ± 0.7	3.0 ± 4.2	9.0 ± 2.8
Pre-Season	42	7.8 ± 1.8	9.5 ± 4.4	6.1 ± 2.1
NZ European	98	8.1 ± 0.9	7.9 ± 4.2	5.4 ± 2.4
Maori	41	7.7 ± 1.0	9.0 ± 4.1	6.5 ± 2.9
Samoan	52	7.9 ± 1.3	8.8 ± 4.8	6.2 ± 2.6
Indian	1	5.5	14.00	9.00
Cook Island Maori	1	8.4	1.00	4.00
Tongan	9	7.3 ± 3.4	11.0 ± 5.7	6.7 ± 3.2
Chinese	3	7.6 ± 0.6	8.3 ± 5.1	6.0 ± 3.5
Other	10	7.7 ± 1.0	8.9 ± 3.3	5.0 ± 1.8
Before 8am	60	7.6 ± 1.7	9.7 ± 4.2	6.5 ± 2.9
8am-5pm	63	8.0 ± 0.8	7.5 ± 3.8	5.4 ± 2.0
After 5pm	76	7.8 ± 1.6	9.4 ± 4.4	6.1 ± 2.9

* An ESS global score > 10 indicates excessive daytime sleepiness
** A PSQI global score of >5 is associated with poor sleep quality

Table 3.3 Percentage distribution of PSQI sub categories by score for athletes (n=175).

Responses pertained to self-ratings during the previous month.

Answer	Sleep Duration	Sleep Disturbance	Sleep Latency	Daytime Dysfunction	Sleep Efficiency	Self-rated Quality	Use of Sleeping Meds
0	76.8%	0.0%	21.0%	12.8%	71.4%	7.3%	84.6%
1	15.3%	65.4%	32.5%	63.4%	20.8%	66.9%	8.0%
2	6.1%	34.6%	33.1%	21.3%	5.2%	22.7%	4.9%
3	1.8%	0.0%	13.4%	2.5%	2.6%	3.1%	2.5%

Table 3.4 PSQI sub category scoring definitions.

Answer	Sleep Duration	Sleep Disturbance	Sleep Latency	Daytime Dysfunction	Sleep Efficiency	Self-rated Sleep Quality	Use of Sleeping Meds
0	≥7h per night	Min Score = No trouble sleeping	≥0 & ≤15m getting to sleep	Min Score = No daytime dysfunction due to sleepiness	≥85%	Very good	Not during the past month
1	<7 & ≥6h per night	A little trouble sleeping	>15 & ≤ 30m getting to sleep	A little daytime dysfunction due to sleepiness	<85% & ≥ 75%	Fairly good	< once per week
2	<6 & ≥ 5h per night	Some trouble sleeping	>30 & ≤ 60m getting to sleep	Some daytime dysfunction due to sleepiness	<75% & ≥ 65%	Fairly bad	Once or twice a week
3	<5h per night	Max Score = Much trouble sleeping	>60m getting to sleep	Much daytime dysfunction due to sleepiness	<65%	Very bad	≥ 3 times per week

3.4 Discussion

The aims of the present study were to (i) characterise normative sleep quality among highly trained team sport athletes, (ii) explore sleep associated issues among this population, including degree and prevalence of daytime sleepiness and prevalence of OSA symptoms, (iii) compare sleep quality between various groups, such as between rugby union, rugby sevens and cricket players, early versus daytime and evening trainers, training phases and (iv) evaluate if there is a relationship between validated sleep quality and self-perceived sleep quality, quality of life, and daytime sleepiness.

Self-reported sleep quality data were obtained from 175 highly trained team sport athletes (Table 3.3). The findings suggest that athletes achieved a reasonable amount of total sleep and this was similar across sports and genders. However, on average participants had poor sleep quality, which was worse during the pre-season training phase, with a resultant high degree of daytime sleepiness across training phases. Early training times (<8am) were associated with less total sleep, higher daytime sleepiness and poorer sleep quality. Alternatively, training between 8am-5pm was associated with the best sleep quality. A large percentage of participants reported snoring, and the prevalence of witnessed apnoeas was high. The prevalence of such risk factors suggests that athletes may be at a higher risk of OSA than the general population.

3.4.1 Total Sleep Time

The amount of sleep required by athletes to support training, recovery and performance is not well understood. While there is no general consensus on the amount of sleep required by athletes to optimise performance (Sargent, Lastella et al., 2014), it has been suggested that approximately 8 hours of sleep per night is required by non-athletes to prevent daytime neuro-behavioural dysfunction (Van Dongen et al., 2003). Athletes in the present study

reported on average 7.9 hours of sleep per night, which is remarkably similar to total sleep hours reported by young Australian adults aged 18-24 years (8 hours per night) (Bartlett, Marshall, Williams, & Grunstein, 2008). Several authors have reported similar findings using actigraphy monitors amongst elite athletes from a variety of sports, under a variety of conditions, showing on average elite athletes receive approximately 6.5-7.0 hours of sleep per night (Antic et al., 2013; Fietze et al., 2009; Leeder et al., 2012; Mah et al., 2011; Sargent, Halson et al., 2014; Sargent, Lastella et al., 2014). Indeed, almost a quarter (22%) of athletes in the present study reported receiving less than seven hours sleep per night.

The Pittsburgh Sleep Quality Index questionnaire has been recommended as an efficient and valuable measure of global sleep and insomnia symptoms (Kryger et al., 2011), and proves helpful in characterising normative data in an athletic population (Antic et al., 2013; Samuels, 2008). However, the efficacy of sleep questionnaires in accurately assessing athlete sleep patterns has been previously challenged (Leeder et al., 2012). Athletes and non-athletes alike may find it difficult to describe their sleep for a variety of reasons, and a discrepancy between an individual athlete's subjective estimate of their sleep and actual sleep quantified by actigraphy has been noted in elite Australian rules players (Richmond et al., 2007). Thus total sleep times reported in the present study may be an over-estimate of the sleep that the athletes were achieving. The present study has highlighted that total sleep time in an elite athletic population appears to be similar to non-athletes at best, and quite possibly less than optimal for a large number of athletes. Early training times have been found to negatively affect total sleep time and fatigue in athletes (Sargent, Halson et al., 2014) and present study results support this finding. Indeed, whilst results from the present study suggest that the majority of athletes obtain a reasonable amount of sleep, one in four is at risk of obtaining inadequate sleep. Further sleep assessment to identify poor sleepers and education on how to extend sleep in those athletes would be prudent (Table 3.4).

3.4.2 Sleep Quality

Half of the elite athletes questioned in the present study experienced poor sleep quality (global score >5) whilst 65% scored five or higher, 22% of athletes scored eight or higher, and 9% scored ten or higher. The latter score may indicate a serious sleep problem that requires further evaluation (Samuels, 2008). Using a poor sleep cut off of five or higher, similar PSQI scores to the present study were obtained on a smaller group (n=24) of the Canadian Bobsleigh Skeleton squad (78% PSQI $\geq$ 5, 26% PSQI $\geq$ 8, 10% PSQI $\geq$ 10) (Samuels, 2008). Whilst the PSQI is a diagnostically sensitive tool for differentiating good sleepers from poor sleepers (Buysse et al., 1989) it uses a definitive scoring value of seven hours sleep as being adequate for an adult. However, seven hours sleep is more than likely inadequate for athletes. Seven hours sleep is also deemed inadequate for an adolescent requiring 8.5-9.5 hours per night as recommended by the Harvard Medical School Division of Sleep Medicine (2015), and would in turn be inadequate for the large number of teenage athletes investigated in the present study (Brand et al., 2010). The difficulties that adolescents face in achieving adequate sleep has been well described (Carskaden, Wolfson, Acebo, Tzischinski & Seifer, 1998; Carskaden, 2005) and previous research indicates that a large proportion of adolescent elite athletes (Brand et al., 2010) and teenagers in general (Dorofaeff & Denny, 2006) do not get enough sleep. As such, the PSQI may underestimate the true prevalence of poor sleep quality in this and other athletic populations.

Whilst athletes may not achieve an adequate total amount of sleep, they also appear to find both getting to sleep and staying asleep, problematic. This observation has been reported by other athlete sleep studies (Leeder et al., 2012; Sargent, Halson et al., 2014). Furthermore, one hundred percent of athletes in the present study population were affected by fragmented sleep. Indeed, poor sleep quality may be caused by a plethora of factors, including needing to rise early for training (Sargent, Halson et al., 2014; Sargent, Lastella et al., 2014)

psychological stress, muscle soreness, pain or injury, caffeine or rising to go to the toilet from over-hydration (Halson, 2008). Should total sleep be compromised, which it appears to be for the majority of athletes studied to date, sleep quality must be optimised to facilitate the recuperative benefits of sleep, or at least ameliorate some of the negative consequences of inadequate total sleep. Sleep may be regarded as a critical component not only of life and good health, but also post exercise recovery. As such, inadequate sleep based recovery may interrupt optimal training adaptation and/or competition performance (Datillo et al., 2011; Hausswirth et al., 2014; Venter, 2014). With regards to improving sleep efficiency, present study results suggest that an effort to help athletes go to sleep more quickly and achieve an uninterrupted sleep, thus optimising their limited time in bed, would appear to be a priority for elite sporting environments.

3.4.3 Daytime Sleepiness

The likelihood of experiencing excessive daytime sleepiness (ESS >10) is significantly higher in people who report they never or rarely get enough sleep (Gander, Marshall, Harris, & Papaarangi, 2005). The prevalence statistics for athletes experiencing a poor sleep in the present study were high, and as such a preponderance of athletes were found to be excessively sleepy in the day (28%). Healthy adult populations globally report an average ESS score of approximately 6 (Gander et al., 2005). The mean ESS score in the present study (8.5) for Maori, Pacific Island, New Zealand European and athletes of other ethnicities were markedly higher than normative mean values reported for non-athletes, and indeed higher than those of most other healthy adult samples (Gander et al., 2005). However, excessive daytime sleepiness (ESS >10) appears to be more prevalent among non-athletes (38%) (Gander et al., 2005) compared to athletes in the present study. High degrees of excessive sleepiness have also been reported in American football players (mean ESS of 7.3, >20% players scored >10, n=302) (George et al., 2003) and Australian Rules football players (mean

ESS 8.1, 34% players scored >10, n=40) (Antic et al., 2013). Similarly, college basketball players have been reported to have on average very high ESS scores (9.64 ± 3.8) (Mah et al., 2011).

Whilst mean ESS results in the present study are within the normal range, results do indicate that the degree of general daytime sleepiness is a significant issue for athletes. The pre-season training phase in particular appears to be a time when athletes are at risk of high degrees of daytime sleepiness, which may be a result of inadequate sleep, and/or a higher sleep requirement from training load and intensity. Athletes may therefore require more education about the value of restorative sleep during the pre-season. Indeed, sleepiness may be considered a state of fatigue, tiredness or a low level of alertness, or a physiological drive usually arising from inadequate sleep. Perhaps more importantly, increased daytime sleepiness is a symptom of OSA (Johns, 1993). Fatigue and a compromised level of alertness are important considerations for an athlete. It is feasible that sleep related fatigue may impact on motivation to train, and importantly for the elite, may negatively affect training intensity. Peripheral issues affected by concentration such as skill execution and practice quality could also be affected. Whilst the impact of excessive daytime sleepiness on athletic performance needs further investigating, reducing ESS scores via sleep extension in athletes has been associated with improved mood and sports performance (Mah et al., 2011). Considering the number of athletes who were sleepy in the present study, investigating ways to mitigate such fatigue as a by-product of inadequate sleep would be a worthy endeavour.

3.4.5 Obstructive Sleep Apnoea

Obstructive sleep apnoea (OSA) or sleep disordered breathing (SDB) is a significant and often unrecognised issue (Emsellem & Murtagh, 2005). Obstructive sleep apnoea impacts negatively on sleep quality, is marked by snoring, apneic episodes and fragmented sleep with

resultant sleepiness, decreased daytime functioning and increased cardiovascular risk (George et al., 2003). In collision sport athletes, including American football and rugby union players, characteristics such as Pacifica and Maori ethnicity, a high BMI (>28) and large neck circumference (>40cm) are often considered performance enhancing assets. However, these same physical traits also predispose an individual to an increased risk of OSA (Emsellen & Murtagh, 2005). Furthermore, the incidence of OSA appears to be high among indigenous men (4.4% Maori Men, 4.1% non-Maori men) (Mihaere et al., 2009) and higher again (14%) in American football players with these physique traits (George et al., 2003). A large proportion of the present athletic population were self-reported snorers (38%), and 8% self-reported having had a witnessed apnea. This may in part explain the increased degree of sleepiness among participants, and creates strong clinical suspicion of OSA. Based on this premise, the actual prevalence of OSA in team sport athletes may in fact be twice that of the general population, and should be investigated further. Based on these findings, snoring and OSA risk factors should be regularly screened within athlete populations, as athletes would otherwise go unnoticed. Such an intervention could dramatically improve not only the long term health of athletes, but also sleep related sports recovery and performance.

3.4.6 Limitations

All questionnaire responses were self-reports. Every care was taken to reassure participants that information was strictly for research purposes, and would not impact on selection for their sport. There is some evidence that the context in which an ESS questionnaire is given may influence subject responses (Gander et al., 2005). One may assume however that the athletes in this study had no prior knowledge of an ESS questionnaire, nor any other questionnaire pertaining to sleep. Sleep data could not be observed for all groups during the in competition phase. Nevertheless, both rugby union and rugby sevens in competition sleep data was obtained. Finally, there is a lack of agreement in the literature regarding the efficacy

of sleep questionnaires in accurately assessing sleep patterns, and thus total sleep times reported in the present study may be an over-estimate of the sleep that the athletes were achieving.

3.5 Conclusion

Elite and developing athletes appear to suffer poor sleep quality, with associated high levels of daytime sleepiness. Based on the significance of the present findings, thorough and regular athlete screening for poor sleep quality, sleep latency, nocturnal disturbances and resultant daytime sleepiness would seem prudent. Improving athlete sleep would address an important aspect of the recovery process (Datillo et al., 2011), may facilitate significant improvements in athletic performance (Mah et al., 2011), and optimise both mental and physical health (Venter, 2008). With respect to team sport athletes, snoring and OSA risk factors should be regularly screened for by team medical personnel, with appropriate referral and treatment pathways identified. Implementing methods to improve sleep quality in athletes, and to mitigate resulting negative effects, should start with sleep hygiene education as well as addressing sleep wake schedules and training times. Doing so may provide a vital competitive edge. More quantitative sleep research methodology among athletes would complement current study findings, and further confirm the high prevalence of poor sleep quality that appears to exist.

3.6 Practical Applications

The findings from this study are of significant importance to athletes. Together with previous findings on sleep in athletes, it would appear that athletes are a very high risk population with regards to sleep, and this risk confers negative consequences at a number of levels. Athlete programmes at adolescent, sub-elite and elite levels should regularly screen for sleep quantity and quality within their athletes. As many as half of a given sports team may be experiencing

sleep difficulties, and one in three may report consequences of poor sleep such as significant daytime sleepiness, or fatigue. The ability to detect those athletes who are troubled by poor sleep would be a powerful adjunctive strategy to developing, optimising and recovering an athlete. Qualitative sleep screening tools are simple to utilise in the field, with a large number of athletes, and global scores enable the identity of red flag players for subsequent evaluation or treatment. Medical teams should in the first instance be empowered to monitor sleep quality, and risk factors for OSA.

The reader should be cognisant that the aforementioned sleep screening tools are subjective and self-reported by the athlete. Whilst the questionnaires are validated tools for assessing adequate sleep, a comprehensive global assessment of an athlete should always be considered if an athlete otherwise presents as fatigued or under-recovered. Quantitative sleep assessment also presents as a logical progression in evaluative accuracy.

Chapter 4

RECOVERY-STRESS BALANCE AND SLEEP IN ATHLETES

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In Review (Appendix 5)

4.0 Prelude

The development of physical attributes employed by collision sport athletes, such as strength, power and both aerobic and anaerobic ability requires exposure to frequent training stressors. Furthermore, competition places extreme pressures upon the collision sport athlete to recover swiftly and adequately to compete again within a short time frame. Central to mitigating these stressors is applying a comprehensive recovery model, and subsequently monitoring the recovery state of the athlete, including sleep quality. The Recovery-Stress-Questionnaire for Athletes (RESTQ-Sport) is a commonly utilised monitoring tool to assess the recovery-stress balance in athletes. Despite its validity to monitor athlete fatigue, the sleep assessment component has received criticism. The aim for this study was to therefore characterise the recovery-stress balance in the large cohort of team sport athletes identified in chapter three and establish whether relationships exist between validated measures of sleep quality and sleepiness and various RESTQ-Sport sub scales, including sleep. This study may be used to highlight either agreement or disagreement between these monitoring tools, and inform future decision making regarding the need for specific sleep monitoring as it pertains to recovery.

4.1 Introduction

Participating in team sport requires athletes to train at high intensity to maintain or improve physical qualities such as speed, power and strength. Training followed by optimal recovery may then lead to favourable physiological and psychological adaptations resulting in improved performance (Hartwig, Naughton & Searl, 2009). However, physiological and psychological limits dictate a need for research that addresses the avoidance of over-training, maximises recovery and successfully negotiates the fine line between high and excessive training loads (Kellmann, 2010). Maximising recovery may encompass a wide range of strategies, including compression, hydrotherapy, massage, stretching (Vaile, Halson & Graham, 2010) nutrition and socialising (Venter, 2014); yet sleep has been identified by athletes as one of the most important aspects of the post-exercise recovery process, and is thought to be a critical component for optimal performance (Venter, 2014). However, the importance of sleep for athletes is largely ignored and/or underestimated (Rosekind, 2010). Furthermore, the evaluation of the state of an athlete, their recovery-stress balance, appears to be one of the most complicated tasks in sports science (Jurimae, Maestu, Purge & Jurimae, 2004). Whilst determining such a balance remains a challenge and few methods exist to quantify and monitor individual responses in team sports (Hartwig et al., 2009), the Recovery-Stress-Questionnaire for Athletes (RESTQ-Sport) (Kellman & Kallus, 2001) is a primary research tool chosen by scholars and practitioners to assess the recovery-stress balance (Filho et al., 2013). The RESTQ-Sport consists of seven general stress scales (General Stress, Emotional Stress, Social Stress, Conflicts/Pressure, Fatigue, Lack of Energy, Physical Complaints), five general recovery scales (Success, Social Recovery, Physical Recovery, General Wellbeing, Sleep Quality), three sport-specific stress scales (Disturbed Breaks, Emotional Exhaustion, Injury), and four sport-specific recovery scales (Being in Shape, Personal Accomplishment, Self-Efficacy, Self-Regulation) (Kellman, 2010). There is

extensive evidence on the predictive validity of this instrument (Faude, Kellmann, Ammann, Schnittker & Meyer, 2011; Filho et al., 2013; Jurimae, Maestu, Purge, Jurimae & Soot, 2002; Jurimae et al., 2004; Kellman & Günther, 2000; Kellmann 2010; Maestu, Jurimae, Kreegipuu & Jurimae, 2006), and it has demonstrated good test-retest reliability for repeated measures (Kellmann & Kallus, 2001).

The sleep subscale of the REST-Q Sport, however, has received criticism. Independent item analysis of the REST-Q Sport sub-scales by Davis, Orzeck and Keelan (2006) suggested that there should be a different factor structure for the under-recovery construct. In particular, the Sleep Quality subscale was shown to be both unreliable and lacking validity suggesting this sub-scale should be redeveloped (Davis et al., 2006). Nonetheless, validated questionnaires such as the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989) and Epworth Sleepiness Scale (ESS) (Johns, 1993) may be used to more thoroughly examine measures of sleep latency, sleep duration, and habitual sleep efficiency, alongside daytime dysfunction. Considering the perceived importance of sleep for athletic recovery and the wide spread use of the REST-Q Sport among different sports and nations to monitor athletes and the impact of training, a closer examination of the relationship between athletes sleep quality and fatigue is warranted. Limited empirical data exists for athletes, with no known studies linking RESTQ-Sport derived psychological responses to training with sleep quality and daytime sleepiness. As such, the aims of the present study were to (i) characterise the recovery-stress state in a large cohort of team sport athletes using the Recovery-Stress-Questionnaire for Athletes (RESTQ-Sport); (ii) specifically characterise the athlete's sleep quality and daytime sleepiness with validated questionnaires (PSQI and ESS); (iii) establish relationships between validated measures of sleep quality and sleepiness and specific REST-Q Sport sub scales.

4.2 Methods

4.2.1 Participants

One hundred and seventy five highly trained male and female athletes from Rugby Union, Rugby Sevens and Cricket, volunteered to participate in the present study. Participants were members of regional training squads and national teams aged 18 years or older and provided written informed consent prior to participation. Participants were recruited from a full time professional rugby union team, full time professional men's and women's sevens rugby teams, a national development Under 20 rugby union team, two development rugby union academies and a professional cricket squad (Table 1). The study was approved by the Auckland University of Technology Ethics Committee.

Table 4.1 Participant demographics by sport (Mean ± SD) (n=175)

	Professional Cricket n=15	Rugby Union Academy 1 n=34	Rugby Union Academy 2 n=9	National U 20 Rugby Union n=48	Professional Rugby Union n=28	Men's Sevens Rugby n=21	Women's Sevens Rugby n=20
Age (yrs)	24.3 ± 5.0	19.6 ± 1.7	19.4 ± 1.3	18.9 ± 0.2	24.2 ± 3.0	23.2 ± 3.4	23.7 ± 3.4
Height (cm)	181.1 ± 9.9	187.6 ± 8.2	189 ± 3.7	186.8 ± 7.9	187.2 ± 8.7	185.2 ± 7.2	170 ± 5.5
Weight (kg)	82.9 ± 9.0	97.8 ± 11.8	101.8 ± 5.4	100.5 ± 14.2	105.1 ± 10.3	92.2 ± 8.7	71.8 ± 9.8

4.2.2 Research Design

A qualitative questionnaire based study design was used to collect ratings of recovery and stress, sleep quality, daytime sleepiness and player training phase information from the athletes during either off season, pre-season or in-season phases for rugby union, rugby sevens and cricket. Measures of recovery and stress were determined by the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport 76) (Kellman & Kallus, 2001); sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI) questionnaire (Buysse et al., 1989) and daytime sleepiness was evaluated using the Epworth Sleepiness Score (ESS) questionnaire (Johns, 1991). Questions were asked relating to recent travel and jet lag history.

