INSTITUTE FOR HEALTH AND SPORT

EFFECTS OF TRAVEL ON PROFESSIONAL RUGBY UNION PLAYERS

Submitted by

Michele Lo

This thesis is submitted in fulfilment of the requirements for the award of

Doctor of Philosophy

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Abstract

Super Rugby is an international competition played in the southern hemisphere with participating teams required to undertake multiple travel during a season. This thesis investigated the direct and complex relationship between regular air travel and athletes' psycho-physiological response and performance. The first two studies investigated the impact of travel on team performance during the first 21 years of the competition (1996-2006). Study 1 showed the predominant role of the away-match disadvantage in determine match results following the longest flights and greatest time zones shifts, whilst the results from study 2 suggests that fatigue related to long-haul travel and the increased physical demand of the game negatively impacted team performance measured using Key Performance Indicators. Study 3 was a socio-physiological analysis of all travel related issues and solutions, as reported by travel managers from eight Super Rugby teams. The results show that psychological and emotional well-being may take primacy over physiological wellness as team culture and cohesion may be as important as biological interventions in controlling the negative effects of travel on players' performance and well-being. Studies 4 and 5 monitored players from four teams and investigated their individual response to long-haul trans-meridian travel, with a focus on sleep (study 4), wellness and performance (study 5). The results suggest that, although the effects of travel on individual performance appear to be limited, long-haul travel had a substantially negative impact on players' sleep and wellness. Further studies should investigate the potential impact of sleep disruptions and reduced wellness on players' general health and well-being. The findings of this thesis should be of interest to all coaches and supporting staff in sports that require international travel to compete.

Student declaration

“I, Michele Lo, declare that the PhD thesis entitled ‘Effects of travel on professional Rugby Union players’ is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Signature: Michele Lo [redacted] Date: 10/08/2018

Acknowledgments

The things you do when you are bored….like travelling to the opposite side of the world just to put the word Doctor before your name (and nope, I'm not a girl nor an Asian person, thanks mom and dad☺).

It has been a long journey, literally and metaphorically, and if I somehow arrived where I am at the moment it is because I had heaps of people backing me up, helping me, re-naming me (Mick), tolerating me, and so forth, you name it. First I need to acknowledge my extended supervising team because you need a great team to make a thesis out of a crazy idea. Andy, Rob and more recently Will, Nic, Brent and Shona thanks for everything you have done for me, I owe you all big time. Andy & Rob, in particular, you had the guts to offer a random, crazy, un-polite, silly Martian (not that you knew anything about that when you first 'hired' me) a once in a life time chance to do a PhD in OZ. I hope I paid you back somewhat (and hope we can keep doing stuff together). It was the hell of a good time.

There are moments, in a PhD life, when you find yourself swimming in a not-so-cool fluid, and you really need a superhero to fish you out! An entire page of acknowledgment won't be enough, but I guess a few lines are a good start. Thank you Kerry!!! You should be included in every new PhD student welcome pack. If it wasn't for you I will probably still be overseas trying to find a way to run my studies. And just to remain overseas, thanks to all 130+ people that got involved in my studies as participants, or else: Dave & Dave, Chris, Theo, Tony, Cam, Leevan, Adam, Stephen, Jason, Alan, The Cambridge Hotel people, those two taxi drivers, just to mention a few of the people that helped me collecting my data. Thanks again to all of you. Another mention of honour for Isabella. Great editor! It takes a big effort to turn editing sessions of a boring lit review (it's actually worth to read) into funny afternoons, although good food, good wine and a good chat helped.

A bit of random acknowledgments before moving forward. A huge thanks to Steve for giving me a job in his clinic and not firing me despite my never-ending, multiple and short-noticed PhD leaves. And a huge thanks to Zoë and all my colleagues at Neurorehab. It is good to do something different from research every now and then. Did I mention that I never played that weird football code that uses a spherical ball before moving to Australia? Thanks to all the World Leaders present, past and future for make me do it, although just the indoor version of it (my elbows are particularly fond of you guys)!!! And an extra special thanks to SAS is also required.

There is a little place, down by the river, -ish, that is called PB201. It's a dark place, cold in winter and hot in summer, where I spent way too much of my time in the last few years. There are a few funny animals living in this place, mostly birds. And sometimes PhD students. I had a great time with all of you. Jacko, you were there from the very beginning (and Mr. Wilkson covered up from when you left). I couldn't hope to have a better desk mate than you, although that may have not be true for you. Suus, you arrived when I was half way, but still made an impact (as in you are bloody annoying but I can still tolerate you). Rhiannon, you arrived toward the end of my journey. Even if you may disagree with that, your contribution to this thesis, my PhD and life in general was great. I'm damn lucky that I met all of you.

Finally, thanks to beer, coffee and the Space Sloth. This baby was built on you and, therefore, is also dedicated to you.

So Long and thanks for all the fish!!!!!!!

Abbreviations

aMT6s	6-Sulphatoxymelatonin
ARU	Australian Rugby Union
AU	Arbitrary Units
CI	Confidence Intervals
CL	Confidence Limits
CV	Curriculum Vitae
D	Day
DLMO	Dim-Light Melatonin Onset
ECG	Electrocardiography
EEG	Electroencephalography
EL	External Load
EMG	Electromyography
EOG	Electrooculogram
GABA	Gamma-Aminobutyric Acid
GPS	Global Position System
H	Hour
HR	Heart Rate
HZ	Hertz
ICSD-2	International Classification of Sleep Disorders

IL	Internal Load
KPIs	Key Performance Indicators
M	Metres
MIN	Minutes
MS	Milliseconds
non-REM	non Rapid Eye Movements
NZRU	New Zealand Rugby Union
PGO (spikes)	Ponto-Geniculo-Ocipital spikes
PSG	Polysomnography
REM	Rapid Eye Movements
RPE	Rating of Perceived Exertion
SANZAAR	South Africa, New Zealand, Australia, Argentina Rugby
SANZAR	South Africa, New Zealand, Australia Rugby
SARU	South Africa Rugby Union
SD	Standard Deviation
sRPE	session Rate of Perceived Exertion
SWS	Slow Wave Sleep
$\dot{V}O_{2max}$	Maximal Oxygen Consumption
$\dot{V}O2peak$	Oxygen Consumption Peak
Y	Year

Publications & presentations

Sections of this thesis will be submitted for publication and/or were presented at relevant scientific conference.

SCIENTIFIC CONFERENCE PRESENTATIONS

Lo M., Aughey R.J., Hopkins W.G., Stewart A. (2018). The effects of games and travel on super rugby players. Is sleep the key? European College of Sport Science, Dublin, Ireland.

Table of contents

List of Tables

List of Figures

Chapter 1: Introduction

Rugby Union is a team sport commonly played around the world, governed by World Rugby that supervise national and international competitions including the Rugby Union World Cup (WorldRugby, 2017). Super Rugby is the most important international Rugby Union competition in the southern hemisphere and arguably the highest expression of rugby at club level. Super Rugby started in 1996 when Rugby Union turned into a professional sport and the three leading countries for the southern hemisphere (South Africa, New Zealand and Australia), created a new governing body called SANZAR (South Africa, New Zealand, Australia Rugby) to organize the competition. In 2016 Super Rugby expanded to include two new countries (Argentina and Japan) to form a Super 18 competition. In 2018 the competition returned to 15 teams spread among five countries. Because of the international nature of the competition, teams have to travel frequently throughout the season. In some cases, flights are as little as one hour, with no time zone change (e.g. Melbourne to Sydney). In other cases, travel takes 24 hours or more to reach the destination with a 12 hour time zone change (e.g. from New Zealand to South Africa).

The main goal for all players and teams involved in Super Rugby, as in any other sport, is to succeed in the competition in which they are involved. One of the keys to achieve this objective is to reach the highest level of performance possible on the day(s) required. However, performance in sport is difficult to define and measure because it is a complex and multifactorial process (Glazier, 2010). The outcome of performance can be influenced by physiological, psychological and environmental factors (e.g. the weather). Frequent air travel, a common feature in sport competitions, can also have detrimental effects on performance (D. Bishop, 2004; Youngstedt & O'Connor, 1999).

Air travel is common not only in Rugby Union but also for numerous other sports, such as skiing, cycling, tennis, basketball, and soccer (Reilly, 2009b; Youngstedt & O'Connor, 1999). Professional athletes in these sports are required to travel for large parts of the year, moving weekly to venues in different countries to compete in international circuits (e.g. the PGA or LPGA Golf Tours or ATP/WTA Tennis Tours), championships (Rugby Union Super Rugby or UEFA Champions League in soccer), specific events (Olympics or World Cups) and sometimes simply for training camps in a specific location (heat or altitude training) (Reilly, 2009b; Waterhouse, Reilly, & Edwards, 2004). There is ample anecdotal support that frequent travel can affect humans via a multitude of factors, including travel fatigue and jet lag (Forbes-Robertson et al., 2012; Leatherwood & Dragoo, 2013; Samuels, 2012). However, the extent to which travel can affect sport performance is still a matter of discussion (Youngstedt & O'Connor, 1999).

Travel fatigue is the summation of physiological, psychological and environmental factors, that accrue after a single trip and accumulates over time (Samuels, 2012). Travel fatigue is characterized by persistent weariness, recurring illness, lack of motivation, changes in mood and behaviour (Samuels, 2012). Jet lag is a common complaint reported by up to two-thirds of all travellers after travelling across more than three time zones (Forbes-Robertson et al., 2012; Herxheimer & Petrie, 2002; Loat & Rhodes, 1989; Rosenberg et al., 2010).

Jet lag is an example of a chronobiological response of a living organisms to environmental time (Waterhouse et al., 2004). Chronobiology is defined as the science that investigates the mechanism of biological time structures and their rhythmic manifestation (Atkinson & Reilly, 1996). All homeostatic functions of the human body show rhythmic variations, called circadian rhythms, which permit the body to respond differently at various times of the day (Czeisler et al., 1999; Srinivasan et al., 2010). Jet lag occurs when these rhythms are disrupted, usually due to travel across time zones (Leatherwood & Dragoo, 2013; Reilly, 2009b).

The majority of chronobiological studies address jet lag issues using animal models and simulating circadian disruptions in a laboratory setting without directly translating the findings to humans (Atkinson, Batterham, Dowdall, Thompson, & van Drongelen, 2014). Nonetheless, the effects of travel and the influence on performance of a general or specific population, such as cabin crews, has been well documented (Grajewski, Whelan, Nguyen, Kwan, & Cole, 2016; Reis, Mestre, Canhao, Gradwell, & Paiva, 2016; van den Berg, Wu, & Gander, 2016), although the effects of travel on performance of athletes are still a matter of considerable discussion (Forbes-Robertson et al., 2012). It has been reported that humans need approximately one day per time zone crossed to recover from jet lag (Leloup & Goldbeter, 2013; Reilly, Atkinson, et al., 2007) although this information derives from research in the aviation industry (Klein, Hermann, Kuklinski, & Wegmann, 1977; Loat & Rhodes, 1989; Reis et al., 2016), and appears to be lacking rigorous investigation in sport (Lemmer, Kern, Nold, & Lohrer, 2002; Waterhouse, Reilly, Atkinson, & Edwards, 2007). Nevertheless, the rate and velocity of recovery can be accelerated through the application of specific strategies including melatonin supplementation (Forbes-Robertson et al., 2012; Herxheimer & Petrie, 2002) and light exposure (Eastman & Burgess, 2009; Forbes-Robertson et al., 2012). However, the efficacy of these strategies in a sporting context and in relation to performance of elite athletes is largely unknown (Forbes-Robertson et al., 2012; Leatherwood & Dragoo, 2013).

The objective quantification of the effects of travel and jet lag on athletes, and the strategies applied to reduce the symptoms, is likely to have many benefits. Purely from a performance perspective, such objective knowledge will enable athletes and coaches to be better equipped to manage the effects of frequent travel. This knowledge has also the potential to increase the health and well-being of athletes, their performance and ultimately the likelihood of success.

The Australian Rugby Union (ARU), the New Zealand Rugby Union (NZRU), the South Africa Rugby Union (SARU) and individual teams were interested in being fully or partially involved in all aspects of this research. The first two studies were a retrospective analysis of the first 21 years of Super Rugby (1996 to 2016), to better understand the extent to which travel affected teams' performance. The third study aimed to identify strategies applied to cope with travel and jet lag within the Super Rugby teams. The last two studies monitored a number of teams to determine the effects of travel, their chosen interventions and the effects on performance. These studies may be the first investigating the effects of multiple flights, both long and short-haul, on a large sample of athletes, analysing their individual physiological and psychological responses and performance. The results of these studies are likely to be of interest, not only to the international and national governing bodies of rugby, but also to a spectrum of high-level athletes in a variety of sports who encounter a similar travel agenda in their respective disciplines.

Chapter 2: Review of literature

Relatively few studies have researched both travel and jet lag from an athletic performance perspective (Leatherwood & Dragoo, 2013). In general, these studies are based on the analysis of single long-haul flights (Bullock, Martin, Ross, Rosemond, & Marino, 2007; Chapman, Bullock, Ross, Rosemond, & Martin, 2012; Lemmer et al., 2002), or on the analysis of several short-haul flights (D. Bishop, 2004; Fowler, Duffield, & Vaile, 2014; Winter, Hammond, Green, Zhang, & Bliwise, 2009). Furthermore, study on the effects of travel and jet lag on athletic performance use markers of performance that are generic and not sport specific (i.e. grip strength, or general physical tests) (Bullock et al., 2007; Lemmer et al., 2002). The application of strategies to cope with jet lag has been studied in the general population (Eastman & Burgess, 2009; Eastman, Gazda, Burgess, Crowley, & Fogg, 2005; Revell et al., 2006; Revell & Eastman, 2005) and the management of jet lag symptoms in athletes is based on the same principles (Reilly, 2009b; Samuels, 2012).

Sections 2.1 and 2.2 of this literature review will focus on the effects of travel and jet lag in general and where possible on athletic performance. Circadian rhythms will first be introduced along with the influence of circadian rhythms on athletic performance and the main techniques used to assess them. Jet lag will then be introduced and analysed as a particular case of circadian rhythm disruption. Travel in general, travel fatigue and the individual and combined effects on performance, along with the effects of jet lag, will then be reviewed. The last part of this section will focus on the main strategies used to counter the effects of travel and jet lag on performance.

Section 2.3 of the literature review will focus on sleep. Sleep is a very important aspect of life for the general population and for athletes in particular. Sleep disruptions might occur after travel, and sleep alteration is a common and arguably the most important symptom of jet lag for athletes. This section of the review will focus on the chronobiologic aspects of sleep and its function and characteristics. An insight on the techniques used to assess sleep and the influence of sleep on performance will close this section of the review.

Section 2.4 of the literature review will focus on athletic performance and training. The concept of training load will be introduced along with the different techniques used to assess it. Similarly, a number of techniques used to assess performance will be introduced.

2.1: Circadian rhythms and jet lag

Circadian rhythms and their disruption are the only factor inducing jet lag and as such, the following section of this review will focus on circadian rhythms and their effect on exercise before concentrating on jet lag and its effects on performance.

2.1.1: Circadian rhythms

Every physiological function and system of the human body follows its own specific and unique rhythmic pattern called circadian rhythm (from Latin *circa dies* = about a day) (Mendoza-Viveros et al., 2017). These rhythms are internally driven biological phenomena with periodic oscillation of 24.2 hours on average (20 to 28 hours range) (Atkinson & Reilly, 1996; Czeisler et al., 1999; Srinivasan et al., 2010) and small inter and intra-individual variations (Czeisler et al., 1999). In humans, the length of biological rhythms is variable. Some of the human rhythms range from milliseconds to minutes and up to 20 hours (ultradian rhythms) (Atkinson & Reilly, 1996). Other rhythms are longer and last months, for instance menstrual cycle in women, (infradian rhythms) (Atkinson & Reilly, 1996) or seasonal cycles (circannual rhythms) (Haus & Smolensky, 2006). However, the majority of the biological rhythms are mostly daily based and synchronized to the external alternation of day and light as natural selection favours all living organisms with internal rhythms similar to that of the planet Earth rotation (Czeisler et al., 1999; Fonken & Nelson, 2016; Pfeffer, Korf, & Wicht, 2017; Wulund & Reddy, 2015).

Mammals can be classified as diurnal or nocturnal based on their behaviours. Humans in particular are diurnal animals (awake by day and asleep by night) (Forbes-Robertson et al., 2012) and most of the functions of the human body follow rhythms with higher values reached during daytime. Examples of these rhythms are body temperature, heart rate, mental and physical performance. Sleep, melatonin and other hormone production are examples of night rhythms (Waterhouse et al., 2004). Even if circadian rhythms are strongly influenced by external factors such as the daily alternation of light and darkness (exogenous component) (Forbes-Robertson et al., 2012), they are internally generated and can persist even in absence of external clues (endogenous components) when an individual is isolated from environmental stimuli (Atkinson & Reilly, 1996; Diekman & Bose, 2016).

The master body clock is located in the suprachiasmatic nuclei at the base of the anterior hypothalamus (Hofstra & de Weerd, 2008; Mendoza-Viveros et al., 2017) in the central nervous system and is responsible for the endogenous component of the rhythms (Kofuji et al., 2016; Potter, Skene, et al., 2016; Reilly, Waterhouse, Burke, Alonso, & International Association of Athletics, 2007; Youngstedt & O'Connor, 1999). The cells from the suprachiasmatic nuclei of mammals are the only brain cells that show autonomous activity and a daily rhythmicity even when cultured *in vitro* (Waterhouse et al., 2004). Based on the diurnal predisposition of humans, the body clock maintains the body in an active status during the day and in a recovery state during the night (Waterhouse et al., 2004).

The endogenous component of the rhythms is synchronized by *zeitgebers* (German word for “time givers”). The *zeitgebers* are all the external clues that synchronize animal life with the solar day influencing the body clock (Waterhouse et al., 2004). Heart rate and blood pressure, for instance, follow a similar endogenous circadian pattern, mediated by the body clock, with a peak at around 3 pm. Despite their endogenous rhythmicity, both functions are strongly influenced by external factors such as posture, exercise and diet (Manfredini, Manfredini, Fersini, & Conconi, 1998). The main *zeitgeber* in humans is the alternation of light and darkness (Haus & Smolensky, 2006; Potter, Skene, et al., 2016; Reilly, Waterhouse, et al., 2007). Bright light, such as the one found outdoor coming from the sun, has a strong effect on regulating the body clock while weaker light, such as artificial light, has smaller effects (Reilly, Waterhouse, et al., 2007; Waterhouse et al., 2004). Nonetheless, even weaker light can contribute to disrupt and desynchronize the body clock.

The intrinsic rhythm of the human body clock is slightly longer than 24 hours (Sack et al., 2007). Entrainment is the daily resynchronization of the body clock with the external clock mediated by the *zeitgebers* (Diekman & Bose, 2016; Hofstra & de Weerd, 2008), and in particular the light/darkness daily circle (Sack et al., 2007; Youngstedt & O'Connor, 1999). Other signals (e.g. social activity) may have some influence on entrainment but the magnitude of their effects is relatively small and unclear compared to light exposure (Duffy & Wright, 2005; Sack et al., 2007; Youngstedt & O'Connor, 1999).

The body clock is linked to the light receptor in the retina via the retino-hypothalamic tract, a pathway that originates from the retina with axonal projection to the central nervous system and pineal gland (Berson, Dunn, & Takao, 2002). The light that enters the eyes is picked up by photoreceptors located in the ganglion cells of the inner retina (Berson et al., 2002; Dijk & Lockley, 2002; Youngstedt & O'Connor, 1999). These ganglion cells are non-rod, non-cone photoreceptors independent from other retinal light receptors that set the circadian clock (Aubin, Kupers, Ptito, & Jennum, 2017; Berson et al., 2002; Sack et al., 2007). Melanopsin is thought to be the photo pigment in charge of the circadian response to light (Dijk & Lockley, 2002; Sack et al., 2007). The signal travels toward the suprachiasmatic nuclei via the retino-hypothalamic tract to drive the resynchronization (Berson et al., 2002) (Figure 2.1). The extent of resynchronization depends on the characteristic of the light (wavelength, intensity and duration of exposure) (Duffy & Wright, 2005; Martin & Eastman, 1998) that reaches the suprachiasmatic nuclei.

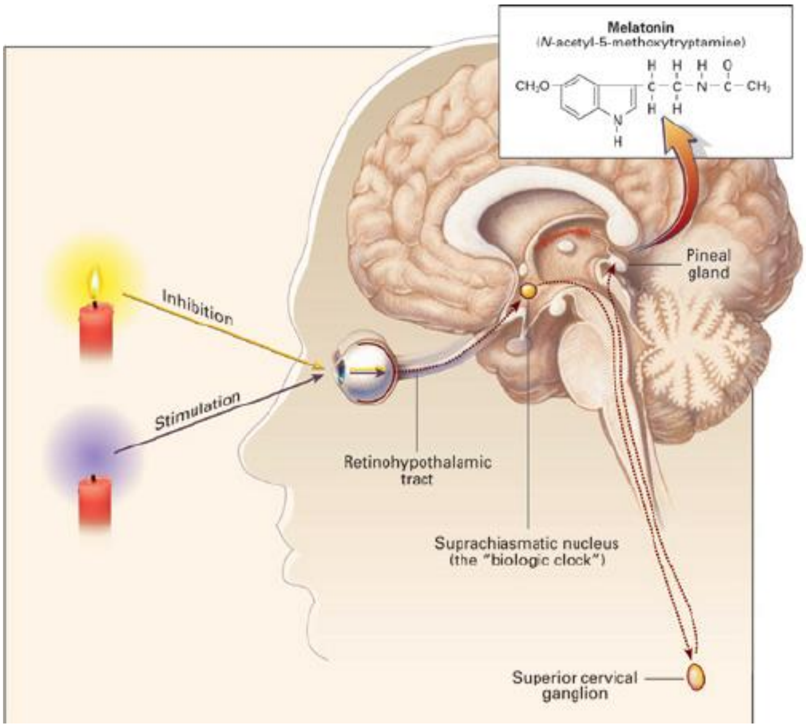


Figure 2.1: Effects of light on melatonin synthesis. Retino-hypothalamic tract connection with the suprachiasmatic nucleus (the body clock) and the pineal gland. Reproduced from (Shirani & St. Louis, 2009).

The suprachiasmatic nuclei is the vertex of a complex hierarchy that coordinates the circadian system (Ko & Takahashi, 2006). Under the suprachiasmatic nuclei and the body clock, at the second level of the hierarchy, there are the peripheral clocks (Evans & Davidson, 2013).

At a molecular level, the regulation of the central clock involves a complex series of feedback loops (Hastings, O'Neill, & Maywood, 2007; Leloup & Goldbeter, 2013; Mendoza-Viveros et al., 2017) and a group of genes known as ‘clock’ genes (Gekakis et al., 1998; Hofstra & de Weerd, 2008; Kennaway, 2010; Leloup & Goldbeter, 2013; Potter, Skene, et al., 2016; Sato et al., 2017). A positive feedback loop starts with two genes, *Bmal1 and clock,* which stimulate the production of two proteins, BMAL1 and CLOCK. These two proteins create a BMAL1-CLOCK complex, which activates the transcription of two genes, Period (Per), and *Cryptochrome*

(*Cry*), and inhibit *BMAL1* transcription. The PER and CRY proteins, produced by *Per* and *Cry,* create a PER-CRY protein complex, which inhibits the BMAL1-CLOCK complex and creates an indirect, negative feedback loop on transcription (Andrews et al., 2010; Leloup & Goldbeter, 2013). When the inhibitor genes fall below a threshold, the positive 'clock' genes turn on again (Gachon, Nagoshi, Brown, Ripperger, & Schibler, 2004) (Figure 2.2).

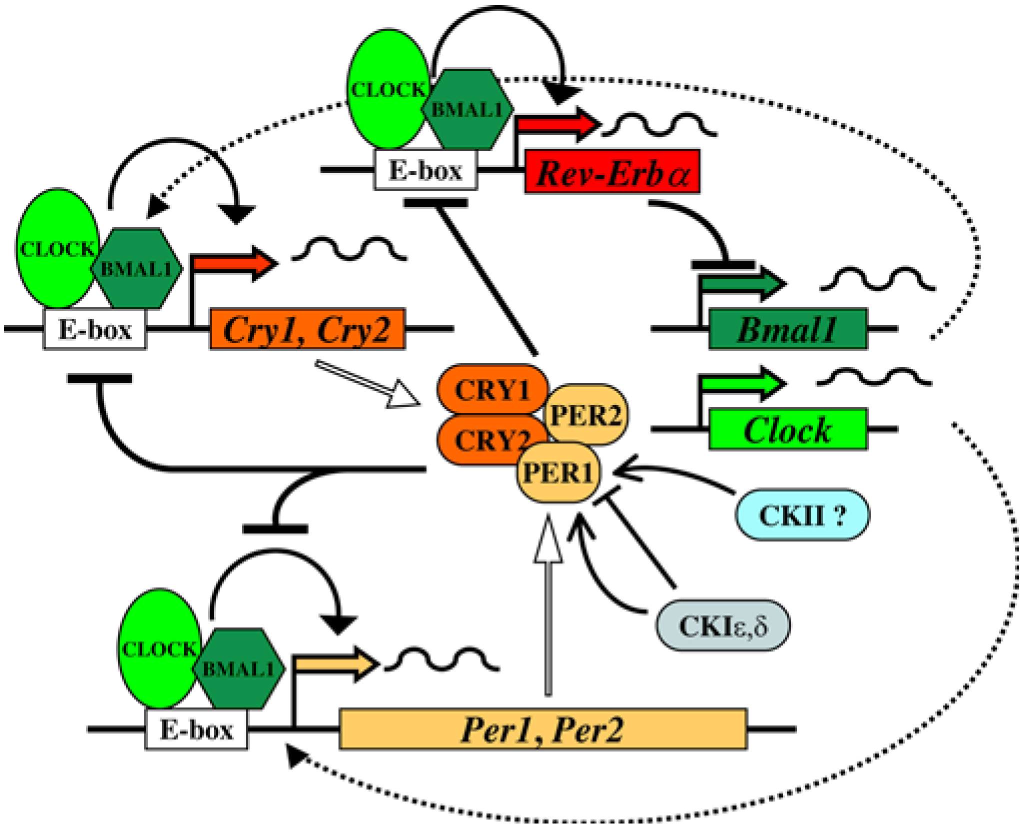


Figure 2.2: Simplified model of the circadian rhythms regulation at molecular level. Reproduced from (Gachon et al., 2004).

The entire mechanism of gene expression from transcription (copying the info of a gene into messenger ribonucleic acid, mRNA) to translation (creation of a specific protein) follows a circadian rhythm for more than 40% of all proteins-coding genes (Potter, Skene, et al., 2016; Wulund & Reddy, 2015).

Clock genes have also been observed in peripheral cells and tissues of mammals demonstrating the existence of peripheral clocks (Mohawk, Green, & Takahashi, 2012; Turek, 2016) controlling physiological functions such as body temperature, and hormone release (Evans & Davidson, 2013). The clock genes also play a critical role in defining structure and function of muscles as well as their mitochondrial content (Andrews et al., 2010). Clock genes can therefore influence an athlete's performance and response to exercise.

2.1.2: Peripheral clocks and measure of circadian rhythms

Since the central body clock activity cannot be directly measured, peripheral clocks are assessed instead (Klerman, Gershengorn, Duffy, & Kronauer, 2002). Theoretically, every human function can be used to assess circadian rhythms with core body temperature, cortisol and melatonin production being the most commonly used (Hofstra & de Weerd, 2008; Klerman et al., 2002).

2.1.2.1 Core Body temperature

The core body temperature is one of the most frequently assessed rhythms (Folkard, 1989) and was considered for a long time one of the best markers of the circadian phase (Hofstra & de Weerd, 2008). Changes in core body temperature are strongly related to the sleep-wake rhythm. Body temperature starts to increase before awakening, reaches its zenith in the early evening at about 6 pm, before decreasing to its nadir at about 4 am and then starting to rise again (Manfredini et al., 1998; Youngstedt & O'Connor, 1999). The nightly decline in body temperature is related to heat loss and distal vasodilatation, which are also events that are part of the chain of events that induce sleep (Cajochen, Krauchi, & Wirz-Justice, 2003; Hofstra & de Weerd, 2008). Body temperature can be easily assessed with minimal intrusive techniques such as oral thermometers. However, the rhythm of the body temperature can be affected by external variables such as posture and activity level (Benloucif et al., 2005; E. N. Brown & Czeisler, 1992; Waterhouse et al., 2005). As such, body core temperature can be used to assess circadian rhythms but it is not the most reliable phase marker (Benloucif et al., 2005).

2.1.2.2: Cortisol

Cortisol is a corticosteroid hormone produced in the zona fasciculate of the adrenal gland (Hofstra & de Weerd, 2008). Cortisol is the principal activator of the hypothalamus-pituitary-adrenal axis, which plays a central role in several homeostatic processes (Jensen, Garde, Kristiansen, Nabe-Nielsen, & Hansen, 2015). The body clock modulates cortisol secretion and the function of the axis via the multi synaptic suprachiasmatic nuclei-adrenal pathway (Hofstra & de Weerd, 2008) and clock genes action (Nagy et al., 2016). Cortisol has a diurnal rhythm (Garde et al., 2009) and its concentration can be measured using blood, urine and saliva samples. (Jensen et al., 2015). However, exercise, food intake and stress can influence cortisol production (Garde et al., 2009; Jensen et al., 2015) and therefore cortisol is not a strong marker of circadian rhythms for athletes.

2.1.2.3: Melatonin

Melatonin is a hormone produced by the pineal gland and both, a circadian rhythms and one of the principal *zeitgebers* for mammals as substantiated by the presence of melatonin receptors on the suprachiasmatic nuclei (Reilly, 2009b). Synthesis and release of melatonin in the blood stream occur at night time under direct control of the suprachiasmatic nuclei over the pineal gland via a neuropathway that induce the release of noradrenalin on the gland (Pfeffer et al., 2017). Melatonin is involved in several homeostatic functions but its main role is to drive the cyclic alternation of wake and sleep states (Atkinson & Reilly, 1996; Cajochen et al., 2003). An objective measure of circadian rhythms can be undertaken through the analysis of melatonin concentration in body fluids such as urine, saliva and blood as clearly illustrated in Figure 2.3 (Benloucif et al., 2008; Voultsios, Kennaway, & Dawson, 1997).

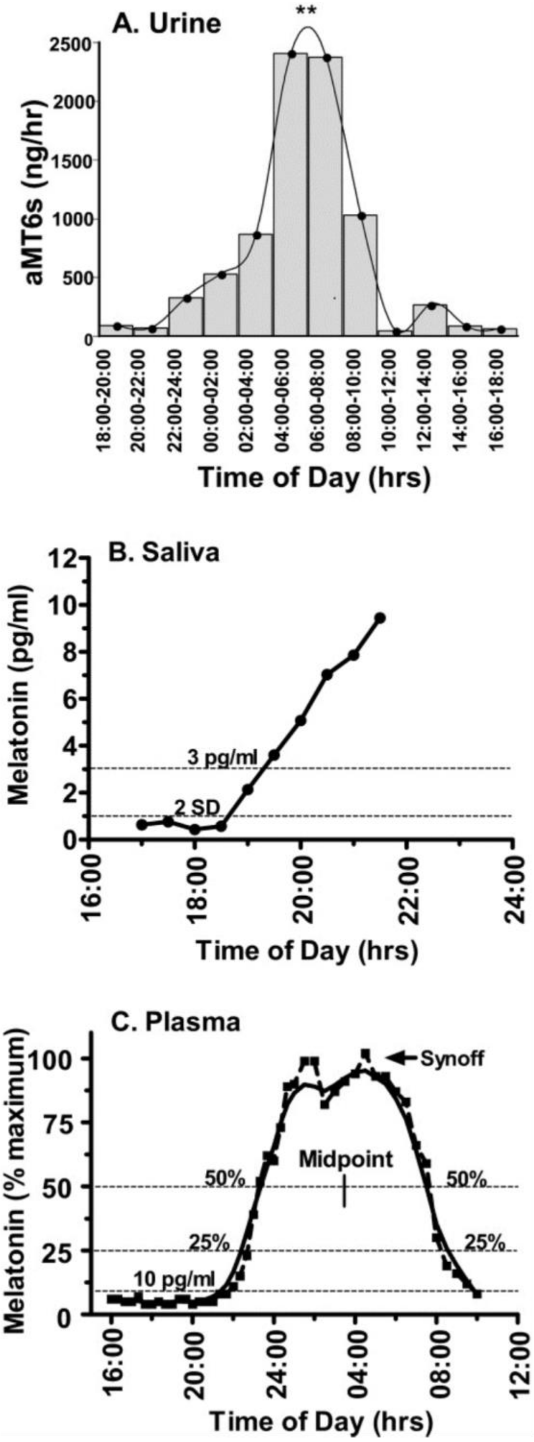


Figure 2.3: Illustrations of 3 melatonin sample types and their associated phase estimates. (A) 24-hour rhythm of the primary urinary melatonin metabolite 6-sulphatoxymelatonin (aMT6s) derived from urine samples. (B) Salivary melatonin profile collected under dim-light conditions. (C) Overnight plasma melatonin profile, plotted as a percentage of maximum (dashed line) and smoothed with a Lowess curve fit to the raw data (solid line). Reproduced from (Benloucif et al., 2008).