Training and demographic data was recorded in a weekly training diary. The questionnaires were administered in a group setting, in national training camps or during team assembly and took approximately 15 minutes to complete.

4.2.3 Procedures

4.2.3.1 Recovery-Stress Assessment

Recovery-Stress Questionnaire for Athletes (RESTQ-Sport 76). The RESTQ-Sport (Kellmann & Kallus, 2001) systematically assesses the recovery-stress state of an athlete. The questionnaire consists of 77 items (arranged in 19 scales, including 12 scales on general stress and recovery and seven sport specific scales of four items each plus one warm up item), which the participants answer retrospectively. A Likert type scale is used with values ranging from zero (never) to six (always) indicating how often the respondent participated in various activities during the past three days/nights. High scores in the stress-associated activity scales reflect intense subjective stress, whereas high scores in the recovery-oriented scales indicate good recovery activities. Seven general stress scales assess general stress, emotional stress, social stress, conflicts/pressure, fatigue, lack of energy and physical complaints. Five general recovery scales include success, social recovery, physical recovery, general wellbeing and sleep quality. Seven sport specific scales include three stress scales (disturbed breaks, emotional exhaustion and injury) and four recovery scales (being in shape, personal accomplishment, self-efficacy and self-regulation) (Kellmann, 2010). High test-retest consistency displays firm results associated with short term shifts of recovery-stress state and fluctuations in function (Kellmann, 2010).

4.2.3.2 Qualitative Sleep and Daytime Sleepiness Assessments

Pittsburgh Sleep Quality Index Questionnaire. The PSQI provides a subscale rating of subjective sleep quality, as well as subscale measures of sleep latency, sleep duration, and

habitual sleep efficiency. Some components relate to sleep disturbances, use of sleeping medication, and daytime dysfunction. The sum of the scores for these seven components yields a global score with a range of 0-21 that is a composite of sleep quantity and quality (Kryger et al., 2011). Acceptable measures of internal homogeneity, reliability and validity have been obtained for the PSQI (Buysse et al., 1989). Furthermore, a global PSQI score >5 has resulted in a diagnostic sensitivity of 89.6% and specificity of 86.5 % in distinguishing 'good' and 'poor' sleepers (Buysse et al., 1989).

Epworth Sleepiness Scale Questionnaire. The ESS is a simple questionnaire measuring the general level of daytime sleepiness, or average sleep propensity, experienced by an individual (Johns, 1993). The questionnaire yields a global score with a range of 0-24. The ESS measure is comparable to all day tests such as the multiple sleep latency tests, is a valid and reliable measure of objective sleepiness (Johns, 1993) and is a practical evaluative tool that has been applied to athletes (Antic et al, 2013; George et al., 2003; Mah et al., 2011). Furthermore, ESS scores have been shown to change with sleep extension in athletes compared to baseline, indicating reductions in daytime sleepiness (Mah et al, 2011). The ESS may compliment the PSQI and provide information on whether the athlete is experiencing a daytime functional disturbance from poor sleep quality, which may impact on cognition and training quality.

4.2.4 Statistical Analysis

Means and standard deviations were calculated for RESTQ-Sport stress and recovery scores, RESTQ-Sport sleep quality sub scale scores, PSQI and ESS scores with respect to gender, sport, ethnicity, training times and phase of season. A percentage distribution was calculated from the resultant values for each PSQI category to indicate the most common outcome for the population.

Pearson product moment correlation (r) was used to establish relationships between the PSQI and ESS scores and RESTQ-Sport sleep quality and general wellbeing sub scores; relationship between PSQI score and RESTQ-Sport lack of energy sub score; and relationship between ESS score and RESTQ-Sport fatigue sub score. The magnitudes of the correlation coefficients were interpreted with Cohen's scale: <0.1 = trivial, 0.1-0.3 = small, 0.3-0.5 = moderate and >0.5 = large (Cohen, 1988). Uncertainty in the correlations was expressed as 90 % confidence limits, estimated for the worst-case scenario of a zero correlation (Hopkins, 2007).

4.3 Results

In total, 167 participants completed the RESTQ-Sport questionnaire correctly for subsequent analysis. Results for recovery, stress and RESTQ-Sport sleep quality are displayed in Table 4.2. RESTQ-Sport stress scores were poorest among rugby by sport and males by gender, and Samoan and Tongan participants by ethnicity, although there was a large degree of individual variability (Table 4.2). RESTQ-Sport sub scores of sleep quality were poorest among male cricket players.

Table 4.2 Mean ± SD of stress, recovery and sleep quality scores within the REST-Q Sport questionnaire in athletes by gender, sport, phase of season, ethnicity and training times (n=167).

	N	Stress	Recovery	RESTQ Sleep Quality
Female	23	55.2 ± 18.7	129.0 ± 28.3	15.0 ± 5.2
Male	144	79.3 ± 25.9	126.0 ± 22.2	13.9 ± 3.7
ALL	167	76.0 ± 26.3	126.4 ± 23.1	14.0 ± 4.0
Professional Cricket	14	75.1 ± 22.1	106.4 ± 24.0	13.9 ± 3.2
Female	3	68.0 ± 28.9	100.7 ± 30.9	17.3 ± 3.2
Male	11	77.0 ± 21.1	108.0 ± 23.4	12.9 ± 2.6
Rugby Union	113	79.7 ± 26.3	127.0 ± 20.9	13.9 ± 3.7
Development Academy 1	30	81.8 ± 28.5	129.9 ± 25.3	14.0 ± 4.2
Development Academy 2	9	83.9 ± 32.4	124.3 ± 15.3	14.1 ± 3.6
National development U20	47	81.9 ± 25.6	125.3 ± 19.3	13.3 ± 3.6
Professional	27	72.3 ± 22.8	127.5 ± 20.4	14.7 ± 3.6
Professional Rugby 7s	40	65.8 ± 25.4	131.8 ± 25.4	14.4 ± 4.8
Mens 7s	20	78.3 ± 26.7	130.5 ± 25.2	14.1 ± 4.1
Womens 7s	20	53.3 ± 16.9	133.2 ± 26.1	14.7 ± 5.4
In Comp	73	70. 0 ± 25.5	130.7 ± 21.7	14.6 ± 4.3
Off Season	55	78.5 ± 26.0	121.4 ± 22.5	13.6 ± 3.5
Pre-comp	2	87.0 ± 15.6	129.5 ± 9.2	11.5 ± 2.1
Pre-season	37	83.6 ± 26.7	125.2 ± 25.8	13.7 ± 4.0
Maori	40	71.5 ± 26.2	128.3 ± 24.0	13.1 ± 4.4
Samoan	49	83.4 ± 28.6	122.8 ± 21.9	13.4 ± 3.9
Indian	1	65.0	105.0	11.0
NZ European	93	74.4 ± 24.9	129.1 ± 22.8	14.6 ± 4.0
Cook Island Maori	1	79.0	98.0	16.0
Tongan	8	86.4 ± 15.5	122.8 ± 16.9	13.5 ± 2.9
Chinese	3	69.7 ± 38.6	136.0 ± 22.5	17.3 ± 5.1
Other	10	68.6 ± 28.8	119.9 ± 24.8	14.0 ± 3.3
Before 8am	57	71.9 ± 26.3	131.4 ± 22.9	14.0 ± 4.4
8am - 5pm	61	78.1 ± 25.3	126.9 ± 24.3	14.1 ± 3.7
After 5pm	71	72.4 ± 23.7	130.2 ± 24.7	14.1 ± 4.3

4.3.1 Sleep Quality

Results for PSQI data with respect to gender, sport, ethnicity, training times and phase of season are displayed in Table 4.3. Half of the athletes were classified as poor sleepers (PSQI >5), with an average PSQI score of 5.9 ± 2.6 (Table 4.3). There was a moderate negative relationship between the PSQI score and RESTQ-Sport sub score of sleep quality (-0.49; ± 0.10). There was a moderate and unclear relationship between the PSQI score and RESTQ-Sport sub score of lack of energy (0.36; ± 0.11) and general wellbeing (0.02; ± 0.13) respectively.

4.3.2 Daytime Sleepiness

A high prevalence of daytime sleepiness was observed (Table 4.3; average global score 8.5). In total, 28% of participants were found to be excessively sleepy during the day (ESS >10). There was a trivial relationship between the ESS score and RESTQ-Sport sub score of sleep quality (0.07; ± 0.13). Similarly there was a small and unclear relationship between the ESS score and RESTQ-Sport sub scores of fatigue (0.11; ± 0.13) and general wellbeing (0.02; ± 0.13) respectively.

Table 4.3 Daytime sleepiness (ESS) and sleep quality (PSQI) questionnaire global scores by gender, sport, phase of season, ethnicity and training times for athletes (n=175) (Mean ± SD)

	N	ESS Score*	PSQI Score**
Female	23	9.0 ± 4.2	8.2 ± 3.3
Male	152	8.5 ± 4.4	5.6 ± 2.3
ALL	175	8.5 ± 4.4	5.9 ± 2.6
Professional Cricket	15	6.1 ± 4.1	6.0 ± 2.1
Female	3	6.3 ± 4.0	6.3 ± 3.1
Male	12	6.1 ± 4.3	5.9 ± 2.0
Rugby Union	119	8.7 ± 4.3	5.6 ± 2.2
Development Academy 1	34	9.9 ± 4.5	6.1 ± 2.1
Development Academy 2	9	8.3 ± 5.0	5.3 ± 2.1
National development Under 20	48	8.9 ± 3.9	5.0 ± 2.7
Professional	28	7.0 ± 4.2	4.8 ± 2.5
Rugby 7s	41	9.0 ± 4.4	7.1 ± 3.3
Mens 7s	21	8.6 ± 4.6	5.8 ± 2.8
Women's 7s	20	9.4 ± 4.2	8.5 ± 3.4
In Comp	75	8.2 ± 4.5	6.2 ± 2.9
Off Season	56	8.5 ± 4.0	5.3 ± 2.2
Pre-Comp	2	3.0 ± 4.2	9.0 ± 2.8
Pre-Season	42	9.5 ± 4.4	6.1 ± 2.1
NZ European	98	7.9 ± 4.2	5.4 ± 2.4
Maori	41	9.0 ± 4.1	6.5 ± 2.9
Samoan	52	8.8 ± 4.8	6.2 ± 2.6
Indian	1	14.0	9.0
Cook Island Maori	1	1.0	4.0
Tongan	9	11.0 ± 5.7	6.7 ± 3.2
Chinese	3	8.3 ± 5.1	6.0 ± 3.5
Other	10	8.9 ± 3.3	5.0 ± 1.8
Before 8am	60	9.7 ± 4.2	6.5 ± 2.9
8am-5pm	63	7.5 ± 3.8	5.4 ± 2.0
After 5pm	76	9.4 ± 4.4	6.1 ± 2.9

*An ESS global score > 10 indicates excessive daytime sleepiness

** A PSQI global score of >5 is associated with poor sleep quality

4.3.3 Phase of Season

Athletes reported longer sleep times during the off-season (8.2 ± 1.1 h) compared to athletes during the pre-season (7.8 ± 1.8 h) or in-competition (7.7 ± 1.1 h) phases (Table 4.3). Similarly PSQI sleep quality scores were best during the off season (5.3 ± 2.2) and poorest during the competition phase (6.2 ± 2.9). Athletes appeared to be most sleepy during the day in the pre-season training phase (ESS score 9.5 ± 4.4). RESTQ-Sport sub scores of sleep quality were highest during the in competition phase (Table 4.3).

4.3.4 Time of Day of Training

Training before 8am was associated with a reduction in total sleep, higher daytime sleepiness and poorer sleep quality. Training during the day (8am-5pm) corresponded with enhanced sleep (Table 4.3). RESTQ-Sport sub scores of sleep quality were similar for participants across all training times (Table 4.3).

4.4 Discussion

The recovery-stress scores of a large cohort of team sport athletes was examined using the Recovery-Stress-Questionnaire for Athletes (RESTQ-Sport 76) and participant's sleep quality and daytime sleepiness were assessed with validated questionnaires (PSQI and ESS). The aims of the present study were to (i) characterise the recovery-stress state in a large cohort of team sport athletes using the Recovery-Stress-Questionnaire for Athletes (RESTQ-Sport); (ii) specifically characterise the athlete's sleep quality and daytime sleepiness with validated questionnaires (PSQI and ESS); and (iii) establish relationships between validated measures of sleep quality and sleepiness and specific REST-Q Sport sub scales.

A high prevalence of poor sleep quality (PSQI) and sleepiness (ESS) was self-reported by the participants. A moderate, negative relationship was observed between the PSQI and RESTQ-Sport sub score of sleep quality. Similarly, there was a moderate relationship between the

PSQI score and RESTQ-Sport sub score of lack of energy and a small relationship observed between the ESS score and RESTQ-Sport sub score of fatigue. All other relationships were trivial or unclear.

The correlation of validated questionnaires exploring sleep quality and sleepiness with the recovery-stress state of a large cohort of highly trained athletes in the present study is unique. The RESTQ-Sport questionnaire has been used widely as a recovery monitoring tool in a variety of sports, including rowing (Jurimae et al., 2002, Jurimae et al., 2004; Kellman & Günther, 2000; Maestu et al., 2006; Purge, Jurimae & Jurimae, 2005), road cycling (Filho et al., 2013), football (Faude et al., 2011), swimming (González-Boto, Salguero, Tuero, González-Gallego & Márquez, 2008) and rugby union (Hartwig et al., 2009) but this is the largest cohort of athletes currently known to the authors to be investigated across different team sports and different stages of respective seasons.

With respect to team sports, attention to recovery demands is particularly high in rugby union due to the large amounts of physical damage incurred via blunt trauma (Takarada, 2003). Reported changes in RESTQ-Sport scores relative to team sport training and competition exposure have been mixed. The RESTQ-Sport has been used to track recovery-stress responses relative to training loads in male adolescent rugby union players. No correlations were observed between change in training volume and change in stress and recovery during the rugby season (Hartwig et al, 2009). The authors suggest this finding may be due to characteristics unique to the adolescent population studied, or insensitivity of the training diary used to record volume over a long period of time (Hartwig et al, 2009). However, within the same study, Hartwig and colleagues (2009) observed a significant reduction in player sleep quality (11.3%, $p=0.043$) on day four compared to day one of an intensive rugby tournament. Similarly, RESTQ-Sport sleep quality sub-scores decreased at

the end of a high level football season and corresponded with increased total stress scores and decreased recovery scores, in conjunction with an increase in training and competition exposure (Faude et al., 2011). Pre-postrace changes in recovery-stress scores and decreased sleep quality have also been observed in elite cyclists competing in a multi-stage race (Filho et al, 2013). With respect to rowing, a strong dose-response relationship has been reported between stress-recovery and training volume using the RESTQ-Sport questionnaire (Jurimae et al., 2002, Jurimae et al., 2004; Kellman & Günther, 2000; Maestu et al., 2006). Furthermore, changes in RESTQ-Sport scores have been observed to reflect performance outcomes in competition (Purge et al., 2005). A correlation between changes in training volume and changes in RESTQ-Sport sleep quality sub scores, with a parallel disturbance in recovery-stress scores ($r = 0.64$ and $r = 0.58$ respectively) has also been observed in rowers (Jurimae et al., 2002; Jurimae et al., 2004). The observation that RESTQ-Sport measured sleep quality appears to respond negatively to high degrees of training and competition stress agrees with quantitative sleep studies among endurance athletes (Hausswirth et al., 2014; Killer, Svendsen, Jeukendrup & Gleeson, 2015). Thus findings from the present study lend support to the validity that RESTQ-Sport changes in sleep quality, relative to exercise volume or intensity, robustly characterise an athlete's sleep and may be relied upon to inform sleep based interventions to enhance recovery.

As sport science seeks to further develop a competitive edge for athletes, quantifying and improving sleep is becoming an increasingly important focus. Poor sleep in athletes has been well documented (Antic et al., 2013; Fietze et al., 2009; Hausswirth et al., 2014; Killer et al., Leeder et al., 2012; Mah et al., 2011; Samuels, 2008; Sargent, Halson et al., 2014; Sargent, Lastella, et al., 2014; Shearer et al., 2015). Poor sleep may be harmful for an athlete at multiple levels, including cognitive function, physical performance, fatigue and recovery (Davenne, 2009). Conversely, sleep extension in athletes has shown to be

performance enhancing (Mah et al., 2011). Whilst optimising sleep is deemed important for performance (Davenne, 2009), accurately monitoring sleep during training phases, as an important aspect of recovery, would seem prudent to promote adaptations to training stimuli (Datillo et al., 2011). Indeed, managing the balance between training stress and recovery is an essential component of the athlete performance equation (Hausswirth et al., 2014). Moreover, sleep may exert the most profound influence over achieving this balance.

As a holistic monitoring tool of stress and fatigue, the RESTQ-Sport appears to be robustly accurate in detecting athlete stress responses to training volume and subsequent recovery when training volume decreases. The questionnaire may help inform coaches of an athlete's under-recovery status, alongside a more thorough athlete assessment (Kellman, 2010). Furthermore, a reported benefit of the RESTQ-Sport is in detecting whether or not a person is using individual recovery strategies, including sleep, and the extent to which these are being used (Kellman, 2010). The RESTQ-Sport sleep sub scale specifically encompasses questions addressing if the athlete fell asleep satisfied and relaxed, had a satisfying sleep, slept restlessly or had an easily interrupted sleep. From the present research findings, it appears that the RESTQ-Sport sleep and lack of energy sub-scales agree with changes in PSQI scores and are sensitive to an athlete's sleep quality. Thus the RESTQ-Sport may robustly yet reliably inform the sports scientist or coach how well an athlete is sleeping, and interpret changes in sleep quality accordingly. However, whilst the fatigue sub-scale asks about getting enough sleep, there was only a small correlation with daytime sleepiness scores.

Due to the preponderance of poor sleep quality observed in a range of athletes (Antic et al., 2013; Killer et al., 2015; Leeder et al., 2012; Fietze et al., 2009; Mah et al., 2011; Samuels, 2008; Sargent, Halson et al., 2014; Sargent, Lastella et al., 2014; Shearer et al., 2015), there is validity to the argument that relying solely on the RESTQ-Sport to monitor sleep quality as a

function of recovery would likely under-evaluate this critical aspect of an athlete's ability to tolerate training stressors. Findings from the present study suggest that athletes are particularly vulnerable to high degrees of daytime sleepiness and poor sleep quality during the pre-season training phase. Therefore, the use of more validated sleep monitoring tools alongside the RESTQ-Sport would be prudent, particularly during intensive training periods. Specifically, the PSQI may differentiate a good sleeper from a poor sleeper, detect sleep quality changes over time, and provide insight into different aspects of sleep that an athlete may require assistance with, such as sleep latency, sleep duration, disturbance and efficiency. In addition, sleepiness is a consequence of poor sleep (Kryger et al., 2011), is prevalent among athletes (Antic et al., 2013; George et al., 2003) and is considered a state of fatigue (Johns, 1993). Thus using the ESS together with the PSQI would complement the RESTQ-Sport and likely improve the effectiveness of sleep specific recovery monitoring.

4.5 Conclusion

In summary, a high prevalence of self-reported poor sleep quality (PSQI) and sleepiness (ESS) was observed in a large cohort of well-trained team sport athletes. There was a moderate negative relationship between the PSQI score and REST-Q Sport sub score of sleep quality (-0.49; ± 0.10). Furthermore there was a moderate relationship between the PSQI score and REST-Q Sport sub score of lack of energy (0.36; ± 0.11). The results of the present study suggest that the RESTQ-Sport does adequately detect poor sleep in athletes. The addition of validated sleep questionnaires such as the PSQI and ESS, alongside the RESTQ-Sport, would more accurately inform coaches about an athletes sleep based recovery, and possibly better position an athlete to enhance their adaptation to training. Further research, applying these questionnaires together as a comprehensive monitoring battery during intense training, is suggested.

4.6 Practical Applications

It appears from results in chapters three and four that athletes are at a high risk of both poor sleep quality and sleepiness. Sleep is integral to a complete recovery plan for athletes, there is a need to detect poor sleep in athletes, and the interpretation of the degree sleep is contributing to an athlete's post exercise recovery is important. Furthermore, natural questions arise for coaches and athletes, such as 'how well is the athlete sleeping', 'is sleep changing during a training phase', and 'how holistically well recovered is the athlete after training?' The RESTQ-Sport was established in chapter four as a reliable and robust tool for detecting poor sleep in athletes. The questionnaire is also designed to be applied longitudinally across a training phase. Thus, utilising the RESTQ-Sport may inform coaches and athletes about sleep quality responses to training stressors, how well engaged the athlete is with sleep behaviour, and whether intervention is required with respect to either improving sleep or adjusting training stress. Importantly, the RESTQ-Sport may inform coaches if an athlete is tolerating a certain amount of training stress, and can possibly cope with more. The ability to absorb large amounts of training places the athlete in a prime position to steepen their adaptation curve to training. Thus more thorough monitoring of training stress and sleep via the RESTQ-Sport may create a competitive edge.

Whilst a strong relationship has been determined between PSQI scores and RESTQ-Sport sub scores of sleep quality and lack of energy, the RESTQ does not appear to be highly sensitive to detecting sleepiness in athletes. Sleepiness has been shown in chapters three and four to be prevalent in athletes. Considering sleepiness may represent fatigue or a lack of readiness to perform, the use of a more accurate monitoring tool to detect sleepiness during training phases would be worthwhile, particularly during hard training. The ESS presents as a validated monitoring tool for this purpose. Furthermore, the PSQI would provide a more thorough investigation of sleep quality than the RESTQ-Sport alone, and could identify

possible reasons for poor sleep quality. Ultimately, data collected on an athlete should translate well to informing decision making on athlete levels of recovery and stress. At this level PSQI data is highly actionable, and may make a very real difference to athlete health, wellness, performance and recovery.

Chapter 5

THE EFFECTS OF A SLEEP EXTENSION INTERVENTION ON VARIABLES OF SLEEP, PERFORMANCE, IMMUNE RESPONSE AND MARKERS OF PHYSICAL STRESS IN PROFESSIONAL RUGBY PLAYERS

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Journal of Australian Strength and Conditioning
In Review (Appendix 6)

5.0 Prelude

In chapter three, it was established that whilst the amount of sleep athletes obtain is similar to non-athletes athletes, they experience a high degree of poor sleep quality. However, total sleep times observed in athletes in chapter three were self-reported, and may be either inaccurate or inadequate, considering the degree of daytime sleepiness or fatigue also observed in this population. The logical progression in sleep assessment to better characterise sleep in elite collision sport athletes is to apply quantitative sleep analysis. The use of actigraphy, or sleep monitors, is a practical and validated method to quantify sleep in athletes. A limited body of research using actigraphy has suggested that athlete sleep quantity and quality is compromised. To date, sleep has not been quantified via actigraphy in collision sport athletes, and this study aimed to address a gap identified in the literature. Furthermore, in chapter two, it was established that sleep may influence both immune function and markers of physical stress. Understanding changes in immune and stress status parallel to changes in sleep indices during an intensive training block was also a focus of this study.

Considering the confirmation of poor sleep in athletes, exploring interventions that may improve sleep quantity and quality are most relevant to athletes and high performance programmes. This is particularly poignant when one considers the apparent health and performance gains that may be available from educating on sleep and achieving sleep extension. A further intention of this study was to introduce a control-trial sleep intervention model to the literature, with a focus on the achievement and effects of sleep extension on indices of elite athlete health, recovery and performance. The unique setting of a professional rugby team and an intervention with a highly applied and practical focus may indeed offer a wide range of sports teams a working model and incentive to improve sleep in athletes.

5.1 Introduction

Adequate sleep is considered critical for optimal performance and has been identified by athletes, coaches, and trainers as an important aspect of the post-exercise recovery process (Samuels, 2008; Davenne, 2008). Indeed sleep has been recognised as the most important recovery modality by a large number of elite team sport athletes, including rugby union (Venter, 2014).

Rugby Union is a repetitive high intensity collision sport where the athlete's ability to train at high intensity to maintain or improve physical qualities such as speed, power and strength and to optimise recovery is vital. This is no more applicable than during the pre-season training phase where the athlete is placed under a high degree of exercise stress to induce adaptations in physical fitness. It would appear that an adequate amount of quality sleep allows these specific adaptations to occur (Datillo et al., 2011). Furthermore, collision sport competition manifests in well documented neuromuscular, biochemical and endocrine changes in the adult athlete (McLellan & Lovell, 2012; Smart et al., 2008; Takarada, 2003; Twist et al., 2012). Team sport athletes and coaches are challenged to address recovery, including quality sleep, to rebalance such stress induced changes (Venter, 2014). Conversely, inadequate sleep ($\leq$ 6h and $<$ 8h sleep, respectively) has been linked with an increased incidence of fatigue related injury in youth athletes (Luke et al., 2011; Milewski et al., 2014), hormonal and metabolic disturbances (Imeri & Opp, 2009; Halson, 2014) and elevated sympathetic nervous system activity (Spiegel et al., 1999).

Whilst the importance of athletes achieving adequate sleep is widely accepted to enable athletic potential, or mitigate decline, it appears that athletes are at risk of poor sleep (Leeder et al., 2012; Mah et al., 2011; Samuels, 2008; Sargent, Halson et al., 2014). Whilst sleep loss has attracted much attention from researchers, the focus area of sleep extension

has not been as thoroughly examined (Mah et al., 2007). Indeed, studies involving extended nightly sleep time in adults are relatively scarce and inconsistent (Kamdar et al., 2004). Moreover, the impact of sleep extension on athletic function and performance has, until recently, been unknown. College basketball players have demonstrated, in an uncontrolled intervention, improvements in total sleep time, sprint and reaction times, goal shooting accuracy, overall ratings of physical and mental well-being, with concomitant decreases in daytime sleepiness following several weeks of nightly sleep extension beyond the participants habitual sleep time (Mah et al., 2011). Furthering value to the strategy of sleep extension, sleep perturbations can alter immune and inflammatory status (Faraut et al., 2012). Associations have been observed between abnormalities of immune function and various forms of sleep disruption (Walsh et al., 2011) as well as increased training load in rugby players (Neville et al., 2008).

Sleep and nervous system recovery also appear to be intricately entwined (Spiegel et al., 1999). Salivary alpha amylase (sAA) is a marker of autonomic nervous system (ANS) stress that is being increasingly utilised. In a review of the literature, Nater and Rholeder, (2009) describe how sAA is increased in states of stress (such as inadequate sleep) when autonomic activation is increased (Nater & Rholeder, 2009). Increases in sAA may therefore reflect changes in ANS function and can be considered a sound marker for sympathetic activity (Fletcher & Bishop, 2011; Nater & Rholeder 2009). However, the application of sAA as a surrogate marker of ANS stress in relation to sleep in athletes appears to be novel. Additionally, with regards to stress in rugby players, cortisol is an identified marker of endocrine response to competitive high intensity combative sports (McLellan & Lovell, 2012). A greater cortisol response has been noted with higher intensity and higher volume exercise (Lac & Berthon, 2000) as well as competitive stress and anxiety (Filaire, Alix, Ferrand, & Verger, 2009). Furthermore, sleep restriction has

been shown to cause increases in cortisol concentrations (Spiegel et al., 1999). Considering that cortisol is the primary catabolic hormone, increasing protein degradation and decreasing protein synthesis (Crewther, Cook, Cardinale, Weatherby & Lowe, 2011), mitigating sources of elevated cortisol may be an important consideration for elite rugby players.

Further sleep extension research on athletes should involve indices of sleep quality, physical performance, immune function and stress with traditional research methodology to further answer the question of what effect improving sleep might have for an athlete's health and competitive advantage. Therefore, the purpose of the present study was to examine the efficacy of sleep extension during a professional rugby pre-season training programme. Specifically the aims were i) to characterise the amount of sleep obtained by elite rugby players and determine changes that may occur in immune function and stress hormone secretion during a pre-season training programme; ii) evaluate the efficacy of a sleep extension intervention in improving sleep quantity and quality and markers of physical stress, immune function and performance.

5.2 Methods

5.2.1 Participants

Twenty five highly trained male Rugby Union athletes volunteered to participate in the present study (age [mean ± *SD*] 25 ± 2.7 yrs; height 1.87 ± 0.07 m; weight 105 ± 12.1 kg). Participants provided written informed consent to participate in the study. All participants were in good health and none had previously been diagnosed with a sleeping disorder. Participants were permitted to consume caffeine, alcohol and training supplements during the course of the study. The study was approved by the Auckland University of Technology Ethics Committee.

5.2.2 Research Design

A pre-post control-trial intervention study design was used to collect data on sleep quantity and quality, salivary markers of immune function, sympathetic nervous activity and physiological stress, skill acquisition and reaction times during a period of two three week training phases during the participant's pre-season training phase. The participants completed an initial three week high intensity training block (control), followed by a two week maintenance period. A sleep extension intervention was then performed during a second three week high intensity training block. Qualitative sleep data was collected weekly, and saliva samples were collected at the beginning and end of the control and sleep extension intervention. Reaction times were tested at baseline during the control, and at the beginning and end of the sleep extension intervention. Skill acquisition testing was performed at the beginning of the sleep extension intervention, and then again ten days after the conclusion of the sleep extension intervention. During the intervention, participants were educated about sleep and how to obtain more quality sleep. Specifically, the importance of sleep for athletic recovery and potential performance improvements was explained at the beginning of the intervention, to help incentivise behaviour change. Participants were educated in small group sessions on how to extend their habitual sleep time, by advancing their regular sleep time by ten minutes per night. An initial goal of increasing habitual nightly sleep time by one hour by the end of the first week of the intervention was established. Participants were asked to continue extending their regular sleep times to try and achieve ten hours sleep per night. Methods to improve sleep scheduling, sleep latency and quality, via effective sleep hygiene habits, were discussed at the beginning of the intervention. Sleep issues and sleep hygiene solutions were discussed during weekly individual appointments with the researcher, at which time sleep watch data was reviewed. Training programmes were designed by the team's Strength and Conditioning coach and both blocks were comparable in volume and intensity.

Weight training consisted of five hypertrophy or strength focussed sessions per week, of one hour duration each, including two lower-body, two upper-body and one posterior chain session. Additionally, four - five 90 minute high intensity running or wrestling based conditioning sessions and one 30 minute session dedicated to neck and core or pilates were performed each week. A ten minute individual warm-up period was performed prior to each training session. Participants trained up to three times per training day. The training programme was not altered to accommodate the study design.

5.2.3 Procedures

5.2.3.1 Qualitative Sleep and Daytime Sleepiness Assessments

Participants self-perceived sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI) questionnaire (Buysse et al., 1989). Daytime sleepiness was assessed using the Epworth Sleepiness Scale (ESS) questionnaire (Johns, 1991). Participants recorded sleep times and naps in sleep diaries which were completed while participants were wearing activity monitors. Questionnaires and sleep diaries were completed in the morning upon arrival at the gymnasium, prior to training. Questionnaires were completed at the end of each week during the control and sleep extension phase.

Pittsburgh Sleep Quality Index Questionnaire. The PSQI provides a subscale rating of subjective sleep quality, as well as subscale measures of sleep latency, sleep duration, and habitual sleep efficiency. Some components relate to sleep disturbances, use of sleeping medication, and daytime dysfunction. The sum of the scores for these seven components yields a global score with a range of 0-21 that is a composite of sleep quantity and quality (Kryger et al., 2011). Acceptable measures of internal homogeneity, reliability and validity have been obtained for the PSQI (Buysse et al., 1989). A global PSQI score greater than five has resulted in a diagnostic sensitivity of 89.6 % and specificity of 86.5 % in distinguishing

‘good’ and ‘poor’ sleepers (Buysse et al., 1989). However, a PSQI value of greater than five rather six was used to define poor sleep due to low participant numbers.

Epworth Sleepiness Scale Questionnaire. The ESS is a simple questionnaire measuring the general level of daytime sleepiness, or average sleep propensity experienced by an individual (Johns, 1993). The questionnaire yields a global score with a range of 0-24. The ESS measure is comparable to all day tests such as the multiple sleep latency tests, is a valid and reliable measure of objective sleepiness (Johns, 1993) and is a practical evaluative tool that has been applied to athletes (Antic et al., 2013; George et al., 2003; Mah et al., 2011). Furthermore, ESS scores have been shown to change with sleep extension in athletes compared to baseline indicating reductions in daytime sleepiness (Mah et al., 2011). The ESS may compliment the PSQI and provide information on whether the athlete is experiencing a daytime functional disturbance from poor sleep quality, which may impact on cognition and training quality.

5.2.3.2 Quantitative Sleep Assessment

Actigraphy

During the study all participants slept in their residential homes. Participants wore wrist watch activity monitors (wGT3Xp, Actigraph, Florida) on their non-dominant wrist, for two to five nights at a time. During the control phase fourteen participants wore activity monitors twice during both early and late stages of the training block. Due to participant drop out, 11 participants wore activity monitors twice during both early and late stages of the sleep extension intervention.

The activity monitor did not filter or accumulate data into epochs. Raw data was collected at a selected sample frequency rate of 30Hz. Sleep times were identified from self-report sleep diaries and were correlated with activity counts from the activity monitors, which

when sufficiently low indicated immobility. When these two conditions coincided, participants were scored as being asleep. Time asleep / awake during the night after sleep onset was automatically calculated using the Sadeh algorithm (Sadeh, Sharkey & Carskadon, 1994). Data was post processed using Actilife 6 data analysis software (Actigraph, Pensacola, FL).

Individual nights of sleep were analysed for the following variables:

- Total time in bed (hrs:min): The amount of time spent in bed trying to sleep overnight and during a next day nap(s).
- Sleep latency (min): The difference between lights out time and sleep onset time.
- Overnight sleep duration (hrs:min): Total time spent asleep between sleep onset and sleep end, minus any wake up time during the night.
- Total sleep time (hrs:min): Sum of actual time spent asleep overnight and during a next day nap(s).
- Sleep efficiency (%): Sleep duration expressed as a percentage of time spent in bed trying to sleep.
- Wake after sleep onset (WASO) (min): The amount of time spent awake overnight between sleep onset and sleep end.
- Number of awakenings: The total number of times the participant woke up during the night between sleep onset and sleep end.

Actigraphy has been validated as a tool to measure sleep patterns in healthy adults (Morgenthaler et al., 2007). A correlation of 90 % has been reported for total sleep time between actigraphy and polysomnography (PSG) (Morgenthaler et al., 2007). Thus actigraphy appears to be a practical and effective method to monitor athletes in their daily training environment.

5.2.3.3 Saliva Sampling

Saliva samples were collected on day four and the final day of the 18 day control phase and on day three and day 19 of the 19 day sleep extension intervention for later analysis of salivary IgA, cortisol and α-amylase. Saliva was collected in the morning immediately upon arrival at the training base. Approximately one hour prior to saliva collection, participants consumed a standardised high carbohydrate, moderate protein and low fat breakfast for the purposes of training quality. Dietary compliance was verbally checked by the researcher. Every attempt was made to keep the participants in their habitual pre-training routines, and to control morning activity and potential stressors at both collection time points.

The saliva collection procedure has been described elsewhere (Cunniffe et al., 2011). For all saliva samples, participants were asked to abstain from drinking water for 10 min prior to collection. Participants were asked to swallow to empty their mouth before timed un-stimulated whole mixed saliva samples were collected into pre-weighed sterile vials (7 ml capacity bijou tubes with screw-top). All collections were made over a 2 min period (electronically timed), unless insufficient volume had been produced, in which case the collection period was increased to 3 min, as necessary. All collections were made with participants seated; leaning forwards and with their heads tilted downwards. Participants were instructed to allow the saliva to dribble into the tube with minimal oro-facial movement. Saliva samples were stored frozen at -20°C at the training facility until analysed.

Saliva volume was estimated by weighing the bijou tubes to the nearest milligram before and after saliva collection. Saliva density was assumed to be 1.00 $g \cdot ml^{-1}$ (Cole & Eastoe, 1988). The saliva flow rate ($\mu l \cdot min^{-1}$) was determined by dividing the volume of saliva by the

collection time. For analysis, samples were thawed and then spun at 13,400 rpm for 2 min, and the saliva was subsequently analyzed for s-IgA, cortisol and α-amylase using ELISA and spectrophotometric methods. The samples from each participant were analyzed on the same microplate, and the same day. Both s-IgA and cortisol concentration were determined using commercially available ELISA kits (DRG SLV-4636 & SLV 2930, New Jersey, USA). The α-amylase activity was measured using a commercially available kit (Infinity TM Amylase Liquid Stable Reagent, Thermo Scientific, UK), with proportional reduction of volumes so that the assay could be carried out in a micro-titration (96-well) plate, as previously described (Fletcher & Bishop, 2011). S-IgA secretion rate was calculated by multiplying s-IgA concentration ($mg \cdot l^{-1}$) by saliva flow rate ($\mu l \cdot min^{-1}$) and dividing by 1000 to give s-IgA secretion rate ($\mu g \cdot min^{-1}$). The secretion rate of α-amylase ($U.min^{-1}$) was calculated by multiplying the saliva flow rate by the α-amylase activity ($U.ml^{-1}$). The intra-assay coefficient of variation was 3%, 3.3% and 1.7% for s-IgA, cortisol and α-amylase, respectively.

5.2.3.4 Skill Acquisition

A rugby ball passing accuracy test was conducted at baseline in the first week of the sleep extension phase, and ten days following sleep extension as participants were unavailable for testing within their regular training programme. A pass off the ground test was selected to represent a fundamental sport specific skill that all playing positions are required to undertake. A rugby passing test has been used previously to examine skill execution and accuracy in rugby players (Cook, Crewther, Kilduff, Drawer & Gaviglio, 2011). Both tests were conducted in the afternoon inside the same gymnasium. Prior to the testing protocol, participants were allowed five minutes to practise warm up passes to each other. For the testing protocol, participants were given five rugby balls and asked to pass five times to their left and right at a marked out target against a wall. The target size was 20 cm x 20 cm

positioned 1.44 m up the wall. Participants were positioned 6.25 m out from the target, and then either 5 m to the right or left of the target, respectively, for each passing direction. Therefore the line of flight for the ball on each pass was 8 m. No formal opportunity to practise passing was provided outside of four lessons provided by the team skills coach. Passing tests were filmed with passing accuracy and passing time determined by coding test film footage, identifying target and bullseye hits on each pass. Each participant was awarded a score for bullseye and target hits for left, right and total passes.

5.2.3.5 Reaction Times

Reaction times were tested at baseline during the control, and at the beginning and end of the sleep extension intervention. The five minute psychomotor vigilance test (PVT) (PVT-192, Ambulatory monitoring, Inc. New York) was selected to test participant reaction times. The PVT is a fully electronic, computerized test-presentation and data capture system for simple visual reaction time monitoring. The PVT is commonly used to assess the impact of sleep loss, sustained wakefulness and time of day on neuro-behavioural performance (Roach, Dawson & Lamond, 2006) and has been applied in a sleep extension study with athletes (Mah et al., 2011). Whilst the PVT is usually conducted over a ten minute period, the abbreviated five minute test was selected due to limited time for testing during the training programme. The five minute PVT is a valid and reasonable substitute for the ten minute PVT when used in the field, and there is a strong correlation in response time between the five and ten minute tests ($r = 0.88$, $p < 0.001$) (Roach et al., 2006). For each test, participants were tested at the same time of day to control for circadian effects on reaction time. Prior to each test, participants were given a standard explanation of test procedures and provided with a standardised 60 second sample visual reaction time trial familiarisation. Data was downloaded from the PVT device to a personal computer and

analysed using React PVT software. Data was analysed for mean reaction time (ms), fastest and slowest 10 % reaction times (ms) and total errors.

5.2.4 Statistical Analysis

All data were analysed using an Excel spreadsheet for analysis of pre-post controlled trials, which was set at 90% confidence limits (Hopkins, 2006). All biochemical data were log-transformed prior to analysis to reduce non-uniformity of error. These data were back transformed and expressed as the parametric median, with errors expressed as 90% confidence limits. Standardised mean changes and differences between the trials changes were used to assess magnitudes of effects by dividing the appropriate between-player standard deviation. Standardised effects were defined as using a modified Cohen scale: <0.2 = trivial, 0.2 - 0.59 = small, 0.6 - 1.19 = moderate, 1.2 – 1.99 = large, >2.0 = very large (Hopkins, Marshall, Batterham & Hanin, 2009). The effect was deemed unclear if its confidence interval overlapped the thresholds for small positive and negative effects.

5.3 Results

5.3.1 Sleep Questionnaires

The control phase baseline values (mean ± SD) for subjective sleep quality (PSQI) and sleepiness (ESS) global scores were 5.1 ± 2.2 and 6.7 ± 3.5 respectively. Sleep extension intervention baseline values (mean ± SD) for subjective sleep quality (PSQI) and sleepiness (ESS) global scores were 4.9 ± 1.8 and 7.0 ± 4.4 respectively. Sleep quality was on average poor throughout the control phase (PSQI>5), and daytime sleepiness scores were high (average ESS global score 7.4). All questionnaire changes between week one and week three of the control phase were unclear (Table 5.1). During sleep extension, sleep quality was on average good (PSQI<5) and daytime sleepiness scores were on average lower than during the control phase (average ESS global score 5.9) (Table 5.1). Sleep quality global

scores were moderately lower in week two ([mean; ± 90% CI] -25.6%; ± 24.1%) and week three (-26.5%; ± 26.1%) during sleep extension compared to week one. Similarly, there was a small decrease in ESS scores in week two (-21.9%; ± 27.4%) compared to week one. Overall, sleep extension resulted in a moderately larger improvement in sleep quality scores (-24.8%; ± 54.1%) compared to the control. The difference in the changes in ESS scores between control and sleep extension intervention was unclear.

5.3.2 Actigraphy

Actigraphy sleep data was collected from 84 nights (control) and 74 nights (sleep extension) of activity monitor wear time. Measures of all sleep variables across both treatment periods are presented in Table 5.2. On average total sleep time (6:25 ± 0:47 h) and sleep efficiency (76.8 ± 6.3%) was poor during the control phase, with a high number of awakenings (29 ± 10.9 awakenings). Between the early and late stages of the control phase, there was a small decrease in total time in bed (TIB) (-5.3%; ± 5.6%) and small decrease in total sleep time (TST) (-4.5%; ± 5.4%) as determined by actigraphy. All other differences in actigraphy data between stages during the control phase were unclear (Table 5.2). During the sleep extension intervention average total sleep time and sleep efficiency as determined by actigraphy was higher than the control phase (7:12 ± 0:41 h and 80.4% ± 5.45 respectively) with a similar number of awakenings compared to the control phase (29 ± 5.4). Between the early and late stages of the sleep extension intervention there was a small improvement in sleep latency (-31%; ± 54.3%) and a small increase in WASO (7.7%; ± 11.1%) and number of awakenings (5.5%; ± 9.1%). All other differences between stages during sleep extension were unclear (Table 5.2). There were small and moderate differences between the control and sleep extension intervention's changes in TST (6.3%; ± 6.3%) and TIB (7.3%; ± 3.6%) respectively. Differences between the control and treatment for all other sleep variables were unclear.