Melatonin is more stable than any other circadian rhythms' markers (Dawson, Lushington, Lack, Campbell, & Matthews, 1992; Duffy & Wright, 2005; Klerman et al., 2002) as its production is directly controlled by the suprachiasmatic nuclei and is only slightly affected by other external factors, including light exposure, meals, posture and exercise (Atkinson, Drust, Reilly, & Waterhouse, 2003; Benloucif et al., 2008; Benloucif et al., 2005; Romsing, Bokman, & Bergqvist, 2006). A twenty-four hour assessment of melatonin release would be ideal to measure circadian rhythms, however, it would be time consuming and might induce discomfort in participants. As such, it is more common to identify the moment when melatonin level starts to rise (the onset) (Hofstra & de Weerd, 2008). Several analysis methods are currently available to assess the circadian phase of melatonin. One of the most common is the dim-light melatonin onset (DLMO) (Benloucif et al., 2008; Hofstra & de Weerd, 2008). The DLMO is usually observed two to three hours prior to sleep and is an approximation of the onset of melatonin synthesis and secretion (Benloucif et al., 2008). Based on the level of melatonin produced and the sensitivity of the assay used, three different techniques can be used to assess the DLMO. The three techniques are a threshold in the range of 2 to 10 $pg^{-1}.mL^{-1}$ (Benloucif et al., 2008; Hofstra & de Weerd, 2008), a threshold calculated at 2 Standard Deviations above the average baseline samples (Benloucif et al., 2008; Hofstra & de Weerd, 2008; Voultsios et al., 1997) (Figure 2.4) and, finally, a visual estimate of the point where there is a rise or decline from the baseline (Benloucif et al., 2008).

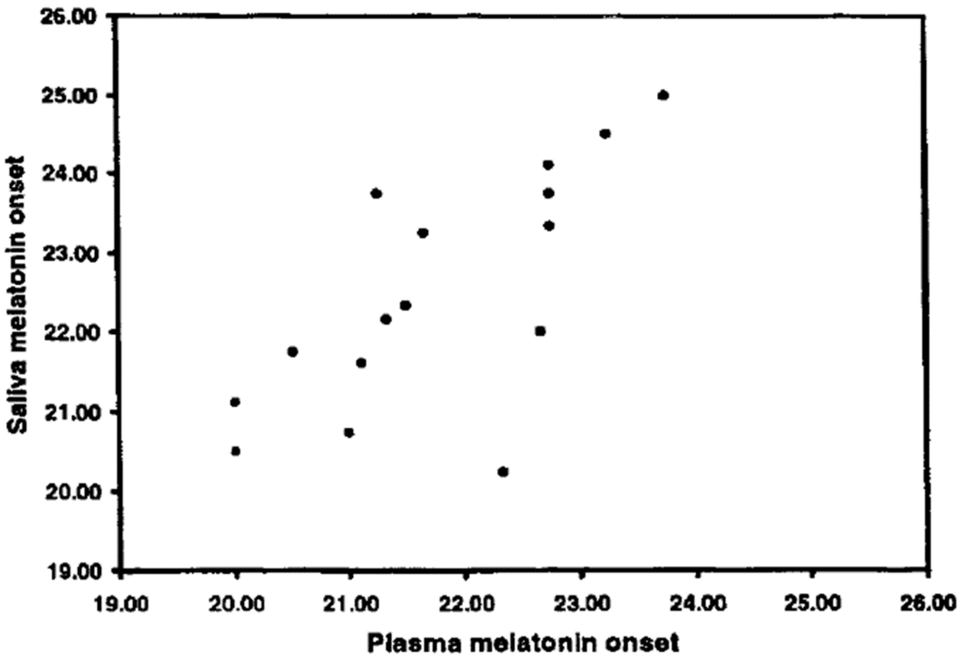


Figure 2.4: Relationship between plasma and saliva melatonin onset as determined by calculating a threshold at 2 SD from the baseline. Coefficients of variations for plasma and saliva were respectively 4.9% and 8.0%. Reproduced from (Voultsios et al., 1997).

2.1.2.4: Masking

A number of different external factors can affect the rhythms of the peripheral clocks and any attempt to measure circadian rhythms is biased by external factors. The influence of these external factors is commonly referred to as masking (Atkinson & Reilly, 1996; Minors & Waterhouse, 1989; Sack et al., 2007). Masking can be related to a direct influence of normal environment or behavioural changes in response to normal or abnormal environments such as that created to match humans' social behaviours (Minors & Waterhouse, 1989).

Masking is a problem for all markers of circadian rhythms (Lewy, Cutler, & Sack, 1999) although it can be controlled. The first solution (gold standard) is to create constant routine to minimize external influences ("demasking") (Folkard, 1989;

Minors & Waterhouse, 1984; Minors & Waterhouse, 1989; Sack et al., 2007). However, as participants of a study can be asked to spend their day in a semi-reclined position in bed and the intake of food controlled over a twenty-four hours period (Minors & Waterhouse, 1984), this solution may not be suitable for athletes. A more feasible “demasking” technique is based on mathematical corrections of the data collected to reduce the noise in the peripheral clock measurement (Minors & Waterhouse, 1989; Sack et al., 2007). Unfortunately, several other factors that can influence the peripheral clock, such as mental activity, cannot be controlled (Folkard, 1989) and therefore the efficacy of both techniques has been debated (Benloucif et al., 2005).

2.1.3: Circadian rhythms and exercise

Circadian rhythms are a prominent factor for many aspects of exercise (Drust, Waterhouse, Atkinson, Edwards, & Reilly, 2005; Reilly, 2009a; Reilly, Atkinson, & Waterhouse, 1997; Reilly & Waterhouse, 2009; Yamanaka & Waterhouse, 2016; Youngstedt & O'Connor, 1999) and many indicators of exercise intensity, including heart rate, perceived exertion and power output, show a daily rhythmicity (Atkinson & Reilly, 1996; Dalton, McNaughton, & Davoren, 1997; Manfredini et al., 1998; Winget, DeRoshia, & Holley, 1985; Yamanaka & Waterhouse, 2016). Similarly, several psychomotor functions and motor skills that can influence performance show a daily rhythm (Atkinson & Reilly, 1996). On the opposite end, the maximal oxygen consumption ($\dot{V}O_{2max}$) appears to be stable across the day (Atkinson & Reilly, 1996; Drust et al., 2005; Reilly, 2009a; Reilly & Brooks, 1982).

The influence of circadian rhythms on sport performance is mediated by external factors, such as environment, motivation and weather conditions, which can influence both physical outputs and circadian rhythms (Atkinson & Reilly, 1996; Manfredini et al., 1998; Reilly & Waterhouse, 2009; Winget et al., 1985). Similarly, endogenous factors such as changes in the central body clock or in the sleep-wake cycle can influence performance and, by definition, circadian rhythms (Reilly & Waterhouse, 2009). However, performance is likely to increase if coaches adapt training based on the understanding of the interactions between circadian rhythms and exercise. (Dalton et al., 1997; Manfredini et al., 1998). Anecdotally it is thought that an athlete's performance reaches its peak in the late afternoon or early evening (between 4 and 8 pm) when many circadian components of exercise tend to peak. Ideally, scheduling training at this time when athletes are ready to work harder and their training response is greater might increase their performance (Atkinson & Reilly, 1996), although other anecdotal evidence suggests performance may increase when training in a fatigued state.

2.1.4: Effects of circadian rhythms disruption and jet lag

The main function of circadian rhythms is to prepare the body to changes that occur every 24 hours such as changes in light or normal alternation between wake and sleep phases (Atkinson & Reilly, 1996; Forbes-Robertson et al., 2012). The body clock can adjust itself to a new condition but this process is slow (Forbes-Robertson et al., 2012). In a natural environment, the light condition changes slowly, as the day duration changes gradually across the different seasons (Forbes-Robertson et al., 2012), but when a sudden change occurs, for instance after trans-meridian travel, the adaptive response does not match the speed of the environmental change and therefore, a disruption of the circadian rhythms occurs (Forbes-Robertson et al., 2012). A shift in circadian rhythmicity affects all the cells of an organism influencing both the central and peripheral clocks (Haus & Smolensky, 2006). Chronic circadian rhythms disruption can have detrimental effects on a number of different physiological and psychological functions of the human body. Continuous shifts of circadian rhythms are considered as a risk factor for different types of cancer (Hastings et al., 2007), cardiovascular and metabolic diseases such as diabetes (S. A. Brown, 2016; Morris, Purvis, Mistretta, & Scheer, 2016; Wong, Hasler, Kamarck, Muldoon, & Manuck, 2015; Wulund & Reddy, 2015). However, these findings are commonly reported in animal based study that simulated circadian disruptions in laboratory settings (Atkinson et al., 2014). Furthermore, cabin crew personnel has been found to be less likely to suffer from any form of cancer despite their high exposure to circadian rhythms disruptions (Atkinson et al., 2014).

The acute negative effects and symptoms associated with the loss of synchronicity between the internal and external clock are commonly referred to as jet lag (Waterhouse et al., 2004). Jet lag usually occurs when more than three time zones are crossed in a short span of time (Forbes-Robertson et al., 2012). Other forms of jet lag exist that are related to shift-work or inappropriate behaviours (social jet lag) (Fonken & Nelson, 2016; Potter, Skene, et al., 2016; Pylkkonen et al., 2015; Wong et al., 2015), however these are not covered in this thesis.

Jet lag is generally seen as a normal consequence of trans-meridian flights. However, the World Health Organization considers jet lag as a disorder of the sleep-wake cycle (Forbes-Robertson et al., 2012) and the American Academy of Sleep Medicine included jet lag in the International Classification of Sleep Disorders (ICSD-2) as one of the six circadian rhythms sleep disorders (Sack et al., 2007). Common signs and symptoms of jet lag are tiredness, daytime sleepiness and difficulty in falling asleep at night, reduced mental and physical performance and gastro-enteric problems (Waterhouse et al., 2004). In 2014, the American Academy of Sleep

Disorders identified three diagnostic criteria for the diagnosis of jet lag. People are considered to suffer jet lag if they report insomnia or sleepiness with impaired total sleep time after crossing at least two time zones (first criterion), if they report impairment of daytime functions, malaise or other somatic symptoms within two days after travel (second criterion) and if there are no other possible causes for the complaints (third criterion) (AASM, 2014; Becker, Penzel, & Fietze, 2015, 2016; Sack et al., 2007).

Jet lag signs and symptoms are in general more severe as the number of time zones crossed increase (Forbes-Robertson et al., 2012; Revell & Eastman, 2005; Sack et al., 2007) but symptoms are also related to the direction of travel, being worst travelling eastward (Herxheimer & Petrie, 2002; Reilly, Atkinson, et al., 2007; Sack et al., 2007). Flying in an eastward direction requires a phase advance while flying westward requires a phase delay. Temporal isolation studies showed that circadian rhythms in humans are slightly longer than 24 hours. Therefore, the human body shows a natural tendency to drift slightly each day and it is easier for the body to cope with a delay than an advance in time. Thus the time required to recover from jet lag symptoms is typically shorter after travelling in a westward direction (Eastman & Burgess, 2009). Symptoms also differ between individuals of various age and fitness levels, with athletes being able to adjust more quickly and more effectively (Atkinson, Edwards, Reilly, & Waterhouse, 2007; Reilly, 2009b; Sack et al., 2007; Waterhouse et al., 2002; Waterhouse et al., 2004). Another important factor to take into account is the individual's chronotype.

The "Morningness-eveningness" questionnaire is the most common tool used to assess chronotypes (Horne & Ostberg, 1976; Kolla & Auger, 2011; Sack et al., 2007) and classify people, according to their daily routine habit, as 'larks' and 'owls'. 'Larks' are individuals that tend to go to bed early, rise early and perform better during the day. ‘Owls’ are people that go to bed late, rise late and perform better during late afternoon and evening hours (Roenneberg, Wirz-Justice, & Merrow, 2003). In terms of jet lag, it seems that larks are better in dealing with an eastward shift because their body clock has a shorter inherent period while the owls are better in the opposite directional shift (Reilly, 2009b; Reilly, Atkinson, et al., 2007; Waterhouse et al., 2004).

Over time, people can recover from symptoms of jet lag and, anecdotally, it seems that it takes one day per time zone crossed to fully recover (Loat & Rhodes, 1989; Reilly, 2009b; Youngstedt & O'Connor, 1999). It also seems that the recovery rate is influenced by the direction of travel (Reilly, 2009b; Youngstedt & O'Connor, 1999). In particular, re-entrainment of the circadian rhythms seems to occur at the pace of 92 $min.d^{-1}$ for westbound travel and 57 $min.d^{-1}$ for eastbound travel (Haus & Smolensky, 2006). Depending on the number of time zones crossed and the direction of travel, re-entrainment might occur in the same direction (orthodromic re-entrainment) or rarely, in the opposite direction (antidromic re-entrainment) (Leloup & Goldbeter, 2013). The most important factor involved into solving jet lag symptoms is light exposure (Youngstedt & O'Connor, 1999).

The disruption of circadian rhythms, in general or after travel, has been investigated in the general population (Benloucif et al., 2008; Klerman et al., 2002; Lewy et al., 1999; Voultsios et al., 1997) or in athletes to analyse the effects of a single travel (Bullock et al., 2007; Lemmer et al., 2002). However, an analysis of the effects of circadian rhythms disruption on the outcome of athletes who travel on an almost weekly basis and an analysis of the influence of different strategies in resynchronise their circadian rhythms have not been previously performed.

2.1.5: Measurement of jet lag

Jet lag is a particular aspect of circadian rhythms disruption and can be measured with the same tools used to assess circadian rhythms. Sleep disruption is probably the most important symptom of jet lag and several studies use sleep assessment as an indirect measure of jet lag (Spitzer et al., 1999). Furthermore, a number of scales and questionnaires have also been validated to specifically assess jet lag. However, the new International Classification of Sleep Disorders (AASM, 2014) does not mention these questionnaires and scales as diagnostic instruments.

2.1.5: Summary of circadian rhythms and jet lag

Circadian rhythms are a fundamental element of human life and an important factor to determine exercise response. However, the link between circadian rhythms, their disruption and consequential performance is still not clear. Understanding this interaction has the potential to enhance training response and performance as well as the physical and mental health status of athletes.

2.2: Effects of travel and jet lag on performance

The next sections of this literature review will analyse the effects of travel on performance. In particular, travel fatigue, the home ground advantage, jet lag and the main strategies used to cope with the effects of travel and jet lag on performance will be analysed.

2.2.1: Effects of travel on athletes

The interest on the effects of travel on sporting performance dates back to the end of the 70s when the possible detrimental effects of travel on performance were first underlined (Antal, 1975). However, practical and logistic problems, including the costs of collecting data ’on the road’, arise frequently, affecting studies on travel and performance. As such, few researchers have shown interest in this kind of study. Furthermore, studies on travel and performance are usually based on a single trip across multiple time zones prior to a competition (e.g. Olympics Games) or training periods scheduled overseas (Beaumont et al., 2004; Bullock et al., 2007; Cardinali et al., 2002; Chapman et al., 2012; Eastman et al., 2005; Fowler, Duffield, & Vaile, 2015; Pierard et al., 2001; Reilly, Atkinson, & Budgett, 2001; Takahashi, Nakata, & Arito, 2002). However, a number of sports require frequent travel during the entire season to compete (e.g. tennis, rugby union, cycling, and golf). As such, an analysis of the cumulative and chronic effects of travel will be more useful for teams and athletes. Very few studies have investigated the effects of travel from a chronic perspective and they assessed performance using match statistics or game results from past seasons (D. Bishop, 2004; Fonken & Nelson, 2016; Haus & Smolensky, 2006; Hofstra & de Weerd, 2008; Potter, Skene, et al., 2016; E. C. Taylor, Bernerth, & Maurer, 2017; Winter et al., 2009; Youngstedt & O'Connor, 1999). A brief review of studies on travel fatigue and home ground advantage is presented in sections 2.2.1.1 and 2.2.1.2. Trans-meridian flight and jet lag are reviewed in section 2.2.1.3.

2.2.1.1: Effects of travel on training and performance

Travel is only one of the many factors that can affect training and performance in professional athletes. Even if it is unclear the extent to which travel *per se* can affect performance, travel fatigue seems to be the main component. Travel fatigue is the summation of physiological, psychological and environmental factors, that accrue after a single trip and accumulates over time (Samuels, 2012). Travel fatigue is characterized by persistent weariness, recurrent illness, changes in mood and behaviour, and lack of motivation (Samuels, 2012). Travel fatigue is related to discomfort from sitting in a restricted space often in association with reduced activity, changes in daily life routine and sleep disruption (Fowler et al., 2014; Fuller, Taylor, & Raftery, 2015; Waterhouse, Reilly, et al., 2007; Waterhouse et al., 2004). Another issue with travel is related to hypoxic exposure inside the flight cabin (Leatherwood & Dragoo, 2013; Waterhouse, Reilly, et al., 2007). Commercial flights have a pressurized cabin for safety reasons and regulatory agencies have established that cabins need to have an average pressure equivalent to 1520-1828 m above sea-level and a maximum of 2440 m (Geertsema, Williams, Dzendrowskyj, & Hanna, 2008).

Travel fatigue is important for its acute effects on performance after a single episode of travel but also for the cumulative effects that might accrue when teams or athletes are required to undertaken multiple journeys during a season (chronic travel fatigue). The effects of travel fatigue on players and team performance have been investigated in a number of different sports, including soccer, netball and American football (D. Bishop, 2004; Fowler, Duffield, Howle, Waterson, & Vaile, 2015; Fowler, Duffield, Waterson, & Vaile, 2015; Jehue, Street, & Huizenga, 1993). Travel fatigue appeared to have no effect on sleep, wellness, training response and injury rate of the athletes (Fowler, Duffield, Howle, et al., 2015; Fowler, Duffield, Waterson, et al., 2015). There are conflicting results on the effects of travel on performance (D. Bishop, 2004; Fowler et al., 2014; Jehue et al., 1993; Morton, 2006). However, in some of these studies the importance of the away-match disadvantage and its contribution to the travel effect was neglected or underestimated to the extent that it was not included in the analysis (D. Bishop, 2004; Jehue et al., 1993). As such, the effect of travel fatigue on team sport performance is still a matter of discussion.

2.2.1.2: *Effects of the Home ground advantage on performance*

Away performance of most teams in any sport has typically been below that associated with performances at home. Various factors are at play here including, but not limited to match location, match status, opposition quality, technical-tactical and strategic plan for the game, and arguably most important that of size (thus noise) coming from home-crowd support having a psychological boost to favour the home team. These effects all contribute to create the so-called home ground advantage (Fowler et al., 2014). The home ground advantage represents the common belief that individuals or teams that compete in a tournament that involves matches played home and away with the same opponents are more likely to win when playing home (Morton, 2006). The different components of the home advantage can be clustered in five main groups (Carron, Loughhead, & Bray, 2005; Courneya & Carron, 1992). The first group (game location) specifies whether a game is played home or away. The second group (game location factors) includes crowd factors, travel factors, and familiarity with the home ground condition. The home ground conditions and the dimensions of the pitch are critical in Rugby Union as they can dictate teams' strategic plans and performance. Altitude is an additional location factor that could have a positive impact on performance of the home team (Aughey et al., 2013). The third and fourth groups (critical psychological state and critical behavioural state) include the psychological and behavioural responses of athletes (effort), coaches (tactical and strategical decisions) and match officials (subjective bias) when at their home ground. The fifth group (performance outcomes) includes primary (skill execution), secondary (points scored/conceded), and tertiary (final game outcome) outcomes of performance to define how the home ground advantage can influence their execution (Figure 2.5).

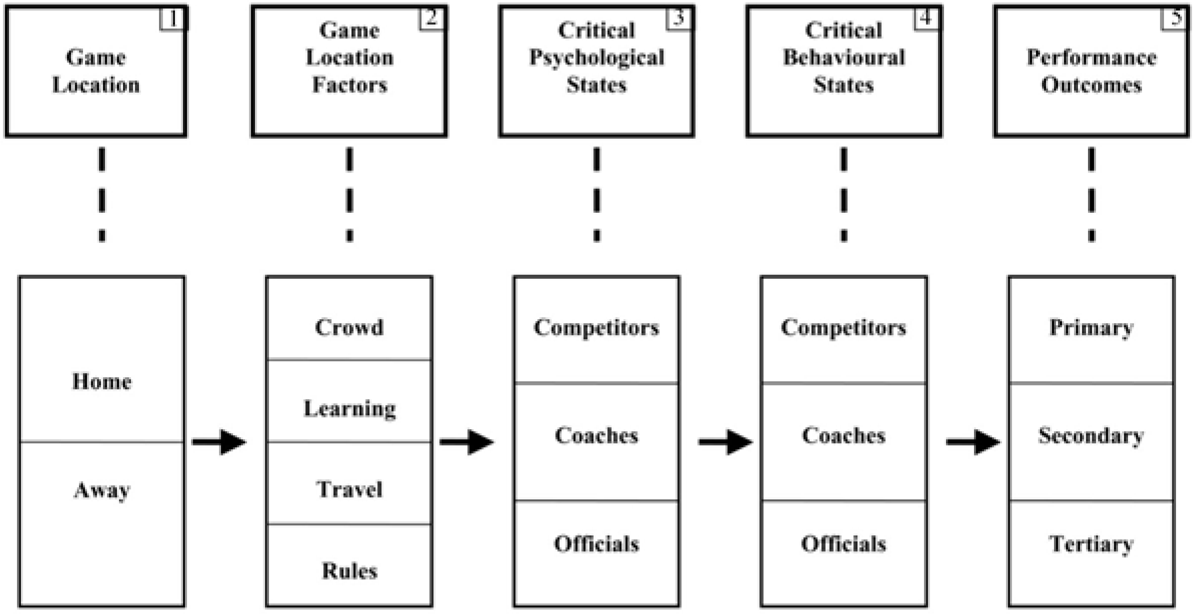


Figure 2.5: The components of the home advantage in sport. Reproduced from (Courneya & Carron, 1992).

The home advantage has been investigated in Super Rugby, although with contrasting results (Du Preez & Lambert, 2007; Morton, 2006). In the first 10 years of the competition (1996 to 2005), teams from South Africa scored more points at home (+6.6 ± 17.4) than away (-6.8 ± 17.3), which confirms the importance of the home advantage, even when a game was played after returning from overseas (Du Preez & Lambert, 2007). However, a different study assessing the ability of all teams to score points over 5 years of competition (2000 to 2004), found that the home advantage was not particularly important and changed for each team (ranging from -0.7 to +28.3 points) and each year (ranging from -36.5 to +31.4 points) (Morton, 2006). As such, it is not clear the extent to which the home advantage can influence performance of Super Rugby teams.

2.2.1.3: Effects of jet lag on training and performance

Athletes have to travel often to compete or train and are likely to experience jet lag (Forbes-Robertson et al., 2012). The effect of jet lag on performance has been studied in both individual and team sports athletes (Bullock et al., 2007; Chapman et al., 2012; Fowler, Duffield, & Vaile, 2015; Fowler, McCall, Jones, & Duffield, 2017; Kolling et al., 2017; Schwellnus et al., 2012). Athletes who compete in individual sports often report sleep disturbances, feeling 'jet lagged' and have disruptions to their peripheral clocks (i.e. cortisol production), potentially impairing their health and well-being. However, jet lag has only a limited effect, if any, on their generic physical performance (i.e. 30 meter dash) (Figure 2.6) and 'real' sporting performance (i.e. ability to win a medal) (Bullock et al., 2007; Chapman et al., 2012; Kolling et al., 2017).

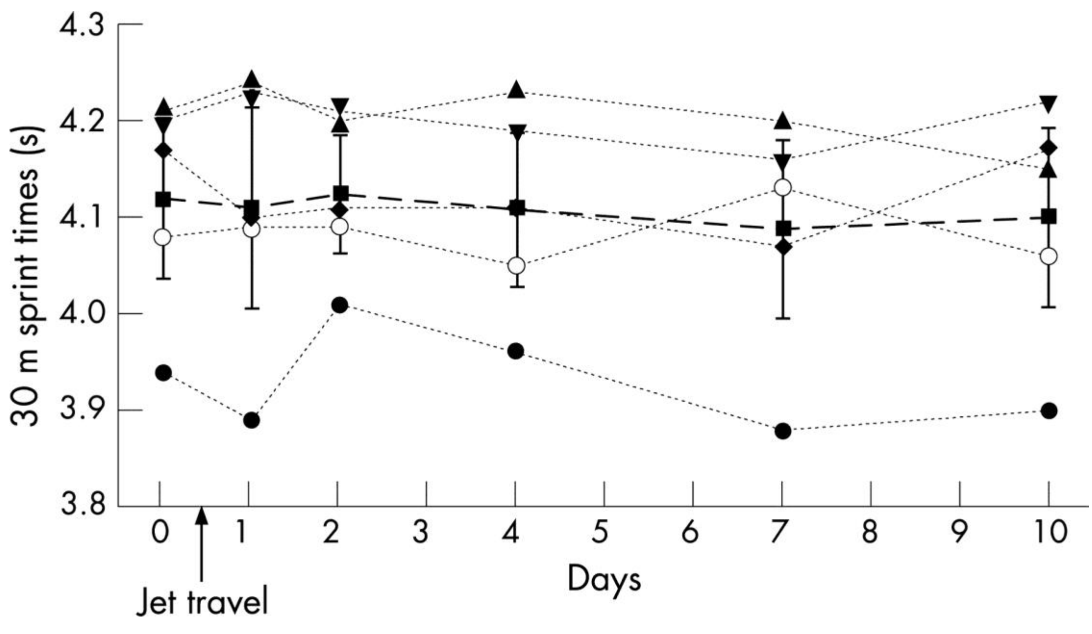


Figure 2.6: Individual and mean (dashed line) ±90% CI for 30m sprint performance for Australian athletes traveling to Canada. Reproduced from (Bullock et al., 2007).

For team sports athletes, jet lag has a detrimental effect on generic physical performance (i.e. Yo-Yo Intermittent Recovery level 1 tests) and sleep (Fowler, Duffield, & Vaile, 2015). Similarly, athletes experience an increase in respiratory, gastro-enteric, cutaneous illness and a reduction in well-being after crossing time zones in both directions of travel (Fowler et al., 2017; Schwellnus et al., 2012).

Studies analysing the effects of jet lag on sporting performance present a number of methodological and logistic issues. It is often difficult to discriminate between travel fatigue and jet lag, making it difficult to demonstrate the magnitude of their effects on performance (Reilly et al., 1997). Furthermore, studies examining the effects of travel on performance tend to focus on a single travel, however, teams often have multiple travel during a season. Finally, match performance is usually not evaluated in these studies. As such, the impact of jet lag on performance, especially for team sports, is still a matter of discussion.

2.2.2: Main strategies used to cope with the effects of travel fatigue and jet lag

Planning travel in advance can help reduce the effect of travel fatigue and jet lag. The preparation of travel may include actions to be taken before, during and after the flight (Waterhouse et al., 2004). Planning the trip to reach the intended destination a number of days pre-competition can give enough time for athletes to recover from jet lag and travel fatigue (Reilly, Atkinson, et al., 2007). During the flight, it is important to take every opportunity to move, stretch limbs, or wear compressive garments to reduce risk of cramping or even deep vein thrombosis in people predisposed to such problems (Reilly, 2009b; Waterhouse et al., 2004). After the flight, if the destination is reached during daytime, a nap of about an hour can be useful. If the destination is reached at night time is important to go to sleep as soon as possible; thereby, the next day, most of the acute effects of travel fatigue will be reduced or have disappeared (Waterhouse et al., 2004). When travel involves crossing time zones, a number of strategies can be used to reduce the symptoms of jet lag (Auger & Morgenthaler, 2009). All these strategies can be clustered into two main groups: behavioural and pharmacological (Reilly et al., 1997). The first group includes pre-adjustment strategies, exercise, light exposure and diet interventions (Reilly, 2009b). The second group includes hypnotics and/or sleeping tablets, melatonin and caffeine supplementations (Beaumont et al., 2004; Reilly et al., 1997). All the strategies are used to reinforce the natural *zeitgebers*. In theory, combing all the strategies will induce the best adaptation to reduce jet lag but the extent of an interactive effect is still unclear (Forbes-Robertson et al., 2012). It is also important to underline that individual factors, especially the chronotype, can influence the way each person adjusts to time shifts and the response to different strategies (Forbes-Robertson et al., 2012). Furthermore, evidence suggests the lack of good quality randomised control trials and the need for further studies to properly identify the best strategies to cope with the effects of jet lag (Atkinson et al., 2014).

2.2.2.1: Pre-adjustment strategies

For brief stays, up to three days, in a destination located in a different time zone there is no time for the body clock to adjust. As such, it is usually suggested to try to maintain life as much as possible on home time (Forbes-Robertson et al., 2012; Waterhouse et al., 2004) but that solution is usually not feasible for professional athletes. Competitions are usually scheduled at particular times that cannot be changed. Trying to maintain the home time may result in poor performance and will reduce the likelihood of success. Furthermore, this suggestion requires additional studies for the effects to be confirmed (Morgenthaler, Lee-Chiong, et al., 2007).

For longer stays (more than three days), pre-adjustment strategies can be used. An example is rescheduling training according to the destination time and seeking or avoiding light according to the destination time while at home (Forbes-Robertson et al., 2012). For instance, for eastward travel, a phase advance can be induced by shifting the bed/wake time by 1-2 hours and by exposing to bright intermittent light after waking up (30 min at ~5000 lux alternating with 30 min at less than 60 lux for 2–3 hours each morning) to resynchronize the body clock prior to departure. The duration of the intervention should be based on the number of time zones crossed during travel (1 day per time zone crossed). Following this intervention, a traveller should reach a destination already having shifted to the new time zone, thus reducing the time required for re-entrainment and the risk of antidromic re-entrainment (Figure 2.7) (Revell & Eastman, 2005). Combining melatonin supplementation (either 0.5 or 3.0 mg) in the afternoon with shifting the sleep-wake time and morning light exposure may increase the magnitude of the phase shift (Revell et al., 2006).

Pre-adjustment strategies appears to be one of the more indicated solutions to reduce jet lag symptoms (Eastman & Burgess, 2009), although the applicability in a sporting context may be limited due to difficulty in combining training schedules with drastic changes in sleep/wake time for athletes.

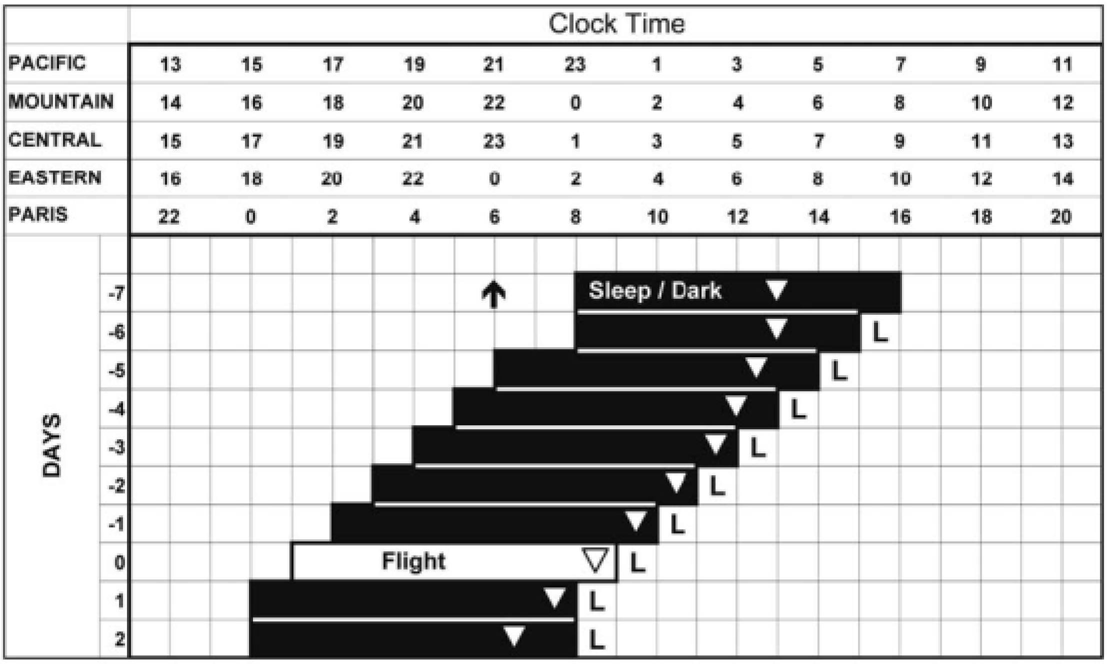


Figure 2.7: Sleep and light schedule to be used to advance circadian rhythms before eastward flight and reduce jet lag. The arrow and triangle show the typical time of the dim light melatonin onset (DLMO) and minimum temperature (Tmin) for that schedule. The Ls show the time for intermittent bright light exposure (2–3 hours each morning). Wake time is advanced 1 hour per day. Reproduced from (Eastman et al., 2005).