5.3.3 Saliva Analysis

Mean salivary IgA and α-amylase secretion rate concentrations and cortisol concentrations are presented in Table 5.3. During the control phase, there was a small increase in cortisol (6.9%; ± 13.3%). During the sleep extension intervention there was a small reduction in cortisol at week three (-13%; ± 18.1%) compared to week one. This resulted in a small difference between the treatments changes in cortisol (-18.7%; ± 26.4%). All other changes between IgA and α-amylase secretion rate concentrations during sleep extension were unclear.

5.3.4 Passing Test

Sleep extension passing test values are shown in Table 5.4. After sleep extension there was no clear change in total bullseye hits or passing time (-5.2; ± 45.7 and 0.5; ± 2.2 respectively) nor was there a clear change in improved total target hits (8.9%; ± 28.4%).

5.3.5 Reaction Times

Sleep extension reaction time variables are shown in Table 5.4. After sleep extension there was a small decrease in mean reaction times (-4.3%; ± 3.1%) and fastest 10% time (-3.3%; ± 2.9%) and a moderate increase in the slowest 10% time (11.7%; ± 7.2%). The change in error rate after sleep extension was unclear.

Table 5.1. Average Pittsburgh Sleep Quality and Epworth Sleepiness Scale Scores (Mean ± SD) in Professional rugby union players (n=25) during two three week rugby pre-season training blocks.

	PSQI Score		ESS Score	
	Control	Intervention	Control	Intervention
Week 1	5.1 ± 2.2	4.9 ± 1.8	6.7 ± 3.5	7.0 ± 4.4
Week 2	4.9 ± 0.5	4.2 ± 1.7 ^	7.5 ± 2.7	4.8 ± 3.5 #
Week 3	5.4 ± 2.7	3.5 ± 1.0 ^	7.9 ± 3.6	6.0 ± 4.3

* ESS > 10 = significant daytime sleepiness; PSQI > 5 = poor sleep quality.
†Magnitude indicates the change from week 1.
Small ^ Moderate

Table 5.2. Sleep variable changes (mean ± SD) in professional rugby union players (n=18) during two three week rugby pre-season training blocks.

	Control		**Sleep Extension**	
	Nights 1-8	**Nights 9-18**	**Nights 1-6**	**Nights 11-17**
Total time in bed (min)	516.0 ± 47.0	488.0 ± 41.0 #	529.3 ± 38.2	548.7 ± 44.8
Sleep latency (min)	17.6 ± 16.8	12.5 ± 11.5	13.0 ± 11.3	7.9 ± 4.9 #
Total sleep time (min)	391.0 ± 56.0	382.0 ± 36.0 #	422.4 ± 38.2	441.5 ± 44.1
Sleep efficiency (%)	75.0 ± 6.7	79.4 ± 4.8	79.9 ± 5.5	80.8 ± 5.4
Wake after sleep onset (WASO) (min)	103.0 ± 29.0	113.0 ± 85.0	93.5 ± 28.6	99.3 ± 28.6 #
Number of awakenings	28.0 ± 6.0	31.0 ± 16.0	28.2 ± 5.8	30.1 ± 4.6 #

† Magnitude indicates the change between night block 1 and night block 2 within each treatment.
# Small ^ Moderate

Table 5.3. Biochemical changes (mean ± SD) in professional rugby union players (n=23) during two three week rugby pre-season training blocks.

	Control		Sleep Extension	
	Week1/Pre	**Week3/Post**	**Week1/Pre**	**Week3/Post**
α - Amylase ($U.min^{-1}$)	163.1 ± 158.9	163.8 ± 155.0	163.5 ± 141.5	176.5 ± 179.7
IgA ($\mu g \cdot min^{-1}$)	31.0 ± 29.4	32.4 ± 27.5	26.2 ± 18.8	27.3 ± 22.7
Cortisol (nM)	14.3 ± 4.0	15.6 ± 5.1 #	6.0 ± 1.4	5.2 ± 1.7 #

† Magnitude indicates the change from week 1 to week 3 within each month.
# Small

Table 5.4. Passing accuracy and reaction time changes (mean ± SD) in professional rugby union players (n=27) after sleep extension during a three week rugby pre-season training block.

	Pre	**Post**
Total bullseye hits	1.8 ± 1.4	1.6 ± 1.1
Total target hits	4.3 ± 1.5	4.7 ± 1.8
Average pass time (sec)	0.9 ± 0.1	0.9 ± 0.1
Mean reaction time (ms)	228.8 ± 24.5	220.0 ± 18.4 #
Errors	2.6 ± 3.0	0.8 ± 1.1
Slowest 10% time (ms)	3.0 ± 0.5	3.3 ± 0.5 ^
Fastest 10% time (ms)	180.4 ± 11.0	175.4 ± 9.3 #

† Magnitude indicates the change from start to end of sleep extension
# Small ^ Moderate

5.4 Discussion

The purpose of the present study was to characterise the amount of sleep obtained by elite rugby players, determine changes that may occur in immune function and stress hormone secretion, and evaluate the efficacy of a sleep extension intervention during a pre-season training programme. Extending sleep resulted in a greater increase in time in bed (TIB), total sleep time (TST) and sleep quality (PSQI), a decrease in physiological stress (salivary cortisol levels) and improved reaction time performance compared to the control. However, sleep extension did not improve indices of daytime sleepiness, immune function (salivary

IgA) or sympathetic nervous system activity (α – Amylase) compared to the control, nor did it improve skill acquisition.

Following the three week sleep extension intervention, improvements in the rugby player's total sleep times agree with findings reported elsewhere (Famodu, 2014; Mah et al., 2011). Mah and colleagues (2011) observed significant improvements in extended night time sleep (average nightly increase 110.9 ± 79.7 min) and average sleep time (507.6 ± 78.6 min), compared to baseline measures (average sleep time 400.7 ± 61.8 min). Similarly, Famodu (2014) found female track athletes significantly increased total sleep time by 22 minutes during a one week sleep extension period. Thus athletes appear to respond well to education and encouragement to sleep more. However, there is a lack of agreement in the literature concerning the benefits of sleep extension.

The beneficial effects of sleep extension include improvements in vigour and fatigue (Barbato, Barker, Bender, Giesen & Wehr, 1994; Kamdar et al., 2004), alertness and reaction time performance (Kamdar et al., 2004; Roehrs et al., 1989). Short increases in sleep time through the use of naps have also shown improvements in sleepiness (Hayashi et al., 1999), vigilance (Dinges et al., 1987; Hayashi et al., 1999) and sprint performance (Waterhouse et al., 2007). Contrary to the present study, baseline sleepiness scores have also been shown to improve in athletes after sleep extension (9.64 ± 3.80 versus 3.36 ± 1.69 respectively) (Mah et al., 2011). Furthermore, sleep extension studies in athletes have demonstrated specific improvements in sprint and reaction times, skill execution, overall ratings of physical and mental well-being (Mah et al., 2011) and mood (Mah et al., 2011; Famodu, 2014). Conversely, sleep extension results in adults have shown only marginal improvements in Multiple Sleep Latency Test scores and not been found to improve subjective sleepiness (Harrison & Horne, 1996), nor to be more effective in reducing sleepiness compared to a

short mid afternoon nap or caffeine (Horne et al., 2008). Moreover, one additional hour of sleep extension in female track athletes showed no significant effects on variables of power, fatigue or reaction times (Famodu, 2014). Considering the contradicting findings between the present study and aforementioned study results regarding a lack of improvement in sleepiness and skill execution, and beneficial changes in reaction times, an athlete's response to sleep extension appears to be highly variable. Indeed, a successful response to sleep extension may depend on various factors, including individual sleep requirements, training load and intensity, the length and timing of sleep extension and the quality of habitual sleep prior to sleep extension.

With respect to habitual sleep among athletes prior to sleep extension, Mah and colleagues also observed similarly poor sleep times measured by actigraphy as compared to the present study. Together, these data support other study findings that have characterised poor normative sleep behaviour in athletes (Fietze et al., 2009; Leeder et al., 2012; Sargent, Halson et al., 2014; Sargent, Lastella et al., 2014). These findings suggest that intensive efforts to improve habitual sleep behaviour in athletes are warranted. Furthermore, sleep times decreased as training progressed during the control phase of the present study. A similar observation has been made in over-reached endurance athletes (Hausswirth et al., 2014), suggesting that athletes are particularly prone to poor sleep during phases of hard training and further highlights the importance of monitoring and educating athletes on sleep.

The length and timing of sleep extension is a likely determinant of the benefits that an athlete may realise from a sleep extension intervention. Participants in the present study were set the same sleep target (10 hours) as in-season basketball athletes in the aforementioned study (Mah et al., 2011), yet did not extend their average nightly sleep to the same degree. In the present study, comparatively less sleep extension may in part explain the lack of difference in

sleepiness scores between the control and intervention phases. Furthermore, the rugby players may have experienced more disrupted sleep due to a higher training volume and intensity within a pre-season phase, hot environmental conditions, or were simply unable to sleep as much as college athletes. From results available, the three week sleep extension period in the present study appears to be more beneficial than one week (Famodu, 2014), but not as effective as 5-7 weeks of extended sleep (Mah et al., 2011). A longer period of sleep extension may allow an athlete opportunity to more fully dissolve existing sleep debt. Indeed, some individuals may enter sleep studies with sizeable sleep debts (Barbato et al., 1994) and the phenomenon of 'binge sleeping', or catching up on lost sleep has been observed in young adults (Oginska & Pokorski, 2006). Similarly, if athletes in other elite environments were provided the opportunity to sleep more, existing sleep debt may promote an increase in total sleep time, through either night time sleep or daytime napping or a combination of the two. Furthermore, the beneficial changes in sleep quality and daytime sleepiness trends observed during sleep extension reinforce the efficacy and value of engaging athletes in a sleep education programme. While sleep extension studies longer than two months are lacking, it would seem prudent to suggest that extending sleep time and improving sleep quality among athletes is a habitual long term consideration, rather than an acute strategy. In particular, an athlete's habitual sleep duration may be a critical consideration to allow physical and neural adaptations adequate time to be realised, thus optimising the competitive advantages that may be available from sleep.

The health and performance benefits available to athletes by reducing sleep debt seem considerable (Halson, 2008; Mah et al., 2011; Rupp et al., 2009). Among these benefits is the potential for sleep to enhance immune function and mitigate elevations in physical stress. Specifically, cortisol is a particularly relevant stress hormone to athletes due to the effect that high volume, high intensity training has in elevating cortisol (Lac & Berthon, 2000) and its

negative influence over body composition (Crewther et al., 2011). Furthermore, there is an emerging concept that cortisol has a dose response effect with training, and may, together with testosterone, regulate long term changes in muscle growth and performance, especially with resistance training (Crewther et al., 2011). In light of the potential benefits of suppressing cortisol during pre-season training, the beneficial effect that sleep extension had on mitigating a rise in cortisol may provide a platform to support enhanced adaptive outcomes.

There was a lack of clear change in markers of immune function and sympathetic nervous activity between the control and intervention in the present study. However, sleep and immune function are intricately linked (Motivala & Irwin, 2007) and upper respiratory tract infection has been associated with changes in s-IgA and alterations in training load in elite rugby union players (Neville et al., 2008). Furthermore, it has been proposed that stress induced increases in cortisol release may contribute to reductions in mucosal immunity, which, when lowered, predispose rugby players to an increased risk of illness (Neville et al., 2008). Study results have consistently shown that sAA, as a marker of autonomic nervous system (ANS) activity, changes in response to psychological stress (Nater & Rholeder, 2009). Sleep deprivation, as a source of stress, is a known stimulant of sympathetic nervous system activity (Spiegel et al., 1999). Whilst there is strong scientific rationale for sleep extension, and parallel reductions in cortisol, to improve markers of immune function and sympathetic nervous activity in athletes, results from the present study do not support this hypothesis. Saliva samples were only taken twice, at baseline and end of treatment. Sampling frequency may have affected results due to the possibility of a high degree of individual variability in bio chemical markers. More frequent sampling of salivary bio markers in future sleep extension studies, with more long term sleep extension periods, is warranted to better explore the effect improved sleep might have on an athlete's immunity and ANS activity.

A further aim of the study was to evaluate the efficacy of a sleep extension intervention in improving athlete performance, specifically reaction times and passing skill acuity. The small beneficial decrease in reaction times after sleep extension agrees with findings by Mah and colleagues (2011), who demonstrated an improvement in mean reaction times, as well as faster sprint times and a 9 % improvement in basketball shooting accuracy. Together these indices reflected a positive change in athlete performance. Such a change in performance may be explained by increased sleep positively influencing adaptation to exercise, sport specific skill learning efficiency and heightened neural functioning. Baseline reaction times were faster in the present study than those reported by Mah et al. (2011), possibly due to the elite professional athletes in the present study possessing more efficient nervous system functioning. Thus, the significant reaction time improvements that were still achieved in the present study point towards a distinct competitive advantage that may be obtained from improved sleep within an elite sporting environment.

Although there was no clear change in passing skill acuity via sleep extension, a wide variety of learning processes in humans requires post-training sleep (Mednick et al., 2003). A range of environmental factors are important to sport skill development, including coaching, practice quality and social influences, and further research is required regarding how sleep can be harnessed to improve skill acquisition (Baker et al., 2003). The length of the sleep extension period in the present study may have been a limiting factor with respect to skill acquisition, and increasing TST beyond what was achieved in the present study may also be important to optimise skill development. Furthermore, the elite level of the athlete participating in the present study, their possession of a high skill base at the start of the study, and the complex and familiar nature of the skill that was studied may have decreased the potential for improvement. Further research could be directed to better understand the relationship between sleep and skill accuracy/acquisition.

5.5 Conclusion

In summary, a sleep extension intervention during a professional rugby pre-season training programme resulted in athletes improving total sleep time and sleep quality, with beneficial changes in stress hormone expression and reaction time performance compared to a control. The amelioration of the sleep extension intervention participants' cortisol response to intense pre-season training, and enhanced neurological functioning, may be attributed to a sleep education programme mediating improvements in athlete sleep indices and / or dissolving sleep debt. Sleep extension in this population did not improve other variables of sleep quality or daytime sleepiness, nor was there a clear change in passing skill acuity. Further sleep extension research is therefore required among elite athletes, involving comprehensive indices of sleep quality, physical health, recovery and performance over longer term periods. The results of the present study do suggest that sleep education and promoting sleep extension among elite athletes is a worthwhile and effective measure in the pursuit of optimal performance.

5.6 Practical Applications

The improvement of poor sleep quantity and quality in elite collision sport athletes appears to confer worthwhile benefits at the level of mitigating physiological stress and enhancing performance during intensive training. These improvements were simply achieved in this study via sleep behaviour changes. It is critical to collect quantifiable data, and this is a large consideration within the sports science field. However, data is only useful if it is used to inform intervening action. Thus sports science practitioners should utilise the collection of sleep data to firstly increase athlete self-awareness of their sleep, but importantly build upon this data with athlete education and encourage behaviour change. Only the athlete has control in governing their own sleep habits. Ultimately, apart from daytime naps or during camp scenarios, many of the gains an athlete might experience from enhanced sleep occur in their own homes. Thus any perceived gains from sleeping better must be made relevant to the athlete, and an element of intrinsic motivation is critical to succeed in achieving better sleep. Prioritising sleep education and allocating generous individual education opportunities are important considerations for team sports.

Injury is a highly relevant consideration to any athlete. An observation was made during this study that the team incurred a reduced incidence of soft tissue (3) and contact injuries (4) compared to the previous season (5 and 5, respectively). This observation may be a result of chance, or other discipline interventions. However, preliminary research is suggesting that sleep shares a direct relationship with risk of sporting injury. There is good scientific rationale for this premise, owing to the positive effects sleep has on neural function, reaction times and muscle recovery. Injury is a common consequence of collision sports, and comes often at a great cost. The potential to modify this risk to the athlete and associated detrimental consequences to team performance via better sleep is deserving of further research.

Finally, it would appear from the results in this study that the athletes were able to tolerate physiological stress to a higher degree from sleeping more, compared to the control. This apparent recovery advantage may have implications for the sports practitioner and coach with respect to the training loads and intensities that an athlete could potentially cope with. Theoretically, absorbing a higher training stress through better sleep may evoke greater sport specific adaptations. Amplifying a given training effect via improved sleep may provide significant performance advantages for athletes and teams. Furthermore, in elite team sports, much consideration is given to optimising a finite amount of time available to train, practice and recover during the day. However, a great opportunity exists to modify and improve recovery during the nocturnal window which competitors may not be utilising. The inclusion of a sleep extension and education programme within elite sporting programmes is therefore recommended to potentially elicit a competitive advantage in sports performance.

Chapter 6

EFFECTS OF TART CHERRY JUICE ON INFLAMMATION, SLEEP AND POST-EXERCISE RECOVERY IN RUGBY PLAYERS

Richard Swinbourne, Nicholas Gill, Joanna Vaile, Daniel Smart

6.0 Prelude

In the previous chapters it has been established that collision sport athletes do not sleep well, with associated recovery and performance costs. However, this athlete picture can be improved with sleep extension via sleep education and behaviour change. Once sleep education has been addressed, additional strategies may be considered to elicit further sleep improvements. A number of sleep-nutrient interventions were highlighted in chapter two that may provide athletes with adjunctive sleep enhancing strategies. Of these sleep-nutrient interventions, tart cherry juice has been commonly used among rugby players with anecdotal sleep and recovery benefits. Therefore, this study aimed to validate the use of tart cherry juice by rugby players during a strength training phase. In particular, tart cherry juice related reductions in secondary inflammation were examined, with subsequent effects on delayed onset muscle soreness, muscle function, and subjective sleep quality, daytime sleepiness and self-perceived mental fatigue.

6.1 Introduction

In an age where developments in sports science seek to provide athletes and sports teams with a competitive edge, sleep is emerging as an increasingly important recovery modality. Appropriate sleep quality has been acknowledged as an important factor required for both optimal health and athletic recovery (Venter, 2008), and thus attention is turning towards sleep enhancement strategies to improve sleep in athletes.

While there are a number of medications to assist sleeplessness, there is also a demand for natural alternatives to improve sleep (D'Anci, 2012). Of the various natural remedies available, agents that raise melatonin levels are a growing area of interest (D'Anci, 2012). Existing literature has identified that athletes commonly suffer inadequate sleep quality (Antic et al., 2013; Fietze et al., 2009; Hausswirth et al., 2014; Leeder et al., 2012; Mah et al., 2011; Sargent, Halson et al., 2014; Sargent, Lastella et al., 2014) and display a preponderance of daytime sleepiness and fatigue (Antic et al., 2013; George et al., 2003; Mah et al., 2011). Sleep-nutrient interactions, including melatonin containing foods, hold the potential to enhance sleep quality (Brzezinski, 1997; Garrido et al., 2009; Garrido et al., 2010, Howatson et al., 2011).

The consumption of Montmorency tart cherries offers a relatively unexplored method of enhancing sleep related recovery via dietary melatonin intake. The consumption of tart cherries as a juice blend or concentrate has produced beneficial effects on subjective reports of late life insomnia (Pigeon et al., 2010) time in bed, actual sleep time and efficiency measured by actigraphy in young healthy adults (18-40 years) (Howatson et al., 2011). The effectiveness of tart cherries in improving sleep in highly trained athletes remains to be elucidated.

The sleep enhancing effect of tart cherry consumption has been attributed to both natural polyphenolic compounds called proanthocyanidins increasing tryptophan availability ("Tart cherry juice may help insomnia," 2014) and elevated circulating melatonin levels, although the interaction of other anti-inflammatory phyto-chemicals cannot be discounted (Howatson et al., 2011). Whilst pro-inflammatory cytokines have been explicitly linked to the physiological control and disruption of normal sleep architecture (Imeri & Opp, 2009), the action of the anti-inflammatory compounds present in tart cherries may present an additional mechanism for the observed sleep benefits.

Tart cherry juice has been successfully explored as a means to mitigate post-exercise muscle damage, both at a symptomatic and functional level (Bell, Walshe, Davison, Stevenson & Howatson, 2015; Connolly et al., 2006; Howatson et al., 2010, Kuehl et al., 2010). The anthocyanin content of tart cherries in particular are likely responsible for accelerated recovery following strenuous exercise, via anti-oxidative and anti-inflammatory effects (Howatson et al., 2011). However, the precise mechanism behind accelerated recovery from consuming tart cherries is yet to be identified. Questions also exist surrounding effective dosing and method of consumption. Specifically, the efficacy of a single early evening dose of tart cherry juice concentrate in improving sleep, mitigating markers of muscle damage and fatigue and resultant effects on athletic performance has not been thoroughly investigated.

The potential for tart cherry juice to mediate muscle damage may be pertinent to collision sports such as rugby union. It has been well documented that competing in collision sports results in neuromuscular, biochemical and endocrine changes in the athlete (McLellan & Lovell, 2012; Smart et al., 2008; Takarada, 2003; Twist et al., 2012). Training for rugby union must also accommodate diverse physical demands, and incorporates intense resistance training for hypertrophy, strength and power (Smart & Gill, 2013), with strong muscle

contractions and potential for associated eccentric muscle damage (Takarada, 2003). A pro-inflammatory state may disrupt normal sleep architecture (Imeri & Opp, 2009), and thus the aetiology of documented poor sleep in athletes (Antic et al., 2013; Fietze et al, 1997; Hausswirth et al., 2014; Leeder et al., 2012; Mah et al., 2011; Sargent, Halson et al., 2014; Sargent, Lastella et al., 2014) may result not only from lifestyle but also biological factors, to which tart cherries may offer a potential solution.

Considering the potential of tart cherry juice supplementation to enhance sleep quality and mitigate symptoms of muscle damage in collision sport athletes, the purpose of the present study was to examine the efficacy of consuming a Montmorency tart cherry juice concentrate once per day during an off-season resistance training and conditioning period. More specifically, the study aimed to investigate the effect of tart cherry juice concentrate on variables of sleep, fatigue, muscle soreness and function, as well as secondary inflammation in response to eccentric muscle damage.

6.2 Methods

6.2.1 Participants

Sixteen highly trained male rugby union athletes volunteered to participate in the present study (age [mean ± *SD*] 19 ± 0.93 years; height 1.85 ± 0.10 m; weight 99.7 ± 12.4 kg). Participants were members of a regional training squad and all but one participant were aged 18 years or older. Participants provided written informed consent, and parental consent was gained for the one underage participant. All participants were in good health and had not been previously diagnosed with a sleeping disorder. Participants were permitted to consume caffeine, alcohol and training supplements as they usually would during the course of the present study. The research was approved by the Auckland University of Technology Ethics Committee.

6.2.2 Research Design

A longitudinal placebo-control study design was used to collect data on subjective measures of sleep quality, daytime sleepiness, pre-training fatigue, muscle soreness ratings and blood markers of inflammation during a period of four weeks. This occurred during the participants initial four week off-season training phase. The participants completed a high intensity resistance training programme, designed by the squad's Strength and Conditioning coach. Training consisted of one whole body and two upper body weight lifting session per week, of one hour duration each. Twelve of the participants were also prescribed two, high intensity, interval running based conditioning sessions per week while training for or playing rugby sevens. The training programme consisted of three weeks of progressive overload, with a fourth week of eccentric loading whereby two high volume, whole body weight lifting sessions were performed to induce localised muscle soreness in the chest, back, hamstrings and biceps. For four weeks, participants consumed one serve of tart cherry juice concentrate (TC) or iso-caloric placebo (PL) per day. Participants were required to dilute the concentrate or placebo with 200 ml of water, and consume the drink with their evening meal.

6.2.3 Procedures

6.2.3.1 Blood Sampling

Blood sampling was conducted by a qualified phlebotomist at baseline and the conclusion of the trial. Samples were obtained from the cubital fossa vein, with participants in a rested state, after a non-training recovery day. Samples were analysed for C-Reactive Protein (C-RP), and a complete blood count to obtain monocyte and neutrophil concentrations, as variables of inflammation. Complete blood counts were derived using a Sysmex XN-1000 B3 analyser. C-Reactive Protein values were obtained using a Multigent CRP Vario Reagent

kit. Results for C-RP were reported in mg/L. Results for monocytes and neutrophils were reported as total count x10^9 per Litre.

6.2.3.2 Delayed Onset Muscle Soreness

A 100 mm visual analogue scale (VAS) was used weekly prior to every resistance training session to quantify the degree of muscle soreness experienced by each participant (Kuehl et al., 2010). “No pain” was indicated at one end of the scale and “worst possible pain” was indicated at the other. Results were recorded as a ten point Likert scale. The VAS has been proven as both a valid (Todd, Funk, Funk & Bonacci, 1996) and reliable (Bijour, Silver & Gallagher, 2001) measure of acute pain intensity and has been used in nutrient intervention studies to assess muscle damage symptoms following strenuous exercise (Howatson et al., 2010; Kuehl et al., 2010).

6.2.3.3 Power Profiling

Each week a linear position transducer (GymAware, Kinetic Performance Technology, Canberra, Australia) was used to measure both power and velocity as variables of muscle function. GymAware is a validated and reliable means of assessing power and velocity and demonstrates a great ability to accurately measure displacement data (Black, 2010). Power measures included peak velocity (m/s) and peak power (W), while a mean value of peak velocity and peak power efforts was recorded from the best performing set. Upper body power was assessed via a bench press throw with a total weight of 50 kg as well as a red band attached between the bar and bench to create additional accommodative resistance. Lower body power was assessed using a counter movement squat jump with 60 kg of weighted resistance. Jump squats with a loaded barbell and bench press throws have been used to assess power in collision sport athletes (Baker & Nance, 1999). Absolute resistance, as opposed to percentages of each individuals maximum strength score, was used as strength

and power training adaptations are predominantly manifested through an improved ability to overcome absolute, rather than relative, loads (Baker & Nance, 1999). Participants tested each exercise on different days. A minimum of two and maximum of three sets of four to six repetitions were self-selected and performed for each exercise, at the beginning of the respective resistance training sessions.

6.2.3.4 Qualitative Sleep and Daytime Sleepiness Assessments

Participants self-perceived sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI) questionnaire (Buysse et al., 1989). Daytime sleepiness was assessed using the Epworth Sleepiness Scale (ESS) questionnaire (Johns, 1991). Participants recorded sleep and wake times using a sleep diary to estimate total sleep times each night. Questionnaires were completed prior to training during week one, end of week two and during week four.

Pittsburgh Sleep Quality Index Questionnaire. The PSQI provides a subscale rating of subjective sleep quality, as well as subscale measures of sleep latency, sleep duration, and habitual sleep efficiency. Some components relate to sleep disturbances, use of sleeping medication, and daytime dysfunction. The sum of the scores for these seven components yields a global score with a range of 0-21 that is a composite of sleep quantity and quality (Kryger et al., 2011). Acceptable measures of internal homogeneity, reliability and validity have been obtained for the PSQI (Buysse et al., 1989). A global PSQI score >5 has resulted in a diagnostic sensitivity of 89.6 % and specificity of 86.5 % in distinguishing ‘good’ and ‘poor’ sleepers (Buysse et al., 1989).

Epworth Sleepiness Scale Questionnaire. The ESS is a simple questionnaire measuring the general level of daytime sleepiness, or average sleep propensity, experienced by an individual (Johns, 1993). The questionnaire yields a global score with a range of 0-24. The ESS is comparable to all day tests such as the multiple sleep latency tests, is a valid and reliable measure of objective sleepiness (Johns, 1993) and is a practical evaluative tool that

has been applied to athletes (Antic et al., 2013; George et al., 2003; Mah et al., 2011). Furthermore, ESS scores have been shown to change with sleep extension in athletes compared to baseline, indicating reductions in daytime sleepiness (Mah et al., 2011). The ESS may compliment the PSQI and provide information on whether the athlete is experiencing a daytime functional disturbance from poor sleep quality, which may impact on cognition and training quality.

6.2.3.5 Pre-training Mental Fatigue

A seven point fatigue scale (Samn & Perelli, 1982) was used weekly prior to every resistance training session to quantify the degree of mental fatigue experienced by each participant. The seven point scale is a well-established subjective measure of fatigue that has been widely used in sleep and fatigue studies (Petrelli, Roach, Dawson & Lamond, 2006; Baulk, Fletcher, Kandelaars, Dawson & Roach, 2009; Ferguson, Paech, Dorrian, Roach & Jay, 2011). The seven point scale categories are displayed in Table 6.1.

Table 6.1 Seven point fatigue scale categories to evaluate pre training mental fatigue in male rugby players during a four week placebo controlled tart cherry juice trial.

1	Fully Alert	Wide Awake	Extremely peppy
2	Very Lively	Responsive	But not at peak
3	Okay	Somewhat fresh	
4	A little tired	Less than fresh	
5	Moderately tired	Difficult to concentrate	
6	Extremely tired	Very difficult to concentrate	
7	Completely exhausted Ready to drop	Unable to function effectively	

*Higher scores indicate a higher degree of subjective fatigue.

6.2.3.6 Dietary Control

Participants were provided with advice with regards to consuming a diet replete in calories and macronutrients to promote lean muscle mass gains. Participants were instructed not to

over consume anti-oxidant rich foods and drinks which may influence or affect their antioxidant status. Participants were encouraged to enjoy a nutritious diet, and were provided with the below instructions. Dietary compliance was verbally checked during individual consultations with the lead researcher.

- Enjoy your usual diet, and do not make any changes to your usual diet (except for the below)
- Keep using your usual recovery protein
- Limit fresh or frozen berries to less than ½ cup per day
- Limit tea and green tea to less than two cups per day
- Limit grape juice or other fruit and vegetable juices to less than one cup per day
- Limit red wine to less than 100 ml (one standard serve) per day
- Do not consume blackcurrant juice or powder
- Do not consume tart cherry juice or other cherry juices
- Do not eat walnuts (other nuts are ok)
- Do not take ZMA or magnesium supplements
- Report any use of sleeping tablets

6.2.4 Statistical Analyses

All data were analysed using an Excel spreadsheet for analysis of pre-post controlled trials, which was set at 90 % confidence limits (Hopkins, 2006). All biochemical, power and sleep data were log-transformed prior to analysis to reduce non-uniformity of error. These data were back transformed and expressed as the parametric median, with errors expressed as the coefficients of variations (CVs) for change scores and 90 % confidence limits for differences in the between group changes. Standardised mean changes in biochemical, sleep and physical data and differences between the changes were used to assess magnitudes of effects by dividing the appropriate between-group standard deviation. Standardised effects were

defined as using a modified Cohen scale: <0.2 = trivial, 0.2 - 0.59 = small, 0.6 - 1.19 = moderate, 1.2 – 1.99 = large, >2.0 = very large (Hopkins, Marshall Batterham and Hanin, 2009). The effect was deemed unclear if its confidence interval overlapped the thresholds for small positive and negative effects.

Pearson product moment correlation (r) was used to establish relationships between the changes in total sleep time and changes in PSQI and ESS questionnaire responses, between changes in fatigue and changes in bench press, and between changes in biochemical markers and changes in perceptions of fatigue and muscle soreness. The magnitudes of the correlation coefficients were interpreted with Cohen's scale: <0.1 = trivial, 0.1-0.3 = small, 0.3-0.5 = moderate and >0.5 = large (Cohen, 1988). Uncertainty in the correlations was expressed as 90 % confidence limits, estimated for the worst-case scenario of a zero correlation (Hopkins, 2007).

6.3 Results

6.3.1 Blood Markers of Inflammation

Pre-trial C-RP values (mean ± *SD* expressed as coefficient of variation [percentage]) (mg/L) for TC and PL groups were 1.0 ± 109% and 0.8 ± 135% respectively. Post-trial the TC group had a decrease in C-RP (-8.5% ± 97.3%) compared to an increase in the PL group (119% ± 174%) over the four week period (Table 6.2), with a moderate difference between the groups' changes (-0.98; ± 1.16). Pre-trial neutrophil and monocyte values (x10^9) for TC and PL groups were (4.6 ± 24.9% and 3.7 ± 54.6% respectively) and (0.6 ± 35.6% and 0.6 ± 27.8% respectively). Among both the TC and PL groups there were decreases in neutrophils (-12.6% ± 37.1% and -7.4% ± 66.6% respectively) and monocytes (-1.8% ± 33.3% and 0.4% ± 32.7% respectively), however the differences between the group's biochemical markers

were unclear. In addition, the relationship between these changes in biochemical markers and changes in perceptions of fatigue and muscle soreness were unclear.

6.3.2 Muscle Soreness and Fatigue

Pre-trial ratings of muscle soreness and fatigue (mean ± *SD*) for TC and PL groups were (2.6 ± 0.5 and 3.1 ± 1.7 respectively) and (2.7 ± 0.6 and 3 ± 1.3 respectively). There were no clear differences between the groups' muscle soreness or fatigue scores (Table 6.3). However, the tart cherry concentrate group tended to report reduced delayed onset muscle soreness in weeks one, two and four and lower subjective scores for pre-training fatigue during each week of the training programme compared to the placebo group. The relationship between changes in fatigue and changes in bench press were unclear.

6.3.3 Power

Pre-trial power values for TC and PL groups are displayed in Table 6.2. Muscle function was improved in both the tart cherry and placebo groups with increases observed in all bench press measures over the four week period. However, the difference between the groups' changes was unclear (Table 6.2). No clear changes in jump squat variables were observed for either group over the trial period (Table 6.2).

Table 6.2 Mean ± *SD* (expressed as coefficient of variation [percentage]) C-RP, Neutrophils, Monocytes and Differences in Power Measures in rugby union players during a four week tart cherry juice or placebo controlled trial.

			Week 1 (mean ± %)	Week 4 (mean ± %)
C-RP (mg/L)		TC	1.0 ± 109.4	0.7 ± 137.8
		PL	0.8 ± 135.5	1.4 ± 107.7
Neutrophils (x10^9)		TC	4.6 ± 24.9	4.0 ± 35.7
		PL	3.7 ± 54.6	3.8 ± 22.8
Monocytes (x10^9)		TC	0.6 ± 35.6	0.6 ± 16.8
		PL	0.6 ± 27.8	0.6 ± 26.2
Bench Press	***Peak Velocity (ms^{-1})***	TC	1.0 ± 15.9	1.1 ±19.1 #
		PL	0.9 ± 36.5	1.1 ± 20.7 #
	Peak Power (W)	TC	691.0 ± 17.3	897.0 ± 31.1 ^
		PL	678.0 ± 44	853.0 ± 27.8 #
	Average Velocity (ms^{-1})	TC	0.9 ± 29.6	1.0 ± 19.8 #
		PL	0.9 ± 36.4	1.1 ± 22.5 #
	Average Power (W	TC	606.0 ± 23.7	777.0 ± 28.6 ^
		PL	596.0 ± 40.3	755.0 ± 29.1 #
Squat Jump	***Peak Velocity (ms^{-1})***	TC	2.4 ± 8.9	2.2 ± 4.3
		PL	2.4 ± 11.1	2.2 ± 4.4
	Peak Power (W)	TC	5524.0 ± 14.9	5133.0 ±13.2
		PL	5506.0 ± 27.9	4954.0 ± 11.2
	Average Velocity (ms^{-1})	TC	2.3 ± 8.4	2.1 ± 5.3
		PL	2.3 ± 11.8	2.1 ± 4.5
	Average Power (W	TC	5146.0 ± 13	4686.0 ± 14.6
		PL	5195.0 ± 29.3	4611.0 ± 9.5

* TC = Tart cherry juice; PL = Placebo

†Magnitude indicates the change from Week 1 to Week 4.

Small, ^Moderate

Table 6.3 Mean ± SD (Mean ± *SD* expressed as coefficient of variation [percentage]) total sleep time and muscle soreness and mental fatigue scores (mean ± *SD*) in rugby union players during a four week tart cherry juice or placebo controlled trial.

		Week 1	Week 2	Week 3	Week 4
TST (hr)	TC	8.3 ± 7.7	8.2 ± 5.0	7.9 ± 11.4	8.0 ± 7.8
	PL	8.7 ± 8.8	7.7 ±13.0	8.6 ± 13.8	8.2 ± 18.1
Fatigue	TC	2.7 ± 0.6	2.7 ± 1.0	3.0 ± 1.1	2.5 ± 0.6
	PL	3.0 ± 1.3	3.5 ± 1.2	3.3 ± 1.3	3.1 ± 1.4
Muscle Soreness	TC	2.6 ± 0.5	1.9 ± 1.0	2.5 ± 1.0	3.6 ± 1.8
	PL	3.1 ± 1.7	3.4 ± 2.5	2.5 ± 1.3	3.8 ± 1.7

* TC = Tart cherry concentrate; PL = Placebo

*Muscle soreness = 10 point Likert scale; Fatigue = 7 point Likert scale

†Changes between week one and week four were unclear

6.3.4 Sleep

Pre-trial values (mean ± *SD*) for subjective sleep quality and sleepiness global scores for TC and PL groups are displayed in Table 6.4. Subjective measures of daytime sleepiness improved in both groups, while only the TC group reported a small beneficial change in sleep quality over the four week period (-0.47 ± 0.57). The TC group also exhibited lower PSQI and ESS scores at baseline compared to placebo, and their scores decreased to a lesser extent across the four weeks (Table 6.4). Both groups average weekly sleep time also decreased over the four week period (Table 6.3).

No clear relationships were established between the changes in total sleep time and changes in PSQI (r = 0.21; ± 0.43) and ESS (r = 0.20; ± 0.43) questionnaire responses, nor between changes in muscle soreness and changes in C-RP values (r = -0.25; ± 0.45) or between changes in fatigue and changes in C-RP, neutrophils or monocytes (r = 0.11; ± 0.47, 0.28; ± 0.41, and 0.29; ± 0.41 respectively). Stronger relationships were established between changes in fatigue and changes in peak power (r = -0.35; ± 0.38) and peak velocity (r = -0.33; 0.39) values for bench press.

Table 6.4 Sleep quality and daytime sleepiness measures (Mean ± *SD*) in rugby union players during a four week tart cherry juice or placebo controlled trial.

		Week 1	Week 4
PSQI	TC	4.1 ± 1.4	3.0 ± 1.3 #
	PL	5.6 ± 2.6	4.2 ± 1.9
ESS	TC	7.4 ± 2.8	6.1 ± 2.2 #
	PL	9.1 ± 4.0	7.5 ± 4.3 #

* TC = Tart cherry juice; PL = Placebo
**ESS > 10 = significant daytime sleepiness; PSQI > 5 = poor sleep quality
†Magnitude indicates the change from week one to week four.
Small

6.4 Discussion

The purpose of the present study was to investigate the effect of a single evening dose of tart cherry juice concentrate (TC) for four weeks on inflammation, physical performance and sleep indices compared to a placebo in provincial rugby union academy players. Consuming TC resulted in a greater decrease in inflammation (C-RP) compared to the placebo. However, regular consumption of TC did not improve variables of sleep, daytime sleepiness, fatigue, muscle soreness or muscle function. Nevertheless, among the TC group there was a small worthwhile change in sleep quality and trend towards greater bench press power across the four week programme. A trend towards greater decreases in white blood cells, fatigue and muscle soreness were also observed in the TC group between week one and week four.

Following the four weeks of TC supplementation, the attenuation in C-RP following eccentric exercise supports the findings reported in other studies. Runners consuming a tart cherry juice before and after a Marathon race had significantly reduced C-RP values ($P<0.01$) compared to a placebo group at 24 and 48 hours post-race (Dimitriou et al., 2015; Howatson et al., 2010). Similarly, increases in high sensitivity C-RP (hsC-RP) values were attenuated ($p = 0.05$) in cyclists consuming tart cherry concentrate prior to stochastic cycling (Bell et al., 2015). In addition, reduced C-RP levels have been reported in healthy participants supplementing their diets with Bing sweet cherries (Jacob et al., 2003; Kelley, Rasooly, Jacob, Kader & Mackey, 2006). In contrast, no effects of twice daily consumption of tart cherry juice concentrate on high sensitivity C-RP values obtained following eccentric knee extensions (Bowtell, Sumners, Dyer, Fox & Mileva, 2011) and similarly no effect on C-RP was found among 47 healthy adults consuming a single 30 ml daily dose of tart cherry concentrate versus placebo for six weeks (Lynn et al., 2014). Whilst C-RP values for both groups in the present study remained within normal physiological parameters, the effect of tart cherry juice in decreasing low grade but chronic inflammation may have implications for

clinical populations (Bell et al., 2014). Considering there is a bi-phasic relationship between inflammatory chemicals and sleep quality, and higher degrees of inflammation may dysregulate sleep (Motivala & Irwin, 2007), reducing inflammation in athletes may have a worthwhile effect on sleep based recovery in particular.

Whilst the mechanism by which tart cherries may improve muscle recovery has not been confirmed, results of the present study suggest a role in ameliorating the secondary inflammatory cascade response to eccentric muscle damage. This hypothesis has been previously postulated (Bell at al., 2014, Connolly et al., 2006). Whilst primary muscle damage is caused by a mechanical disruption of myofibrils, extensive damage triggers a local inflammatory response, attracting neutrophils to the injury site (Connolly et al., 2006). Thus present findings suggest that compounds within the TC exert a beneficial effect on secondary inflammation, and C-RP values in particular. Whilst white blood cell effects in the present study were not clear, supplementation with a powdered tart cherry product versus placebo before and after an intense endurance running event has been shown to significantly reduce white blood cells ($p=0.034$) (Goodenough et al., 2014). Conversely, the same powdered tart cherry product showed no effect on white blood cells following an acute bout of resistance exercise (Dalton et al, 2014). The downwards trend in the TC group's white blood cells in the present study does lay a foundation for future study designs with larger participant numbers and a higher dosage to better identify the role of tart cherries in promoting anti-inflammatory muscle recovery after resistance exercise.

While there was a lack of change in ratings of fatigue and muscle soreness between the groups, the TC group tended to report lower subjective scores for muscle soreness in weeks one, two and four. Indeed, study findings regarding the efficacy of tart cherries in reducing muscle soreness following exercise are inconsistent, demonstrating both significant

(Connolly 2006; Kuehl et al., 2010; Levers et al., 2014) and non-significant (Bell et al., 2015; Howatson et al., 2010) effects. The present study used a single daily dose from concentrate versus a double dose of either a proprietary juice blend or juice concentrate in the aforementioned studies, and involved a different athletic population. Therefore, it could be postulated that improvements in perceived muscle soreness may be anthocyanin dose dependent and an increased dose is required to optimise both the anti-inflammatory and analgesic qualities of tart cherry supplementation. Indeed, the benefits of exposing an athlete to pro-inflammatory conditions for the purposes of exercise adaptations are debated (Bell et al., 2014). However, within collision sports there are a multitude of scenarios where applying the anti-inflammatory effect of tart cherries may be considered beneficial. For example, reducing muscle pain or improving muscle function between games during a rugby sevens tournament, where three matches are typically played each day for two consecutive days, may create a competitive advantage. Similarly, training intensity may be supported during intensive rugby campaigns or competitions, whereby muscle damage may be accrued.