2.2.2.2: Light exposure

Light is the most important of all the *zeitgebers* (Forbes-Robertson et al., 2012; Sack et al., 2007). Timing, intensity and wavelength of light are important to induce adaptation of circadian rhythms (Duffy & Wright, 2005; Forbes-Robertson et al., 2012). Lux is the measure of light intensity or illumination according to the International System (Sack et al., 2007). Light of high intensity (3000-10,000 lux) produces larger effects on circadian rhythms but even modest intensity (50-600 lux) can induce a phase shift in people coming from a dark/dim light environment to a lighter one (Sack et al., 2007). Light exposure, continuous or intermittent (Duffy & Wright, 2005), can be obtained by outdoor exposure or by using a commercial Light Box (Auger & Morgenthaler, 2009; Danielsson, Jansson-Frojmark, Broman, &

Markstrom, 2016; Duffy & Wright, 2005). However, artificial light entrains to a minor extent than natural light (Reilly, Waterhouse, et al., 2007; Skeldon, Phillips, & Dijk, 2017). In general, light in the morning advances circadian rhythms while light exposure by the evening induces a delay. According to this ‘phase response curve’, timing of light exposure can be adapted according to the direction of travel. For instance, after eastward travel, light should be sought in the morning (home, not destination time) to induce a phase advance (Reilly, Atkinson, et al., 2007; Revell et al., 2006). Photic stimulation is likely to be the most effective strategy to hasten recovery from jet lag especially when combined with other strategies including melatonin supplementation (Cardinali et al., 2002; Forbes-Robertson et al., 2012). However, the efficacy of light-based strategies for reducing jet-lag symptoms in elite athletes is unclear (Atkinson et al., 2014; Thompson et al., 2013).

Light avoidance when required, for instance during the night (home, not destination time) after eastward travel, can also magnify the effects of light exposure in resetting the body clock. Particular glasses with blue light filter are available on the market for such a purpose (Samuels, 2012) and the efficacy of these glasses is based on the fact that melatonin production and suppression depends on the wave length of the light that reaches the suprachiasmatic nuclei. In particular, blue light, which is between 446 and 477 nm of the visible spectrum, seems to suppress melatonin production (Geerdink, Walbeek, Beersma, Hommes, & Gordijn, 2016; Kozaki, Kubokawa, Taketomi, & Hatae, 2016; Sasseville, Paquet, Sevigny, & Hebert, 2006). Furthermore, melanopsin, the photo pigment of the retinal receptors, is particularly sensitive to this particular area of the light spectrum (Forbes-Robertson et al., 2012; Geerdink et al., 2016; Kozaki et al., 2016; Sack et al., 2007).

2.2.2.3: Exercise

Physical activity can potentially influence sleep and circadian rhythms (Forbes-Robertson et al., 2012). The American Sleep Disorders Association includes exercise in its sleep hygiene and non-pharmacological intervention to improve sleep (Driver & Taylor, 2000). The effects of exercise on sleep are mostly related to intensity, duration and timing of the training (Forbes-Robertson et al., 2012). Training for more than an hour at moderate to high intensity (50-75% of the $\dot{V}O_{2max}$) (Buxton, Lee, L'Hermite-Balériaux, Turek, & Cauter, 2003; Edwards, Waterhouse, Atkinson, & Reilly, 2002) may enhance sleep, whilst short sessions at any intensity appears to have no effect on sleep (Driver & Taylor, 2000). The ideal time window for performing physical activity is broad and can change according to individual characteristic such as age and fitness level (Baehr et al., 2003).

As sleep disruption is also one of the main symptoms of jet lag, exercise is considered an important non-photic factor that helps to reduce the effects of jet lag, especially if used in combination with other interventions, including light exposure (Haus & Smolensky, 2006). However, there is no consensus on the ideal intensity, timing and the extent to which training can influence circadian rhythms (Atkinson et al., 2007; Atkinson & Reilly, 1996; Forbes-Robertson et al., 2012). Furthermore, it is difficult to discriminate between the effects of exercise *per se* and the effects related to light exposure during a workout (Waterhouse, Reilly, et al., 2007; Yamanaka & Waterhouse, 2016).

In the first days after travel athletes may be fatigued, making it important to adjust the exercise load accordingly (Reilly, Atkinson, et al., 2007). In particular, for endurance training, volume, intensity, and frequency should be reduced (Samuels, 2012). Relaxation and breathing exercises have been suggested to enhance sleep

(Halson, 2008) and can be used after international travel to improve sleep and reduce jet lag.

2.2.2.4: Diet interventions

Diet interventions may help athletes to counteract the detrimental effects of travel (Armstrong, 2006), although there is no clear evidence that diet can reduce symptoms of jet lag (Atkinson et al., 2014; Herxheimer, 2008). During a flight, travellers are exposed to hypoxia and dry air due to pressurization of the cabin. Exposure to both factors can induce mild to moderate dehydration that can alter the normal physiological functions and reduce mental and physical performance (Armstrong, 2006). Water and fruit juice should be consumed to reintegrate fluids while other beverages with diuretic effects such as alcohol should be avoided (Reilly, Atkinson, et al., 2007). The symptoms of dehydration also tend to disappear upon arrival when fluids are reintegrated into the body (Reilly, Atkinson, et al., 2007).

Feeding can be considered as both a *zeitgeber* (S. A. Brown, 2016; Tahara & Shibata, 2013) and an endogenous rhythm (Forbes-Robertson et al., 2012). Feeding patterns follow a circadian rhythm, which is masked by the social timing of the meals (Forbes-Robertson et al., 2012). As a *zeitgeber*, nutritional interventions can help to reduce the effects of jet lag (Armstrong, 2006). However, it is not clear if the resynchronization is linked to the nutrients intake or just to the timing of the meals (Potter, Cade, Grant, & Hardie, 2016; Reilly, Atkinson, et al., 2007; Reilly, Waterhouse, et al., 2007).

Specific food can be used to indirectly reduce jet lag due to their capacity to influence sleep. Valerian, and to a minor extent other sedative herbs, are suggested to improve sleep with limited side effects (Halson, 2008, 2014b). Tart cherries and their juice are rich in melatonin (Halson, 2008, 2013a), which is able to reduce inflammatory response and promote sleep (Halson, 2014b; Howatson et al., 2012). Sleep can also be induced through the ingestion of tryptophan-containing foods such as milk, eggs, peanuts, meat and fish. Tryptophan is an essential amino acid and the precursor of two important sleep related neurotransmitters, gamma-Aminobutyric acid (GABA) and serotonin (Halson, 2013a, 2014b). Serotonin production can also be enhanced through the ingestion of high glycaemic index carbohydrates (Halson, 2008), better if consumed more than one hour before bedtime (Halson, 2013a, 2014b).

2.2.2.5: Hypnotics and sleeping tablets

Benzodiazepines and non-benzodiazepine drugs have soporific effects (Reilly, Atkinson, et al., 2007). Some benzodiazepines have also a potential chronobiotic effect, facilitating a shift of the body clock (Reilly, Atkinson, et al., 2007). Benzodiazepines hypnotic action occurs through their interactions with GABA receptors, which are similar to those located in the suprachiasmatic nuclei (Reilly et al., 2001). Even if anecdotally these drugs are commonly used to induce sleep after trans-meridian travel, their efficacy is not confirmed (Donaldson & Kennaway, 1991; Reilly et al., 2001). Furthermore, the muscles-relaxant effects of these drugs last longer than the hypnotics and their use can increase the risk of injuries during training (Reilly, Atkinson, et al., 2007).

In general, hypnotics and sleeping tablets are effective to induce sleep in people with insomnia related to jet lag. However, the efficacy of these drugs in reducing daily symptoms is still unknown. Any benefits related to the use of these drugs should be weighed against the risk of side effects, especially in athletes (Sack et al., 2007).

2.2.2.6: Caffeine

Caffeine is a weak psychostimulant commonly consumed by the general population that seems to help in reducing jet lag symptoms while maintaining arousal during the day (Pierard et al., 2001; Roehrs & Roth, 2008). However, it is not clear whether caffeine has a chronobiotic function (Burgess & Emens, 2016; Haus & Smolensky, 2006). The role of caffeine in counteracting jet lag seems to be related to its action on A2b adenosine receptors of the pineal gland (Beaumont et al., 2004; Roehrs & Roth, 2008; Shilo et al., 2002). Caffeine also mitigates the effects of fatigue during the resynchronization of the circadian rhythms (Samuels, 2012) and in particular caffeine can temporarily reduce sleepiness and enhance cognitive response in jet lagged travellers (Armstrong, 2006). Caffeine taken during the evening can negatively influence subsequent sleep patterns although there are wide differences in individual response (Halson, 2008; Reilly, 2009b). The negative effects of caffeine are particularly relevant for athletes who usually take caffeine prior to evening matches and training (Halson, 2008). On the other hand, taking caffeine prior to a short nap of no more than 30-45 minutes, showed positive effects on cognitive function in people with sleep disruptions (Samuels, 2012).

2.2.2.7: Melatonin

Melatonin has a fundamental role as both a marker of circadian rhythms disruption, for instance after travel across time zones, and as an effective treatment of jet lag symptoms (Auger & Morgenthaler, 2009; Cajochen et al., 2003; Romsing et al., 2006). Melatonin also improves sleep quality (Auger & Morgenthaler, 2009; Cajochen et al., 2003). Exogenous melatonin induces a phase advance in the production of endogenous melatonin with an additive effect if taken in the late afternoon. As such, Melatonin is in general considered as a chronobiotic drug (Reilly, Atkinson, et al., 2007). However, it is not clear whether the efficacy of melatonin is related to a soporific or chronobiotic effect (Waterhouse, Reilly, et al., 2007). The availability of commercial melatonin varies from country to country; melatonin is available over the counter in some countries such as the USA, while it is sold by prescription in other countries (Burgess & Emens, 2016; Noyek, Yaremchuk, & Rotenberg, 2016; Samuels, 2012). If taken at the wrong time, melatonin can provoke a phase delay, antagonising the entraining function of light (Herxheimer & Petrie, 2002), and also induce daily sleepiness and sleep disturbances (Sack et al., 2007).

Concern was initially raised regarding the potential side effects of melatonin in athletic performance. A study found that melatonin did not have any particular side effects on athletes, but also did not have any positive effect on sleep (Atkinson, Buckley, Edwards, Reilly, & Waterhouse, 2001). On the other hand, another study showed how melatonin combined with exercise and light exposure increased the recovery rate of professional soccer players travelling across 12 time zones (Cardinali et al., 2002).

A Cochrane review analysed 10 trials and found that melatonin clearly reduces the effects of jet lag after crossing five or more time zones (Herxheimer & Petrie, 2002). In five of the trials analysed, melatonin helped in reducing daily sleepiness and enhanced both sleep latency and quality. In two trials, the mood of the participants showed an increase in vigour/activity and a decrease in fatigue when using melatonin. The authors also analysed the trials to identify the best dosage of melatonin needed. According to their analysis, a daily dose of 0.5 mg had similar effects to 5 mg but participants seemed to fall asleep quicker and sleep better after taking 5 mg. A higher dosage of 8 mg was not more effective than 5 mg. Finally, 2 mg of slow release melatonin is less effective then bursts of melatonin. In general though, it seems that the timing of intake is more important than dosage taken (Sack et al., 2007).

2.2.3: Summary of the effects of travel on performance

It is not clear to what extent travel and jet lag can have detrimental effects on athletes' performance. A number of strategies, such as melatonin supplementation and light exposure, have been identified and are currently used to reduce the detrimental effects of travel (Table 2.1). Further research is required to quantify the influence of travel and jet lag on athletes' performance and identify the best strategy to reduce their effects. These findings will have the potential to enhance athletes' performance and also improve their quality of life.

Table 2.1: Main strategies to induce a phase advance or a phase delay after east and west travel.

STRATEGY	EAST (PHASE ADVANCE)	WEST (PHASE DELAY)
Pre-adjustment	Shift sleeping and eating time 1/2 hours earlier than usual	Shift sleeping and eating time 1/2 hours later than usual
Light exposure	Seek like exposure in the early morning (home not destination time)	Seek light exposure in the evening (home not destination time)
Exercise	Training at 50-75% of the VO2max in the evening	Training at 50-75% of the VO2max in the morning
Diet interventions	Consume sleep friendly food (food rich in melatonin, tryptophan or sedative herbs)	Consume sleep friendly food (food rich in melatonin, tryptophan or sedative herbs)
Hypnotics	Sleeping tablets only if needed	Sleeping tablets only if needed
Caffeine	Consume caffeine during the day to maintain arousal	Consume caffeine during the day to maintain arousal
Melatonin	Supplement melatonin in the late afternoon (home not destination time) destination time)	Supplement melatonin in the early morning (home not destination time) destination time)

2.3: Effects of travel and jet lag on sleep

Sleep deprivation is one of the main concerns of travelling athletes and a main symptom of jet lag. As such, the next section will focus on the characteristics of sleep and its influence on performance. Finally, the main strategies used to enhance sleep will be reviewed.

2.3.1: Sleep as a circadian rhythm

A particular circadian rhythm is the sleep-wake cycle (Czeisler, Weitzman, Moore-Ede, Zimmerman, & Knauer, 1980; Goichot et al., 1998; Kandel, Schwartz, & Jessell, 2000). The body clock plays a fundamental role in regulating this cycle (Dijk & Lockley, 2002). The cycle is also the most discernible being associated with the alternation of daylight activity and sleep by night (Reilly & Edwards, 2007). Sleep is a reversible behavioural state in which an individual is perceptually disengaged from and unresponsive to the environment (Halson, 2013b, 2014b). Sleep is common in all animals but its function is not fully understood (Halson, 2008, 2014b). Furthermore, sleep is a complex phenomenon, which makes even more difficult to understand the function of each of its component (Maquet et al., 2000). However, it is generally accepted that sleep permits the recovery from previous wakefulness fatigue and to prepare the body for the subsequent wake phase (Halson, 2013b, 2014b; Nedelec et al., 2013; Robey et al., 2013).

Sleep is very important to maintain general health as sleep disruption seems to be an associated risk factor for several diseases (Chennaoui, Arnal, Sauvet, & Leger, 2015). Sleep is also very important to enhance brain functions. Neuroplasticity, learning and memory, for instance, are all positively influenced by sleep (Diekelmann & Born, 2010; Halson, 2008). Sleep is related with several biological rhythms such as body temperature, blood pressure, melatonin and other hormonal production. Sleep itself can be seen as a restorative circadian process (L. Taylor, Chrismas, Dascombe, Chamari, & Fowler, 2016). The cyclic alternation of sleeping and awakening phases is determined by a combination of genetic and environmental factors in a two-process model that regulates sleep (Beersma, 1998). Each individual has a preferred sleep schedule that matches the circadian phase. However training, school, work or other social commitments can impact the synchronicity between circadian rhythms and sleep scheduling (Samuels, 2008).

Under entrained conditions, a circadian pacemaker opposes sleepiness enhancing the neurobehavioral functions during the day and reduces these functions favouring sleep during the evening. In a parallel mode, melatonin production increases and promotes the thermoregulatory cascade that reduces body temperature and induces sleep (Cajochen et al., 2003). In general, two interacting processes govern the sleep-wake cycle: the sleep homeostasis, or process S, and the circadian regulation, or process C. Light and feedback from the sleep-wake cycle itself are also important (Dijk & Lockley, 2002). The sleep homeostat is responsible for giving an adequate amount of sleep based on the length of the previous awakening phase (Akerstedt, 2007; Dijk & Lockley, 2002; Kolla & Auger, 2011). Homeostatic pressure to sleep increases linearly when awake and declines drastically during the first phase of sleeping (Beersma, 1998; Stepanski & Wyatt, 2003).

The circadian regulation opposes the homeostatic regulation based on the intrinsic circadian rhythms of the body and the gene feedback loop that regulates the rhythms themselves (Akerstedt, 2007; Auger & Morgenthaler, 2009). Under normal conditions the circadian regulation induces wakefulness in the last part of the day and maintains sleepiness in the last part of a sleep opportunity (Stepanski & Wyatt, 2003). The combined action of sleep homeostat and circadian pacemaker contributes in maintaining alertness during the day and stabilizes sleep by night (Kolla & Auger, 2011; Stepanski & Wyatt, 2003) (Figure 2.8). Nonetheless, a study that forced people to live in an isolated environment without time cues, showed that the length of sleep is mostly due to the action of the body clock (Czeisler et al., 1980).

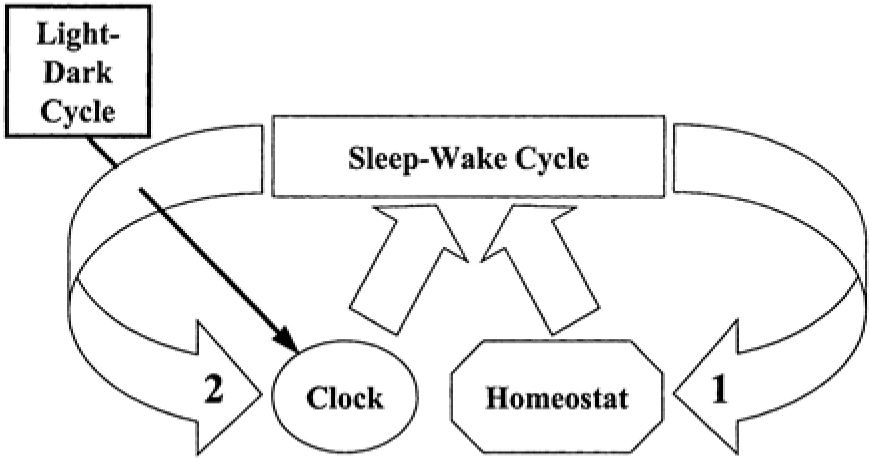


Figure 2.8: The human sleep-wake cycle as an interaction of a circadian regulator or pacemaker (clock), a sleep homeostat and the light/darkness cycle. Reproduced from (Dijk & Lockley, 2002).

2.3.2: Sleep generality

In general, sleep is characterized by a reduction of most physiological functions, a decreased ability to respond to stimulation, and a relatively easy reversibility that permits to distinguish sleep from other pathological conditions such as being in a coma.

From a neuroanatomy perspective, the portions of the brain mainly involved in sleep are the cortex, neocortex, pons and thalamus. In particular, the thalamus and cortex are linked by strong reciprocal projections, with the thalamus being the main gateway to direct information toward the cortex (Kandel et al., 2000). The thalamus modulates the amount of input received by the cortex being able to switch the brain from an aroused/alert state toward a sleep state (Sejnowski & Destexhe, 2000).

From a neurophysiological perspective, sleep can be organized in two main phases, non-REM and REM, which happen cyclically during the sleep periods (Kornum & Mignot, 2015). The name of the two phases is based on the presence, or not, of Rapid Eye Movements (REM) (Kandel et al., 2000; Kornum & Mignot, 2015). The first non-REM phase occurs when humans fall asleep. This first stage is characterized by a reduction in neurological and metabolic processes (Åkerstedt &

Nilsson, 2003) and there is also a reduction in heart rate and blood pressure due to a reduction in sympathetic activity (Chennaoui et al., 2015). The non-REM phase can be further divided in four stages based on brain activity patterns (Figure 2.9).

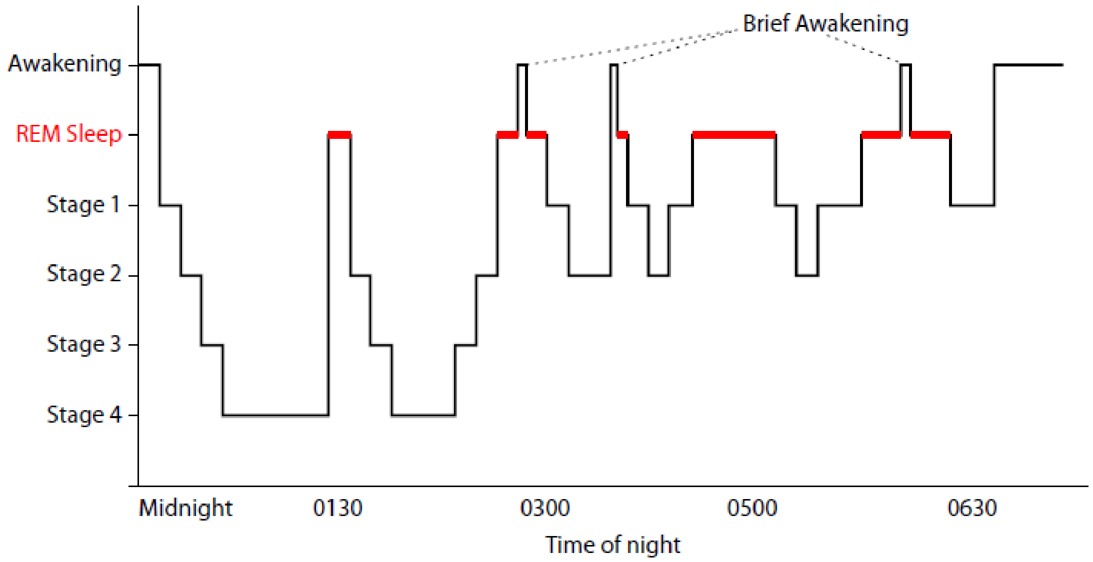


Figure 2.9: Simplified graphical representation of the different phases of sleep (hypnogram). Reproduced from (Kornum & Mignot, 2015).

The first phase is a transition from wakefulness to sleepiness. The electroencephalographic (EEG) activity shows an intermediate pattern. When still awake the EEG activity slowly decreases and shows a sinusoidal rhythm (alpha) and low voltage (10-30 µV and 16-25 Hz). During the first stage the EEG frequency declines to 6-8 Hz. In this stage, it is still possible to detect a minimal muscular activity for muscle tonus remains relatively high and slow rolling eye movements are detectable. It also seems that the recuperative function of sleep during the first stage is negligible (Åkerstedt & Nilsson, 2003). The second stage of sleep is characterized by bursts of sinusoidal waves known as sleep spindles (12-16 Hz) followed by high voltage biphasic waves called K complex (4-8 Hz). Both, sleep spindles and K complex, happen on the background of a continuous low-voltage EEG activity.

During this stage, muscle tonus falls further. The second stage covers around half of a sleep period. Furthermore, the recovery function of sleep starts during this second stage (Åkerstedt & Nilsson, 2003). The third and fourth stages are usually grouped together and referred to as Slow Wave Sleep (SWS). Both stages show high amplitude slow delta waves (0.5-4 Hz). The waves are evident respectively during 20% and 50% of the total time spent in phase three and four (Åkerstedt & Nilsson, 2003; Kandel et al., 2000) but are not equally distributed in the brain. The hippocampus area, for instance, shows brief sharp waves (50-100 ms) called large irregular amplitudes, associated with brief period of fast oscillation (100-200 Hz) called ripples (Sejnowski & Destexhe, 2000). Slow wave sleep and in general the slow wave activity of the brain during sleep are considered markers of the sleep homeostatic process (Dijk & Lockley, 2002). Slow wave sleep and slow brain activity are preserved even in animals with lesions in the suprachiasmatic nuclei (Dijk & Lockley, 2002). During slow wave sleep, muscle tonus keeps declining and metabolism falls (Kandel et al., 2000). Slow breathing, low heart rate and low cerebral blood flow are common futures of these stage. At the same time the anabolic function increases drastically while other metabolic or stress related functions such as cortisol production are suppressed (Fullagar, Skorski, et al., 2015). The increased anabolism and reduced metabolism that characterizes the slow wave sleep stages are fundamental aspects of the mechanism of restitution. Restitution is the body response to the time spent awake and permits recovery (Åkerstedt & Nilsson, 2003; Waterhouse, Reilly, et al., 2007). Restitution, and therefore slow wave sleep, are particularly important to promote recovery in athletes (Halson, 2014b; Nedelec et al., 2013).

The REM sleep phase is also called paradoxical sleep, as the brain activity and metabolism rise to resemble the waking state. During the REM phase, brain EEG resembles both the wake and stage one traces of the non-REM phase, with a low-voltage and mixed-frequency pattern (Kandel et al., 2000). Particularities of the EEG during the REM phase are bursts of activity (high-voltage spikes called ponto-geniculo-occipital spikes or PGO spikes) generated in the pontine reticular formation, hippocampus and amygdala that propagate through the lateral geniculate nucleus to the occipital cortex. Ponto–geniculo-occipital spikes are related to the eye movements typical of the REM phase and can also be evoked in wake subjects by sudden stimulations (Kandel et al., 2000). Interestingly, the prefrontal areas of the brain, which are consistently active during awakening, are not active during paradoxical sleep (Åkerstedt & Nilsson, 2003). It is known that dreams occur during the REM phase although dreams can be reported in other stages of sleep (Åkerstedt & Nilsson, 2003). As the EEG activity increases during the REM sleep, many other functions, such as brain temperature and metabolic rate, rise during this phase well above waking levels. On the other hand, during the REM sleep, skeletal muscles lose most of their tone (atonia) and drastically reduce their activity to prevent the acting-out of dreams (Åkerstedt & Nilsson, 2003). The few muscles that maintain their normal tone are the diaphragm and the muscles controlling the movement of the eyes (Kandel et al., 2000). Phasic twitches of the muscles also happen frequently. REM and non-REM phase alternate during sleep (Kandel et al., 2000).

Usually people go through the four stages of non-REM in bouts of 15-25 minutes. After 70 to 80 minutes there is a return to stage three or two followed by the beginning of the first REM phase, which lasts approximatively five to ten minutes. This alternation of the two phases is repeated four to six times per night (Kandel et al., 2000) with the last two sleep cycles usually missing stage three and four (Åkerstedt & Nilsson, 2003).

Any alteration in the sleep cycle can induce a sleep disorder having a negative impact on athletes' performance (Reilly et al., 1997). A common sleep disturbance is insomnia. Insomnia is characterized by difficulty in falling asleep and maintaining sleep over night. Insomnia is of particular importance from a chronobiologic perspective because one of the main reasons behind transitional episodes are circadian rhythms disruptions (Kandel et al., 2000). In particular, jet lag after travelling eastward and shift-work can result in the delayed sleep phase syndrome, which is the inability to fall asleep and awake at conventional times. Usually people with this syndrome tend to fall asleep early in the morning (e.g. 3 to 6 am) and to wake up late in the morning/early afternoon (e.g. 11 am to 2 pm). After travelling westward, jet lag can induce the advanced sleep phase syndrome. In this particular condition, a person falls asleep early in the evening (e.g. 8 to 9 pm) and rises early in the morning (e.g. 3 to 5 am).

2.3.3: Measurement of sleep

The gold standard for measuring sleep is polysomnography (PSG) (Halson, 2014b; Littner et al., 2003; Morgenthaler, Alessi, et al., 2007; Pollak, Tryon, Nagaraja, & Dzwonczyk, 2001). Polysomnography is commonly used for assessing clinical sleep disorders (Halson, 2013b). Polysomnography is the combination of encephalogram (EEG), electro-oculogram (EOG), electrocardiography (ECG) and electromyogram (EMG). The combination of the EEG, EOG and EMG traces permits the identification of the different stages of sleep (Åkerstedt & Nilsson, 2003; Halson, 2014b) (Figure 2.10). However, polysomnography has some limitations such as cost of analysis and discomfort (use of multiple scalp electrodes, sleep in an unfamiliar environment such as a laboratory) that limits its use in applied research (De Chazal et al., 2011; Halson, 2014b).

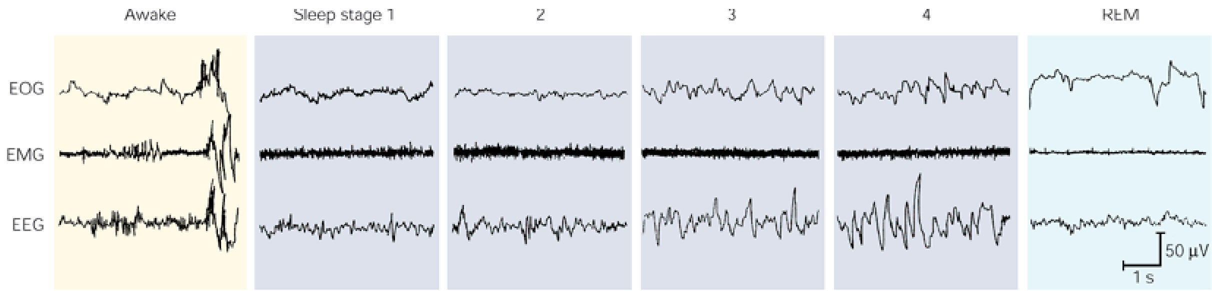


Figure 2.10: Simplified Representation of the activity of the eyes (EOG), muscles (EMG) and brain (EEG) measured via Polysomnography (see next section below for description of the technique) during the different stages of a sleep cycle. Reproduced from (Kandel et al., 2000).

Sleep can also be assessed using subjective tools. A basic evaluation is asking people to recall the amount of time they thought they spent asleep based on the time they went to bed and awoke. However, people tend to overestimate their sleep when subjective reports are compared with objective screen results (Stenholm, Kronholm, Bandinelli, Guralnik, & Ferrucci, 2011). A Sleep diary can be used to assess sleep and evaluate circadian rhythms sleep disorders (Sack et al., 2007) although people can misperceive and misreport their sleep habits. Compliance is also of concern. As such, sleep diaries are best used in combination with activity monitors devices (actigraphy) (Kolla & Auger, 2011; Sadeh & Acebo, 2002). Actigraphy and sleep diaries are a common alternative to PSG due to their portability and non-invasiveness (Halson, 2013b; Sargent, Halson, & Roach, 2014). They also permit a continuous analysis of sleep for long periods of time (Lotjonen et al., 2003; Sadeh & Acebo, 2002; Sargent et al., 2014; Van Someren, 2007). This method is also less expensive than polysomnography (Halson, 2014b) and combines both quantitative and qualitative sleep records.

Actigraphs are wristwatch-like accelerometer devices that monitor and collect data regarding the movement of the body (Lotjonen et al., 2003; Sadeh & Acebo, 2002) across different epochs (normally one minute) (Halson, 2014b) because it is known that when sleeping, all animals, including human beings, mostly stop moving (Pollak et al., 2001). The validity for activity monitor devices has been calculated using the polysomnography as criterion in a number of studies (Cole, Kripke, Gruen, Mullaney, & Gillin, 1992; Sadeh & Acebo, 2002; Sadeh, Sharkey, & Carskadon, 1994; Weiss, Johnson, Berger, & Redline, 2010). The correlation between polysomnography and actigraphy is very large (r>0.80) in measuring total sleep quantity (Hopkins, 2002; Sadeh & Acebo, 2002; Weiss et al., 2010) and moderate to large (0.6<r>0.8) in detecting the amount of time spent asleep as a percentage and in function of the time spent awake (sleep efficiency) (Hopkins, 2002; Weiss et al., 2010). However, activity monitors tend to slightly overestimate both total sleep time and sleep efficiency (Weiss et al., 2010). Inter device variability between units is moderate to large (0.6<r>0.96) (Sadeh et al., 1994) but the reliability of sleep estimate increases with the amount of nights monitored (Lotjonen et al., 2003; Van Someren, 2007). It is not clear if wearing the unit in the dominant or non-dominant wrist can affect the recording because of the inter device variability (Sadeh et al., 1994). It seems that is more important to assign the same unit to the same participant during a study in order to enhance reliability (Sadeh et al., 1994).

In association with actigraphy, a sleep diary should be completed by participants to report the beginning and the end of sleep periods (night time and any ‘naps’) (Halson, 2014b; Littner et al., 2003). When the activity registered by the actigraph is as low as to indicate the subject is immobile and the sleep diary indicates that the subject is lying down and trying to sleep, such a scenario is considered sleep time (Halson, 2014b; Sargent et al., 2014). By combining the two tools, it is possible to derive different variables such as bed and arise time (expressed in clock time), sleep onset and offset time (respectively the clock time when a participant fell asleep at the start of a sleep period and woke at the end of such a period), sleep latency (the period of time between bedtime and sleep onset time expressed in minutes), time spent in bed (expressed in hours) and total sleep time (the total amount of sleep obtained during a sleep period expressed in hours). The same tools allow the evaluation of sleep efficiency (the time in bed spent asleep expressed as percentage of total bed-time), moving minutes (the amount of time spent moving during time in bed expressed in minutes) and sleep fragmentation, wake after sleep onset (the amount of time spent awake after sleep has been initiated as a percentage of sleep), subjective sleep quality (self-rating of sleep quality on a 5-points Likert scale where 1 means very good and 5 very poor), and daytime nap duration (expressed in hours) (Lastella, Roach, Halson, & Sargent, 2015; Sargent et al., 2014).