A further aim of the present study was to explore the influence of TC consumption on muscle function during resistance training. There was no clear change in muscle function between the groups, although the TC group did show a trend towards better bench press performance over the four week training period. Tart cherry juice supplementation (twice per day) has demonstrated an attenuation of maximal isometric strength loss versus placebo (4 % vs 22 %) (Connolly et al., 2006), improved recovery of isokinetic knee extension versus placebo (Bowtell et al., 2011) and isometric strength recovery following a marathon run (Howatson et al., 2010). Conversely, the recovery of isokinetic knee extension/flexion maximum voluntary contractions was unaffected by the consumption of a powdered tart cherry supplement before and after an acute bout of resistance exercise (Dalton et al., 2014). Like the effect on perceived pain, it is possible that a higher dose is required to better influence

muscle function. However, the present study monitored muscle function during a longitudinal training programme as opposed to a more acute bout of exercise in the aforementioned studies. Strength changes have been shown after 15 weeks of training in adolescent rugby players (Smart & Gill, 2013) and thus monitoring strength differences between the groups in the present study over a longer period of time may have been required to better appreciate differences in strength acquisition and muscle function. A longer training and monitoring period and higher TC treatment dose may be applied in future research to better understand the possible benefits of applying tart cherries for exercise adaptation and performance.

Despite a small improvement in sleep quality in the TC group, the lack of clear differences in sleep changes between groups in the present study contrasts with previous findings that have shown a beneficial effect of cherry consumption on sleep variables. Modest improvements in subjective measures of late life insomnia have been reported following consumption of a fresh pressed cherry juice and apple juice blend (Pigeon et al., 2010). Consuming whole Jerte valley cherry fruit (not Montmorency cherries) (Garrido et al., 2010) and a nutraceutical Jerte valley cherry product (Garrido et al., 2009) had beneficial effects on sleep time, total nocturnal activity and assumed sleep, as well as increasing total melatonin levels and antioxidant capacity in young, middle aged and elderly participants. Furthermore, a randomised, double blind, placebo controlled, crossover sleep study by Howatson and colleagues (2011) used actigraphy to observe improvements in sleep time and quality following consumption of tart cherry juice concentrate in 20 young healthy adults (mean age 26.6 ± 4.6 years). Participants consumed a similar tart cherry concentrate as used in the present study but at a higher dose, supplementing twice per day for seven days. Therefore, it is possible the lack of significant sleep changes in the present study were influenced by small participant numbers, a reduced tart cherry concentrate dose or possibly altered bio-

availability compared with whole fruit, fresh juice or proprietary blends, or the method of sleep assessment was insensitive to changes in sleep quality between groups. Whilst it remains difficult to prescribe an optimal dose of TC to improve sleep, two serves of TC per day may be required to better influence sleep variables, particularly in the presence of elevated levels of inflammation. However, actigraphy monitoring of participants undertaking regular physical training while consuming a single daily dose of tart cherry concentrate would be prudent before consolidating such advice.

Interestingly the TC group's ESS and PSQI scores decreased to a lesser extent across the four weeks. This finding may be explained by the treatment group exhibiting lower PSQI and ESS scores at baseline compared to placebo, or via a placebo effect influencing sleep scores. The TC group were better sleepers at baseline, and it could be postulated they had less potential for improvement. However, the TC group did tend to report lower subjective scores for pre-training fatigue during each week of the training programme, perhaps reflecting their better intrinsic sleep quality, although the influence of tart cherries in improving sleep quality and related fatigue cannot be discounted. Both groups average weekly sleep time also decreased over the four week period. The disintegration of sleep during hard training has been observed among endurance athletes in an overreached state (Hausswirth et al., 2014). Therefore the findings of the present study support the notion that sleep deteriorates during hard training blocks, emphasising the need for regular periods of unloading to absorb training, enable recovery and promote adaptation.

6.5 Conclusion

In summary, consuming a single evening dose of Montmorency tart cherry juice concentrate for four weeks mitigated increases in inflammation (C-RP) in highly trained rugby players compared to a placebo group during an off season resistance training programme. The

amelioration of secondary inflammation may be attributed to the anthocyanin content or other potent compounds present in the TC. A single dose of TC in this population did not induce substantial changes in sleep variables, fatigue, muscle function, soreness or white blood cell concentrations. However, beneficial trends were noted among the TC group. Therefore, further research is required to establish a minimal effective dose of TC to fully realise the potential for sleep, recovery and performance benefits. The results of the present study suggest tart cherry juice supplementation may be an important component of post-exercise recovery nutrition to mitigate inflammation when this is considered important for an athlete.

6.6 Practical Applications

Building lean muscle mass, strength and power are common training goals for collision sport athletes. However, such training invokes eccentric muscle damage and resultant secondary inflammation, which may be performance limiting. The finding in this study that tart cherry juice effectively mitigates training induced inflammation may be harnessed by athletes and sports practitioners to assist athlete recovery. Managing inflammation is a polarising area of debate among sports scientists, as summarised by Bell and colleagues (2014), due to a hesitation to disturb the physical adaptation process, which is most relevant during training phases. However, there are clearly situations where it is advantageous to manage inflammation, such as during intensive competition, or when frequent repeat performances are required.

In this study, tart cherry juice was consumed during a training phase. Damping down inflammation did not significantly improve muscle function or sleep, but importantly, nor did it exert a negative effect on these indices. From findings in chapter two and the trends observed in the present study, it is conceivable that better managing inflammation via antioxidant rich foods may improve sleep and training quality, with a resultant positive effect

on adaptation in the strength athlete. Whilst an optimal prescription schedule and dose of tart cherry juice is yet to be determined, it appears from these results that a single daily dose is inadequate to effect significant changes in muscle soreness or function, or improve sleep.

Future research should aim to answer these aforementioned questions concerning recovery, adaptation and establish effective supplementation guidelines. In particular, a natural progression in future research designs would be to introduce a higher daily dose of tart cherry juice and observe resultant effects on inflammation, sleep and athletic function. In addition, the introduction of a morning dose of tart cherry juice, or a double evening dose, would be pertinent to investigate. Meanwhile, practitioners should evaluate the overall antioxidant intake of an athlete, and ensure that rich sources of antioxidants from natural foods are consumed during a training phase to meet daily health and recovery needs. In particular, dark skinned green, red and purple vegetables and fruit, including tart cherries, should be included in the daily diet at regular intervals, including the evening meal and / or before bed.

Chapter 7

SUMMARY, PRACTICAL APPLICATIONS AND FUTURE RESEARCH DIRECTIONS

7.1 General Summary

The overall aim of this PhD was to characterise sleep in elite collision sport athletes, develop and apply interventions to improve their sleep quantity and quality, and investigate resultant recovery and performance benefits. The initial step in this investigative process was to comprehensively review existing literature, canvasing sleep as a behaviour and function of health, recovery and performance in athletes. The literature review then informed the research direction and applied methodology utilised within this thesis.

The literature review revealed sleep as an area of critical investigative need as it pertains to athletes, due to the brevity of current research available, and the potential for sleep to exert positive effects on athlete specific health, recovery and performance. Specifically, the literature review generated a defined set of research objectives for this PhD. These aims were to characterise sleep and recovery-stress balance in a large number of team sport athletes utilising qualitative assessment tools (Chapter 3 and 4), and to progress sleep analysis to a quantitative level through the use of actigraphy with professional rugby players (Chapter 5). A further aim of Chapter 5 included observing parallel changes in immune function and markers of physiological stress alongside sleep patterns during an intensive pre-season training phase. In addition, Chapter 5 attempted to examine the efficacy of a sleep education programme on promoting sleep extension in elite athletes, and observing what effect sleep extension might have on variables of immune function, physiological stress, performance and skill acquisition. Finally, Chapter 6 aimed to investigate the efficacy of consuming a tart cherry juice concentrate (TC) during a rugby off-season resistance training and conditioning period. Indices of inflammation, muscle soreness and function, sleep and fatigue were monitored during a four week period.

Sleep is regarded as a cornerstone of human health, post-exercise recovery and performance (Venter, 2012). Despite the severe consequences of inadequate sleep (Halson, 2014) and the

apparent advantages of improving sleep (Mah et al., 2011), globally little is known about athlete sleep habits or sleep quality. The objective of Chapter three was to characterise normative sleep quality among a large cohort of highly trained team sport athletes. Sleep was assessed in 175 elite or highly trained rugby sevens, rugby union and cricket athletes using validated questionnaires; the Pittsburgh Sleep Quality Index (PSQI), and the Epworth Sleepiness Scale (ESS). On average athletes reported a reasonable amount of total sleep per night (7.9 ± 1.3 hr). The average PSQI score was 5.9 ± 2.6, and 50 % of athletes were found to be poor sleepers (PSQI >5). Daytime sleepiness was prevalent throughout the population (average global score of 8.5) and clinically significant (ESS score of ≥10) in 28 % of athletes. A considerable number of athletes (38 %) defined themselves as snorers and 8 % reported having a witnessed apnoeic episode, twice that of the general population. Obstructive sleep apnoea (OSA) may therefore be an important clinical consideration within athletic populations. The relationship between self-rated sleep quality and actual PSQI score was strong (Pearson correlation of 0.4 ± 0.1; 90 % confidence limits), suggesting athletes to be sensitive to their own sleep quality. This study was powerful and successfully characterised the sleep landscape among highly trained collision sport athletes in particular. Indeed, the study in Chapter 3 has unearthed a significant and dynamic problem that was previously unrealised within the cohort of interest. Based on these results, it was concluded that team sport athletes may suffer a preponderance of poor sleep quality, with associated high levels of daytime sleepiness and OSA risk. Subsequent studies in this PhD utilised these sleep assessment questionnaires or actigraphy to further investigate athlete sleep as an area of need. Some strong and actionable recommendations may be derived from the findings in Chapter 3. Firstly it is recommended that athletes are regularly screened for poor sleep and OSA risk factors. Athletes should also routinely receive education about how to improve their sleep wake schedules, extend total sleep time, and attempt to improve sleep quality.

Considering the perceived importance of sleep for athletic recovery (Venter, 2012), a closer examination of the relationship between athletic sleep quality and fatigue is important. The RESTQ-Sport Questionnaire is used among different sports to monitor athletes and the impact of training on recovery-stress balance. Sleep quality is included within this monitoring tool. Limited empirical data exists for athletes with no known studies linking RESTQ-Sport derived psychological responses to training with sleep quality and daytime sleepiness. Thus Chapter 4 was novel and contributed significantly to the current body of knowledge on athlete sleep and recovery monitoring. Chapter 4 assessed the reliability of the RESTQ-Sport to accurately monitor sleep among good and poor sleepers observed in Chapter 3. Various RESTQ-Sport sub-scale scores of recovery, including sleep quality, were compared against respective PSQI and ESS scores. The results suggested that the RESTQ-Sport does adequately detect poor sleep in athletes. However, the RESTQ-Sport is not highly sensitive to daytime sleepiness. These results are important, as it has been observed that athletes consistently display poor sleep quality and efficiency (Fietze et al., 2009; Leeder et al., 2012; Mah et al., 2011; Sargent et al., 2014; Shearer et al., 2015) and high levels of sleepiness (Antic et al., 2013; George et al., 2003; Mah et al., 2011). Based on the results outlined in Chapter 4, coaches may rely on the RESTQ-Sport to robustly monitor for poor sleep quality in athletes, and use it to appreciate who is well engaged in pursuing sleep as a recovery modality. Furthermore, it may be recommended that the addition of validated sleep and importantly, sleepiness questionnaires, alongside the RESTQ-Sport, would more accurately inform coaches about an athletes sleep based recovery, and possibly better position an athlete to enhance adaptations to training.

The nature of elite rugby union demands that players train with high intensity to maintain or improve physical qualities such as speed, power and strength. Vital to this performance equation is optimising recovery to enable adaptation to occur (Datillo et al., 2011). Of the

recovery variables available to rugby players, sleep is considered the most important (Venter, 2014). In Chapter 3 it was determined via qualitative means that sleep quality was poor among high level rugby players. Thus Chapter 5 aimed to quantify sleep in this population using actigraphy, during an intensive training phase where sleep quality is critical to supporting training and recovery demands. Changes in immune function and markers of physiological stress during the initial three week training phase were also observed. The objective was then determined to improve sleep via sleep extension, through the delivery of a sleep education and behaviour change programme. The pre-post control trial intervention design of this study was bold, and to the author's knowledge the first of its kind with elite athletes in an applied training environment. Resultant effects on changes in immune function and physiological stress, performance and skill acquisition were observed. Sleep quality was on average poor throughout the control phase (PSQI >5), and daytime sleepiness scores were high (average ESS global score 7.4). Sleep extension resulted in a moderately larger improvement in PSQI sleep quality (-24.8 %; ± 54.1 %) compared to the control. The sleep education programme was successful in changing athlete sleep behaviour, with small and moderate differences observed between the treatments changes in total sleep time (TST) (6.3 %; ± 6.3 %) and time in bed (TIB) (7.3 %; ± 3.6 %) respectively. Differences for all other sleep variables were unclear. Sleep extension had a beneficial effect on physiological stress with a small difference between changes in cortisol (-18.7 %; ± 26.4 %). After sleep extension there was no clear change in passing skill acuity, although sleep extension did result in a small decrease in mean reaction time (-4.3 %; ± 3.1 %) and fastest 10 % time (-3.3 %; ± 2.9 %). Interestingly, a moderate increase in the slowest 10 % time was observed (11.7 %; ± 7.2 %). It was concluded that professional rugby players are at high risk of poor sleep during pre-season training, with concomitant rises in physical stress. However, sleep extension can improve sleep quantity, successfully mitigate stress hormone expression, and

create beneficial changes in performance. Thus the contribution of this elite athlete focused study to the area of applied sleep science is noteworthy. Undertaking research in applied performance settings is challenging, and yet the results are of considerable value with respect to the cohort of interest. As such, implementing a sleep extension programme among professional athletes is strongly recommended. The potential sleep, recovery and performance benefits that are available to the athlete from such an intervention are considerable.

The behaviour change intervention described in Chapter 5 is an important initial step in improving athlete's sleep and where most sleep related gains will be achieved. However, given elite athletes look for every possible performance gain to secure a competitive edge, it is necessary to investigate other strategies to improve sleep. Many sleep-nutrient interactions have been suggested, including TC. Anecdotally, TC is often consumed by rugby players for sleep and recovery purposes, particularly inflammation and soreness. Therefore, Chapter 6 aimed to investigate whether TC was effective in reducing secondary inflammation in rugby players during a resistance training phase. In addition to changes in inflammation, variables of delayed onset muscle soreness and muscle function, subjective sleep quality and daytime sleepiness, and self-perceived mental fatigue were observed. At the completion of the four week trial, the TC intervention demonstrated a decrease in C-Reactive Protein concentration (-8.5 % ± 97.3 %) compared to an increase in the placebo control (119 % ± 174 %), with a moderate difference in the change in C-RP between the groups (-0.98; ± 1.16). The effect of TC on measures of sleep and daytime sleepiness, fatigue and muscle soreness were inconclusive. However, beneficial trends were noted among the TC intervention participants, including decreases in white blood cells related to the secondary inflammation cascade, improved delayed onset muscle soreness and bench press performance, and lower subjective scores for pre-training fatigue. Only the TC intervention participants reported a small

beneficial change in sleep quality over the four week period (-0.47 ± 0.57). Relationships were also established between changes in fatigue and changes in peak power (r = -0.35 ± 0.38) and peak velocity (r = -0.33 ± 0.39) values for bench press.

The amelioration of secondary inflammation in this study is of significant importance to collision sport athletes, who experience a high degree of physiological damage (McLellan & Lovell, 2012; Smart et al., 2008; Takarada, 2003; Twist et al., 2012). The anti-inflammatory benefits observed may be attributed to the anthocyanin content or other potent compounds present in TC juice (Howatson et al., 2011). Tart cherry juice supplementation may be an important component of a post-exercise recovery nutrition programme to mitigate inflammation when this is considered important for an athlete. For example, TC juice may be helpful during intensive or between repeat bouts of competition, such as rugby 7s tournaments, during rehabilitation from injury, or indeed during intense training phases. Perhaps more significantly, reducing inflammation in athletes may have a worthwhile effect on sleep based recovery in particular. The fact that there is a bi-phasic relationship between inflammatory chemicals and sleep quality, and higher degrees of inflammation may dysregulate sleep (Motivala & Irwin, 2007), suggests that the research in Chapter 6 was of high investigative importance. Further research is required to establish both a minimal effective dose of TC juice for sleep and performance, and to better inform supplementation guidelines. Quantifying the impact of supplementation on changes in sleep variables alongside changes in secondary inflammation, across a variety of training models, would be a logical and progressive step towards better understanding the potential in this fascinating fruit. Whilst there are potential benefits for sleep, recovery and performance from consuming tart cherry juice, athletes should be guided in how to consume a balanced anti-oxidant rich diet to support daily training and recovery demands.

The research outcomes of this PhD have contributed greatly to the current body of knowledge that exists on sleep in athletes. Indeed, prior to this PhD research project, there were no studies examining sleep in athletes of any level in New Zealand, and little quantifiable sleep research on collision sport athletes globally. Sports practitioners are now strongly positioned to continue monitoring sleep quality, daytime sleepiness and OSA risk factors among athletes, with the revelation that both sleep quantity and sleep quality are poor among highly trained collision sport athletes. Sleep questionnaire global score cut offs, actigraphy data and clinical suspicion may be used to inform practitioners and coaches about athletes who are not sleeping well, and prioritise interventions to improve sleep. Indeed, alongside progressive sleep analysis research in collision sport athletes, novel interventions to improve sleep were explored, with promising benefits for recovery and performance. Education and nutrient based interventions appear capable of improving indices of total sleep time, sleep quality, stress hormone secretion, reaction times and whole body inflammation.

7.2 Limitations

The study of sleep in humans as it relates to indices of health, recovery and performance is multifaceted. While sleep is in itself a highly complex biological process that is not completely understood, both the biology of sleep and sleep behaviour are influenced by a multitude of factors. Such influences may include light, circadian rhythms, genetics, environmental factors such as noise and temperature, degrees of preceding mental and physical stress and social influences, among others. Furthermore, indices of stress and recovery display a high degree of inter-individual variability, and performance may be influenced by intrinsic motivation, concentration and familiarisation. Whilst these sources of bias are acknowledged, they were difficult to control within the scope of these studies.

Additional limitations of this PhD include:

- Chapter three utilised subjective self-assessment questionnaires to evaluate total sleep time, sleep quality and sleepiness. Subjective estimates of sleep time may differ from data obtained via quantifiable means, thus total sleep times reported in Chapter 3 may be inaccurate.
- The context in which an ESS questionnaire is given may influence participant responses. Competitive athletes are often cognisant of threats to selection, which may alter the information they are willing to volunteer.
- In Chapter 5, changes in markers of immune function and sympathetic nervous activity may have been affected by inter-individual variability, and testing time of day. Only one sample was collected at each time point during the study, which may have exacerbated the effect of variance.
- Due to the professional training requirements of the athletes, saliva samples were collected after feeding. As such, the direct comparison of results with previous research that used a fasted protocol is difficult.
- Not all subjects participated in all variables tested in Chapter 5, which may have affected the significance of results.
- A finite set of eight sleep watches were available for monitoring sleep in the sleep extension study (Chapter 5), meaning that watches had to be cycled among participants, and therefore sleep was not recorded for every night for every participant. Therefore the number of sleep watches available may have affected pre-post comparisons of each intervention.
- Despite napping being commonplace, participants did not record a great deal of naps while wearing sleep watches in the sleep extension study. Thus total sleep times derived from naps may be underestimated.

- Skill acquisition baseline testing was not conducted during the control phase in the sleep extension study, but rather at the beginning of the sleep extension phase. It was not possible to accommodate the assessment or testing of passing skills during the control trial due to the coach driven emphasis of resistance and conditioning training only during this period.
- The length of the sleep extension period may have been a limiting factor with respect to skill acquisition, and increasing total sleep time beyond what was achieved in the study may also be important to optimise skill development.
- Comparing skill acquisition improvements with other sleep extension research is difficult due to the elite level of the athlete involved in this study and the high level of pre-existing skill.
- Training squad size studied in Chapter 6 (n=16) likely impacted on the significance of the results, particularly for sleep, fatigue, muscle soreness and muscle function variables. Specifically, the placebo controlled design meant that only eight participants were available for each intervention group. The applied training programme was not of adequate length to accommodate a cross over design, including inadequate time for a wash out period between treatments.
- In Chapter 6, it is likely that a higher dose of TC may have elicited more significant changes in the variables examined. However, an important aim of the study was to examine the efficacy of a comparatively lower TC dose than that used in other research. Therefore these findings remain important.
- With regards to muscle function and strength changes in Chapter 6, monitoring strength differences between the groups over a longer period of time may have been required to identify differences in strength acquisition and muscle function due to the time course of adaptation.

- With regards to monitoring sleep variables in Chapter 6, the method of sleep assessment via questionnaires may have been insensitive to identify changes in sleep quality between groups. As described in chapter five, sleep watches could have been used to monitor sleep, but again watches would have been inadequate in number for every participant to wear every night.
- Finally, the use of sleep questionnaires in Chapter 6 makes comparisons with quantitative TC sleep research difficult. However, questionnaires were used to enable the recording of regular sleep data for every participant throughout the study period.

7.3 Practical Applications

Sleep is considered critical for optimising athlete physiological and cognitive health (Fullagar et al., 2015), is an essential element of exercise adaptation (Datillo et al, 2011) and post-exercise recovery (Venter, 2014) and is strongly correlated with sport specific performance (Fullagar et al., 2015; Mah et al., 2011). The principle applications of this PhD thesis for sports science practitioners and coaches include:

- Highly trained collision sport athletes are at risk of inadequate sleep quantity and display a preponderance of poor sleep quality and daytime sleepiness.
- Therefore, team sport athletes should be regularly screened for sleep quantity and quality to better monitor respective recovery-stress states.
- Once sleep monitoring is established, the utilisation of a sleep extension programme during periods of intense training may confer powerful benefits to athletes.
- The consideration of other potential sleep and recovery strategies such as sleep-nutrient interactions and specifically, TC supplementation, is prudent in highly trained collision sport athletes.

I. It would appear that athletes are a very high risk population with regards to obtaining inadequate sleep quantity and experiencing poor sleep quality. Poor sleep efficiency and a high degree of sleep fragmentation in particular appear to disrupt the total amount of sleep athletes are able to achieve. Of significance, as many as one in every two team sport athletes may be experiencing sleep difficulties, and one in three may report consequences of poor sleep such as significant daytime sleepiness, or fatigue. The physical characteristics of collision sport athletes, such as a high BMI and large neck circumference, may predispose them to a greater risk of OSA. The prevalence of OSA risk factors in highly trained collision sport athletes is approximately twice that of the general population, and the sports science and medical practitioner should remain cognisant of this potential threat to an athlete's health, recovery and performance.

II. Regular screening of sleep with the PSQI and ESS questionnaires offers a robust and valid method to detect those athletes who may suffer poor sleep. These questionnaires generate a global score, are simple to complete, and can be easily hand scored. Sleep questionnaires may be considered in the first instance to gain a rapid account of a team's sleep status, and identify individuals who may benefit from further evaluation or treatment. In addition, actigraphy watches create the potential to accurately quantify athlete indices of sleep quantity and quality. Actigraphy should be utilised in conjunction with a sleep diary to cross check sleep wake times and naps. Actigraphy watches can be expensive, and require more time and human resource to utilise. However, actigraphy does engage an athlete effectively and the generation of data creates good leverage for influencing behaviour change. Close liaison between sports scientists and a squad's medical team is also important with regard to screening for snoring and associated sleep

disordered breathing. Screening for sleep quality via qualitative or quantitative means would be a powerful strategy to developing, optimising and recovering the collision sport athlete.

III. Monitoring the recovery-stress state of an athlete with a validated fatigue monitoring tool such as the RESTQ-Sport allows the sports science practitioner and coach to accurately gauge an individual's response to training, and evaluate how much training stress can be tolerated. The RESTQ-Sport also helps identify which recovery modality an athlete is engaging with, or not performing effectively. Of the available recovery modalities, sleep is arguably the most important. Furthermore, sleep quality is susceptible to disintegrating under heavy training. The RESTQ-Sport sub scales of sleep quality and lack of energy have been shown to correlate highly with the PSQI, and may detect poor sleep in athletes. However, the RESTQ-Sport is not highly sensitive to sleepiness levels in athletes. Considering sleepiness is prevalent among athletes, and may represent fatigue or a lack of readiness to perform, the use of a more accurate monitoring tool to detect sleepiness during training phases may be worthwhile, particularly during hard training. The ESS presents as a validated monitoring tool for this purpose. Furthermore, the PSQI provides a more thorough investigation of sleep quality than the RESTQ-Sport alone, and could identify possible reasons for poor sleep quality. Importantly, the RESTQ-Sport may inform coaches if an athlete is tolerating a certain amount of training stress. The ability to absorb large amounts of training places the athlete in a prime position to steepen adaptation in response to training. Thus more thorough monitoring of training stress and sleep in athletes via the RESTQ-Sport is a worthwhile intervention.

IV. The improvement of poor sleep in elite collision sport athletes appears to confer worthwhile benefits regarding the absorption of physiological stress and enhancing performance during intensive training. Sleep extension education and sleep related behaviour change during intensive training phases is therefore strongly recommended in conjunction with sleep monitoring. Education is appropriate at a group level, but ensuring adequate time with individual athletes, even in busy elite programmes, should be prioritised for optimal learning and outcomes. Athletes appear to respond well to seeing their individual sleep data, and use this as an incentive to improve habits. Whilst educating athletes in the area of sleep hygiene and sleep extension is important, empowering them with opportunities to sleep via appropriately planned training programmes is a prudent consideration. Factors such as family and social circumstances, work, study and commute times to trainings in large cities, as well as early and late training times may all disrupt sleep opportunities. Training times are often a controllable factor for coaches to be mindful of. Indeed coaches may amplify training adaptations by prioritising sleep when scheduling training. Sleep may be considered an anabolic and restorative process, allowing an athlete to mitigate physiological stressors. An alternative way to consider this point is that a well slept athlete may tolerate more training stress, possibly resulting in greater adaptation. Neurocognitive performance improvements are also possible during intense training phases, and extending sleep extension into competition phases may be beneficial for team sports where neurocognitive performance is an essential element of sporting success.

V. Supplementing resistance trained athletes with TC once per day exerts a positive influence on reducing whole body inflammation. Therefore, TC may be used to

enhance recovery in collision sport athletes, who endure high degrees of physiological damage from training and competition. The trends detailed in Chapter 6 including improved muscle function and decreased soreness may be significant within the context of rugby 7s, where intensive competition over two-three days involves accrued muscle damage, and associated symptoms potentially limiting performance. Reducing inflammation and soreness may also improve sleep quality. Debate exists around appropriate dosing and timing of TC supplementation. However, sports science practitioners should consider at least one and possibly two TC doses per day, to exert beneficial anti-inflammatory effects, and possibly promote additional sleep based recovery and performance effects via phyto-chemical support. Practitioners should also evaluate the overall antioxidant intake of the athlete, to take full advantage of the immune, anti-inflammatory and anabolic benefits of fresh fruit and vegetables. In particular, dark skinned green, blue, purple and red produce, including tart cherries, should be included in the daily diet at regular intervals, including the evening meal and/or before bed. Finally, consumption after evening training or with an evening meal are both appropriate times to consume TC.

7.4 Future Research Directions

The research field of sleep in athletes is relatively embryonic compared to other areas of sports science. The studies compiling this PhD thesis have filled a significant void in what was previously unknown about sleep in collision sport athletes. Furthermore, this body of research may prove a catalyst for future investigative work on why athletes do not sleep well, how sleep may be enhanced in different situations, and to what effect.

Research designs investigating sleep and athletic potential are difficult to design. There is a brevity of, and yet a great desire for, quality research using traditional methodology such as control trial interventions among elite athletes. Applied research brings with it a unique set of challenges, and variables have the potential to be difficult to control. However, future research should strive to explore 'real life' sleep and elite athlete responses to sleep interventions; as such findings become highly applicable to elite environments. The use of controls must also be balanced against the consideration of denying a group of athletes potentially performance enhancing strategies. Blinding sleep studies is also not feasible. Nevertheless, future research should aim to incorporate placebo and controlled trials within applied methodology. Responses to interventions within artificially induced competition may be difficult to evaluate, due to a heightened psychological response to real competition. However, off season and pre-season training phases present an opportune time to investigate athletes with respect to monitoring and introducing novel sleep studies. The question of how sleep enhancement may influence or possibly accelerate physical adaptations to training such as strength and power remains to be answered. Within collision sports, further sleep extension studies may also be applied during a competition phase, and correlated with sport specific performance outcomes.

Methods to assess and monitor sleep should not be limited to those used in this thesis. The use of overnight sleep respiratory studies, obtaining quantitative data on snoring, respiration, blood oxygen saturation and cardiovascular patterns through the night, as well as sleep cycle architecture, would add invaluably to sleep data characterised in this thesis. Furthermore, the prevalence and severity of sleep disordered breathing may be further defined in collision sport athletes. Additionally, with technological advancements in wireless sleep analysis technology, and the potential practicality of using these with athletes, future studies should aim to validate their use. The addition of validated sleep questionnaires such as the PSQI and ESS alongside the routine use of the RESTQ-Sport would more accurately inform coaches about an athletes sleep based recovery, and possibly better position an athlete to enhance adaptation to training. Further research, applying these questionnaires together as a comprehensive monitoring battery during intense training, is required.

Adolescents have different sleep patterns and needs compared to adults; they experience a delayed sleep phase and prefer a later waking time (Carskaden, 2005). Therefore, adolescent athletes may be at greater risk of inadequate sleep due to school and early training commitments. Therefore, further research aimed at better characterising sleep and understanding the possible impact poor sleep has on adolescent health and sport performance are warranted.

Injury prevention is an important focus for sport science and sports medicine. Methods to improve sleep hold the potential to reduce injury risks in athletes at both the adolescent, sub-elite and elite level. Only a small amount of research has begun to explore this important aspect of athlete health (Luke et al., 2011; Milewski et al, 2014). Future studies addressing the relationship between sleep quality and injury are suggested and may contribute significantly to the areas of injury prevention, recovery and indeed performance.

The effects of sleep extension need to be studied more thoroughly in athletes. Preliminary results from this thesis and previous research suggest significant benefits are available to athletes at a recovery and performance level if they simply sleep more. A longitudinal sleep extension study greater than three weeks in duration may illuminate potential benefits concerning enhanced skill acquisition in particular. Biomarkers of immune response and physiological stress may also be better monitored in future studies by obtaining repeated samples at each time point, to accommodate the high degree of variability inherent in these tests.

When studying elite athletes, obtaining access to adequate participant numbers is important for statistical significance. Further investigating the effects of TC consumption within a larger cohort, and possibly utilising a crossover design, would add to the results discussed in this thesis. Furthermore, repeating the TC study design described in this thesis, but examining the effects of two daily serves rather than one, would be an important step towards informing effective dosing guidelines. Supplementing with a double evening dose, perhaps separated by two hours (with dinner and immediately before bed), would also add a novel investigation to existing literature.

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APPENDICES

Appendix 1. Ethics Approval Forms

Appendix 1a. Ethics application number 12/262

(Chapters 3 and 4)

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

AUTEC SECRETARIAT

20 November 2012

Nic Gill
Faculty of Health and Environmental Sciences
Dear Nic
Re Ethics Application: **12/262 - Qualitative assessment of sleep quantity and quality in academy and elite athletes in New Zealand - A pilot study.**
Thank you for providing evidence as requested, which satisfies the points raised by the AUT University Ethics Committee (AUTEC).
Your ethics application has been approved for three years until 16 November 2015.
As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online throughhttp://www.aut.ac.nz/research/research-ethics/ethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 16 November 2015;
- A brief report on the status of the project using form EA3, which is available online throughhttp://www.aut.ac.nz/research/research-ethics/ethics. This report is to be submitted either when the approval expires on 16 November 2015 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,

Dr Rosemary Godbold
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Richard Swinbourne swinbourne@xtra.co.nz

Appendix 1b. Ethics application number 13/348

(Chapter 5)

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

A U T E C
S E C R E T A R I A T

27 November 2013

Nic Gill
Faculty of Health and Environmental Sciences

Dear Nic

Re Ethics Application: **13/348 What are the effects of a 4 week Super 15 rugby training programme on variables of sleep, immune response and markers of physical stress.**

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

Your ethics application has been approved for three years until 27 November 2016.

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

- A brief annual progress report using form EA2, which is available online throughhttp://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 27 November 2016;
- 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 27 November 2016 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: Richard Swinbourne swinbourne@xtra.co.nz

Appendix 1c. Ethics application number 13/373

(Chapter 5)

AUTEC SECRETARIAT

18 December 2013

Nic Gill
Faculty of Health and Environmental Sciences

Dear Nic
Re Ethics Application: **13/373 What are the effects of a sleep hygiene education programme and sleep extension on variables of sleep, exercise adaptation and skill acquisition, immune response and markers of physical stress during a Super 15 rugby training programme?**
Thank you for providing evidence as requested, which satisfies the points raised by the AUT University Ethics Committee (AUTEC).
Your ethics application has been approved for three years until 18 December 2016.
As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online throughhttp://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 18 December 2016;
- 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 18 December 2016 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: Richard Swinborune swinbourne@xtra.co.nz

Appendix 1d. Ethics application number 14/303

(Chapter 6)

AUTEC
SECRETARIAT

2 October 2014

Nicholas Gill
Faculty of Health and Environmental Sciences

Dear Nicholas

Re Ethics Application: **14/303 Effect of tart cherry juice on sleep, recovery, exercise adaptation and markers of immune response and inflammation in rugby union players: A randomised placebo controlled trial.**

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

Your ethics application has been approved for three years until 2 October 2017.

We note that your NZRU email address is being used as the contact detail, please amend this to your AUT email address.

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

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 2 October 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 2 October 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.

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: Richard Swinbourne swinbourne@xtra.co.nz

Appendix 2. Consent forms

Appendix 2a. Qualitative Sleep and Recovery Assessment

Consent Form

Questionnaire based study

Project title: **Qualitative assessment of sleep quantity and quality in academy and elite athletes in New Zealand – A Pilot Study**

Project Supervisor: ***Dr Nicholas Gill, Dr Jo Vaile***

Researcher: ***Richard Swinbourne***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 23rd September 2012.
- ○ 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.
- ○ If I withdraw, I understand that all relevant information, or parts thereof, will be destroyed.
- ○ 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:

.....……

Participant's name:

.....……

Participant's Contact Details (if appropriate):

……..

……..

……..

……..

Date:

Approved by the Auckland University of Technology Ethics Committee on 20th November 2012

AUTEC Reference number 12/262

Appendix 2b. Quantitative Sleep Assessment and Biochemical Analyses

Consent Form

Project title: ***What are the effects of a 4 week Super 15 rugby training programme on variables of sleep, immune response and markers of physical stress?***

Project Supervisor: ***Dr Nicholas Gill, Dr Jo Vaile***

Researcher: ***Richard Swinbourne***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 6th November 2013.
- ○ 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.
- ○ If I withdraw, I understand that all relevant information, or parts thereof, will be destroyed.
- ○ I understand and consent to my data being stored for future use in a subsequent study.
- ○ I understand and consent that information will not be shared with an identified team doctor/medical team/team management in the case of a sleep disorder or sub-optimal sleep being diagnosed, unless I give my explicit and prior consent to do so, so that help or medical referral can be actioned. The team doctor may not share information about me with coaches and management without my consent.
- ○ Salivary samples will be collected during this study to collect data on immune status and physical stress. Please indicate if you wish to have your saliva samples returned to you at the conclusion of the study.

  I wish to have my saliva returned to me at the end of the research

  (please tick one): Yes○ No○

- ○ 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: .....……
Participant's name: .....……
Participant's Contact Email Details:……
Date:

Approved by the Auckland University of Technology Ethics Committee on 27th November 2013
AUTEC Reference number 13/348

Appendix 2c. Sleep Extension Intervention

Consent Form

Project title: ***What are the effects of a sleep hygiene education programme and sleep extension on variables of sleep, exercise adaptation and skill acquisition, immune response and markers of physical stress during a Super 15 rugby training programme?***

Project Supervisor: ***Dr Nicholas Gill, Dr Jo Vaile***

Researcher: ***Richard Swinbourne***

○ I have read and understood the information provided about this research project in the Information Sheet dated 20th November 2013.

○ 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.

○ If I withdraw, I understand that all relevant information, or parts thereof, will be destroyed.

○ I understand and consent that information will not be shared with an identified team doctor/medical team/team management in the case of a sleep disorder or sub-optimal sleep being diagnosed, unless I give my explicit and prior consent to do so, so that help or medical referral can be actioned. The team doctor may not share information about me with coaches and management without my consent.

○ Salivary samples will be collected during this study to collect data on immune status and physical stress. Please indicate if you wish to have your saliva samples returned to you at the conclusion of the study.

I wish to have my saliva returned to me at the end of the research

(please tick one): Yes○ No○

○ 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: .....

Participant's name: .....

Participant's Contact Email Details:……

Date:

Approved by the Auckland University of Technology Ethics Committee on 18th December 2013
***AUTEC Reference number* 13/373**

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Appendix 2d. Sleep-Nutrient Intervention

Consent Form

Project title: ***Effect of two fruit juices on sleep, recovery, exercise adaptation and markers of immune response and inflammation in rugby union players.***

Project Supervisor: ***Dr Nicholas Gill, Dr Jo Vaile***

Researcher: ***Richard Swinbourne***

○ I have read and understood the information provided about this research project in the Information Sheet dated 09 September 2014.

○ 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.

○ If I withdraw, I understand that all relevant information, or parts thereof, will be destroyed.

○ I understand and consent that information will not be shared with an identified team doctor/medical team/team management in the case of a sleep disorder or sub-optimal sleep being diagnosed, unless I give my explicit and prior consent to do so, so that help or medical referral can be actioned. The team doctor may not share information about me with coaches and management without my consent.

○ Blood samples will be collected during this study to collect data on immune status and physical stress. Please indicate if you wish to have your blood samples returned to you at the conclusion of the study.

I wish to have my blood returned to me at the end of the research

(please tick one): Yes○ No○

○ 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: .....

Participant's name: .....

Participant's Contact Email Details:.....

Date:

Approved by the Auckland University of Technology Ethics Committee on 2nd October 2014
***AUTEC Reference number* 14/303**

Appendix 3. Study Information Sheets

Appendix 3a. Qualitative Sleep and Recovery Assessment

Participant Information Sheet

Date Information Sheet Produced:

23-9-12

Project Title

Qualitative assessment of sleep quantity and quality in academy and elite athletes in New Zealand – A Pilot Study

An Invitation

My name is Richard Swinbourne. I am the High Performance Nutritionist for the NZRU and I am doing my PhD in the area of sleep for athletic performance and recovery. I would like to invite you to take part in this questionnaire, which will contribute towards my PhD. Your participation is completely voluntary, and you are free to withdraw at any time prior to the completion of data collection. If you chose not to participate in this questionnaire there will not be any consequences. There is no pressure to participate, I am not in a position of selection within this team; my dual role is simply as a nutritional assessor and educator and researcher.

What is the purpose of this research?

There are a large number of adult New Zealanders who have a sleep problem, or do not sleep enough, but we do not know if this applies to athletes. Compared to other areas of sports science relatively little is known about sleep behaviour and sleep quality in elite athletes. It is essential we better understand sleep, it's relationship with nutrition and stress/recovery, and determine the extent of poor sleep among leading sports in New Zealand. This study will also help to identify which athletes are experiencing adequate or inadequate sleep quality, so that education and help can be provided, with an aim to enhancing both health and performance. Results from this research will contribute towards my PhD, may be presented at scientific conferences, and will be published in a scientific journal.

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

You have been identified because you are an athlete within a sporting team / sport and or organisation which was targeted for this research, and with whom I the researcher work. You are being invited to participate in this research because you are a member of an athletic group of interest with respect to sleep.

What will happen in this research?

This study requires you to fill out three different questionnaires. The first is a sleep screening questionnaire. The second is a stress and recovery questionnaire, looking at how you have felt as a result of your training / competition in the past 3 days. The third is a food frequency questionnaire, which looks at the types of foods you have eaten and supplement use in the past month, and how often you have consumed them. The data I collect from you will only be used for the purposes of this PhD. It may guide future studies, and it may also assist you as an athlete if you are identified with sleep or recovery problems, as a management and treatment plan can be designed for you.

What are the discomforts and risks?

There are no discomforts or risks to completing these questionnaires.

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What are the benefits?

Your participation will certainly benefit me in gaining my PhD doctorate qualification. Answering honestly also puts you in a beneficial and unique position as an athlete to learn about your sleep scores, and possibly receive help if you require it which would be fundamental to enhancing your recovery and sports performance.

How will my privacy be protected?

All data and consent forms will be kept confidential and stored securely for an indefinite time. Data may be used in future research, as this area is very novel. You will record your name and email on the questionnaires to facilitate follow up education and / or medical referral and to receive your results, and responses will not be anonymous to the me, the researcher, but will be confidential and not witnessed by other persons. All data will be stored securely at the researcher's office. You will understand and consent that information may be shared with an identified team doctor in the case of a sleep disorder or sub-optimal sleep being diagnosed, so that help or medical referral can be actioned. The team doctor may discuss this medical issue with the coaches and management team as they see fit.

What are the costs of participating in this research?

The only cost to you is your time, approximately 30 minutes to complete the questionnaires, on two or three occasions throughout the season.

What opportunity do I have to consider this invitation?

You have approximately one week to consider this invitation before I enter camp to seek your voluntary participation and consent, and you may withdraw at any time before completion if you do not wish to continue.

How do I agree to participate in this research?

You need to sign a consent form, which I will give to you prior to participating in the study.

Will I receive feedback on the results of this research?

Yes you will, an anonymous team average sleep score will be provided to team management, and your individual sleep score and recovery score will be emailed to you, (and possibly discussed in person while I am in camp with you), once data is scored.

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 Nicholas Gill, Research fellow, AUT, Nicholas Gill Nicholas.Gill@nzrugby.co.nz, ph 0274 888 699

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Dr Rosemary Godbold, *rosemary.godbold@aut.ac.nz* , 921 9999 ext 6902.

Whom do I contact for further information about this research?

Researcher Contact Details:

Richard Swinbourne, Swinbourne@xtra.co.nz

Project Supervisor Contact Details:

Dr Nicholas Gill, Strength and Conditioning Coach, All Blacks, Nicholas Gill Nicholas.Gill@nzrugby.co.nz, ph 0274 888 699

Approved by the Auckland University of Technology Ethics Committee on 20th November 2012
AUTEC Reference number 12/262

Appendix 3b. Quantitative Sleep Assessment and Biochemical Analyses

Participant Information Sheet

Date Information Sheet Produced: 6-11-2013

Project Title: What are the effects of a 4 week Super 15 rugby training programme on variables of sleep, immune response and markers of physical stress.

An Invitation

My name is Richard Swinbourne. I am the High Performance Nutritionist for the NZRU and I am doing my PhD in the area of sleep for athletic performance and recovery. I would like to invite you to take part in this study, which will contribute towards my PhD. Your participation is completely voluntary, and you are free to withdraw both your data and participation at any time prior to the completion of data collection. If you chose not to participate in this study there will not be any consequences. There is no pressure to participate, I am not in a position of selection or influence within this team.

What is the purpose of this research?

I appears that there are a large number of elite athletes in New Zealand who are not sleeping well. Compared to other areas of sports science relatively little is known about sleep behaviour and sleep quality in elite athletes, and how this changes and effects immune strength and physiological stress during a Super 15 pre-season training programme. It is essential we better understand sleep, it's relationship with immune strength and stress/recovery, and determine the extent to which these change during hard training. This study will also help to identify which athletes are experiencing adequate or inadequate sleep quality, so that education and help can be provided, with an aim to enhancing both health and performance. Results from this research will contribute towards my PhD, may be presented at scientific conferences, and will be published in a scientific journal.