2.3.4: Sleep and athletic performance

There is a strong relationship between sleep, exercise and performance. The reciprocal effects between the three are modulated by individual characteristics, including age, fitness level, and type of exercise (aerobic/anaerobic, acute/chronic, and indoor/outdoor) (Chennaoui et al., 2015). Sleep has an important role in enhancing physical adaptation in response to training (Åkerstedt & Nilsson, 2003; Robey et al., 2013; Samuels, James, Lawson, & Meeuwisse, 2016; Walters, 2002), mood and wellbeing (Chennaoui et al., 2015; Juliff, Halson, & Peiffer, 2015; Walters, 2002), and learning and skill acquisition (Antony, Gobel, O'Hare, Reber, & Paller, 2012; Nishida & Walker, 2007; Robey et al., 2013; Sejnowski & Destexhe, 2000; Walters, 2002).

Sleep is also commonly recognised as one of the most important recovery strategies for athletes in both individual and team sports, including Rugby (Bird, 2013; Chennaoui et al., 2015; Juliff et al., 2015; Samuels et al., 2016; Sargent et al., 2014; Swinbourne, Gill, Vaile, & Smart, 2016; Walters, 2002). Duration, quality and timing of sleep determine the restorative effect of sleep (Fullagar, Duffield, Skorski, Coutts, et al., 2015). However, the interaction between sleep and all physiological and psychological aspects of recovery is not completely understood (Fullagar, Duffield, Skorski, Coutts, et al., 2015).

Good quality sleep combined with well-prescribed exercise is likely to improve performance, whilst inadequate sleep can have negative effects (Belenky et al., 2003; Souissi et al., 2013). These negative effects also include increased risk of injuries (Halson, 2014b), negative mood (Fullagar, Duffield, Skorski, Coutts, et al., 2015; Waterhouse, Atkinson, Edwards, & Reilly, 2007), reduced cognitive functions, metabolic and immune system disruption (Chennaoui et al., 2015; Evans & Davidson, 2013; Haus & Smolensky, 2006; Hirotsu, Tufik, & Andersen, 2015; Krueger, Majde, & Rector, 2011), with a decrease in the number of natural killer cells (Reilly & Edwards, 2007), and an increase in inflammatory response (Chennaoui et al., 2015; Halson, 2014b; Irwin & Olmstead, 2012; O'Connor et al., 2009; Vgontzas et al., 2003).

The amount of sleep required for different population may vary (Halson, 2013b). However, it is commonly recommended that an adult should sleep approximately 8 hours per night (Halson, 2013b) in order to maintain health status (Stenholm et al., 2011). In general, athletes require more sleep (Reilly & Edwards, 2007), which may be due to lesser quality sleep (Bird, 2013; Halson, 2014b; Samuels et al., 2016), although the amount of sleep required depends on the sport an athlete practices (Lastella et al., 2015).

Total sleep deprivation can drastically impair both the mental and physical performance of athletes (Skein, Duffield, Minett, Snape, & Murphy, 2013). However, athletes are more likely to experience acute bursts of partial sleep restriction (Halson, 2013b; Juliff et al., 2015). Sleep restriction in athletes can be related to changes in circumstance in everyday life (L. Taylor et al., 2016), including family situations (Waterhouse, Atkinson, et al., 2007), travel (i.e. travel fatigue, jet lag, sleeping in an unfamiliar environment) (Fullagar, Duffield, Skorski, Coutts, et al., 2015; Lastella et al., 2014; Pitchford et al., 2016; Waterhouse, Atkinson, et al., 2007) and match factors (i.e. anxiety, high physical and mental stress) (Bird, 2013; Fullagar, Duffield, Skorski, White, et al., 2015; Gupta, Morgan, & Gilchrist, 2017; Juliff et al., 2015). In particular, in the southern hemisphere, rugby matches are mostly scheduled in the evening. The exposure to artificial light, the need to perform at peak level and caffeine consumption (caffeine tablets or caffeine-based energy drinks) prior to bedtime can have a negative effect on the subsequent night of sleep (Fullagar et al., 2016; Halson, 2008; Nedelec et al., 2015). Sleep can also be affected by overreaching and overtraining, which are respectively a short and long term decrement in performance following accumulation of training and/or non-training stress (Halson & Jeukendrup, 2004). However, it is not clear whether sleep disruption causes overreaching (or overtraining) or whether overreaching (or overtraining) causes sleep disruptions (Fullagar, Duffield, Skorski, Coutts, et al., 2015; Halson, 2008).

Anecdotally, athletes believe that good sleep helps them to perform at their best (Lastella et al., 2015). However, several elite Australian athletes appear to sleep less than 7 hours per night or experience problems falling asleep the night before a sporting event (Lastella et al., 2015). In particular, individual athletes sleep less than team athletes. Such an outcome may be due to training early in the morning, which is a legacy from the non-professional sport age (Lastella et al., 2015; Sargent et al., 2014). Despite that, some evidence shows that early morning training can have a negative impact on swimmers' sleep and therefore their performance (Sargent et al., 2014).

As sleep can influence exercise, exercise can also influence sleep. Regular physical activity appears to have positive effects on sleep (Chennaoui et al., 2015; Driver & Taylor, 2000), however, the intensity of exercise can influence sleep. High intensity exercise (similar to what athletes experience during training in competition period) can have a negative impact on sleep (Fullagar, Skorski, et al., 2015; Robey et al., 2013; Swinbourne et al., 2016).

2.3.5: Main strategies used to enhance sleep

Athletes and sport practitioners are concerned about the relationship between sleep disruption and performance, especially with frequent travel (Reilly, Waterhouse, & Edwards, 2005; Richmond et al., 2007). Two main strategies have been identified and used in sport to enhance sleep; pharmacological (i.e. sleeping tablets) (Nedelec et al., 2015; L. Taylor et al., 2016) and sleep hygiene interventions (Fullagar, Duffield, Skorski, Coutts, et al., 2015; Halson, 2008, 2013a; Nedelec et al., 2015; Robey et al., 2013).

Sleep hygiene is an umbrella term to cover different behaviours, environmental conditions and strategies used to enhance sleep quality and quantity (Stepanski & Wyatt, 2003). Sleep hygiene strategies generally aim to avoid behaviours that interfere with sleep and engage in behaviours that promote sleep (Bird, 2013; Stepanski & Wyatt, 2003), including avoidance of caffeine and alcohol in the late afternoon or early evening (Stepanski & Wyatt, 2003). However, a regular wake up and bed-time routine is the most important of these strategies as it facilitates the synchronization of the circadian rhythms (Bird, 2013; Stepanski & Wyatt, 2003). A similar beneficial strategy used by athletes is taking short naps, between 5 and 30 minutes during the day (Lastella et al., 2014; Lastella et al., 2015; Waterhouse, Atkinson, et al., 2007). Nutritional strategies are also important to improve both recovery and sleep (Nedelec et al., 2013). In general terms, it is thought that athletes can only benefit from correct sleep education and increased sleep time (Mah, Mah, Kezirian, & Dement, 2011; Samuels, 2012; Van Ryswyk et al., 2017).

2.3.6: Summary of the effects of travel and jet lag on sleep

Sleep is important for athletes' recovery and skill acquisition, which are likely to contribute in enhancing their performance. However, athletes are usually poor sleepers, due to a variety of reasons. Furthermore, travel and jet lag, which may occur whenever athletes have to travel to train or compete, can further disrupt sleep. Correct sleep hygiene seems the more efficient solution to reduce sleep issues for athletes.

2.4: Training load and performance

Training is a common feature of an athlete's life. It is through training that athletes might enhance their performance and increase their chance of being successful in competition. The next session will introduce and review the concept of training load, performance and all the different methods used to assess these outcomes.

2.4.1: Training generality, training load and measure of training load

Training is a key factor to achieve success in a competition. One of the goals of sport science is to enhance the quality of training to improve performance. To achieve such a result it is important to have an objective measure of training, training load.

Training load represents a combination of external and internal load (Foster, Daines, Hector, Snyder, & Welsh, 1996; Impellizzeri, Rampinini, & Marcora, 2005; B. R. Scott, Lockie, Knight, Clark, & Janse de Jonge, 2013). External load is a measure of the physical work an athlete performed (B. R. Scott et al., 2013). Internal load refers to the perceived psychological/physiological response to these stimuli (Foster et al., 2001). An important aspect of internal load is wellness, a measure of the quality of life perceived by athletes (Gastin, Meyer, & Robinson, 2013).

Training load is commonly used by sport scientists to monitor athletes during both training and competition (Alexiou & Coutts, 2008; Aughey, 2011; Aughey & Falloon, 2010; Buchheit, Racinais, et al., 2013; Varley, Gabbett, & Aughey, 2014). However, there is a lack of investigation on the changes in training load after travel and the influence of these changes on game performance. Training load can be assessed by analysing its three components (external load, internal load and wellness). The next section will give an insight on these components and on the methods used to assess them.

2.4.1.1: External Load

External load is a measure of the physical output of athletes during their activity (Foster et al., 2001). External load in rugby can be assessed using a number of different techniques such as Global Position System devices (GPS) and accelerometers (Howe, Aughey, Hopkins, Stewart, & Cavanagh, 2017; Lovell, Sirotic, Impellizzeri, & Coutts, 2013; Reardon, Tobin, & Delahunt, 2015; Varley et al., 2014).

The physical output of an athlete during training can be measured recording the distance covered throughout the whole session with a Global Position System device (GPS) (Aughey, 2011; Costa et al., 2013; Cummins, Orr, O'Connor, & West, 2013). The GPS devices permit to record the subjective pattern of movement of each athlete without requiring an external observer (MacLeod, Morris, Nevill, & Sunderland, 2009). The devices have an inbuilt receiver linked to a network of satellites. This system permits the calculation of the location of the devices using the time required by the signal to travel from the satellite to the receiver (Aughey, 2011). The use of GPS devices in sport is increasing due to the possibility of providing global and real-time data on the output of an athlete’s performance during training and matches to coaches and sport scientists (Cummins et al., 2013; Jennings, Cormack, Coutts, Boyd, & Aughey, 2010). The GPS data can be used to objectively quantify load and changes in physiological demands (McLellan, Lovell, & Gass, 2011) and GPS units are commonly used in contact sports such as Rugby Union, Rugby League and Australian Rules football to measure external load (Aughey, 2013; Cummins et al., 2013; Varley et al., 2014).

Currently, several GPS units, sampling at either 1, 5 or 10 Hz, are available from different companies. Increases in speed reduce the accuracy of measurements in distance for units sampling at lower frequencies (Coutts & Duffield, 2010; Jennings et al., 2010; Petersen, Pyne, Portus, & Dawson, 2009), especially with changes in direction (Coutts & Duffield, 2010; MacLeod et al., 2009; Portas, Harley, Barnes, &

Rush, 2010). Units that sample at 1 or 5 Hz may also underestimate small rapid movements such as maximal accelerations or physical contacts, which are frequent in Rugby. Therefore, they do not accurately measure external load (Boyd, 2011; Boyd, Ball, & Aughey, 2013; Buchheit, Al Haddad, et al., 2014; Coutts & Duffield, 2010; Jennings et al., 2010; Portas et al., 2010). Units sampling at 10 Hz are able to better detect and quantify acceleration, deceleration, and constant velocity running (Varley, Fairweather, & Aughey, 2012). However, 10 Hz units are unable to properly detect changes in direction or impacts (Reardon et al., 2015; Varley et al., 2012). Furthermore, GPS data analysts base their analysis on the identifications of arbitrary ranges of velocity. At least in Rugby Union, individual bands of velocity are preferable to avoid error in the determination of training load for individual players (Reardon et al., 2015).

Tri-axial accelerometers are motion sensors that measure frequency and magnitude of body movements in three dimensions (Boyd et al., 2013). External load (EL) calculated using accelerometers is usually expressed in arbitrary units (AU) as the square root of the sum of the squared instantaneous changes in acceleration in each of the three spatial dimension (X, Y and Z axis) and divided by 100 (EL=√(ay1-ay-1)2+(ax1-ax-1)2+(az1-az-1)2/100) (Boyd, 2011). Accelerometers overcome some of the limitations of GPS units and enhance the estimation of external load in contact sports (Boyd, 2011; Boyd, Ball, & Aughey, 2011; Boyd et al., 2013; Cormack, Mooney, Morgan, & McGuigan, 2013; Cunniffe, Proctor, Baker, & Davies, 2009; Gabbett, Jenkins, & Abernethy, 2010). For instance, accelerometers can be used both indoors or outdoors, can sample movements at a higher rate than GPS and can measure contacts (Boyd et al., 2011; Boyd et al., 2010). However, it may be difficult to discriminate between a ‘real’ contact and trivial impacts (i.e. players sitting on the bench after being subbed). Nonetheless, accelerometers appear to be more sensitive than GPS units in detecting external load in contact sport such as rugby (Boyd, 2011; Boyd et al., 2011, 2013; Cormack et al., 2013; Howe et al., 2017).

2.4.2.2: Internal Load

Internal load (IL) is part of the assessment of the total training load and it represents the athlete's response to training, matches or, in general, any physical stimulus (Foster et al., 2001; Impellizzeri et al., 2005; B. R. Scott et al., 2013). Athletes' response to training can be measured using physiological markers such as heart rate, lactate production, particular hormones or perceived exertion (Borresen & Lambert, 2009; Halson, 2014a). Examples of methods to assess internal load using physiological markers include Edwards Heart Rate (HR) methods (Edward, 1993), training impulse (TRIMP, a unit of physical effort that is calculated using training duration and maximal, resting, and average HR during the exercise session) (Banister, 1991; Banister & Calvert, 1980) and Lucia's training impulse (TRIMP calculated using individual heart rate zone based on individually determined lactate thresholds and onset of blood lactate accumulation to define exercise intensity) (Lucia, Hoyos, Perez, & Chicharro, 2000).

The rating of perceived exertion (RPE) is based on the idea that athletes can self-monitor their response to training and provide information on their perceived effort after training or competition (Halson, 2014a). The RPE can be measured using the Borg' Perceived Exertion scale (6-20) (Borg, 1998) or a modified version of the Borg scale (0-10) with visual anchors (session Rating of perceived Exertion or sRPE) (Foster et al., 1995), which is completed 30 minutes after the end of each session (Foster et al., 2001) (Figure 2.11). Multiplying the sRPE (effort) for the training session duration in minutes (volume) it is possible to obtain the training load value (Foster et al., 2001; Foster et al., 1995; Lovell et al., 2013) expressed in arbitrary units (Buchheit, Racinais, et al., 2013).

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

Figure 2.11: Scale of Perceived Exertion for sRPE. Reproduced from (Foster et al., 2001).

Training load measured using the sRPE shows large to very large correlations with other measurements of internal and external load including heart rate (0.75<r>0.90) (Foster, 1998), peak oxygen consumption ($\dot{V}O_2peak$, r=0.76) (Herman, Foster, Maher, Mikat, & Porcari, 2006), and total distance (r=0.82) and distance at customized high velocity (r=0.62) measured by GPS/accelerometers units (Lovell et al., 2013).

The session RPE method is a simple, non-invasive and inexpensive method to assess internal load and training load (Gabbett & Domrow, 2007; Lovell et al., 2013; T. J. Scott, Black, Quinn, & Coutts, 2013). However, sRPE is subjective and requires greater familiarization prior to use (Wallace, Slattery, Impellizzeri, & Coutts, 2014).

Furthermore, it might be useful to integrate this method with other tools (HR monitors, GPS and accelerometer units) to have more complete training data (Halson, 2014a; T. J. Scott et al., 2013).

2.4.2.3: Wellness

Another important aspect of internal load is the measure of perceived level of wellness. Maximising the effects of training is crucial to achieve high levels of performance. However, excessive training might induce negative effects on athletes, including overtraining or overreaching, which could deteriorate performance for an extended period of time (Halson & Jeukendrup, 2004; Hooper & Mackinnon, 1995). In order to avoid these conditions, it is important to monitor the quality of life of athletes and their response to training and competition (Gastin et al., 2013; McLean, Coutts, Kelly, McGuigan, & Cormack, 2010; Saw, Main, & Gastin, 2015a, 2015b). A specific questionnaire has been developed to provide a cost effective method to monitor the well-being of Rugby players (McLean et al., 2010). The questionnaire assesses fatigue, sleep quality, general muscle soreness, stress levels and mood on a five-point scale (scores of 1 to 5, where 1 represent the poorest level and 5 the best level). The overall well-being can be calculated by summing up the five scores (McLean et al., 2010) (Figure 2.12).

	5	4	3	2	1	Record Score
FATIGUE	Very fresh	Fresh	Normal	More tired than normal	Always tired	
SLEEP QUALITY	Very restful	Good	Difficulty falling asleep	Restless sleep	Insomnia	
GENERAL MUSCLE SORENESS	Feeling great	Feeling good	Normal	Increase in soreness/tightness	Very sore	
STRESS LEVELS	Very relaxed	Relaxed	Normal	Feeling stressed	Highly stressed	
MOOD	Very positive mood	A generally good mood	Less interested in others &/or activities than usual	Snappiness at team-mates, family and co-workers	Highly annoyed/ irritable/down	

Figure 2.12: Wellness Questionnaire. Reproduced from (McLean et al., 2010).

The wellness questionnaire has also been used in other contact sports and found that changes in training load (calculated as sRPE*session duration) had a small correlation with the different dimensions of wellness (0.28<r<0.36). On the other hand, changes in physical performance, measured using the Yo-Yo Intermittent Recovery test level 2 (Bangsbo, Iaia, & Krustrup, 2008), had a large correlation (r=0.58) with changes in total wellness score (Buchheit, Simpson, et al., 2013) (Figure 2.13).

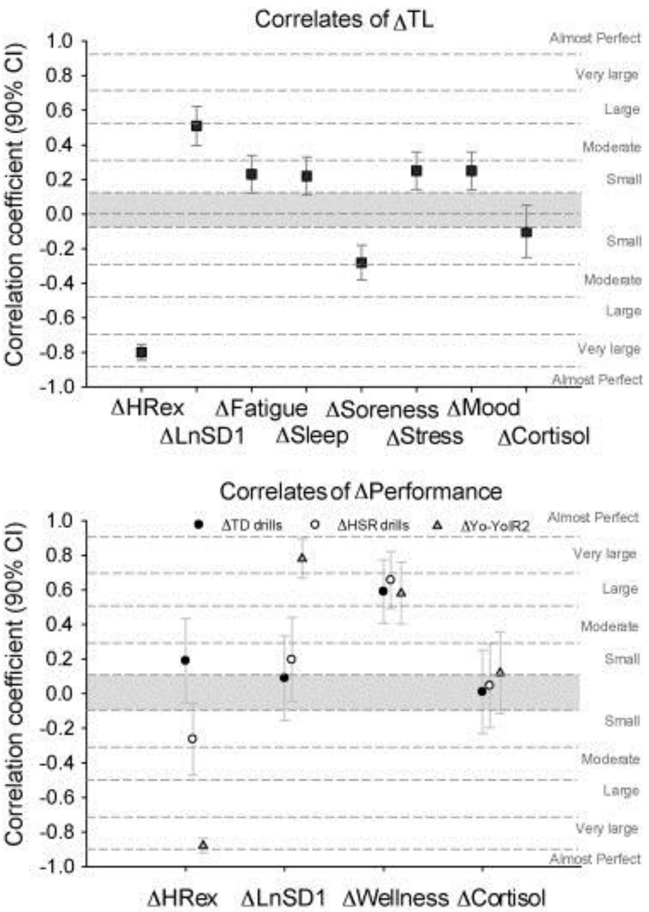


Figure 2.13: Correlation between wellness, training load and performance. Reproduced from (Buchheit, Racinais, et al., 2013).

2.4.2: Performance

Maximizing Performance is a key factor to reach success in competition, which is the main goal of each professional person involved in sport. However, performance in sport is difficult to define and measure because it is a complex and multifactorial process (Glazier, 2010). The outcome of performance can be influenced by physiological, psychological and external factors (e.g. the weather) and by other factors that are sport specific, for instance, skills and technical/tactical aspects (Armstrong, 2006; Glazier, 2010). The ability of a player to adjust behavioural functions in the presence of an opponent and environmental constraints also affects performance (Passos, Cordovil, Fernandes, & Barreiros, 2012). In team sports, a clear marker of performance is the final result of a game. Nonetheless, team sports are built around a number of different players with their different skills. As such, performance analysis in team sports should consider all the different factors that might affect team outcomes (Jones, James, & Mellalieu, 2008). Individual outcomes of performance may also be influenced by the different levels of expertise or the ability to use the right skill at the right time (Mohammed, Shafizadeh, & Platt, 2014; Thomas, French, & Humphries, 1986). It is also worth considering that in team sports, sometimes, match results and performance do not coincide as a team can lose after a good performance or win despite a bad performance (Lago & Martin, 2007).

Performance analysis can be approached from different points of view and different methodologies (Gabbett & Abernethy, 2012; Hughes & Bartlett, 2002; Passos et al., 2012). An approach designed specifically for team sports is notational analysis (Hughes & Bartlett, 2002). Such an approach is based on the study of appropriate performance indicators, which are a selection or combinations of action variables that define performance or successful outcomes (Hughes & Bartlett, 2002). Notational analysis studies the interaction between players of a team, their movements and behaviours focusing on general (e.g. match result), tactical and technical indicators (Hughes & Bartlett, 2002). These variables can be categorized in scoring indicators (e.g. tries and drop kicks) and quality indicators (e.g. turnovers and tackles) (Hughes & Bartlett, 2002). The comparison of these quality indicators should be expressed as ratios rather than as isolated data to reduce the risk of bias (Hughes & Bartlett, 2002). Such an approach has been applied in Rugby Union to define common and position specific indicators of performance (James, Mellalieu, & Jones, 2005) including successful or unsuccessful tackles (e.g. a tackle is deemed successful when the offensive action of an opponent is interrupted, for instance bringing the player to the ground), successful or unsuccessful carries (e.g. a successful carry occurs when a player carries the ball beyond the advantage line), successful or unsuccessful passes (e.g. a successful pass occurs when the ball reaches a team mate) for single players, and tries scored, penalties conceded and result of the match for the team (James et al., 2005).

Notational analysis is only one of the several possible methodologies to assess performance and it is not exempt from the risk of bias such as a univocal definition of successful or unsuccessful gestures (James et al., 2005). However, it is practical, relatively inexpensive, and commonly adopted by coaches to evaluate the performance of their team (Barris & Button, 2008).

2.4.3: Summary of training load and performance

There are several methods to assess training and performance. Accelerometers and GPS can both be used to assess external load, although accelerometers may be a better choice in contact sports such as Rugby Union. Session RPE and wellness are the best measures of internal load and well-being for athletes. Notational analysis can be used to assess in-game players' performance and is arguably the most applicable tool to assess performance.

Chapter 3: Study 1

3.1: Out of your zone? 21 years of travel and performance in Super Rugby

3.1.1: Introduction

Success in competition is the ultimate goal for every professional athlete or team. One of the keys to achieve success is to reach the highest level of performance possible on the competition day(s) required. However, performance in sport is a complex and multi-factorial process (Glazier, 2010) that can be influenced by physiological, psychological, environmental and sport specific factors (Armstrong, 2006; Glazier, 2010). For team sports in particular, frequent air travel may have a negative influence on performance (D. Bishop, 2004; Jehue et al., 1993; Winter et al., 2009) that seems to be related to travel fatigue and jet lag (Forbes-Robertson et al., 2012; Fowler et al., 2014; Leatherwood & Dragoo, 2013).

Travel fatigue is the summation of physiological, psychological and environmental factors that accrue after a single trip and accumulate over time (Samuels, 2012). Travel fatigue is characterized by persistent weariness, recurrent illness, changes in mood, and lack of motivation (Samuels, 2012). Jet lag is a common complaint that travellers report after travelling across time zones (Herxheimer & Petrie, 2002). All the physiological functions and systems of the human body show a rhythmic pattern called circadian rhythm (from Latin circa dies = about a day). These rhythms are internally driven biological phenomena with periodic oscillation of 24.2 hours on average (Czeisler et al., 1999). Jet lag occurs whenever the rhythms are not synchronized with the external clock, for instance after rapid travel across time zones (Waterhouse et al., 2004). Jet lag symptoms include sleep disturbances, fatigue, changes in mood and a deficit in cognitive skills (Eastman et al., 2005). The duration and severity of these symptoms depend on the number of time zones crossed (Revell & Eastman, 2005) and the direction of travel (Herxheimer & Petrie, 2002).

The effects of travel fatigue and jet lag on athletes' performance have been investigated before. However, performance was evaluated mostly for athletes competing in individual sports (Bullock et al., 2007; Lemmer et al., 2002). When assessing team sports athletes' performance, the markers used were generic or not sport specific (i.e. grip strength, or general physical tests) (Fowler, Duffield, & Vaile, 2015; Reilly et al., 1997). Only a few studies have assessed the effects of travel fatigue and jet lag on team sport, using match outcomes and points scored to assess performance for away-matches (D. Bishop, 2004; Jehue et al., 1993; Winter et al., 2009). However, in most of these studies, the importance of the away-match disadvantage was neglected or underestimated.

Frequent travel and its effects on performance are particularly important in Super Rugby, which is one tier down from international rugby and the most important Rugby Union competition in the southern hemisphere. During the history of Super Rugby, the competition format and number of participating teams changed. Originally, the tournament involved 12 teams, which grew first to 14 and then 15 from Australia, New Zealand and South Africa. In 2016, the competition expanded to include two new countries (Argentina and Japan) and three new teams (SuperRugby, 2014a). Depending on the format of the competition and the number of teams involved in each season, teams played a number of weekly matches, ranging from 11 to 17 rounds in the first phase followed by two to three rounds of finals. Away-matches were played by a team in its own country against a local opponent, or in a different country and against an overseas opponent. As such, teams had to travel frequently throughout each season. Travel could have been as little as a one-hour flight with no time zone change or up to 24 hours, crossing up to 12 time-zones. The nature of the competition makes Super Rugby a perfect sample to analyse the effects of travel on team performance.

The purpose of this study was to determine the effects of travel on match outcomes and points scored in Super Rugby from its first season in 1996 until the last completed season at the time of the analysis (2016). The importance of the away-match disadvantage in determining the effect of travel on team performance was also investigated.

3.1.2: Methods

Archival data from 21 years of Super Rugby matches (1996-2016) were retrieved from the official SANZAAR (South Africa, New Zealand, Australia, Argentina Rugby) web site, (http://www.sanzarrugby.com/superrugby). SANZAAR governs and operates all international Rugby Union competitions in the Southern hemisphere. The analysis was conducted according to the ethical guidelines of the authors' institution. All data are from a public domain so did not require ethical approval. All data were de-identified prior to inclusion. Match outcomes and difference in points scored were used for the statistical analysis. Individual and team performance indicators are available only for the last ten years of the competition and were not used. Number of time zones crossed and flight duration were calculated based on the relative position and distance between the city where a match was played and the location of both teams the previous week. Number of time zones crossed was also adjusted for Daylight Saving time when required. Travel time was calculated considering the shortest itinerary of all the possible available solutions. In total, 3,854 observations from 1,927 Super Rugby matches were used.

The analysis covered all iterations of the competition. In particular, 690 matches (1,380 observations) from the Super 12 era (1996-2005), 470 matches (940 observations) from the Super 14 era (2006-2010), 625 matches (1,250 observations) from the Super XV era (2011-2015) and 142 matches (284 observations) from the Super Rugby era (2016) were analysed. For the New Zealand teams, matches that were not played at their home ground but in a nearby location in their union territory were also considered home-matches. When a match was played in a neutral ground (one match in England in 2011 and one in Fiji in 2016) they were considered away for both teams. The matches played in Singapore by the Japanese team in 2016 were considered home-matches for home ground advantage calculation. However, the distance covered whilst travelling by the Japanese team was included in the analysis. In 2011, a New Zealand team was unable to play at their home-ground due to an earthquake. In the analysis, unless played in their union territory, all matches played by this team were considered away-matches, due to travel.

Statistical analysis: Data were imported into the Statistical Analysis System (version 9.4, SAS Institute, Cary, NC) for analysis. The match outcomes were analysed with logistic regression using a generalized linear mixed model (Proc Glimmix). Effects were derived as odds ratio and then converted to extra matches won or lost every ten close matches played. Match outcome was modelled as the log of the odds of a team winning. For the effect of differences in the predictor variable between teams and within years on match outcome, the effect was estimated as the ratio of the odds of winning for a typically high value of the predictor (+1 between-team within year SD) compared with a typically low value (–1 between-team within year SD) . The odds ratios were converted to the difference or change in per cent probability of winning a close match defined by centring the two probabilities on 50% (Higham, Hopkins, Pyne, & Anson, 2014; Hopkins, Hawley, & Burke, 1999; Lazarus, Hopkins, Stewart, & Aughey, 2017; Liu, Hopkins, & Gomez, 2015). Linear numeric fixed effects were included for the number of time zones crossed in each direction of travel (east, west), for flight duration, and for the away-match disadvantage (0=home 1=away). To estimate and adjust for differences in the winning ability of teams, their identity was included as a random effect. Separate analyses were performed initially for each year of the competition. Year of competition was then included as a linear numeric fixed effect interacted with the fixed effects to estimate overall trends in these effects, their predicted means over the 21 years, and their predicted means at the beginning and end of this period. This model included a random effect for the interaction of team identity and year as a nominal effect to estimate and adjust for changes in the winning ability of teams over years.

The effects of travel and crossing time zones were evaluated for the maximum values in the Super Rugby competitions: 24 hours and 12 time-zones respectively (Auckland to Cape Town). These effects were combined with the away-match disadvantage to get the combined effect on match outcomes when competing at a remote venue. Each effect was also assessed separately for its pure contribution on match outcomes. Finally, the combined effect of travel and number of time zones crossed, excluding the away-match disadvantage, was assessed to determine the real importance of long-haul travel. Similar analyses were performed for difference in points scored in each match using a general linear mixed model (Proc Mixed).

Uncertainty in the two outcomes was expressed as 90% confidence limits and as probabilities that the true effect was substantially positive and negative (derived from standard errors, assuming a normal sampling distribution). Reference Bayesian inference with a disperse uniform prior was used to make probabilistic assertions about the magnitude of the true effects (Hopkins & Batterham, 2018). The smallest worthwhile effect for the match outcomes analyses was set to one extra match won every 10 matches played (Higham et al., 2014). Magnitudes of clear effects were evaluated as follows: ≤1, trivial; >1 and ≤3, small; >3 and ≤5, moderate; >5 and ≤7, large; >7 and ≤ 9, very large. The smallest worthwhile effect and the other magnitude thresholds for the difference in points scored were as follows ≤1, trivial; >1 and ≤3, small; >3 and ≤5.3, moderate; >5.3 and ≤8.3, large; >8.3, very large; these were based on 0.3, 0.9, 1.6 and 2.5 of the variation in the points scored by a team in an evenly matched match (Higham et al., 2014; Hopkins, Marshall, Batterham, & Hanin, 2009). To account for inflation of Type 1 error, only clear effects clear with 99% confidence intervals were highlighted (Liu et al., 2015). Uniformity and linearity where assessed through visual inspection of residuals vs predicteds as well as residuals vs predictors analyses. Both inspections showed no evidence of non-linearity or non-uniformity.

3.1.3: Results

The combined effects of travel on match outcomes each year are presented in Figure 3.1 for away-matches involving travel east and west. The predicted effects at each end of the monitored period were substantial, and there was a substantial positive trend (Figure 3.2), although the trend was clear only at the 90% level. When the competition began in 1996, teams were likely to lose 4.1 more matches for every 10 played (90% confidence limits ±1.3; small, *most likely* negative effect) after travelling eastward. After travel westward, teams were likely to lose 3.2 more matches for every 10 played (±1.5; moderate, *very likely* negative effect). At the end of the 2016 season teams were likely to lose 2.3 more matches (±1.3; small, *likely* negative effect) when travelling east and 1.5 more matches (±1.3; small, *possibly* negative effect) when travelling west. Over the 21 years, teams increased their ability to win 2.0 more matches (±2.3; small, *likely* positive effect) travelling east and 1.5 more matches (±2.4; small, *possibly* positive effect) travelling west.