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

You have been identified because you are an athlete within the Hurricanes Super 15 rugby team, which was targeted for this research. You are being invited to participate in this research because you are a member of an athletic group of interest with respect to sleep.

What will happen in this research?

This study requires you to wear an actigraph sleep monitoring watch for 3-4 nights at a time, on 2-3 occasions during December. This watch will monitor the time you spend awake and asleep each day. You will also need to write down the times you go to sleep and wake up each day in a sleep diary, including naps. You will do this when you report to training in the morning, or at home on weekends. You will need to perform a reaction time test each week (5 minutes) which is computer based, and fill out a sleep quality

questionnaire and a sleepiness questionnaire each week (on different days). You will undertake all fitness training and testing sessions and body composition testing as part of your normal Hurricanes preparation. This will include strength, power, and speed tests, and an aerobic yo yo running test. Of note, you will also need to provide a saliva sample on three occasions during the December training phase, which will test for immune antibody IgA (immune function/strength), cortisol (stress) and alpha amylase enzyme (nervous system stimulation). Injury and illness rates will also be collected by the team doctor and physio. The data I collect from you will only be used for the purposes of this PhD. It may guide future studies, and it may also assist you as an athlete if you are identified with sleep or recovery problems, as a management and treatment plan can be designed for you to carry forward into future campaigns if you consent to this.

In addition there will be a control group of rugby players undertaking similar training and tests to you to compare results, and generate baseline information for a subsequent study next year.

What are the discomforts and risks?

There are no discomforts or risks to completing these tests other than those recognised as a part of your rugby profession (musculo-skeletal injury during physical testing).

What are the benefits?

Your participation will certainly benefit me in gaining my PhD doctorate qualification. Participating honestly also puts you in a beneficial and unique position as an athlete to learn about your sleep and recovery scores and how these relate to performance, and possibly receive help if you require it which would be fundamental to enhancing your recovery and sports performance.

How will my privacy be protected?

All data and consent forms will be kept confidential and stored securely for an indefinite time. Data may be used in future research, as this area is very novel. You will record your name and email on the questionnaires to facilitate follow up education and / or medical referral and to receive your results, and responses will not be anonymous to me, the researcher, but will be confidential and not witnessed by other persons. All data will be stored securely at the researcher's office for at least 10 years, and consent forms will be stored at AUT for at least 10 years. I understand and consent that information will not be shared with an identified team doctor/medical team/team management in the case of a sleep disorder or sub-optimal sleep being diagnosed, unless I give my explicit and prior consent to do so, so that help or medical referral can be actioned. The team doctor may discuss this medical issue with the coaches and management team, but only if you consent to this first. Saliva samples will be held frozen at the Hurricanes training site until analysed, after which you may have these returned to you if you wish. No medical information will be shared with me by the medical team, only summary statistics on injury/illness rates.

What are the costs of participating in this research?

The only cost to you is your time, you have to wear the sleep monitor watch on occasions, and record your sleep and wake up time each day in a diary (1 minute each day) as well as fill in 2 short questionnaires each week (5 minutes), do a 5 minute reaction time test each week and provide a saliva sample 3 times (2-3 minutes each time). All associated costs for running this project have been paid for by me, the researcher, with the assistance of research scholarships from New Zealand Rugby Union and High Performance Sport New Zealand, administered by AUT.

What opportunity do I have to consider this invitation?

You have 4 days to consider this invitation before I seek your voluntary participation and consent, and you may withdraw at any time before completion if you do not wish to continue.

How do I agree to participate in this research?

You need to sign a consent form, which I will give to you prior to participating in the study.

Will I receive feedback on the results of this research?

Yes you will, an anonymous team average sleep score will be provided to team management, and your individual data summary and score will be emailed to you, once data is analysed.

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 Nicholas Gill, Research fellow, AUT, Nicholas Gill Nicholas.Gill@nzrugby.co.nz, ph 0274 888 699. Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Dr Kate O'Connor, *ethics@aut.ac.nz* , 921 9999 ext 6038.

Whom do I contact for further information about this research?

Researcher Contact Details: **Richard Swinbourne, swinbourne@xtra.co.nz**
Project Supervisor Contact Details: Dr Nicholas Gill, Strength and Conditioning Coach, All Blacks, Nicholas Gill Nicholas.Gill@nzrugby.co.nz, ph 0274 888 699

Approved by the Auckland University of Technology Ethics Committee on 27th November 2013
AUTEC Reference number 13/348

Appendix 3c. Sleep Extension Intervention

Participant Information Sheet

Date Information Sheet Produced: 20-11-2013

Project Title:

What are the effects of a sleep hygiene education programme and sleep extension on variables of sleep, exercise adaptation and skill acquisition, immune response and markers of physical stress during a Super 15 rugby training programme?

An Invitation

My name is Richard Swinbourne. I am the High Performance Nutritionist for the NZRU and I am doing my PhD in the area of sleep for athletic performance and recovery. I would like to invite you to take part in this study, which will contribute towards my PhD. Your participation is completely voluntary, and you are free to withdraw at any time prior to the completion of data collection. If you chose not to participate in this study there will not be any consequences. There is no pressure to participate, I am not in a position of selection or influence within this team.

What is the purpose of this research?

It appears that there are a large number of elite athletes in New Zealand who are not sleeping well or sleeping long enough. Furthermore, it seems that if athletes sleep more, they adapt to exercise and get fitter faster, learn sports skills more quickly and start performing better in their sport. Compared to other areas of sports science relatively little is known about sleep quality and this relationship with performance though, and nothing is known about this in rugby. It is also an unknown in elite athletes how sleeping more changes and effects immune strength and physiological stress during a Super 15 pre-season training programme. It is essential we better understand sleep, its relationship with exercise adaptation, skill learning, immune strength and stress/recovery, and determine the extent to which these changes during hard training. This study will also establish whether a sleep education programme in a Super rugby environment can change and improve pre sleep behaviour and sleep quality. Results from this research will contribute towards my PhD, may be presented at scientific conferences, and will be published in a scientific journal.

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

You have been identified because you are an athlete within the Hurricanes Super 15 rugby team, which was targeted for this research. You are being invited to participate in this research because you are a member of an athletic group of interest with respect to sleep.

What will happen in this research?

This study requires you to try and sleep longer each night, aiming for 10 hours per night, and have a nap during the day if you feel like it, to extend your daily sleep. You will have to wear an actigraph sleep monitoring watch for 3-4 nights at a time, on 2-3 occasions during December. This watch will monitor the time you spend awake and asleep each day. You will also need to write down the times you go to sleep and wake up each day in a sleep diary, including naps. You will do this when you report to training in the morning, or at home on weekends. You will need to perform a reaction time test each week (5 minutes) which is computer based, and fill out a sleep quality questionnaire and a sleepiness questionnaire each week (on different days). You will undertake all fitness training and testing sessions and body composition testing as part of your normal Hurricanes preparation. This will include strength, power, and speed tests, and an aerobic yo yo running test. You will have to perform a passing drill through a target each week. Of note, you will also need to provide a saliva sample on three occasions during the December training phase, which will test for immune antibody IgA (immune function/strength), cortisol (stress) and alpha amylase enzyme (nervous system stimulation). Injury and illness rates will also be collected by the team doctor and physio. The data I collect from you will only be used for the purposes of this PhD. It may guide future studies, and it may also assist you as an athlete if you are identified with sleep or recovery problems, as a management and treatment plan can be designed for you to carry forward into future campaigns if you consent to this. In addition there will be a control group of rugby players undertaking similar training and tests to you to compare results, and generate baseline information for a subsequent study next year.

What are the discomforts and risks?

There are no discomforts or risks to completing these tests other than those recognised as a part of your rugby profession (musculo-skeletal injury during physical testing).

What are the benefits?

Your participation will certainly benefit me in gaining my PhD doctorate qualification. Participating honestly also puts you in a beneficial and unique position as an athlete to learn about your sleep and recovery scores and how these relate to performance, and possibly receive help if you require it which would be fundamental to enhancing your recovery and sports performance.

How will my privacy be protected?

All data and consent forms will be kept confidential and stored securely for an indefinite time. Data may be used in future research, as this area is very novel. You will record your name and email on the questionnaires to facilitate follow up education and / or medical referral and to receive your results, and responses will not be anonymous to me, the researcher, but will be confidential and not witnessed by other persons. All data will be stored securely at the researcher's office for at least 10 years, and consent forms will be stored at AUT for at least 10 years. I understand and consent that information will not be shared with an identified team doctor/medical team/team management in the case of a sleep disorder or sub-optimal sleep being diagnosed, unless I give my explicit and prior consent to do so, so that help or medical referral can be actioned. The team doctor may discuss this medical issue with the coaches and management team, but only if you consent to this first. Saliva samples will be held frozen at the Hurricanes training site until analysed, after which you may have these returned to you if you wish. No medical information will be shared with me by the medical team, only summary statistics on injury/illness rates.

What are the costs of participating in this research?

The only cost to you is your time, you have to sleep more, wear the sleep monitor watch on occasions, and record your sleep and wake up time each day in a diary (1 minute each day) as well as fill in 2 short questionnaires each week (5 minutes), do a 5 minute reaction time test each week and provide a saliva sample 3 times (2-3 minutes each time). All associated costs for running this project have been paid for by me, the researcher, with the assistance of research scholarships from New Zealand Rugby Union and High Performance Sport New Zealand, administered by AUT.

What opportunity do I have to consider this invitation?

You have approximately one week to consider this invitation before I seek your voluntary participation and consent, and you may withdraw at any time before completion if you do not wish to continue.

How do I agree to participate in this research?

You need to sign a consent form, which I will give to you prior to participating in the study.

Will I receive feedback on the results of this research?

Yes you will, an anonymous team average sleep score will be provided to team management, and your individual data summary and score will be emailed to you, once data is analysed.

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 Nicholas Gill, Research fellow, AUT, Nicholas Gill Nicholas.Gill@nzrugby.co.nz, ph 0274 888 699. Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Dr Kate O'Connor, *ethics@aut.ac.nz* , 921 9999 ext 6038.

Whom do I contact for further information about this research?

Researcher Contact Details: **Richard Swinbourne, swinbourne@xtra.co.nz**
Project Supervisor Contact Details: Dr Nicholas Gill, Strength and Conditioning Coach, All Blacks, Nicholas Gill Nicholas.Gill@nzrugby.co.nz, ph 0274 888 699

Approved by the Auckland University of Technology Ethics Committee on 18th December 2013
AUTEC Reference number 13/373

Appendix 3d. Sleep-Nutrient Intervention

Participant Information Sheet

Date Information Sheet Produced: 09-09-2014

Project Title:

Effect of two fruit juices on sleep, recovery, exercise adaptation and markers of immune response and inflammation in rugby union players.

An Invitation

My name is Richard Swinbourne. I am doing my PhD in the area of sleep for athletic performance and recovery. I would like to invite you to take part in this study, which will contribute towards my PhD. Your participation is completely voluntary, and you are free to withdraw at any time prior to the completion of data collection. If you chose not to participate in this study there will not be any consequences. There is no pressure to participate, I am not in a position of selection or influence within this team.

What is the purpose of this research?

It has been found that athletes do not get adequate sleep (Samuels, 2008), and my own PhD research findings to date agree with this finding. Furthermore, specific improvements in athletic performance have been observed following sleep extension, suggesting that sleep duration may be associated with achieving peak athletic performance. Nutritional interventions with the ability to manipulate sleep patterns in athletes offer the sports scientist and athlete a relatively unexplored method of enhancing sleep related recovery. Fruit juices naturally rich in melatonin and anti-oxidants are one such food, likely to naturally influence sleep mediated recovery in athletes. Most research using such fruit juices have focused on recovery from muscle damage, rather than sleep, but the two may be linked and share a relationship that requires further study. Applying anti-oxidant juice drinks to rugby athletes engaged in an off season, muscle damage inducing gym training programme, presents an ideal opportunity to extend this novel area of research.

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

You have been identified because you are an athlete within the TRFU Academy rugby squad, which was targeted for this research. You are being invited to participate in this research because you are a member of an athletic group of interest with respect to sleep and muscle damage.

What will happen in this research?

On October 13th you will assemble to commence your off-season gym training to develop strength and muscle hypertrophy. You will undertake physical testing which is routinely conducted by strength and conditioning staff, and results are gathered to interpret your fitness levels and to prescribe individual programmes. Once you have provided written informed consent, you will be randomly assigned to one

of two groups, and provide baseline measures of sleep quantity (sleep diary), sleep quality (Pittsburgh sleep quality index, PSQI questionnaire), daytime sleepiness (Epworth sleepiness scale, ESS questionnaire), a blood sample measuring markers of inflammation (Uric acid, C-Reactive Protein), and immune function (serum neutrophil and monocyte concentration), as well as indicate your muscle soreness level on a drawn scale. You will perform a 50kg squat jump and red band bench press for power output measurement and indicate your readiness to train/fatigue. These variables will be monitored intermittently during a three week training period. Training will consist of a three week 'accumulate to intensify' high volume resistance training programme. You will be asked to train 4 times per week, for 90-120 minutes per session. You will be given one of two fruit juices depending on your group, and be asked to drink the juice daily in the evening, 30 minutes before dinner. I will text you reminders. You will then be asked record your sleep in a sleep diary (Sleep time app, which is free to download) each morning, and complete the above questionnaires and tests each week for three weeks (except for the blood test, not taken in week two). At the conclusion of the three weeks training and juice consumption, we will take a second blood sample, looking at the same variables as in the first blood test. Finally, you will be given a short list of anti-oxidant rich foods and drinks to avoid or limit for the three weeks of the study. You will still be able to enjoy a nutritionally complete diet.

What are the discomforts and risks?

There are discomforts or risks to completing these tests as a part of your rugby profession (musculo-skeletal injury during physical testing and muscle soreness from training). One of the juices may give you vivid dreams. With respect to giving a blood sample, a qualified phlebotomist will be taking the blood samples. There is a small risk of infection whenever a needle pierces your skin. There is mild discomfort when the needle enters your skin and a small risk of bruising at the puncture site afterwards.

What are the benefits?

Your participation will certainly benefit me in gaining my PhD doctorate qualification. Participating honestly also puts you in a beneficial and unique position as an athlete to learn about your sleep and recovery scores and how these relate to performance, and possibly receive help if you require it which would be fundamental to enhancing your recovery and sports performance.

How will my privacy be protected?

All data and consent forms will be kept confidential and stored securely for an indefinite time. Data may be used in future research, as this area is very novel. You will record your name and email on the questionnaires to facilitate follow up education and / or medical referral and to receive your results, and responses will not be anonymous to me, the researcher, but will be confidential and not witnessed by other persons. All data will be stored securely at the researcher's office for at least 10 years, and consent forms will be stored at AUT for at least 10 years. I understand and consent that information will not be shared with an identified team doctor/medical team/team management in the case of a sleep disorder or sub-optimal sleep being diagnosed, unless I give my explicit and prior consent to do so, so that help or medical referral can be actioned. The team doctor may discuss this medical issue with the coaches and management team, but only if you consent to this first. Blood samples will be held at the Medlab New Plymouth lab until analysed, after which you may have these returned to you if you wish. No medical information will be shared with me by the medical team, only summary statistics on injury/illness rates.

What are the costs of participating in this research?

The only cost to you is your time, you have to drink a juice each evening 30 minutes before dinner, record your sleep and wake up time each day in a diary (1 minute each day) as well as fill in two short questionnaires each week (10 minutes), do a 5 minute power test each week and provide two blood samples (5 minutes each time). All associated costs for running this project have been paid for by me, the researcher.

What opportunity do I have to consider this invitation?

You have approximately one week to consider this invitation before I seek your voluntary participation and consent, and you may withdraw at any time before completion if you do not wish to continue.

How do I agree to participate in this research?

You need to sign a consent form, which I will give to you prior to participating in the study.

Will I receive feedback on the results of this research?

Yes you will, an anonymous team average sleep score will be provided to team management, and your individual data summary and score will be emailed to you, once data is analysed. In this instance, contact details will be obtained from the TRFU Academy in case of follow up education or referral.

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 Nicholas Gill, Research fellow, AUT, Nicholas Gill Nicholas.Gill@nzrugby.co.nz, ph 0274 888 699. Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Dr Kate O'Connor, *ethics@aut.ac.nz* , 921 9999 ext 6038.

Whom do I contact for further information about this research?

Researcher Contact Details: **Richard Swinbourne, swinbourne@xtra.co.nz**
Project Supervisor Contact Details: Dr Nicholas Gill, Strength and Conditioning Coach, All Blacks, Nicholas Gill Nicholas.Gill@nzrugby.co.nz, ph 0274 888 699

Approved by the Auckland University of Technology Ethics Committee on 2/10/14
AUTEC Reference number… 14/303

Appendix 4. Abstracts of Chapters in Press or in Review

Appendix 4a. Chapter 3: European Journal of Sports Science

Swinbourne, R., Gill, N., Vaile, J., Smart, D. (2015). Prevalence of poor sleep quality, sleepiness and obstructive sleep apnoea risk factors in athletes. *European Journal of Sports Science.* Accepted 10th November 2015.
(Chapter 3)

Purpose: Despite the perceived importance of sleep for athletes, little is known regarding athlete sleep quality, their prevalence of daytime sleepiness or risk factors for obstructive sleep apnoea (OSA) such as snoring and witnessed apnoeic episodes. The purpose of the present study was to characterise normative sleep quality among highly trained team sport athletes.

Methodology: 175 elite or highly trained rugby sevens, rugby union and cricket athletes completed the Pittsburgh Sleep Quality Index (PSQI), Epworth Sleepiness Score (ESS) and Quality of Life questionnaires and an OSA risk factor screen.

Results: On average, athletes reported 7.9 ± 1.3 h of sleep per night. The average PSQI score was 5.9 ± 2.6, and 50% of athletes were found to be poor sleepers (PSQI >5). Daytime sleepiness was prevalent throughout the population (average global score of 8.5) and clinically significant (ESS score of ≥10) in 28% of athletes. OSA may be an important clinical consideration within athletic populations, as a considerable number of athletes (38%) defined themselves as snorers and 8% reported having a witnessed apnoeic episode. The relationship between self-rated sleep quality and actual PSQI score was strong (Pearson correlation of 0.4 ± 0.1, 90% confidence limits).

Conclusion: These findings suggest that this cohort of team sport athletes suffer a preponderance of poor sleep quality, with associated high levels of daytime sleepiness. Athletes should receive education about how to improve sleep wake schedules, extend total sleep time and improve sleep quality.

Appendix 4b. Chapter 4: International Journal of Sports Science and Coaching

Swinbourne, R., Gill, N., Vaile, J., and Smart, D. Recovery-Stress Balance and Sleep in Athletes. *The Sport Psychologist*. In review 8th December 2015.
(Chapter 4)

Purpose: The purpose of the present study was to examine the relationship between Recovery-Stress-Questionnaire for Athletes (RESTQ-Sport 76) derived psychological responses to training with validated measures of sleep quality and sleepiness in team sport athletes.

Methodology: One hundred and seventy five highly trained male and female athletes from Rugby Union, Rugby Sevens and Cricket, volunteered to participate and were assessed for measures of recovery, stress, sleep quality and daytime sleepiness.

Results: Fifty percent of the athlete cohort were classified as poor sleepers (PSQI >5). The RESTQ-Sport adequately detected poor sleep quality in athletes (r = -0.49; ± 0.10). However, the questionnaire was not highly sensitive to daytime sleepiness.

Conclusion: Results suggest that the RESTQ-Sport helps detect poor sleep in athletes. The addition of validated sleep questionnaires would more accurately inform coaches about athlete sleep based recovery.

Appendix 4c. Chapter 5: Journal of Australian Strength and Conditioning

Swinbourne, R., Gill, N., Vaile, J., Smart, D., & Dulson, D. The effects sleep extension on sleep, performance, immunity and physical stress in rugby players. *European Journal of Sport Science*. In review 8th December 2015.
(Chapter 5)

Purpose: The purpose of the present study was to examine the efficacy of sleep extension in professional rugby players. The aims were to i) characterise sleep quantity in elite rugby players and determine changes in immune function and stress hormone secretion during a

pre-season training programme; ii) evaluate the efficacy of a sleep extension intervention in improving sleep, markers of physical stress, immune function and performance.

Methodology: Twenty five highly trained athletes from a professional rugby team (age [mean ± *SD*] 25 ± 2.7 yrs; height 1.87 ± 0.07 m; weight 105 ± 12.1 kg) participated in a six week pre-post control-trial intervention study. Variables of sleep, immune function, sympathetic nervous activity, physiological stress, skill acquisition and reaction times were measured.

Results: Sleep extension resulted in a moderate improvement in sleep quality scores ([mean; ± 90% confidence limits] -24.8%; ± 54.1%) and small to moderate increases in total sleep time (6.3%; ± 6.3%) and time in bed (7.3%; ± 3.6%). In addition, a small decrease in cortisol (-18.7%; ± 26.4%) and mean reaction times (-4.3% ± 3.1%) was observed following the intervention, compared to the control. Following sleep extension there was no clear change in passing skill acuity.

Conclusion: Professional rugby players are at risk of poor sleep during pre-season training, with concomitant rises in physical stress. Implementing a sleep extension programme among professional athletes is recommended to improve total sleep, with beneficial changes in stress hormone expression and reaction time performance.

Appendix 5. Copyright Permissions

Appendix 5a. Chapter 3 Copyright Permission

Chapter 3 is derived in part from an article accepted for publication in the European Journal of Sports Science on 10th November 2015, *available online: http://wwww.tandfonline.com/ [doi:* 10.1080/17461391.2015.1120781*]*. *Guidance on reusing my work was obtained from http://authorservices.taylorandfrancis.com/wp-content/uploads/2015/07/guide-for-reusing-content.pdf*