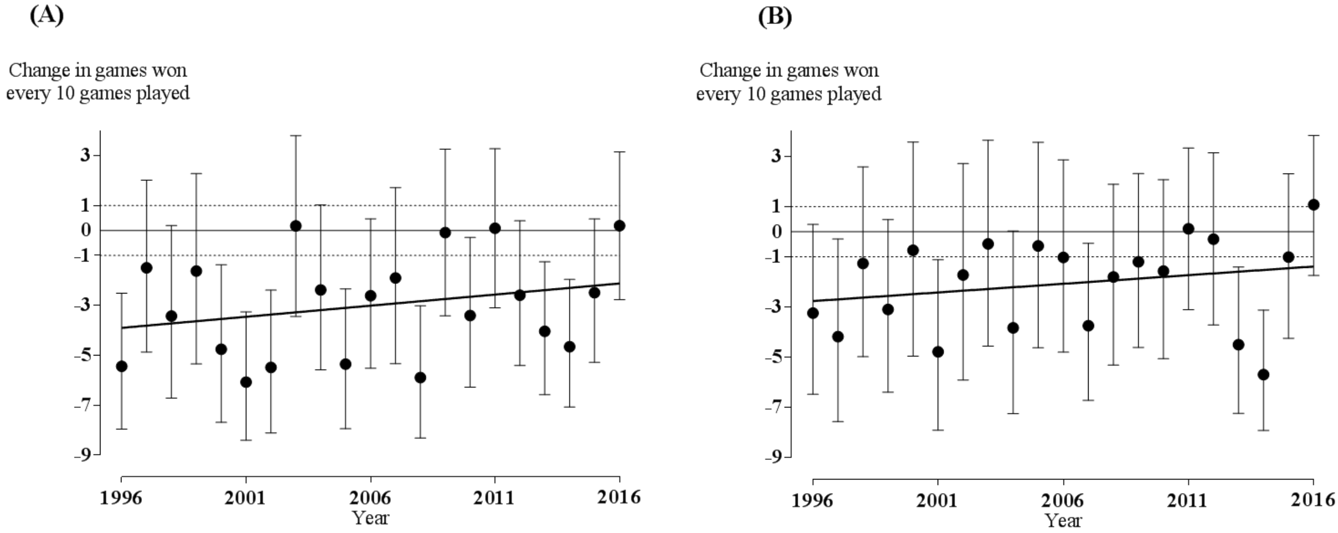


Figure 3.1: Combined effects of the away-match disadvantage with eastward (A) and westward (B) long-haul travel (12 time zones, 24 h travel) on close-match outcomes in Super Rugby. Data points are the predicted values from by-year analysis, with 90% confidence limits. Continuous lines were derived from the regression analysis of all data. Dotted lines are thresholds for the smallest important effect.

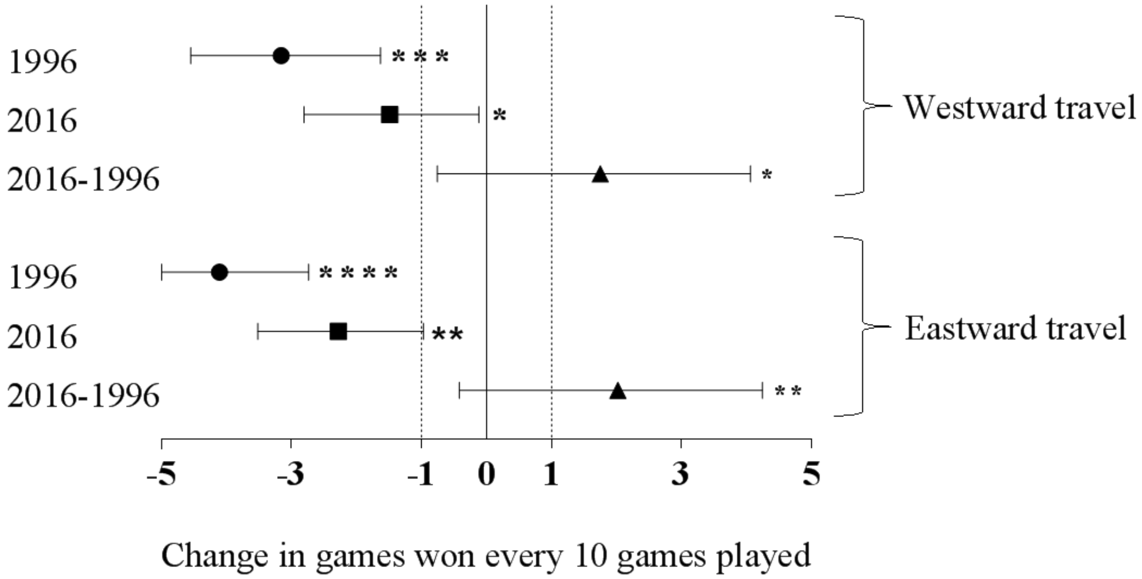


Figure 3.2: Predicted changes over 21 years (1996-2016) in the combined effects of the away-match disadvantage with eastward (A) and westward (B) long-haul travel (12 time zones, 24 h travel) on close-match outcomes in Super Rugby. Data points are the predicted values for 1996, 2016 and their difference, with 90% confidence limits. Dotted lines are thresholds for the smallest important effect. Asterisks indicate clear substantial effects as follows: *possibly, **likely, ***very likely, ****most likely; larger asterisks indicate effects clear at the 99% level.

The pure effect of flight duration, number of time zones crossed in both directions, and away-match disadvantage on match outcomes are presented in Figure 3.3. The away-match disadvantage appeared to account for most of the long-haul effect showed in the previous figures. In 1996 teams were more likely to lose 3.2 more matches for every 10 played (±0.6; moderate, *most likely* negative effect). In 2016 the away-match disadvantage accounted for the loss of 2.3 extra matches for every 10 played (±0.8; small, *most likely* negative effect). Over the 21 years the effect of the away-match disadvantage reduced and teams increased their ability to win by 1.0 extra match for every 10 played (± 0.9; small, *possibly* positive effect). The corresponding effects of travel time and number of time zones crossed were mainly trivial or, at most, small but unclear.

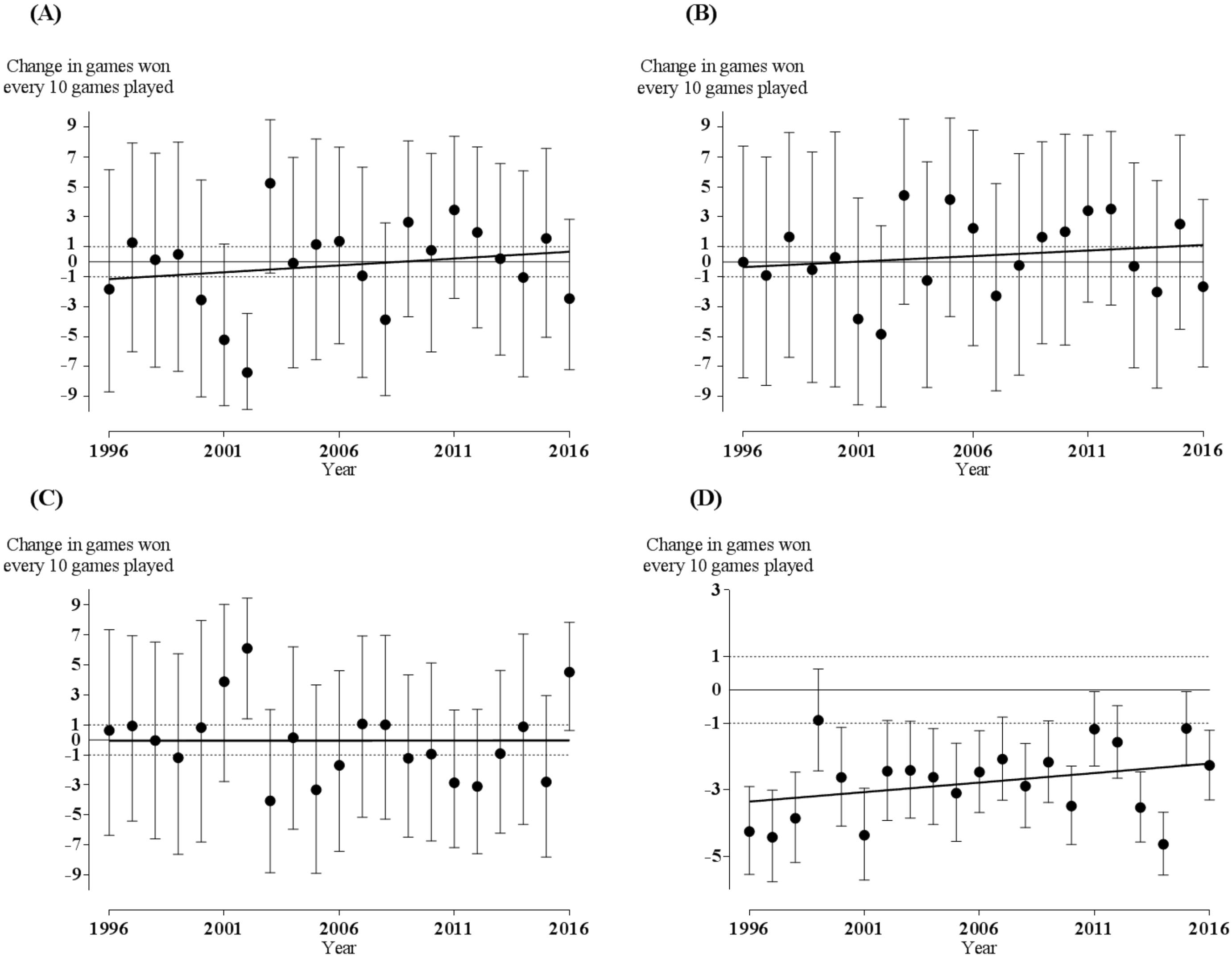


Figure 3.3: Pure effects of travelling eastward across 12 time zones (A), travelling westward across 12 time zones (B), flight duration (24h) (C) and the away-match disadvantage (D) on close-match outcomes in Super Rugby. Bars are 90% confidence intervals. Data points are the predicted values from by-year analysis, with 90% confidence limits. Continuous lines were derived from the regression analysis of all data. Dotted lines are thresholds for the smallest important effect.

When the effects of travel duration and crossing time zones were combined, the resulting long-haul travel effects were sometimes clear but still only trivial to small (Figure 3.4). In 1996, travel east made teams more likely to lose 1 extra match every 10 played (±1.4; small, *possibly* negative effect). After travelling west, teams were likely to win 0.1 extra matches every 10 played (±1.6; trivial, unclear effect). At the end of the 2016 season teams were likely to win 0.0 more matches (±1.3; trivial, unclear effect) when travelling east and 0.9 more matches (±1.3; trivial, *possibly* positive effect) when travelling west. Over the 21 years teams increased their ability to win up to 1 more match (±2.2, small, unclear effect) travelling east and 0.8 more matches (±2.4, trivial, unclear effect) travelling west. The mean effect of travel over the 21 years was *likely* trivial for both directions of travel (losing 0.5 ±0.7 extra matches travelling east and winning 0.5 ±0.8 extra matches travelling west).

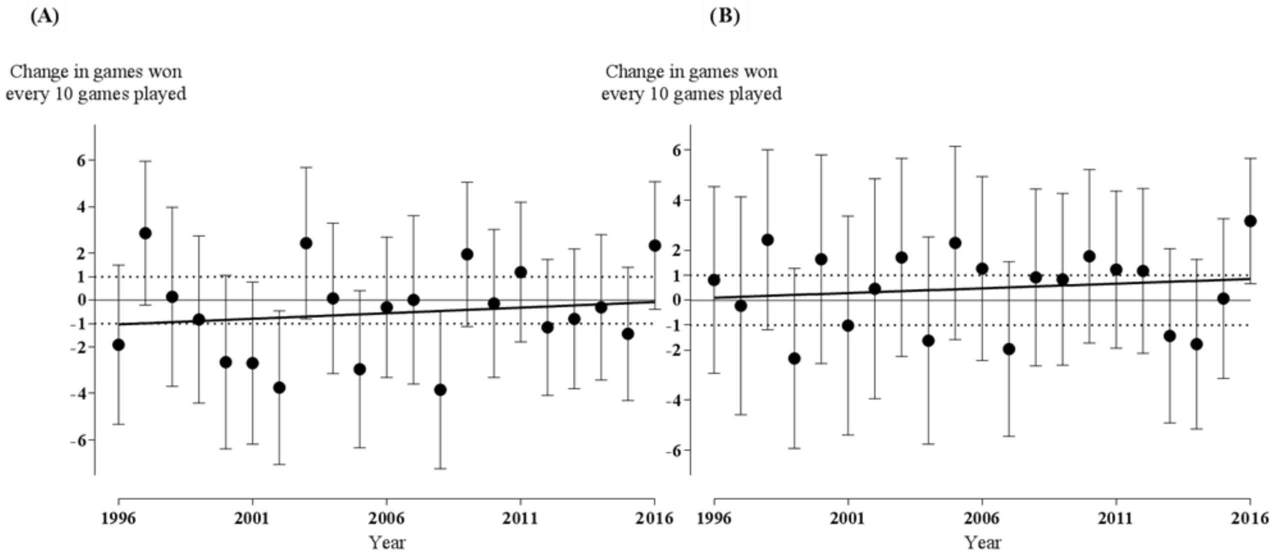


Figure 3.4: Effects of eastward (A) and westward (B) long-haul travel (12 time zones, 24 h travel) on close-match outcomes in Super Rugby. Data points are the predicted values from by-year analysis, with 90% confidence limits. Continuous lines were derived from the regression analysis of all data. Dotted lines are thresholds for the smallest important effect.

The combined effects of travel, crossing time zones and away-match disadvantage on difference in points scored for close matches were similar to the effects for match outcomes. The predicted effects at each end of the monitored period were substantial and there was a positive trend (Figure 3.5), although the trend was unclear. When the competition began, the difference in points scored was on average -5.8 travelling east (±3.5; large, *very likely* negative effect) and on average -6.4 travelling west (±3.5; large, *very likely* negative effect). After the last season analysed, the difference in points scored was on average -3.7 travelling east or west (±3.0; moderate, *likely* negative effect). Over the 21 years, teams increased their ability to score (by 2.0, ±5.5 points travelling east; 2.7, ±5.5 points travelling west), although these effects were unclear.

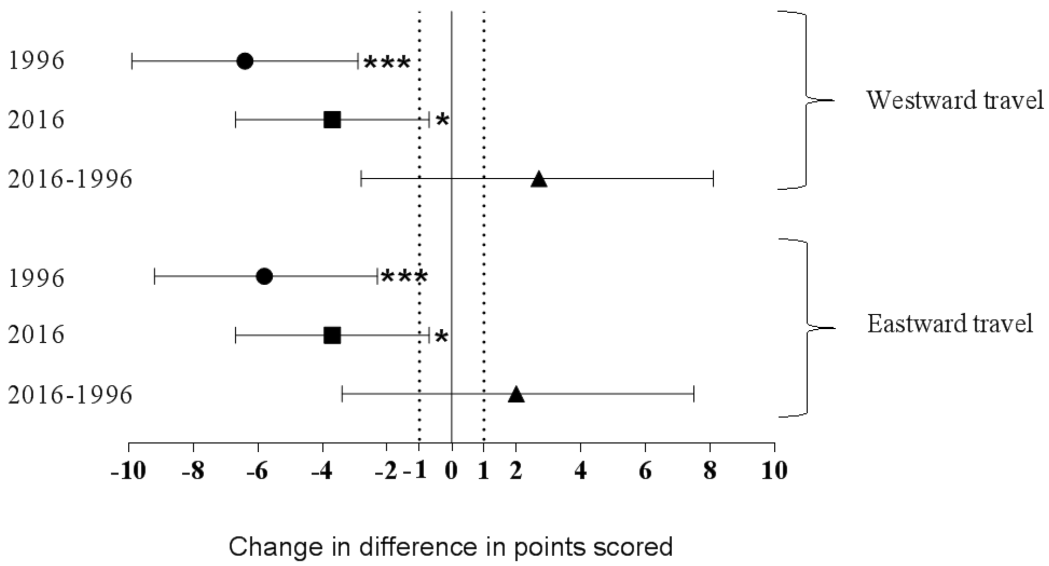


Figure 3.5: Predicted changes over 21 years (1996-2016) in the combined effects of the away-match disadvantage with eastward and westward long-haul travel (12 time zones, 24 h travel) on difference in points scored for close-matches in Super Rugby. Data points are the predicted values for 1996, 2016 and their difference, with 90% confidence limits. Dotted lines are thresholds for the smallest important effect. Asterisks indicate clear substantial effects at the 90% level as follows: *possibly, **likely, ***very likely, ****most likely. No effects clear at the 99% level.

Pure and long-haul travel effects on the difference in points scored were similar to the effects on match outcomes. For the away-match disadvantage in particular, in 1996 the difference in points scored was -5.7 (±1.4; large, *most likely* negative effect). In 2016 the difference in points scored was -5.2 (±1.1; moderate, *most likely* negative effect). Over the 21 years, the effect of the away-match disadvantage reduced and teams narrowed the margin by 0.5 points (±2.1; trivial, unclear effect). For the long-haul travel effect, in 1996, travel east changed the difference in points scored by -0.1 (±3.3; trivial, unclear effect). After travel west, the difference was -0.7 (±3.4; trivial, unclear effect). At the end of the 2016 season the difference in points scored was an increase of 1.4 (±2.8; small, unclear effect) when travelling east and

1.5 (±2.9; small unclear effect) when travelling west. Over the 21 years, the difference in points scored increased by 1.5 (±5.1; small, unclear effect) travelling east and by 2.2 (±5.3; small, unclear effect) travelling west. The mean effect of travel over 21 years was trivial and *possibly* positive for eastward travel (0.7, ±1.6 points) and unclear for westward travel (0.4, ±1.7 points).

3.1.4: Discussion

Throughout the first 21 years of Super Rugby, there was a substantial impairment of performance following the longest flights and greatest time zones shifts, although there was a gradual reduction of the impairment. By 2016, eastward travel had a substantial likely small impairment while there was only a substantial possible trivial impairment after westward travel. The major contributor to this performance impairment was the away-match effect, which also declined somewhat, such that by 2016 the impairment was still small to moderate. In contrast, by 2016, the combined contribution of travel time and zones shift for the longest flights was unclear for eastward travel with a range of uncertainty from a small disadvantage to a small advantage, whilst for westward travel the range was trivial through to a small advantage. These findings are in contrast with previous reports supporting the popular idea that travel fatigue and jet lag are the main factors accounting for the effects of travel (Forbes-Robertson et al., 2012; Fowler et al., 2014; Leatherwood & Dragoo, 2013). A possible explanation is that over 21 years teams may have introduced new strategies to reduce the effect of travel on performance. However, it was not possible to retrieve this information from the official SANZAAR web site.

Travel length and crossing time zones, when analysed in isolation, had an unclear effects on match outcomes, which may be related to a problem of collinearity. The limited effect of travel length and consequent travel fatigue on performance can also be explained by the fact that Super Rugby teams reach the venue at least one day prior to the match and a full night of rest is usually enough to recover from the effects of travel fatigue (Reilly et al., 1997). Similarly, crossing time zones appears to minimally impair performance, although to a marginally larger extent. Although several other factors such as the disruptions of normal sleeping habit may have also impaired performance, the direction of travel seems to largely dictate the magnitude of this effect, with eastward travel being slightly more detrimental than westward travel. Eastward travel requires a phase advance of the circadian rhythms whilst travelling westward requires a phase delay. As circadian rhythms are, on average, slightly longer than 24 h when measured in temporal isolation conditions (Czeisler et al., 1999; Srinivasan et al., 2010), the human body shows a natural tendency to drift slightly each day and, therefore, is more capable to cope with a delay than an advance in time (Eastman & Burgess, 2009). Thus, after eastward travel, the symptoms of jet lag are more severe (Herxheimer & Petrie, 2002; Srinivasan et al., 2010), the time required to recover is longer (Eastman & Burgess, 2009) and performance may be more impaired (Jehue et al., 1993).

The combination of travel duration and crossing time zones represents what happens when a team travels. This combination appears to have a stronger effect on match outcomes than the isolated components. However, most of the observed substantial negative effect of travel on performance can be ascribed to the away-game disadvantage, which is a combination of factors that deteriorate the psychological and behavioural states of athletes, along with their performance, when a match is played away (Carron et al., 2005; Courneya & Carron, 1992; Lazarus et al., 2017). The estimated changes in the away-game disadvantage were based on the reasonable assumption that this disadvantage is the same for matches played either overseas or after short, internal travel. As such, it was possible to isolate the away-game disadvantage from all the other travel factors and determine its predominant role on impairing match performance after long-haul flights across multiple time zones.

A possible limitation of this study is that the number of matches and the distance covered travelling by the Super Rugby teams have changed during the history of the competition. However, the changes in format (e.g. the creation of national conferences and loosely geographical groups in 2016) that occurred during the history of Super Rugby helped to maintain the amount of travel required (SuperRugby, 2015). Another possible limitation is that the local time when a match was played was not considered. Super Rugby matches are usually scheduled for late afternoon and several physiological functions reach their peak at this time (Drust et al., 2005; Reilly, 2009a; Reilly & Waterhouse, 2009). As such, players should be able to perform at their best. However, each person has an internal clock that, in entrained conditions, is synchronized with the day/night cycle (Atkinson & Reilly, 1996; Czeisler et al., 1999). After trans-meridian travel, the body requires a certain amount of time to resynchronize with the new environment (Reilly, Atkinson, et al., 2007; Samuels, 2012). That means a match may have been played when the physiological responses of athletes were not at their peak, thus affecting their performance. Further research should investigate the rate of desynchronization at the time of a match kick-off to better understand the individual response of each player after travel. Finally, individual and team indicators of performance were not analysed. These data are available on the SANZAAR web site, however starts only from the 2006 season. The purpose of this research was to analyse the effect of travel on the entire history of the competition up to 2016. As such, all partially available data were excluded.

In summary, it appears that continuous long-haul travel influences team performance. However, at least in Rugby Union, the away-match disadvantage is likely to be the main cause of these negative effects. The reduction in the effects of travel over time suggests that teams in Super Rugby are successfully dealing with long-haul travel and should now focus on reducing the effects of the away-match disadvantage. The findings of this research can be of interest for all the coaches and supporting staff in sports that require international travel to compete.

Chapter 4: Study 2

4.1: The longest journeys in Super Rugby: 11 years of travel and performance indicators

4.1.1: Introduction

Maximizing performance and succeeding in competition are the final goals of every professional athlete and coach. Measuring performance and its variations during a season is crucial to increase the chance of winning a competition. Notational analysis is based on the identification of Key Performance Indicators (KPIs) and it is the most common form of performance assessment in team sports (Hughes & Bartlett, 2002) as it is relatively inexpensive and the results are easy to be understood by both coaches and athletes (Barris & Button, 2008). However, performance in team sport is a complex process and several constraints can influence athletes' outcomes (Glazier, 2010). Frequent air travel is one of these constraints (Leatherwood & Dragoo, 2013) that appears to induce a decline in performance because of travel fatigue and jet lag (Forbes-Robertson et al., 2012; Leatherwood & Dragoo, 2013).

Travel fatigue is a state of persistent weariness, recurrent illness, changes in mood, and lack of motivation that accrues after a single trip and tends to accumulate over time (Samuels, 2012). Jet lag occurs when the circadian rhythms, the rhythmic pattern of all the physiological functions and systems of the human body (Czeisler et al., 1999), are not synchronized with the external clock, typically after rapid travel across time zones (Waterhouse et al., 2004). The number of time zones crossed and direction of travel dictate the duration and severity of jet lag symptoms, which include sleep disturbances, fatigue, changes in mood and a deficit in cognitive skills (Herxheimer & Petrie, 2002; Revell & Eastman, 2005).

The effect of travel fatigue and jet lag on athletes' performance has been investigated before but mostly for athletes competing in individual sports (Bullock et al., 2007; Lemmer et al., 2002), or using non-specific markers of performance (i.e. grip strength, or general physic tests) (Fowler, Duffield, & Vaile, 2015; Reilly et al., 1997). Only a few studies assessed the effects of travel fatigue and jet lag on team sport using match outcomes and points scored to assess performance for away matches (D. Bishop, 2004; Jehue et al., 1993; Winter et al., 2009). However, these studies are mostly based on teams travelling locally or crossing only a small number of tome zones (McGuckin, Sinclair, Sealey, & Bowman, 2014; Richmond et al., 2007). Furthermore, in these studies, the importance of the away-match disadvantage was neglected or underestimated.

Frequent travel is particularly common in Super Rugby, which is arguably the most important club Rugby Union competition for the southern hemisphere. The competition currently is played by teams from five countries (South Africa, New Zealand, Australia, Argentina and Japan) (SuperRugby, 2014a) and therefore travel is a key factor. Travel in Super Rugby ranges from a one hour flight with no time zone change to a 24 hour flight crossing 12 time-zones. As such, Super Rugby teams are a perfect sample to analyse the effects of travel on performance.

The purpose of this study was to determine the effect of travel on team KPIs in Super Rugby. The study analysed the history of the competition from the first season with available KPI data (2006) until the last completed season (2016) at the time of the analysis. The importance of the away disadvantage in determine the effect of travel on team performance was also investigated.

4.1.2: Methods

Archival data from 11 years of Super Rugby (2006-2016) were retrieved from the official SANZAAR (South Africa, New Zealand, Australia, Argentina Rugby) web-site, (http://www.sanzarrugby.com/superrugby). SANZAAR operates all international Rugby Union competitions in the Southern hemisphere. The analysis was conducted according to the ethical guidelines of the authors' institution. All data were from a public domain so did not require ethical approval. All data were de-identified prior to inclusion. The number of time zones crossed and flight duration were calculated based on the location of the city where a match was played and the location of the city where the previous match was played. The time shift after crossing time zones was adjusted for daylight-saving time when required. Travel time was calculated considering the shortest possible itinerary. In total, 2,474 observations from 1,237

Super Rugby matches were used, covering all iterations of the competition from 2006.

For the New Zealand teams, matches that were not played at their home ground but in a nearby location in their union territory were also considered home-matches. When a match was played in a neutral ground (one match in England in 2011 and one in Fiji in 2016) they were considered away for both teams. The matches played in Singapore by the Japanese team in 2016 were considered home-matches for home ground advantage calculation. However, the distance covered whilst travelling by the Japanese team was included in the analysis. In 2011, a New Zealand team was unable to play at their home-ground due to an earthquake. In the analysis, unless played in their union territory, all matches played by this team were considered away-matches, due to travel.

All available KPIs were retrieved from the web site. KPIs related to infrequent events (e.g. drop goals), and KPIs available for less than eight years (e.g. mauls) were not included in the analysis. The KPIs included were: counts per match for carries, clean breaks, conversions defenders beaten, kicks in play, missed tackles, offloads, passes, penalties conceded, tackles, tries, turnovers conceded, rucks won (%), scrums won (%), lineouts won (%), and metres (m) run with the ball. The KPIs are shown in tables in two groups: those for which an increase would presumably represent an enhancement of team performance and those presumably representing an impairment (missed tackles, penalties conceded, and turnovers conceded).

Statistical analysis: Data were imported into the Statistical Analysis System (version 9.4, SAS Institute, Cary, NC). The effects on KPIs were estimated with generalized linear mixed models (Proc Glimmix). For counts the model was over-dispersed Poisson regression and for proportion the model was over-dispersed logistic regression. Linear numeric fixed effects were included for the number of time zones crossed in each direction of travel (east, west), for flight duration, and for a secular trend. Dummy variables were included for the away-match disadvantage (0 = home, 1 = away), for a set of amendments to the laws of Rugby Union implemented in Super Rugby in 2008 (0 = pre2008, 1 = post2007) (InternationalRugbyBoard, 2008), and for a change in competition format (introduction of a conference system) that occurred in 2011 (0 = pre2011, 1 = post2010) (SuperRugby, 2014b). To estimate and adjust for differences between teams and for changes within teams between years, team identity and its interaction with year of competition as a nominal variable were included as random effects. Finally, to account for annual deviations from the secular trend, year of competition was also included as random effect. Simpler analyses, excluding all year effects, were performed for each year to justify inclusion of linear trends for the fixed effects in the full model.

The effects of crossing time zones and travel were evaluated for the maximum values in the Super Rugby competitions: 12 time-zones and 24 hours respectively (Auckland to Cape Town). These effects were combined with the away disadvantage to get the predicted effect on team KPIs when competing at a remote venue. Each of these effects was also assessed separately for its pure contribution to team KPIs. The combined effect of travel and number of time zones crossed, excluding the away-match disadvantage, was assessed to determine the real importance of long-haul travel. The secular trend was evaluated for the 11 years of competition analysed.

Effects were reported in percent unit with 90% confidence limits (Hopkins et al., 2009). Magnitude of the effects were assessed using standardization, with threshold values for small, moderate, large and very large calculated as 0.20, 0.60, 1.2 and 2.0 of the observed between-teams standard deviation for each KPI in 2016; this standard deviation was estimated from the random effects and over-dispersed Poisson or logistic variance in the log- or logistic-transformed domain (Hopkins, 2016). Uncertainty in each effect was expressed as 90% confidence limits and as probabilities that the true effect was substantially positive and negative (derived from standard errors, assuming a normal sampling distribution). Reference Bayesian inference with a disperse uniform prior was used to make probabilistic assertions about the magnitude of the true effect (Hopkins & Batterham, 2018): if the probabilities of the effect being substantially positive and negative were both >5%, the effect was reported as unclear; the effect was otherwise clear and reported with the probability that it was either substantial or trivial, usually whichever was the larger. The scale for interpreting the probabilities was as follows: >25 and ≤75%, possible; >75 and ≤95%, likely; >95 and ≤99.5%, very likely; >99.5%, most likely. To account for inflation of Type 1 error, only effects clear with 99% confidence intervals were highlighted (Liu et al., 2015). Visual inspection of residuals vs predicteds and residuals vs predictors showed no evidence of non-uniformity and non-linearity.

4.1.3: Results

The mean and standard deviation for each KPI in 2016 are shown in Table 4.1 along with the secular trend and the effects of the changes in rules and competition format in 2008 and 2011. Figure 4.1 shows the mean and standard deviations for each year and the secular trend using the KPI carries as an example. The secular trend represents clear small to moderate increases for the majority of the KPIs, with only penalties conceded and tackles showing clear decreases. The remaining KPIs showed trivial changes that were unclear, except for turnovers conceded. The changes in rules and competition format had clear substantial effects on all KPIs, ranging from trivial (e.g. offloads) to mainly small increases (e.g. carries) and decreases (e.g. clean breaks).

Table 4.1: Mean and standard deviation for each KPI in 2016 along with the secular trend and the effects of the changes in rules in 2008 and 2011. Effects are reported in percent unit with 90% confidence limits.

			Effect of rule changes	
	Mean ± SD in 2016 (n=284)	Secular trend, ±CL[a]	from 2008, ±CL[a]	from 2011, ±CL[a]
Carries	107 ± 23	7.1 ,±9.1 ^{S*}	14.6 ,±5.0 ^{S****}	7.5 ,±5.0 ^{S**}
Clean breaks	10.2 ± 5.4	98.9 ,±46.3 ^{M****}	-29.7 ,±8.3 ^{S****}	-12.7 ,±11.5 ^{S*}
Conversions	2.3 ± 1.9	63.9 ,±49.2 ^{M***}	1.0 ,±14.8 $^{T\circ\circ}$	-25.0 ,±12.2 ^{S**}
Defenders beaten	19.7 ± 7.8	64.8 ,±26.1 ^{M****}	-9.5 ,±7.5 ^{S*}	10.4 ,±9.9 ^{S*}
Kicks in play	22.0 ± 7.2	-0.0 ,±13.6 ^{T}	n/a	-12.1 ,±6.3 ^{S**}
Lineouts won %	87 ± 11	10.0 ,±0.4 ^{M****}	n/a	-2.0 ,±0.2 $^{T\circ\circ}$
Metres	430 ± 140	5.1 ,±12.5 ^{T}	9.6 ,±8.1 ^{S*}	-7.8 ,±6.0 ^{S*}
Offloads	10.8 ± 5.2	42.8 ,±24.3 ^{M***}	2.5 ,±9.08 $^{T\circ\circ}$	-2.4 ,±9.3 $^{T\circ\circ}$
Passes	140 ± 35	11.0 ,±11.5 ^{S**}	6.3 ,±5.6 ^{S*}	5.3 ,±6.1 ^{T*}
Rucks won %	94.0 ± 3.1	0.0 ,±1.0 ^{T}	-2.0 ,±1.0 ^{S****}	1.0 ,±1.0 ^{S**}
Scrums won %	89 ± 15	-1.0 ,±4.0 ^{T}	-1.0 ,±2.0 $^{T\circ\circ}$	-3.0 ,±2.0 ^{T*}
Tackles	104 ± 28	-9.0 ,±8.0 ^{S**}	19.5 ,±25.0 ^{M****}	10.6 ,±5.3 ^{S**}
Tries	3.2 ± 2.2	60.9 ,±30.5 ^{M****}	0.8 ,±9.6 $^{T\circ\circ\circ}$	-25.8 ,±7.7 ^{S***}
Missed tackles	19.7 ± 7.8	63.1 ,±23.5 ^{M****}	-10.2 ,±6.9 ^{S*}	8.2 ,±8.9 ^{T*}
Penalties conceded	9.3 ± 3.0	-30.2 ,±10.1 ^{M****}	13.7 ,±8.2 ^{S**}	10.6 ,±8.9 ^{S*}
Turnovers Conceded	16.4 ±4.0	5.2 ,±10.2 ^{T*}	6.1 ,±5.2 ^{S*}	-5.1 ,±5.1 ^{T*}

[a]Superscripted letters indicate effect size as follows: ^{T}Trivial, ^{S}Small, ^{M}Moderate, ^{L}Large.
Symbols indicate the probability of an effect being substantial or trivial (whichever was the larger).
Asterisks indicate clear substantial effects as follows: *possibly, **likely, ***very likely, ****most likely; larger asterisks indicate effects clear at the 99% level.
Degree symbols indicate trivial effects as follows: °possibly, °°likely, °°°very likely, °°°°most likely; larger degree symbols indicate effects trivial at the 99% level.

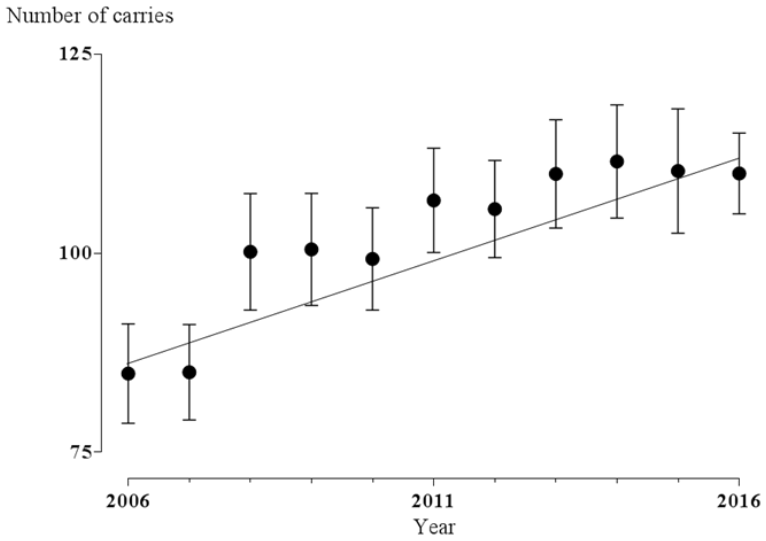


Figure 4.1: Example of a secular trend in Super Rugby matches using the KPI carries. Data points are means and standard deviations from the by year analysis. The continuous line represent the secular trend.

The pure effects of the away-match disadvantage and the combined effect of flight duration and time zones crossed for longest travel in both directions on each KPI are presented in Table 4.2. Figure 4.2 shows these effects for each year and the overall trend using the KPI carries as an example. The pure effects of the away-match disadvantage were mostly clear and trivial for 2016 and the 11-year trend. The travel effects in 2016 were trivial to moderate for both directions of travel and generally clearly negative travelling eastward and either positive (e.g. tries) or negative (e.g. carries) travelling westward. Trends were generally negative travelling eastward and either positive or negative travelling westward, although mostly unclear for both directions of travel, and ranging from trivial to moderate.

Table 4.2: Pure effects of the away-match disadvantage and of eastward and westward long-haul travel, 12 time zones, 24 h travel on team KPIs in 2016 and the 11-year trend over the monitored period (2006-2016). Predicted values are expressed as percent variation with 90% confidence limits.

	Means in 2016, ±CL[a]			11-year trend, ±CL[a]		
	Away-match disadvantage	Travel east	Travel west	Away-match disadvantage	Travel east	Travel west
Carries	-3.2, ±2.5 $^{T\circ\circ}$	-9.3, ±6.4 ^{S**}	-9.4, ±6.6)^{S**}	3.4, ±5.1 ^{T*}	-14.3, ±11.1 ^{M**}	-1.5, ±13.6 ^{T}
Clean breaks	-16.7, ±5.5 ^{S**}	-21.1, ±14.8 ^{S**}	8.7, ±18.9 ^{T*}	-6.8, ±11.4 $^{T\circ\circ}$	-28.5, ±23.5 ^{S**}	18.2, ±40.1 ^{S}
Conversions	-20.5, ±7.36 ^{S**}	-9.6, ±23.4 ^{T*}	23.8, ±29.6 ^{S*}	-3.7, ±16.4 $^{T\circ\circ}$	10.7, ±53.2 ^{T}	8.8, ±50.0 ^{T}
Defenders beaten	-13, ±3.9 ^{S***}	-11.2, ±11.0 ^{S*}	3.6, ±12.5 $^{T\circ\circ}$	-9.6, ±8.0 ^{S*}	-9.9, ±21.4 ^{S}	17.9, ±29.1 ^{S*}
Kicks in play	-2.2, ±4.4 $^{T\circ\circ\circ}$	-0.2, ±11.9 ^{T}	-0.6, ±12.1 ^{T}	1.0, ±11.1 ^{T}	-15.7, ±24.2 ^{S}	-3.3, ±29.8 ^{T}
Lineouts won %	0.0, ±2.0 $^{T\circ\circ\circ}$	0.0, ±4.0 ^{T}	-1.0, ±4.0 ^{T}	1.0, ±4.0 ^{T}	-3.0, ±10.0 ^{S}	-1.0, ±10.0 ^{T}
Metres	-8.8, ±3.2 ^{S**}	-14.5, ±8.2 ^{S**}	0.8, ±9.5 ^{T}	-2.4, ±6.5 $^{T\circ\circ}$	-19.9, ±14.0 ^{M**}	-4.8, ±17.6 ^{T}
Offloads	-6.6, ±5.1 $^{T\circ\circ}$	-10.9, ±13.5 ^{S*}	-1.1, ±14.5 ^{T}	-4.4, ±9.9 $^{T\circ\circ}$	-10.2, ±25.3 ^{S}	10.2, ±31.7 ^{T}
Passes	-2.4, ±2.7 $^{T\circ\circ\circ}$	-10.0, ±6.9 ^{S**}	0.3, ±7.7 ^{T}	3.8, ±5.4 ^{T*}	-11.0, ±12.5 ^{S**}	4.4, ±15.2 ^{T}
Rucks won %	0.0, ±0.0 $^{T\circ\circ}$	0.0, ±1.0 ^{T}	0.0, ±1.0 ^{T}	1.0, ±1.0 ^{T*}	0.0, ±2.0 ^{T}	-1.0, ±2.0 ^{T}
Scrums won %	2.0, ±2.0 ^{T*}	3.0, ±5.0 ^{T*}	-6.0, ±4.0 ^{S**}	-2.0, ±3.0 ^{T*}	-2.0, ±8.0 ^{T}	-10.0, ±8.0 ^{M**}
Tackles	3.0, ±3.3 $^{T\circ\circ}$	5.6, ±8.9 ^{S*}	10.0, ±9.6 ^{S**}	-4.7, ±5.7 ^{T*}	-9.8, ±13.8 ^{S*}	25.9, ±21.1 ^{M***}
Tries	-18.7, ±6.4 ^{S**}	-16.0, ±18.7 ^{S*}	22.5, ±25.0 ^{S*}	2.1, ±14.7 $^{T\circ\circ}$	-7.4, ±37.2 ^{T}	17.5, ±45.9 ^{S}
Missed tackles	13.8, ±5.3 ^{S*}	12.0, ±13.4 ^{S*}	8.0, ±13.5 ^{T*}	6.3, ±9.7 ^{T*}	-2.4, ±22.6 ^{T}	34.5, ±35.0 ^{M**}
Penalties conceded	6.6, ±4.6 ^{T*}	-6.9, ±10.9 ^{S*}	7.1, ±12.5 ^{T*}	-0.6, ±7.6 $^{T\circ\circ}$	-10.0, ±18.2 ^{S}	-4.8, ±19.9 ^{T}
Turnovers conceded	0.6, ±3.3 $^{T\circ\circ\circ}$	5.0, ±9.1 ^{T*}	-3.5, ±8.8 ^{T*}	0.6, ±6.0 $^{T\circ\circ}$	0.2, ±15.5 ^{T}	1.4, ±17.0)^{T}

[a]Superscripted letters indicate effect size as follows: ^{T}Trivial, ^{S}Small, ^{M}Moderate, ^{L}Large.
Symbols indicate the probability of an effect being substantial or trivial (whichever was the larger).
Asterisks indicate clear substantial effects as follows: *possibly, **likely, ***very likely, ****most likely; larger asterisks indicate effects clear at the 99% level.
Degree symbols indicate trivial effects as follows: °possibly, °°likely, °°°very likely, °°°°most likely; larger degree symbols indicate effects trivial at the 99% level.

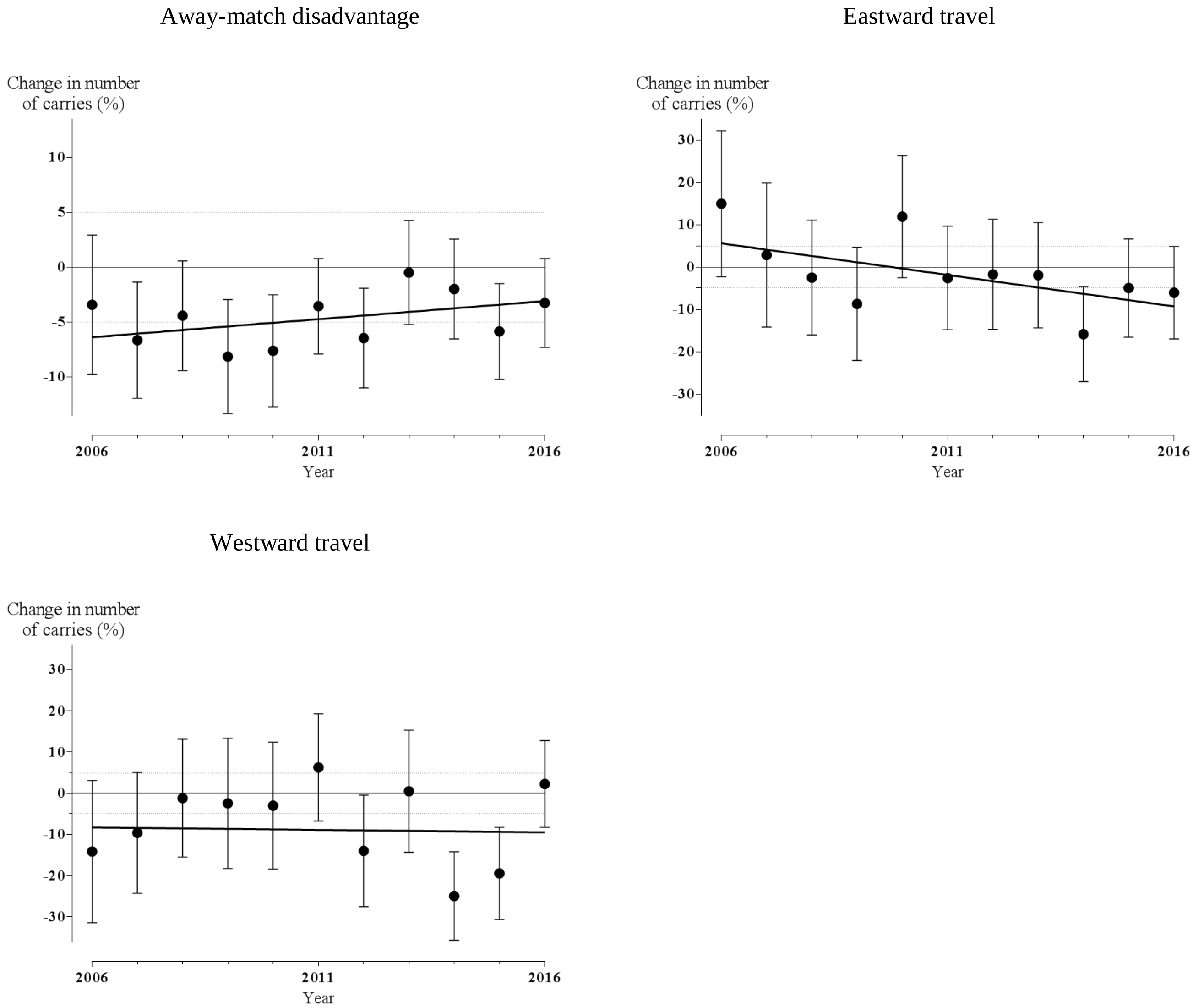


Figure 4.2: Pure effects of the away-match disadvantage and effects of eastward and westward long-haul travel (12 time zones, 24 h travel) on the number of carries, expressed as a percent variation, in Super Rugby matches. Data points are the predicted values from by-year analysis, with 90% confidence limits. Continuous lines were derived from the regression analysis of all data. Dotted lines are thresholds for the smallest important effect.

4.1.4: Discussion

This study analysed the effects of travel on team KPIs in Super Rugby over 11 years. The main focus was the effects of long-haul travel consisting of 24 hours of travel across 12 time-zones, but these effects were derived from an analysis of all available KPIs from all Super Rugby matches during this period. By doing so, it was possible to properly adjust for secular trend, effects of rule and format changes, and the away-match disadvantage. The effects of the long-haul travel were predicted from a model based on the assumption that the travel and time-zone shift had simple linear numeric effects. The apparent absence of non-uniformity in the plots of residuals justified this assumption.

The positive secular trends for most of the KPIs are consistent with the evolution of the game becoming more physical despite clear reductions with the changes in rules and competition format. Rugby union is a sport in continual evolution, with rules changed to increase safety of players as they become stronger and faster (WorldRugby, 2018). Similarly, Super Rugby expanded to include new countries and changed the competition format to make the game more entertaining and lucrative (SuperRugby, 2015). Despite the changes in rules, the moderate increases in clean breaks, defenders beaten, and tries, along with a similar increase in missed tackles, show that the game shifted toward a more offensive and physically demanding style, while the moderate decrease in penalties conceded could be due to the effects of changes in rule or an improvement in players' discipline.

The away-match disadvantage is due to a combination of factors including changes in the psychological states of athletes (Carron et al., 2005; Courneya & Carron, 1992). When isolated from the travel components, the away-match disadvantage had only generally trivial effects on performance. The estimation of the effects was based on the reasonable assumption that the disadvantage was the same for matches played either overseas or after short, internal travel. If the away match disadvantage was greater overseas, for example, then the effects of travel would be biased high. Unfortunately, all matches after long-haul travel are away matches and there is no way to separately estimate an away disadvantage in a remote location. Previous studies on the away-match disadvantage in Super Rugby have only focussed on match outcomes showing a substantial difference in points scored (Du Preez & Lambert, 2007; Morton, 2006), although the travel effect was only included in one of these studies (Du Preez & Lambert, 2007). Given the largely trivial although unclear effects of the away-match disadvantage it is suggested that playing away from home could be affecting tactical and strategic aspects of super rugby matches rather than technical skills and physical performance of players.

Throughout the monitored period the changes in KPIs are consistent with an impairment of performance following eastward long-haul travel across multiple time zones, while performance did not change or slightly improved following westward travel. These findings support the idea that travelling east is usually more detrimental that travelling west. Eastward travel requires a phase advance of circadian rhythms while travelling westward requires a phase delay. As circadian rhythms are, on average, slightly longer than 24 h (Czeisler et al., 1999; Srinivasan et al., 2010), the human body shows a natural tendency to drift slightly each day and, therefore, is more capable to cope with a delay than an advance in time (Eastman & Burgess, 2009). Thus, after eastward travel, the symptoms of jet lag are more severe (Herxheimer & Petrie, 2002; Srinivasan et al., 2010), the time required to recover is longer (Eastman & Burgess, 2009), and performance is more impaired (Jehue et al., 1993).

Rugby is an intermittent high intensity team sport (Gill, Beaven, & Cook, 2006) and fatigue may negatively influence players' performance (Kempton, Sirotic, Cameron, & Coutts, 2013). As the changes due to travel were more substantial for KPIs requiring repeated high intensity efforts (e.g. carries) (Sayers & Washington-King, 2005), fatigue may be the key factor that impaired performance after travel. Even if a full night of rest is usually enough to recover from travel fatigue (Reilly et al., 1997), fatigue related to jet lag affects performance for several days (Waterhouse, Reilly, et al., 2007). The 11-year trends for the travel effects showed that in recent years the impairment in performance was more substantial for some KPIs, especially for eastward travel. A possible speculative explanation is that there has been a gradual decrease in the time between arrival and match-day, resulting in inadequate time to fully recover. The shift toward a more demanding game style may also have interacted with travel to increase player fatigue and affected performance.

A possible limitation of this study is that match outcomes (win or lose) have not been included. A decline in team KPI after trans-meridian travel may have affected the chance of a team to win a match. However, the main aim of this study was to assess changes in performance indicators and, as winning is not just a matter of numbers, changes in KPI may not be indicative of changes in wining capability. As several components contribute in determining the outcome of a match, the introduction of the match result in the analysis may have only introduced an element of noise. It might be that players and teams performed worse in terms of sheer 'match statistic' after travel but perform better overall (i.e. won the match). Even if an improvement in KPIs influenced the chance of winning matches in Rugby 7's (Higham et al., 2014) that may not be true for Rugby Union. Rugby Union is a peculiar game where territory occupation is as important as ball possession to achieve a victory (L. Bishop & Barnes, 2013) especially when compared with rugby 7's where the disproportion between the number of players and the field dimension may enhance the importance of individual action in achieving victory. All the KPIs analysed were related to situations of ball possession (e.g. clean breaks) or non-possession (e.g. tackles), set pieces (scrums and lineouts) and discipline (penalties conceded). A reduction on these indicators does not automatically lead to a less functional occupation of the territory and therefore may not impact the ability of a team to win.

Another possible limitation is that the local time when a match was played was not considered. Several physiological functions that relate to performance reach their peak in the late afternoon and early evening which is considered the best time for sporting performance (Drust et al., 2005; Reilly, 2009a; Reilly & Waterhouse, 2009). After a trans-meridian travel, the internal clock of an athlete, which in homeostatic condition, is synchronized with the day/night cycle (Atkinson & Reilly, 1996; Czeisler et al., 1999) might be de-synchronized and a number of days is required to adapt to the new environment (Reilly, Atkinson, et al., 2007; Samuels, 2012). Super Rugby matches are usually played in the late afternoon or evening of the local time. As such, players might compete when their physiological response is not at its peak, thus affecting performance. Further research should investigate the rate of desynchronization at the moment of a match to better understand the individual response of each player after travel.

In summary, the findings of the present study suggest that fatigue related to long-haul travel and the increased physical demand of the game negatively impact players and team performance when overseas. The findings of this research can be of interest for all the coaches and support staff in sports that require international travel to compete.

Chapter 5: Study 3

5.1: The road goes ever on and on-A socio-physiological analysis of travel related issues in Super Rugby

5.1.1: Introduction

Air travel is a common future of several individual and team sports such as cycling, tennis, basketball, soccer and rugby (Reilly, 2009b; Youngstedt & O'Connor, 1999). Frequent air travel can have a negative influence on human performance and this influence is related to travel fatigue and jet lag (D. Bishop, 2004; Forbes-Robertson et al., 2012; Leatherwood & Dragoo, 2013; Samuels, 2012). Travel fatigue is a state of persistent exhaustion combined with recurring illness, lack of motivation and changes in mood that appears after a single trip and tends to accumulate over repeated travel (Samuels, 2012). Jet lag is a combination of gastrointestinal and sleep disturbances, fatigue, depressed mood, and a deficit in concentration and other cognitive skills that occurs after travelling across time zones (Eastman et al., 2005). Shifting time zones creates a de-synchronization between the circadian rhythms, the rhythmic pattern of all the physiological functions and systems of the human body (Czeisler et al., 1999), and the external clock which ultimately leads to jet lag (Herxheimer & Petrie, 2002; Waterhouse et al., 2004).

Air travel is a key factor in Super Rugby which is a competition currently played by teams from five countries (South Africa, New Zealand, Australia, Argentina and Japan) (SuperRugby, 2014a) and arguably the most important rugby union competition in the southern hemisphere. Although direct travel costs (e.g. travel and accommodation fares) are covered centrally for each team, travel may still have indirect costs as teams are less likely to win away games in particular if long-haul travel is required to reach the venue of the match (D. Bishop, 2004; Jehue et al., 1993). Losing away games reduces the chances of finishing high in the ladder and therefore minimises likelihood of competing in the finals. Such results can have a negative impact on the club’s financial position (e.g. low attendance at home matches, low supporter memberships the following season, less interest from sponsors, etc.). Therefore, any intervention that could mitigate the effect of travel and increase performance might be an important focus area for teams involved in a competition such as Super Rugby that requires to undertake an important amount of travel.

A number of specific strategies have been used in an attempt to reduce the negative effects of travel (Forbes-Robertson et al., 2012). Such strategies, can be applied prior to departure, during, and after the flight (Samuels, 2012). The pre-flight strategies are based on planning a trip to reach the intended destination at a certain time or a number of days pre-competition to give enough time for athletes to recover (Reilly, Atkinson, et al., 2007). The in-flight strategies aim to reduce the effect of travel fatigue. For instance, as a flight cabin is a cramped area, athletes are suggested to take every opportunity to move or wear compressive garments to reduce risk of cramping or even deep vein thrombosis in people predisposed to such problems (Reilly, 2009b; Waterhouse et al., 2004). After trans-meridian flights, the main strategies aim to quickly resynchronize the circadian rhythms to the new environment. These strategies are mostly based on pharmacological interventions (i.e. sleeping tablets) to enhance sleep (Donaldson & Kennaway, 1991; Reilly, Atkinson, et al., 2007) or melatonin supplementation (Cardinali et al., 2002; Herxheimer & Petrie, 2002) and light exposure/avoidance (Geerdink et al., 2016; Revell et al., 2006; Sasseville et al., 2006) to hasten the resynchronization rate. Overall, it appears that the majority of the strategies used to reduce the negative effect of travel on athletes focus on a clinical management of the symptoms, for instance sleep disruption, rather than to a more holistic approach.

The aim of this study was to identify the current practice to reduce the detrimental effects of long distance travel on performance and to understand the rationale behind these interventions. Furthermore, the perceived effect of travel on players' well-being and performance were investigated.

5.1.2: Methods

The Australian Rugby Union (ARU), the New Zealand Rugby Union (NZRU), the South Africa Rugby Union (SARU) and individual teams were asked to participate. The Japanese and Argentina teams and unions were not involved as they joined the competition recently (2016) and their participation would have raised a number of logistic and methodological issues. Three teams from Australia, three from New Zealand and two from South Africa accepted to be part of this study for a total of eight participants. Three participants were Strength and Conditioning Coaches while the remaining five were Medical Doctors for their team. Each participant was responsible for managing the effects of long distance travel and recovery. All participants were informed of any associated risks and provided verbal and written informed consent prior to the commencement of the study. The study was approved by the institutional Human Research Ethics Committee (HRE15 -288).

Participants were interviewed either face to face or via phone/Skype calls. The first questions were related to the strategies, if any, applied in each team to cope with travel. Subsequent questions were focused on the awareness of the interviewees of the current recommendations to cope with travel and jet lag. During the interviews, the questions were presented in an order that was conducive to the flow of conversation. The interviewer provided clarification as required to assist participants' understanding of the questions. Likewise, the interviewer asked for clarification and more information regarding a participant's responses if required. All interviews were digitally recorded and transcribed. Additionally, curricula of participants have been retrieved from public domain sources.

Following a preliminary analysis of the interviews' transcripts, participants received via e-mail a follow up questionnaire to address further aspects of the effects of travel on team and players' performance and well-being. Seven participants returned the questionnaire. A discourse analysis was undertaken to identify commons themes and differences between participants' answers (Bryman, 2016). Given the closed nature of the competition and in order to protect the privacy and identity of the participants, all data have been de-identified and represented here as two fictionalised amalgams (Grenfell & Rinehart, 2003). Fictionalised amalgams are useful in capturing the knowledge of participants' whilst ensuring confidentiality and anonymity. As such these amalgams are blended characters from the data representing a general division in the ways the medical/S&C staff responded to the questions. Each amalgam is represented via the following two pseudonyms. Bob tended to approach the issues of travel from an individualised clinical approach, while Peter, utilised a more holistic approach that considered other factors such as group dynamics and team culture.

5.1.3: Results

All interviewed participants thought that travel and jet lag can have a negative impact on players' performance. Fatigue and sleep disruption after travel are considered as the main issues. Both symptoms are thought to affect training response and subsequent match performance.

> We notice with the change in time zone and stuff like that, it affects sleep patterns. So if it affects your sleep patterns, it affects the player's perception of fatigue and also not just perception but the reality of fatigue. So that combined with other factors like altitude, playing time and all that sort of stuff has a profound effect on their physical and their mental ability when they're playing (Peter).

Considering the collective agreement of the practitioners charged with managing the teams' travel, sleep and recovery, it was interesting to note the enormous diversity of practices that they utilised. All teams are currently using one or more strategies to cope with the effects of travel and jet lag. These can be broken into two general practices, namely in-flight management and arrival/return strategies once on the ground at the destination (Table 5.1).

Table 5.1: Strategies currently used by Super Rugby teams to cope with the effects of travel. Both in-flight management (Travel) and arrival/return strategies once on the ground at the destination (Arrival) are listed.

TRAVEL	ARRIVAL
Modifications of Flight Schedule	*Supplementations and pharmacological interventions*
Delay departure following a previous game to avoid the addictive effect of travel fatigue and match fatigue	Melatonin
	Tart cherry Juice
	Multivitamins (specifically vitamin B12)
Aim for a specific arrival time at destination	Probiotics
Schedule intermediate stop-overs to facilitate resynchronization	Sleeping tablets if needed
	Sleep Education
Modifications of Fluids Intake	Avoid napping
Increase water intake	Afternoon naps (less than 1 hour)
Avoid caffeine and alcohol	Afternoon naps (less than 1 hour) with preload of caffeine
Supplementations	
Electrolytes	Maintaining normal sleep routine (based on individual habits)
Immune system boosters	
Others	*Light Exposure*
Humidification devices (face masks and moisturising spray)	Customized spreadsheets to calculate time and duration of light exposure
Compression garments	Training scheduled at specific times to seek/avoid light exposure
Filters for ‘blue light' (orange glasses)	
	Wearing or avoid sunglasses at specific times to seek/avoid light exposure
	Others
	Reduced carbohydrate intake
	Changes in training volume

Both Peter and Bob based their intervention on the use of sleep medication such as melatonin and sleeping tablets. However, Peter underlined the importance of a correct sleep education for the players ‘not only on tour but also in their normal daily routines to make sure they get adequate rest and recovery’. Short naps, lasting around 45 minutes, were mentioned by both characters and either prohibited or permitted but not encouraged during the players’ time off, for example in between training sessions. Bob, in particular, may permit the players to nap only after a pre-load of caffeine as ‘the caffeine hopefully has the effect of keeping them alert or the alertness from the caffeine hits them as they wake up so they don’t get that drowsy feeling post an afternoon nap, and they’re structured in the day’.

A common ‘in-flight’ strategy is based on planning the flight in advance. Most of the teams try to fly overseas immediately after a game in order to facilitate acclimation at destination. However, one of the teams tried to delay departure to avoid the additive effect of travel fatigue and match fatigue, whilst other teams tried to have a long stop-over in between travel ‘and acclimatize a bit and then head over’. Finally, most of the teams will aim to a specific arrival time, either morning or evening, based on direction of travel and travel duration. However, in-flight management is complex for a number of reasons. Teams are reliant on existing airline schedules to make their transit and many of the flight departures are not at favourable times.

It seems the decision for a particular strategy is based on a mix of anecdotal evidence, practice and literature evidence. However, literature is not considered as the main source of information. Common sense, experience and expertise are considered as a more valid and reliable source of information than literature and they seem to be at the basis of every intervention used.

The range of practices to deal with the negative aspects of travel were varied across all of the practitioners interviewed. These practices were developed through a variety of approaches best summarised by Peter as ‘So there’s a bit of science and there’s a bit of art in terms of the strategy we use’. These strategies drew variously on previous research evidence ‘well documented in studies’ (Bob); uncertainty, ‘there’s so many factors it’s hard to know exactly what works’ (Peter); player feedback and anecdote, ‘all I can go on is the more subjective and anecdotal stuff, looking at players and talking to players; measurement (Peter and Bob), ‘we will have some nice data because we are recording who exactly it is who has sleeping issues’ (Bob); word of mouth and imitation, ‘our plan is based on a couple of readings and also from chatting to the Springbok doctor’(Peter and Bob); and finally what can be described as a ‘gut feeling’, ‘sometimes it’s based on what the head coach feels as well… he might have a rationale for why he wants to do it a certain way and he might have a certain philosophy’(Peter).

Following the first round of interviews I was interested in investigating if and how both Peter and Bob considered problems that might extend beyond individual responses to traveling. In particular I used the second round of interviews to find out how significant things like homesickness, team culture and support, sharing rooms, and leadership were on the players’ ability to deal with travel. Bob’s response drew upon a medical and individual understanding, for example ‘some players will respond quickly to travel based on genetics, others will respond quickly based on previous experience with travel'. This approach places the solutions to the effects of travel on performance squarely inside the individual either due to genetics or adaptation. Peter, on the other hand, was far more likely to attribute significance to cultural and social aspects of travel:

> A team culture is very important, and the senior players can either positively or negatively define the wellbeing of players. A tighter team culture with a culture of caring, creates a more homogenous routine within the group and generally leads to better recovery and control of habits.

Indeed Peter suggests that:

> Travel fatigue and jet lag are factors but not the most important factors in determining success when travelling. Mental and emotional support are important to develop a supportive environment that encourages a positive and happy environment. Players that are comfortable and confident perform better and this comes from the touring ethos, and team culture fostered from pre-season onwards.

This type of response from Peter is juxtaposed to Bob when replying to the same question about other factors that determine performance, for example, 'I think altitude changes play a more important role'. Similarly, when asked about team culture, Bob responded:

> Definitely (culture matters) especially around the strategies with light to assist with body clock acclimation. They can promote the value of why we are doing what we do and promote compliance.

In the context of these questions Bob maintains clinical and individualised responses, and importantly doesn't engage with the more humanistic approaches of Peter:

> Having that camaraderie with a group comes in many shapes and forms. It comes in players enjoying each other's company. It comes in regards to constructed opportunities to be social and likewise have time by themselves or in small groups. As I said before every personality is different. Some people like to have their time by themselves. Some people like to have their time as part of a crowd and some people like to spend time with just people that they feel comfortable with.

Even in relation to sleeping arrangements and routine Bob and Peter posit different approaches.

> Obviously, one needs take into account the fact that these guys have roommates now whereas at home they may sleep in their own rooms and they're sleeping with someone else and there could be snoring issues (Bob).
>
> We put thought into who people room with the try to incorporate a balance of team/fun activities to keep up team morale and personal/free-time for people to have some personal space (Peter).

Peter's response is more concerned with the collective well-being of the group and that the dynamics of sleeping arrangements are linked into other important traveling considerations such as personal space and group activities. Bob differs as again the focus is on the individual and individual behaviours around sleep (such as snoring) but not necessarily about how the broader dynamics of putting people together might have other ramifications to the team harmony and cohesion.

Finally, Peter and Bob do agree on one thing in relation to homesickness and being on the road, namely 'by the end of a four week tour all players and management are very keen to get home, and are happy to be leaving'.

5.1.4: Discussion

Considering the potential impact of travel on Super rugby performance and the importance of winning 'on the road' it is interesting that there are such philosophically divergent practices being utilised. The major difference between the approaches of Bob and Peter is that in many ways Bob sees the issue as something *internal* to each individual while Peter perceives it to be something *external* between individuals. Based on the methods and interventions used Bob is slightly more scientifically/evidence based and Peter is slightly more intuitive or relying on common sense. Whilst there is no definitive way of evaluating which approach works best the responses of Peter and Bob do speak to a more general argument about the application of sport science and medical knowledge. A criticism of sport science over the past thirty years has been on its tendency to treat athletes in a machine-like manner (Hoberman, 1988; Maguire, 2011) and hence the solution to issues of performance have been by and large measurement, intervention, response. This approach has been criticised for the risk it runs in dehumanising the athlete and critics have suggested that a more holistic approach be taken regarding the athlete and indeed the knowledge that is administered on their body. This would include utilising a multi-disciplinary approach to address the problems and find the solutions to maximising performance. It is clear from the practitioners, especially Peter, that they are indeed trying to find solutions that draw on more than just bio-medical interventions. However, in trying to deal with the psycho-social and cultural elements of traveling and collective interaction, one might legitimately question whether this is within their realm of expertise and training.

Practitioners from sport medicine and strength and conditioning backgrounds rarely have strong training in the fields of psychology, sociology, or management. An examination of the participants' CV's found online clearly demonstrate this. The professional development trajectory of a sports medical practitioner is grounded within particular sport science, medical or clinical settings. In the case of those from strength and conditioning backgrounds the navigation of their career to a Super rugby team is marked by a history of steps through a range of sports settings where measurability of performance (for example rates of injury, individual testing, team success or fitness) are constantly under scrutiny. What this means is that those who make it to the Super Rugby level are most likely those who have best succeeded in satisfying the metrics placed on them.

The competitive nature of this labour market may also go some way to explaining the lack of handover in relation to strategies related to travel. Neither Bob nor Peter indicated that their current practices built on or developed from their predecessor's. Whether this is a result of wanting to hold onto intellectual property or an indication of the importance placed on travel management is unclear. What is clear is that the complexity of travel management and the range of practices used to combat these complexities indicates that it is a space for innovation that could result in a substantial improvements not only in performance but also team culture and cohesion.

Travel variables are too many to control and therefore there is not a final solution to address all travel related issues. However, psychological and emotional well-being may take primacy over physiological wellness as team culture and cohesion may be as important as biological interventions in controlling the negative effects of travel on players' performance and well-being.

Chapter 6: Study 4

6.1: Travel and match related changes in sleep of Super Rugby players

6.1.1: Introduction

Sleep is a behavioural state in which an individual is perceptually disengaged from, and unresponsive to the environment (Halson, 2013b, 2014b); although common in all animals its function is not fully understood (Halson, 2008, 2014b). However, it is generally accepted that sleep can positively influence mood, wellbeing and permits recovery from previous wakefulness fatigue to prepare the body for the subsequent wake phase (Halson, 2013b, 2014b; Nedelec et al., 2013; Robey et al., 2013; Van Ryswyk et al., 2017). The brain activity that occurs during sleep is also involved with the mechanism of neuroplasticity, which plays a key role in learning and skill acquisition (Sejnowski & Destexhe, 2000; Walker, Stickgold, Alsop, Gaab, & Schlaug, 2005). All these factors may be particularly important to elite athletes (Halson, 2014b).

Athletes, require more sleep than other populations and believe good sleep is important to perform at their best (Lastella et al., 2015; Reilly & Edwards, 2007). However, an athlete's sleep is usually disrupted (Halson, 2014b) and of poor quality (Bird, 2013; Lastella et al., 2015). Rugby players in particular are exposed to additional stressors including frequent trans-meridian travel and high intensity contacts or other strenuous activity that are likely to negatively impact their sleep, performance and quality of life (Fullagar, Duffield, Skorski, White, et al., 2015; Fullagar et al., 2016). Travel fatigue and jet lag appear to be main reasons behind the negative effect of trans-meridian travel on sleep (Leatherwood & Dragoo, 2013). Travel fatigue is the summation of physiological, psychological and environmental factors that accrue after a single trip and accumulate over time (Samuels, 2012). Jet lag occurs when the circadian rhythms, the rhythmic pattern of all the physiological functions and systems of the human body are not synchronized with the external clock, for instance after rapid travel across time zones (Waterhouse et al., 2004).

The purpose of this study was to determine the influence of trans-meridian travel and matches on the sleep of a group of players from four Super Rugby teams during the 2017 Super Rugby season.

6.1.2: Methods

Four professional Super Rugby teams, two from New Zealand and two from South Africa, agreed to participate. A total of 122 male players (age range 18-35 y) gave written informed consent to participate. All players' data were de-identified prior to analysis. The study was conducted according to the Declaration of Helsinki and approved by the authors' institutional Human Research Ethics Committee, the teams and the New Zealand Rugby Union (HRE15-287).

The study was conducted during the 2017 Super Rugby season. Participants were monitored from three days prior to and up to three days post matches for matches played in their own country. For matches played overseas, players were monitored from at least one day prior to departure. Teams were also monitored for at least one day upon return and including matches when possible. Each team was monitored for at least three matches (two in their own country and one overseas). A total of 19 matches, including 8 overseas, were monitored.

Participants' sleep/wake behaviour was monitored using sleep diaries, where participants recorded the start and end time for all sleep periods, and with activity monitors (Philips Respironics, Actiwatch 2, Murrysville, Pensylvania). The activity monitors are wrist-watch accelerometer devices that recorded participants' movement (set for 1-min epochs).The validity for activity monitor devices has been calculated using the polysomnography as criterion showing high correlations for total sleep duration (r>84) (Sargent et al., 2014). Although the reliability of this particular devices has not been tested yet, tests on similar devices showed that the inter device variability between units is moderate to large (0.6<r>0.96) (Sadeh et al., 1994) but the reliability of sleep estimate increases with the amount of nights monitored (Lotjonen et al., 2003; Van Someren, 2007). Participants wore the device on the same wrist for the duration of the study, excluding training and matches. As in previous studies, participants were considered asleep when the diary indicated they were in bed and the activity recorded by the watches was sufficiently low to indicate absence of movement (Sargent et al., 2014).

For the matches played overseas and upon return, the number of time zones crossed and the number of days following travel were included in the analysis. To account for the difference in day length during trans-meridian flights, travel days were merged with the first day upon arrival and then scaled to a normal 24 hours. The number of time zones crossed was calculated based on the relative position between the city where a match was played and the previous location of the monitored teams. Data were collected in multiple periods and at different times during the season. Before the beginning of each monitored period, players spent at least one week in their own country. Thus, participants would have already recovered from any travel that might have occurred outside of the monitored periods. Details on the monitoring agenda are presented in Table 6.1.

Table 6.1: Temporal order of matches around which sleep was monitored for each team, showing location where each match was played, number of time zones crossed and direction of travel to reach the match venue.

Team	Match	Match location	Number of time zones crossed	Travel direction
A	1	Overseas	2	West
	2	Away	2	East
	3	Home	-	-
	4	Overseas	10	West
	5	Home	10	East
B	1	Overseas	3	West
	2	Home	3	East
	3	Away	-	-
	4	Home	-	-
	5	Overseas	10	West
	6	Overseas	6	East
	7	Home	4	East
C	1	Away	-	-
	2	Home	-	-
	3	Overseas	5	West
D	1	Home	-	-
	2	Overseas	10	East
	3	Overseas	-*	-*
	4	Away	-	-

*Match played in the same time zone as for the previous match.
Dashed lines indicate non-monitored periods.

Statistical analysis: Data were imported into the Statistical Analysis System (version 9.4, SAS Institute, Cary, NC). Separate analyses were performed for each team using a general linear mixed model (Proc Mixed). Fixed effects predicted a mean value for all normal nights at home, for each night following travel overseas and for each night following return from overseas, with dummy variables to adjust for pre-match, match and post-match nights. A random effect for player identity accounted for repeated measurements of the players and thereby adjusted for individual mean differences between players and for any missing data.

A within-player random effect, given by a dummy variable with a value of 0 for normal nights and 1 for any night including and following travel, was included to estimate individual differences in the response to travel. This effect and the player random effect were assigned an unstructured covariance matrix to allow for a correlation between the two effects. This correlation was evaluated as the effect of ±1 SD of the true differences between players (the square root of the variances given by the player random effect) on the individual differences; from first principles this effect is given by the covariance divided by the real between players standard deviation. Confidence limits for this effect have yet to be derived.

To allow for individual changes in each player's sleep on normal nights in their own country and individual changes on each of the nights following travel (not accounted for by the within-player random effect), a different residual variance was specified for these nights. The between-player variance and the residual variance for normal nights were combined to estimate a between-player observed standard deviation for normal nights, which was then averaged across the four teams to assess the magnitude of the predicted effects. The magnitude thresholds for small, moderate, large and very large effects were 0.2, 0.6, 1.2 and 2.0 of the observed standard deviations and were therefore evaluated as follow: ≤15 min, trivial; >15 and ≤45 min, small; >45 and ≤80 min, moderate; >80 and ≤150 min, large; >150 min, very large. The magnitude of the standard deviations representing the individual responses to travel, was evaluated by halving these thresholds (Smith & Hopkins, 2011).

Uncertainty in the outcomes was expressed as 90% confidence limits. Reference Bayesian inference with a disperse uniform prior was used to make probabilistic assertions about the magnitude of the true effects for each team (Hopkins & Batterham, 2018). The probabilities that the true effect was substantial and trivial were calculated from the standard error of the effect and the threshold for small effects, on the assumption that the effect had a normal sampling distribution (Hopkins et al., 2009). If either of the probabilities was very likely (>95% chance) or very unlikely (<5% chance), the effect was reported as clear with the observed magnitude of being trivial or substantial, whichever was the larger (Hopkins & Batterham, 2018). The likelihood that the true effect was trivial or substantial was also reported qualitatively using the following scale: >25 and ≤75%, possible; >75 and ≤95%, likely; >95 and ≤99.5%, very likely; >99.5%, most likely (Hopkins et al., 2009). To account for inflation of error, effects clear with 99% confidence intervals were highlighted (Liu et al., 2015).

6.1.3: Results

Sleep on normal nights (mean ± SD, in minutes) was as follows: Team A, 391±11; Team B, 456±15; Team C, 411±12 and Team D, 467±13. The individual responses to travel for each team were as follow: Team A, ±26 (moderate); Team B, ±24 (moderate); Team, C ±17 (small); and Team D ±39 (moderate). The effects of +1 between-player SD on the individual responses were as follows: Team A, -13 (trivial); Team B, -20 (small); Team, C -5 (trivial); and Team D -26 (small).

Changes from the mean normal sleep time for each team on each monitored day spent overseas and upon return are showed in Figure 6.1. Inspection of the figure shows that disruption often continued beyond the first night, although there is no consistent effect of travel across all the teams. However, three of the teams, on average, had a small to moderate decrease on their sleep time, up to one hour, when overseas while one team (Team A) experienced a small increase. On return from travel two teams showed trivial changes on their sleep, while the team that was monitored for only one night upon return (Team C) experienced a moderate sleep loss (Figure 6.2).

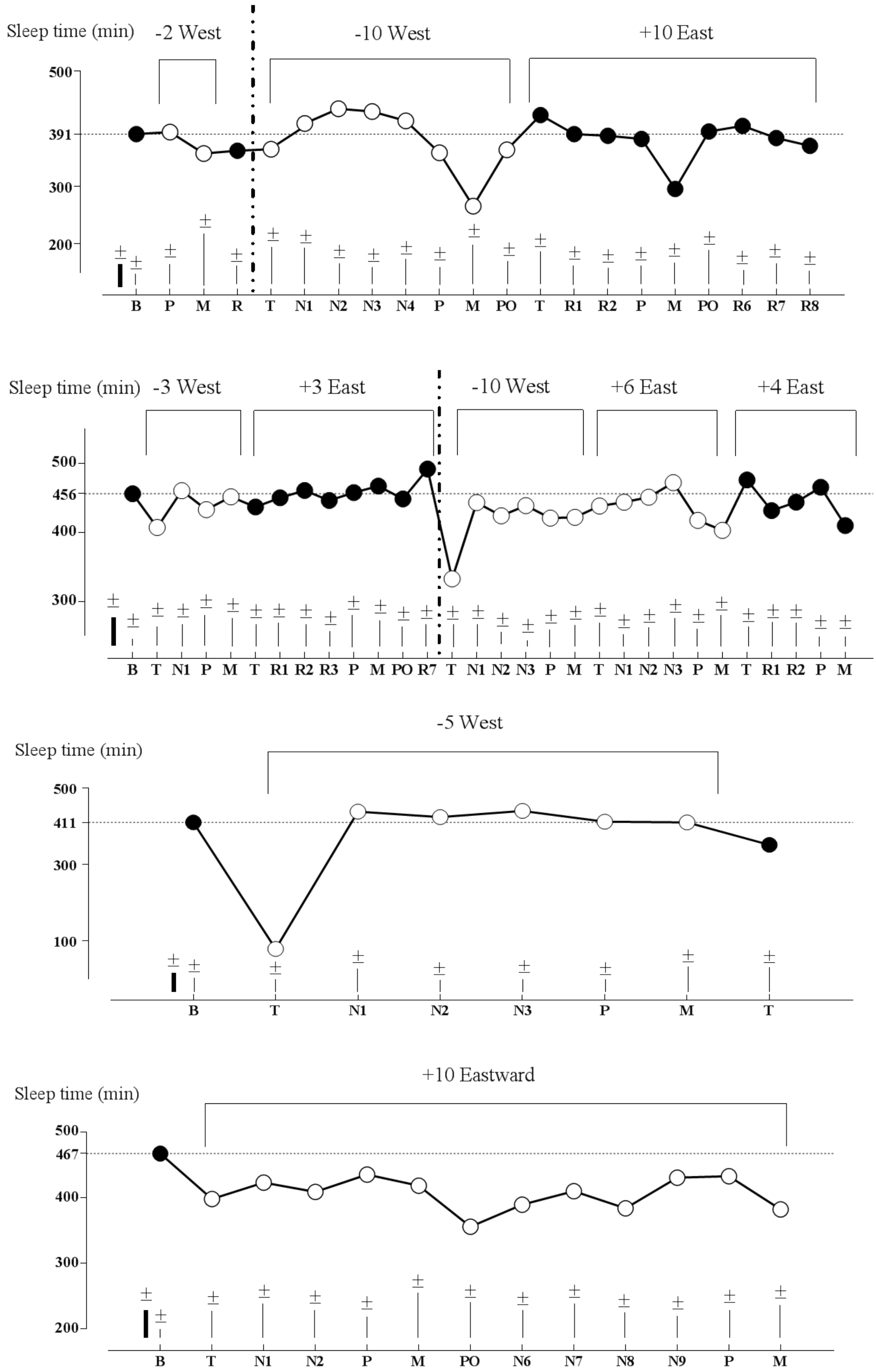


Figure 6.1: Changes in sleep time during nights spent overseas and upon return compared to normal nights. Thin lines are within players SD for each day. Thick lines are between players SD for each team. Dotted lines are normal sleep duration for each team. The 'mixed' vertical lines represent a time skip occurred during data collection. Square brackets report number of time zones crossed and direction of travel. Black symbols are home nights, empty symbols are overseas nights. Bs are normal nights, Ps are pre-match nights, Ms are match nights, POs are post-match nights, Ts are travel, Ns are overseas nights, Rs are returns nights.

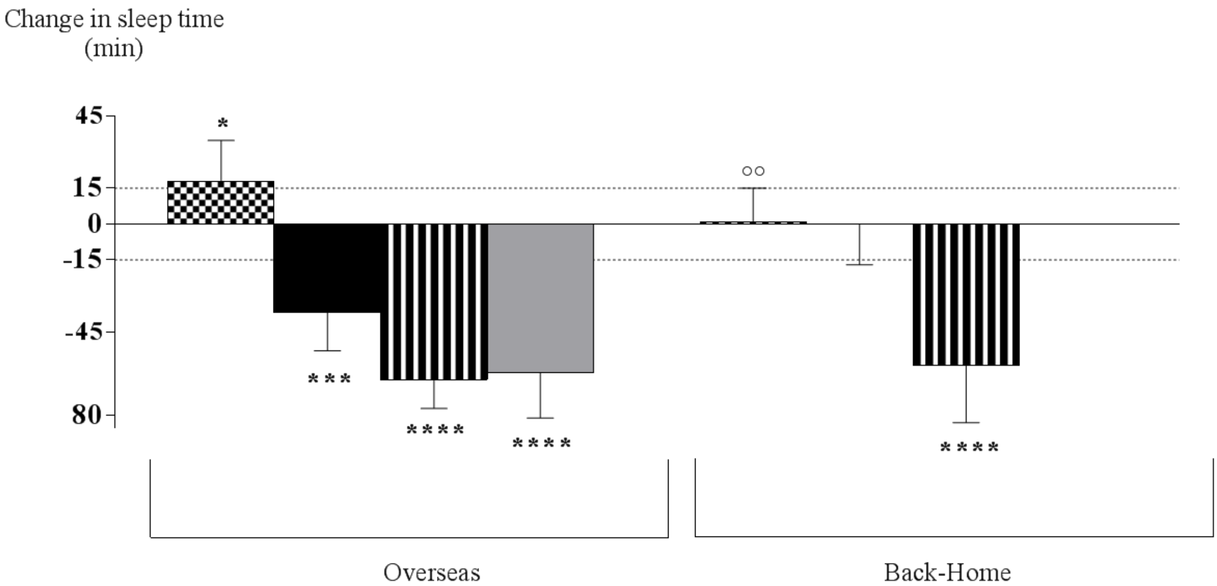


Figure 6.2: Predicted changes in sleep during nights spent overseas and upon return for each monitored team with 90% confidence limits compared to normal nights (0 line). Dotted lines are thresholds for the smallest important effect. Asterisks indicate clear substantial effects as follows: *possibly, **likely, ***very likely, ****most likely; all effects were clear at the 99% level. Degree symbols indicate trivial effects as follows: °possibly, °°likely, °°°very likely, °°°°most likely, all trivial effects were clear at the 90% level.

The above effects were adjusted for any change in sleep on the peri-match nights. These changes from normal sleep are shown in Figure 6.3. The night before a match three teams had a small increase in their sleep time while one team had a small decrease (Team D). The night following a match three teams had a moderate to large decrease on their sleep time whilst one team (Team A) had a small increase. On the following night, three teams had a trivial to moderate decrease in their sleep, while one tam had a small increase (Team C). Sleep balance, represented by the amount of sleep gained and lost over the peri-match nights, was negative for three teams (small to large loss) and positive for one team (Team A, moderate gain).

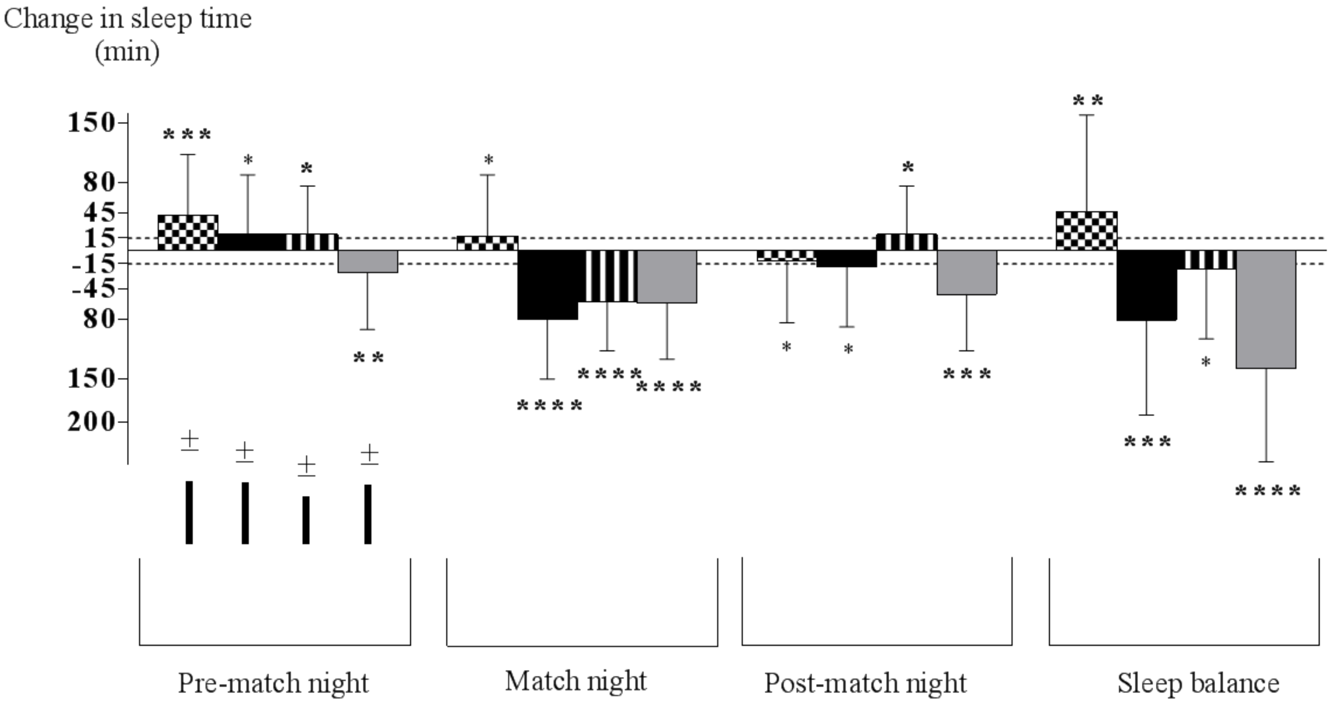


Figure 6.3: Predicted changes in sleep time during peri-nights and sleep balance for matches played home and away by Super Rugby teams compared to normal nights (0 line). Each block represents a team, error bars are within players SD. Thick lines are between players SD for each team. Dotted lines are threshold for the smallest worthwhile effect. Asterisks indicate clear substantial effects as follows: *possibly, **likely, ***very likely, ****most likely; larger asterisks indicate effects clear at the 99% level.

6.1.4: Discussion

The main focus of this study was on the sleep of Super Rugby players following long-haul travel. Travel was associated with substantial sleep deprivation for three of the teams when overseas, which can be explained by travel fatigue, jet lag and a disruption of the normal sleep habit (sleeping in a non-familiar environment and sharing room with a team-mate). This finding is consistent with previous studies that showed a larger impact of travel fatigue on the first night following travel with jet lag affecting the following nights (Fullagar, Duffield, Skorski, White, et al., 2015; Reilly et al., 1997). Players from only one team (Team A) slept more than normal whilst overseas. This team also had the lowest mean sleep at home. According to information reported by the coaching staff, this team scheduled home training very early in the morning, and players had to wake early to commute to the training facility. Apparently, travel provided players in this team with an opportunity to catch up on sleep loss.

For two of the three teams monitored upon return, sleep returned to normal values when teams travelled home. A possible explanation is that players returned to a familiar environment. Furthermore, players may not have completely resynchronized to the new time zone before flying home. As such, they virtually crossed less time zones during the return flight and therefore their recovery was more rapid. Players from only one team (Team C) did not return to normal sleep upon return. However, this team was monitored for only one day after travel and fatigue may have affected their first night of sleep, as shown in Figure 6.1 by some of the other teams and after long-haul travel.

A novel aspect of the analyses was estimation of the individual response to travel. The individual responses were substantial across the four teams. This could reflect sensitivity to travel fatigue and jet lag or difference between individual approaches to sleep issues after travel. The individual responses had a substantial negative association with normal sleep. Evidently, players who sleep more than average should take more care about avoiding sleep loss after long-haul travel, and therefore team should individualize their intervention, as those players could be more affected by sleep deprivation (Monroe, 1967).

The analyses of the changes in sleep when overseas involved quantification and adjustment for the changes in sleep on pre-match, match and post-match nights. The night before matches, players generally slept more than normal suggesting an attempt to increase sleep time (for instance going to bed earlier than usual) and potentially improve preparedness for the match, which is consistent with studies in rugby and Australian football (Richmond, Dawson, Hillman, & Eastwood, 2004; Shearer, Jones, Kilduff, & Cook, 2015). Only one team (Team D) showed an opposite trend. However, this team was monitored before matches played against direct competitors for a spot in the play-offs and pre-match anxiety may have affected their sleep.

The negative effect of playing a match on the subsequent night of sleep is consistent with previous studies (Richmond et al., 2004; Shearer et al., 2015) and can be explained by several factors. For instance, Super Rugby matches are usually scheduled for late evening and the post-match routine for the players (shower, dinner, media window etc.) delay their time to bed (Youngstedt, O'connor, & Dishman, 1997). Furthermore, the stress accumulated during the match, soreness, and consumption of caffeine or other ‘energetic’ drinks have a negative impact on the quality and quantity of sleep after a match (Halson, 2008). Only players from one team (Team A) had a longer sleep after matches. A chance to sleep more than usual the day after a match, when players did not train early in the morning to permit recovery and, as previously discussed, the low baseline sleep of these players may have provided players in this team with another opportunity to catch up on sleep loss.

The reduction in sleep the day after a match for all teams, excluding one (Team C), is possibly associated to an aftermath of all the match-related issues that players faced during match day. As such, the amount of sleep lost in these nights is less relevant when compared to the night following a match.

The final sleep balance for each match period was negative for most of the teams and players. Given the hectic schedule of Super Rugby, with matches played every week and a short recovery between matches, players may constantly lose part of their sleep during the season. This chronic sleep deprivation has the potential to affect health and wellbeing of the players (Juliff et al., 2015). Only players from one team (Team A) had a somewhat positive sleep balance. However, their particularly low baseline sleep suggests they may suffer of chronic sleep deprivation to a larger extent than players from other teams.

Sleep deprivation in vicinity of matches, especially when played overseas, may have negative effect on players’ health, training response and performance. As the individual responses were substantial across the four teams, teams should carefully monitor the sleep of their players with particular attention to those who sleep more than average as they may suffer of the effects of sleep disruption to a larger extent than their peers.

Despite its limitations, including the heterogeneity of the data collected as the number of travel and the number of days monitored were not consistent between teams due to logistical issues and the somewhat small number of nights monitored, the findings from this study can be of interest for all the coaches and supporting staff in sport that require international travel to compete. Further investigations should aim to identify the extent to which athletes experience sleep deprivation and the best strategy to increase sleep duration for athletes during the entirety of a season and in particular for matches played overseas.

The findings of this research suggest that Super Rugby players may suffer of chronic sleep deprivation with acute bursts in vicinity of matches, especially when they are played overseas, which may affect their performance, health and wellbeing.

Chapter 7: Study 5

7.1: The effects of matches and travel on Super Rugby players' wellness training and performance. Is sleep the key?

7.1.1: Introduction

Super Rugby is the most important Rugby Union competition for the southern hemisphere at a club level. The competition currently involves 15 teams from five different countries (Argentina, Australia, Japan, New Zealand and South Africa) playing each other home or away during the season. As such, teams have to travel frequently throughout the year. Even if international travel is common for several sports, there is no other competition with such a large travel demand for athletes.

The main goal for all players and teams involved in Super Rugby, or any other sport, is to perform at their best and potentially win the competition. However, frequent air travel can have detrimental effects on athletes' sleep (Fullagar, Duffield, Skorski, White, et al., 2015), training response (Fowler, Duffield, Waterson, et al., 2015), wellness (Fowler et al., 2017) and performance (Leatherwood & Dragoo, 2013). The negative effects of travel are mostly related to travel fatigue and jet lag (Reilly et al., 2005; Youngstedt & O'Connor, 1999). Travel fatigue is a state of persistent weariness, recurrent illness, changes in mood and lack of motivation that can occur after a single trip and accumulate over time (Samuels, 2012). Jet lag is the desynchronisation between the body clock and the external clock that occurs after traveling across time zones, with a shift of the external clock and a change on the cues that drive the body clock (Forbes-Robertson et al., 2012; Leatherwood & Dragoo, 2013). Jet lag symptoms include sleep disturbances, fatigue and depressed mood (Eastman et al., 2005). A number of strategies, including supplementation of melatonin (Herxheimer & Petrie, 2002), sleeping tablets (Reilly, Atkinson, et al., 2007) and light exposure protocols (Revell & Eastman, 2005) are commonly used by athletes to reduce the detrimental effects of travel (Forbes-Robertson et al., 2012). The purpose of this study was to determine the influence of international travel on the sleep, wellness, training response and performance of Super Rugby players.

7.1.2: Methods

Four professional Super Rugby teams, two from New Zealand and two from South Africa, agreed to participate. A total of 122 male players (aged between 18 and 35 years old) gave written informed consent to participate as volunteers. All data were de-identified prior to inclusion. The study was conducted according to the Declaration of Helsinki and approved by the institutional Human Research Ethics Committee, the teams and the New Zealand Rugby Union (HRE15-287).

The study was conducted during the 2017 Super Rugby season. Participants were monitored from three days prior to and up to three days post matches for matches played home or away. For the matches played overseas, players were monitored from at least one day prior to departure and, when possible, at least one day upon return. Each team was monitored for at least three matches (one home, one away, and one overseas) A total of 19 matches were monitored (7 home, 4 away, 8 overseas). Home and away (not overseas) periods and matches were considered baseline as the travel required was not enough to induce a noteworthy effect.

For the matches played overseas, the number of time zones crossed and the direction of travel were included in the analysis. To account for the difference in day length during trans-meridian flights, travel days were merged with the first day upon arrival and then normalized to 24 hours. Number of time zones crossed and direction of travel were calculated based on the relative position between the city where a match was played and the previous location of the monitored teams. Data were collected in multiple periods and at different times during the season. Before the beginning of each monitored period, players spent at least one week in their own country. Thus, participants would have already recovered from any travel that may have occurred outside of the monitored periods. Details on the monitoring agenda are presented in Table 7.1.

Table 7.1: Temporal order of matches monitored for each team, showing location where each match was played, number of time zones crossed and direction of travel to reach the match venue.

Team	Match	Match location	Number of time zones crossed	Travel direction
A	1	Overseas	2	West
	2	Away	2	East
	3	Home	-	-
	4	Overseas	10	West
	5	Home	10	East
B	1	Overseas	3	West
	2	Home	3	East
	3	Away	-	-
	4	Home	-	-
	5	Overseas	10	West
	6	Overseas	6	East
	7	Home	4	East
C	1	Away	-	-
	2	Home	-	-
	3	Overseas	5	West
D	1	Home	-	-
	2	Overseas	10	East
	3	Overseas	-*	-*
	4	Away	-	-

*Match matches played in the same time zone as for the previous match.
Dashed lines indicate non-monitored periods.

Participants' sleep/wake behaviour was measured using sleep diaries, where participants recorded the start and end time for all sleep periods, and activity monitors (Philips Respironics, Actiwatch 2, Murrysville, Pensylvania). The activity monitors are wrist-watch accelerometer devices that record participants' movement (set for 1-min epochs). Participants wore the device on the same wrist for the duration of the study, excluding training and matches. As in previous studies, participants were considered asleep when the diary indicated they were in bed and the activity recorded by the watches was sufficiently low to indicate absence of movement (Sargent et al., 2014).

Wellness and training load were monitored using data provided by each team. Wellness was collected by each team using different scales and, to account for this difference, all data were converted in a score ranging from 0 to 100. Training load data, both external and internal load, were provided by all teams.

External load was monitored by each team using different GPS/accelerometer devices. In particular, two teams used respectively VX340b and VX350 units sampling at 10 Hz (VX Sport, Lower Hutt, New Zealand), one team used Catapult OptimEye S5 units sampling at 10 Hz (Catapult Innovations, Melbourne, Australia) and one team used SPI HPU units sampling at 15 Hz (GPSports, Canberra, Australia). Although the validity and reliability of these devices were not directly assessed due to logistic reasons, all devices, excluding the VX350, have been tested before for team sport use or in a laboratory setting showing acceptable accuracy (Barr, Beaver, Turczyn, & Cornish, 2017; Buchheit, Allen, et al., 2014; Nicolella, Torres-Ronda, Saylor, & Schelling, 2018). One team provided external load data only as a weekly average of all training sessions and therefore their data were not included. Furthermore, teams used different customized speed bands to evaluate external load. Total Distance (metres run in total) and average distance (m.min-1) were retrieved and analysed from all teams as their measurement is not based on speed bands. Two teams used the same threshold to define High-Speed Distance (metres run above 4.17 m.s-1) and therefore their data were included. The third team did not provide any High-Speed Distance data.

Internal load was calculated by each team as a product of the session rating of perceived exertion (sRPE) and the duration of each session (Foster et al., 1995). Two teams directly provided internal load data, while one team provided both sRPE score and training duration that permitted the calculation of internal load. One team provided internal load as an average from a different sample of players for each training session and therefore their data were not included.

All teams granted access to their match reports for the analysis of individual players' Key Performance Indictors (KPIs). The reports included many KPIs but only 10 were included in the analysis. The selected KPIs were chosen as they are common to each role and position. In particular, changes in metres run with the ball, number of carries, number of defenders beaten, number of clean breaks, number of passes and number of points scored were included to assess 'offensive' performance. Number of tackles and missed tackles, number of turnovers conceded and number of penalties conceded were used to assess 'negative' performance. Carries, defenders beaten and clean breaks were also analysed together (combined offensive KPIs) as a global indicator of offensive performance. Similarly, turnovers conceded, penalties conceded and missed tackles were assessed together (combined negative KPIs) as a global indicator of negative performance. Specific KPIs such as kicks in play, lineouts thrown or drop kicks have been excluded as they are either infrequent or commonly performed only by a small number of players.

Statistical analysis: Data were imported into the Statistical Analysis System (version 9.4, SAS Institute, Cary, NC). Separate analyses were performed for each team using a general linear mixed model (Proc Mixed) to estimate changes in sleep, wellness, internal load and external load whilst overseas and upon return. The changes in sleep are discussed in detail in Chapter 6. The mediating effect of sleep was included in each analysis and calculated as twice the between players standard deviation for each team (Hopkins et al., 2009). For all other outcomes, fixed effects predicted a mean value for all normal day at home, for each day following travel overseas and for each day following return from overseas, with dummy variables to adjust for pre-match, match and post-match days (peri-match days). A random effect for players' identity accounted for repeated measurements of the players and thereby adjusted for individual mean differences between players and for any missing data. To allow for individual changes in each player's response on normal days in their own country and on each of the days following travel, a different residual variance was specified for these days. The between-player variance and the residual variance for normal days were combined to estimate a between-player observed standard deviation for normal days, which was then averaged across the four teams to assess the magnitude of the predicted effects via standardization. The magnitude thresholds for small, moderate, large and very large effects were 0.2, 0.6, 1.2 and 2.0 of the observed standard deviations and effects were reported with 90% confidence limits (Hopkins et al., 2009).

A normal score was also calculated for each KPI analysed as an average of all the monitored home or away (not overseas) matches. Estimate changes in KPIs for the matches played overseas and upon return were analysed with a generalized linear mixed model (Proc Glimmix) for the fixed effects of the direction of travel, the difference in ranking with the opposition (calculated as the difference in the ladder position at the end of the season), changes in sleep and the away-match disadvantage. Assuming it takes one day per time zone crossed to fully recover (Reilly, 2009b), a ratio between the number of time zones crossed for each direction of travel and the number of days upon travel and before a match (travel ratio) was calculated and included in the analysis. Players' identity was also included as a random effect to account for repeated measurements of the players and thereby adjusted for individual mean differences between players and for any missing data. Effects were reported in standardized and percent unit with 90% confidence limits (Hopkins et al., 2009). Magnitude of the effects were assessed using standardization, with threshold values for small, moderate, large and very large calculated as 0.20, 0.60, 1.2 and 2.0 of the observed between players standard deviations for each KPI (Higham et al., 2014; Hopkins et al., 2009); this standard deviation was estimated from the random effects and over-dispersed Poisson or logistic variance in the log- or logistic-transformed domain (Hopkins, 2016).

Uncertainty in each effect was expressed as 90% confidence limits and as probabilities that the true effect was substantially positive and negative (derived from standard errors, assuming a normal sampling distribution). These probabilities were used to make a qualitative probabilistic non-clinical magnitude-based inference about the true effect (Hopkins et al., 2009): if the probabilities of the effect being substantially positive and negative were both >5%, the effect was reported as unclear; the effect was otherwise clear and reported with the probability that it was either substantial or trivial, usually whichever was the larger. The scale for interpreting the probabilities was as follows: >25 and ≤75%, possible; >75 and ≤95%, likely; >95 and ≤99.5%, very likely; >99.5%, most likely (Hopkins et al., 2009). To account for inflation of Type 1 error, only effects clear with 99% confidence intervals were highlighted (Liu et al., 2015).

7.1.3: Results

The combined effect of travel across time zone, adjusted for the mediating effects of sleep and peri-match days on wellness are presented in Figure 7.1. The predicted effects were substantially negative when overseas with players recording lowest level of wellness (from 21.6 to 41.4 points less, moderate to large most likely negative effect). Upon return, wellness tended to generally improve for all teams despite remaining in the negative domain for two teams (respectively 4.9 points less, trivial possibly negative effect and 13.8 points less, small most likely negative effect). Sleep changes had only a trivial effect on wellness.

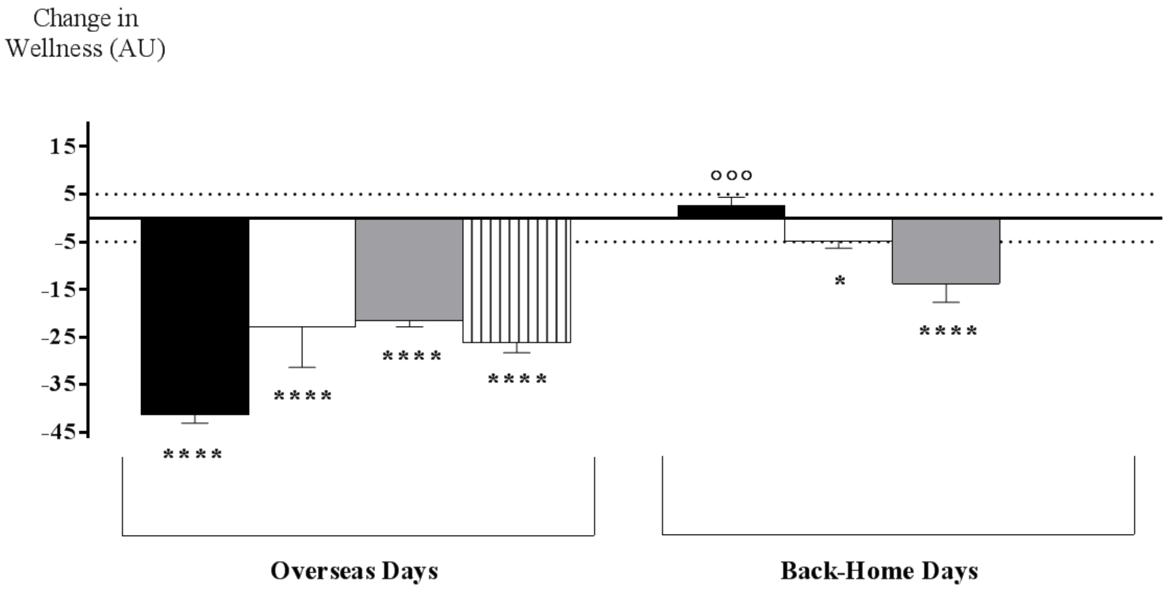


Figure 7.1: Predicted changes in wellness from baseline during the time spent overseas and upon return for each monitored team with 90% confidence limits. Each coloured box represents a team. Dotted lines are thresholds for the smallest important effect. Asterisks indicate clear substantial effects as follows: *possibly, **likely, ***very likely, ****most likely; All effects were clear at the 99% level. Degree symbols indicate trivial effects as follows: °possibly, °°likely, °°°very likely, °°°°most likely. All effects were trivial at the 99% level.

The combined effect of travel across time zone, adjusted for the mediating effects of sleep and peri-match days on external load (distance, distance rate and high-speed distance) are presented in Figure 7.2. The predicted effects overseas and upon return were substantial and generally negative, although one of the team increased both distance and distance at high-speed whilst overseas (respectively 3966 metres more, very large most likely positive effect, and 313 metres more, moderate likely positive effect).

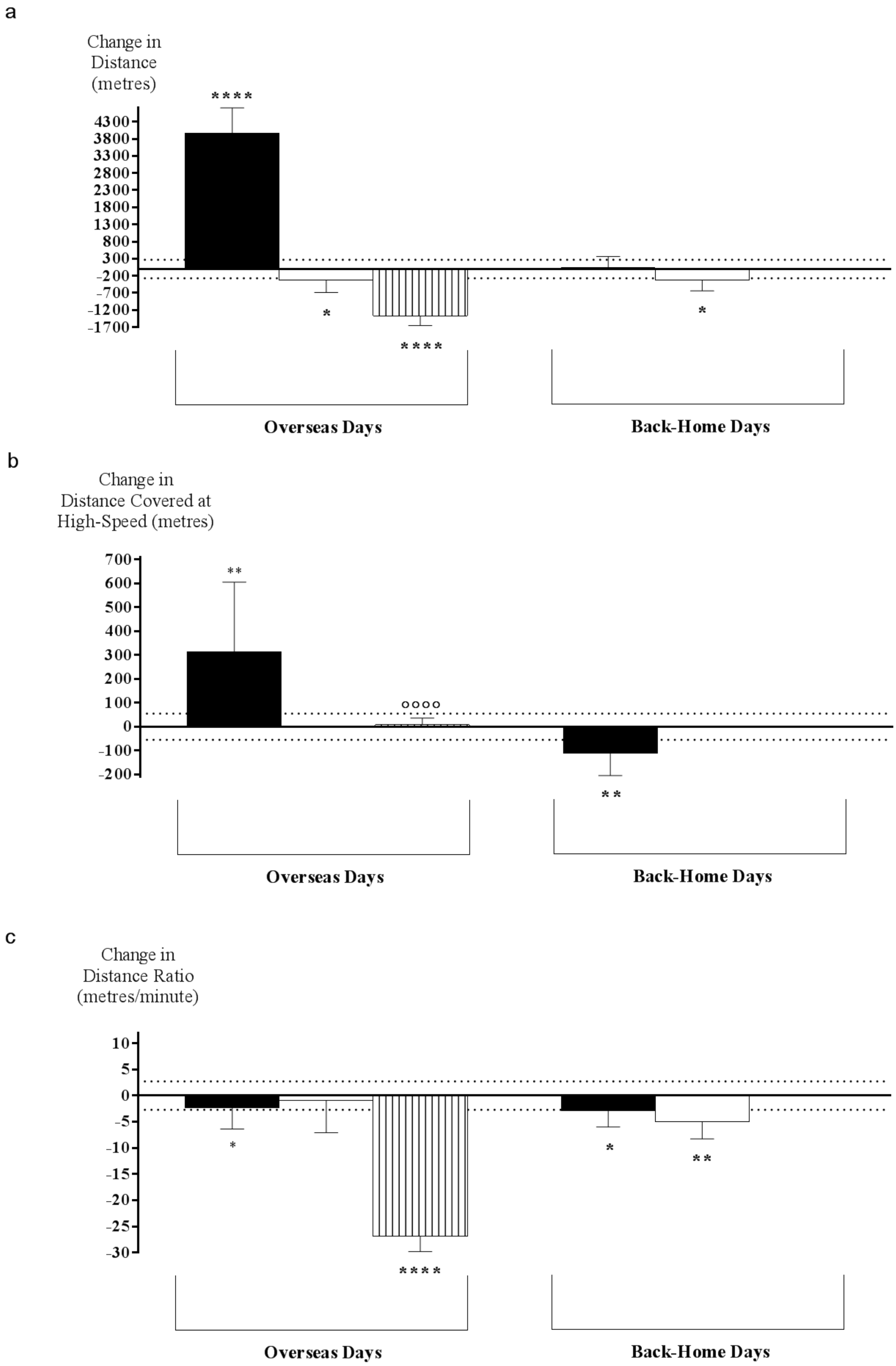


Figure 7.2: Predicted changes from baseline for Distance (a), Distance at High-Speed (b) and Distance Ratio (c) during time spent overseas and upon return for each monitored team with 90% confidence limits. Each coloured box represents a team. Dotted lines are thresholds for the smallest important effect. Asterisks indicate clear substantial effects as follows: *possibly, **likely, ***very likely, ****most likely; larger asterisks indicate effects clear at the 99% level. Degree symbols indicate trivial effects as follows: °possibly, °°likely, °°°very likely, °°°°most likely; all trivial effects were clear at the 99% level.

The combined effect of travel across time zones, adjusted for the mediating effects of sleep and peri-match days on internal load are presented in Figure 7.3. The predicted effects were substantially negative when overseas as players perceived their training as less demanding than when at home (from -57 AU, small possibly negative effect, to -312 AU, large most likely negative effect). Upon return, the predicted effects were trivial and internal load was close to baseline value (-14 and -17 AU, likely trivial effect). For both internal and external load, the mediating effect of changes in sleep was moderate.

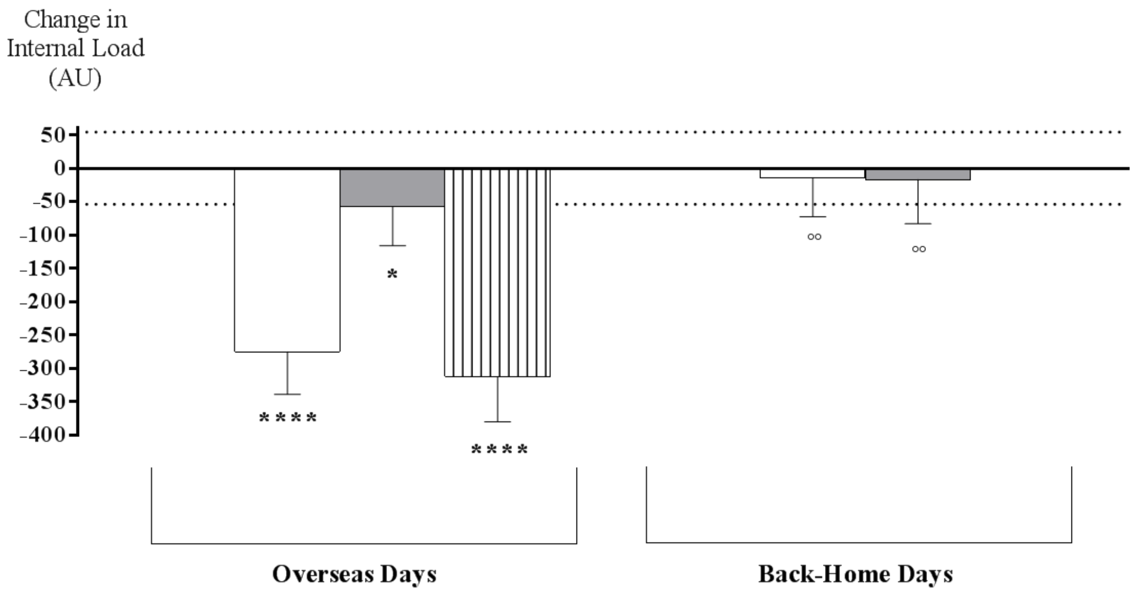
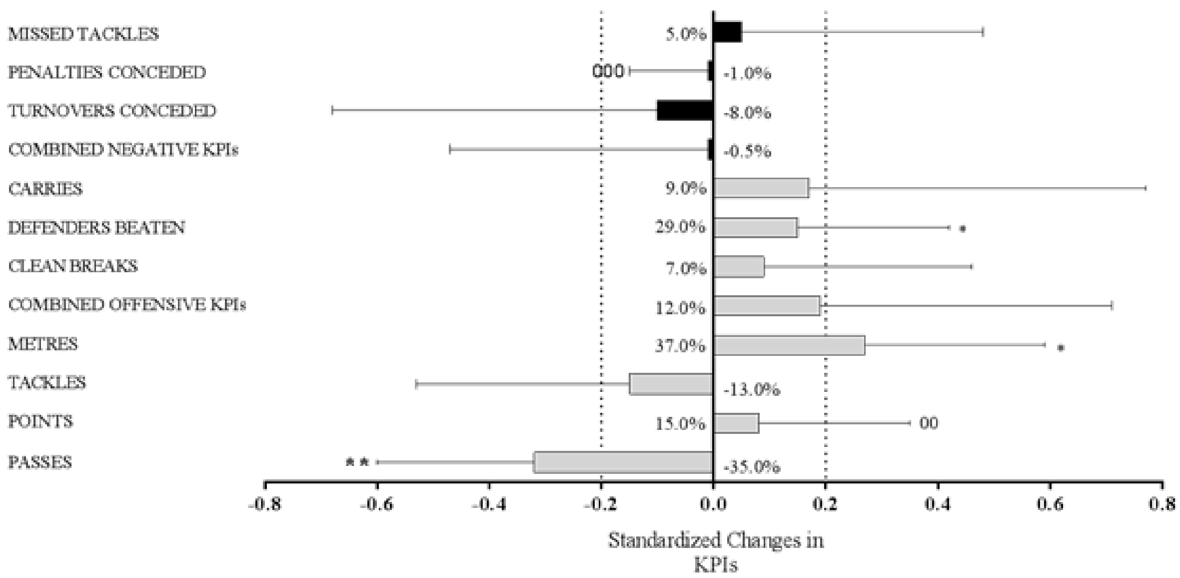


Figure 7.3: Predicted changes in internal load from baseline during time spent overseas and upon return for each monitored team with 90% confidence limits. Each coloured box represents a team. Dotted lines are thresholds for the smallest important effect. Asterisks indicate clear substantial effects as follows: *possibly, **likely, ***very likely, ****most likely; larger asterisks indicate effects clear at the 99% level all effects clear at the 99% level. Degree symbols indicate trivial effects as follows: °possibly, °°likely, °°°very likely, °°°°most likely; all trivial effects were clear at the 90% level.

The combined effects of the away-match disadvantage, difference in ranking, travel ratio on each KPI for both direction of travel and adjusted for the mediating effect of sleep are presented in Figure 7.4 as an average for all teams. Travelling eastward had trivial effects on all KPI with the exclusion of defenders beaten (small, possibly positive effect), metres (small, possibly positive effect) and passes (small, likely negative effect). Similarly, travelling westward had a clear effect only on tackles (small, likely positive effect) and passes (trivial, possibly positive effect). For both directions of travel and each KPI, the mediating effect of sleep was trivial.

a



b

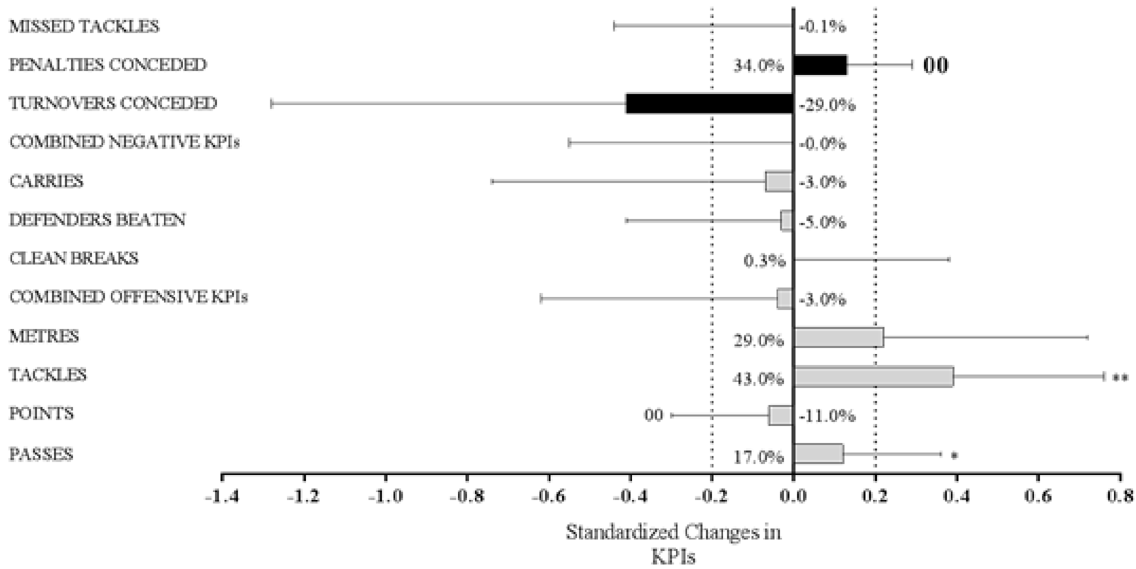


Figure 7.4: Predicted changes in KPIs from baseline after eastward (a) and westward (b) travel with 90% confidence limits in standardized and percent units. Black bars are 'negative' KPIs. Grey bars are 'offensive' KPIs. Dotted lines are thresholds for the smallest important effect. Asterisks indicate clear substantial effects as follows: *possibly, **likely, ***very likely, ****most likely; larger asterisks indicate effects clear at the 99% level. Degree symbols indicate trivial effects as follows: °possibly, °°likely, °°°very likely, °°°°most likely; larger degree symbols indicate effects clear at the 99% level.

The pure effects of the away-match disadvantage and difference in ranking with the opposition are presented in Table 7.2. The effect of the away-match disadvantage was mostly trivial although had a possibly negative impact on clean breaks, metres and missed tackle. The difference in ranking had a small to moderate positive effect on performance.

Table 7.2: Pure effects of the away-match disadvantage (AMD) and difference in ranking on KPIs. Predicted values are expressed in standardized units with 90% confidence limits.

	Away-Match Disadvantage (±CL)	**Ranking Difference (±CL)**
Missed tackles	0.22 (±0.39) ^{S***}	0.17 (±0.32) ^{T*}
Penalties conceded	0.09 (±0.18) $^{T\circ\circ}$	-0.18 (±0.13) ^{T*}
Turnovers Conceded	-0.12 (±0.38) ^{T}	0.13 (±0.36) ^{T}
Combined Negative KPIs	0.06 (±0.38) ^{T}	0.00 (±0.29) ^{T}
Carries	-0.07 (±0.38) ^{T}	0.54 (±0.36) ^{S**}
Defenders beaten	-0.05 (±0.26) ^{T}	0.39 (±0.26) ^{S**}
Clean breaks	-0.13 (±0.26) ^{T*}	0.41 (±0.23) ^{S**}
Combined Offensive KPIs	-0.07 (±0.35) ^{T}	0.63 (±0.34) ^{M***}
Metres	-0.12 (±0.32) ^{T*}	0.59 (±0.34) ^{S***}
Tackles	0.10 (±0.31) ^{T}	-0.05 (±0.26) ^{T}
Points	0.09 (±0.21) $^{T\circ\circ}$	0.17 (±0.19) ^{T*}
Passes	0.06 (±0.16) $^{T\circ\circ}$	0.17 (±0.16) ^{T*}

Superscripted letters indicate effect size as follows: ^{T}Trivial, ^{S}Small, ^{M}Moderate, ^{L}Large.
Symbols indicate the probability of an effect being substantial or trivial (whichever was the larger).
Asterisks indicate clear substantial effects as follows: *possibly, **likely, ***very likely, ****most likely; larger asterisks indicate effects clear at the 99% level.
Degree symbols indicate trivial effects as follows: °possibly, °°likely, °°°very likely, °°°°most likely; larger degree symbols indicate effects trivial at the 99% level.

7.1.4: Discussion

This study analysed the effects of trans-meridian travel on sleep, wellness, training and performance of professional Rugby players. Sleep disruption is common following long-haul travel (Fullagar, Duffield, Skorski, White, et al., 2015) and may have a potentially negative impact on wellness, training response and performance of athletes (Fullagar, Skorski, et al., 2015). However, consistent with previous reports (Fullagar, Duffield, Skorski, Coutts, et al., 2015) the results of this study show that after travel, despite being disrupted, sleep had only a trivial to small negative effect on players' wellness, training response and performance.

Travel across time zones had a substantial negative effect on players' wellness, with destination appearing to have a larger influence than direction of travel on determine this impairment. Although eastward travel is generally seen as more detrimental than westward travel (Herxheimer & Petrie, 2002; Srinivasan et al., 2010), teams travelling east to get home had a lesser decrease in their wellness than following overseas westward travel. A possible explanation is that well-being is complex and multidimensional (Camfield & Skevington, 2008) and the combined effect of multiple factors, including 'home-sickness', being in a non-familiar environment and match factors (Fowler, Duffield, Howle, et al., 2015) had a larger impact on wellness than direction of travel. As athletes perform at their best when they feel well (Gastin et al., 2013) and are less prone to injury (Fowler, Duffield, Waterson, et al., 2015), the reduction in wellness may have had a negative impact on players' performance and general health.

Travel overseas had a substantial negative effect on training load, with only one team showing a drastic increase in external load although this change was mostly due to a single, very intense training session. Similarly, internal load was lower than baseline showing that players perceived their training sessions as less intense. Teams tend to modify training when overseas, for instance planning 'technical/tactical' rather than physical sessions (e.g. less tackles or contact phases than usual), to reduce the stress of travel on players (Fowler, Duffield, Waterson, et al., 2015). As both internal and external load tended to return to baseline upon return, changes in training load appears to be related to periodization more than to a travel effect.

The effects of trans-meridian travel on KPIs were mostly unclear and trivial for both directions of travel, which is in in contrast with previous reports supporting the popular idea that travel fatigue and jet lag are the main factors accounting for the effects of travel (Forbes-Robertson et al., 2012; Leatherwood & Dragoo, 2013). The limited impact of travel fatigue can be explained by the fact that monitored teams reached the overseas venue a number of days prior to the match giving them enough to recover from the effects of travel fatigue (Reilly et al., 1997). Similarly, crossing time zones in both directions of travel appeared to minimally impair or even slightly improve performance. A possible explanation is that when isolated from the travel components the difference in ranking, which permits to account for difference in relative strength between teams (Trewin, Hopkins, & Pyne, 2004), had a substantial positive impact in many of the analysed KPIs. Facing opponents that ranked below them, boosted the performance of players and possibly mitigated any negative effect of travel on performance.

The predominant role of the difference in ranking on boosting performance also justifies the limited and mostly trivial impact of the away-match disadvantage on players' performance when isolated from other travel components. The away-match disadvantage is due to a combination of factors including changes in the psychological states of athletes (Carron et al., 2005; Courneya & Carron, 1992) that has a negative impact on performance, although the difference in ranking between teams was generally not taken into account (Du Preez & Lambert, 2007; Lazarus et al., 2017; Morton, 2006).

Previous studies proved the existence of an away-match disadvantage and its negative impact on performance (Du Preez & Lambert, 2007; Lazarus et al., 2017; Morton, 2006) although the difference in ranking between teams was not taken into account. Given the largely trivial, although unclear, effects of the away-match game disadvantage in this study, it is suggested that difference in relative strength has a larger impact on player's performance than travel and the away-match disadvantage.

Performance is very challenging to evaluate especially in team sport (Glazier, 2010), as it is complex and multifactorial. Rugby in particular is a peculiar game where territory occupation and position on the field are crucial to determine performance (L. Bishop & Barnes, 2013). All KPIs analysed were simple counts and did not provide any indication about the portion of the field where they occurred and therefore several performance information were missing. For instance, the count of missed tackles alone is not enough to properly evaluate individual performance as missing a tackle in front of the defensive try line is arguably more detrimental that missing a table in the offensive area of the pitch. In order to properly detect changes in rugby players' performance in general and following travel, further studies should integrate the counts of KPI with information related to the portion of the field where they occurred.

A possible limitation of this study is that only four team were recruited and only a relatively small number of matches was analysed. Similarly, the difference in strength between the monitored teams and the oppositions made it difficult to clearly detect the magnitude of the effects of travel and the away-match disadvantage on performance. However, the results of this study show that travel had a somewhat negative impact on rugby players and further studies should recruit more teams and monitor more matches over a longer time period to better understand the effect of travel on performance.

In summary, the findings of the present study suggest that sleep has only a limited impact on rugby players’ wellness and performance. Although the effects on performance are largely unclear, trans-meridian travel has a substantial negative impact on the well-being of athletes, which may have a negative impact on their general health. The findings of this research can be of interest for all the coaches and supporting staff in sports that require international travel to compete.

Chapter 8: General discussion

8.1: Introduction

This thesis investigated the effect of travel on professional rugby union players. Although air travel is common in numerous sports, including cycling, tennis and basketball (Reilly, 2009b; Youngstedt & O'Connor, 1999), and despite somewhat consistent support to the popular idea that travel can affect humans (Forbes-Robertson et al., 2012; Leatherwood & Dragoo, 2013), the effects of travel on performance have only been well documented for specific populations, such as cabin crews (Grajewski et al., 2016; Reis et al., 2016; van den Berg et al., 2016). Only a few studies have investigated the effects of travel on athletes assessing performance using generic and not sport specific markers, including grip strength or other generic outcomes of physical performance (Bullock et al., 2007; Leatherwood & Dragoo, 2013; Lemmer et al., 2002) and monitoring athletes for single long-haul flights (Bullock et al., 2007; Chapman et al., 2012; Lemmer et al., 2002) or multiple short-haul flights (D. Bishop, 2004; Fowler et al., 2014; Winter et al., 2009).

Similarly, the effects of travel on athletes' wellness (Fowler et al., 2017), training load (Fowler, Duffield, Waterson, et al., 2015) and sleep (Fullagar, Duffield, Skorski, White, et al., 2015) have been evaluated before. However, these studies focussed only on single travel, monitoring the athletes over short periods of time and did not fully analyse the mutual interactions between sleep, wellness, training and athletes' performance. This thesis may be the first to have investigated the complex interactions between individual physiological and psychological responses to multiple long and short-haul flights and their effects on match performance over a long period of time.

8.2: Effects of trans-meridian travel on performance

Match outcome and KPIs, chosen to assess performance in its purest way, instead of other indirect generic markers, somewhat declined after trans-meridian travel. Travel fatigue and jet lag are commonly considered the main factors accounting for the negative effects of travel (Forbes-Robertson et al., 2012; Leatherwood & Dragoo, 2013), with travelling east being generally more detrimental than travelling west

(Diekman & Bose, 2017). However, in this thesis, travel had only limited effects on players' performance, although the direction of travel largely dictated the magnitude of these effects. The major contributor to the negative effects of travel on match outcome, as reported in Chapter 3, was actually the away-match effect (Carron et al., 2005; Courneya & Carron, 1992). However, as reported in Chapters 4 and 7, the away-match disadvantage did not have a substantial impact on KPIs. A possible explanation is that playing away from home could have affected tactical and strategic aspects of super rugby matches, which influence match outcomes (Lazarus et al., 2017), rather than the technical skills and physical performance of players, which influence individual performance and KPIs (Kempton et al., 2013).

Chapter 3 analysed 21 years of history of Super Rugby from 1996, the first year the competition was played at professional level, to 2016. The results suggest that, overall, travel had a clear impact on match outcomes. As team and players' performance data were available only from the 2006 season, Chapter 4 narrowed the focus to 11 years of competition (2006-2016) showing that KPIs also tended to decline after trans-meridian travel. A trend confirmed by Chapter 7 that presented the results of a study where four teams were directly monitored during the 2017 Super Rugby season. Chapter 7 was a prospective observational study to further narrow the focus of this thesis and to get detailed information on the effects of travel on rugby players. However, the effects of travel on KPIs appeared to be smaller and less clear than the correspondent effects of travel on match outcomes. As the sample size for Chapter 3 was substantially larger than the sample size for Chapter 4 and 7, it was easier to quantify changes in match outcomes than changes in players' performance after trans-meridian travel. As reported in Chapter 5, considering the potential impact of travel on Super Rugby performance and the importance of winning 'on the road', teams are currently applying a number of strategies to reduce the detrimental effects of travel and hasten the resynchronization of the circadian rhythms. However, further studies should recruit more teams and monitor more matches to better understand the effect of travel on performance.

Performance is very difficult to evaluate especially in team sport (Glazier, 2010), as it is complex and multifactorial. Rugby in particular is a peculiar game where position on the field is crucial to determine performance (L. Bishop & Barnes, 2013). All KPIs analysed were those commonly employed by teams, but represent simple counts and did not provide any indication about the portion of the field where they occurred and therefore several performance information were missing. For instance, the count of missed tackles alone is not enough to properly evaluate individual performance as missing a tackle in front of the defensive try line is arguably more detrimental that missing a tackle in the offensive area of the pitch. Furthermore, changes in KPIs may not be indicative of changes in wining capability. As several components contribute in determining the outcome of a match, it might be that players and teams performed worse in terms of so-called KPIs after travel but perform better overall (i.e. won the match). Furthermore, in Rugby, a team's occupation of the field is as important as ball possession to achieve a victory (L. Bishop & Barnes, 2013). All the KPIs analysed were related to situations of ball possession (e.g. clean breaks) or non-possession (e.g. tackles), set pieces (scrums and lineouts) and discipline (penalties conceded). A reduction on these indicators does not automatically lead to a less functional occupation of the territory and therefore may not impact the ability of a team to win.

Another possible limitation for Chapters 3, 4 and 7 is that the local time when a match was played was not considered. Super Rugby matches are usually scheduled for late afternoon and several physiological functions reach their peak at this time (Drust et al., 2005; Reilly, 2009a; Reilly & Waterhouse, 2009). As such, players should be able to perform at their best. However, each person has an internal clock that, in homeostatic conditions, is synchronized with the day/night cycle (Atkinson & Reilly, 1996; Czeisler et al., 1999). After trans-meridian travel, the body requires a certain amount of time to resynchronize with the new environment (Reilly, Atkinson, et al., 2007; Samuels, 2012), which means a match may have been played when the physiological responses of athletes were not at their peak, thus affecting their performance. As reported in Chapter 5, teams are currently applying a number of strategies to help athletes resynchronize their circadian rhythms when overseas. Although there is no definitive way of evaluating which approach works best, the complexity of travel management and the range of practices used to combat all travel related issues leave space for further investigations to better understand the individual response of each player to travel and to travel-management strategies.

In order to properly quantify changes in rugby players' performance (both in general and following travel), the counts of KPI should also be integrated with information related to the portion of the field were the counts occurred and information about the team's occupation of the territory. Players' interactions should also be considered as individual response to travel may negatively impact on-field team dynamics and performance. Electronic positioning systems, including GPS units, provide positional data that can be used to retrieve information about the overall players' position and spatial distribution (Memmert, Lemmink, & Sampaio, 2017; Sampaio & Maçãs, 2012) that can be used to integrate counts of KPIs. Approximate entropy, which permits the identifications of regular movement patterns for individual players (Sampaio & Maçãs, 2012) and of the interactions between players in the space (Memmert et al., 2017) can also be used to integrate the assessment of teams and players' performance in relation to the occupation of the field (Passos et al., 2012). Inter-player coordination on the field can be explored analysing dominant regions, portions of the field a player can reach before any other (Taki & Hasegawa, 2000), or using relative phase procedures to describe the synchronisation between two players or two groups of players and assess changes in performance during a whole game and between halves (Memmert et al., 2017). Further studies should identify the ideal techniques to be integrated with counts of KPIs in order to properly understand the effects of trans-meridian travel on performance. Furthermore, as travel can affect the physiological response of athletes, further research should aim to identify which KPIs are more likely to be impaired after travel due to physiological changes in athletes.

8.3: Effects of trans-meridian travel on sleep, wellness and training load

Chapter 6 confirmed that rugby players experience bouts of sleep deprivation when overseas and in general when playing matches. However, the individual responses suggest different sensitivity to match-related issues, travel fatigue and jet lag or difference between individual in the compliance to travel strategies. Given the hectic schedule of Super Rugby, with matches played every week and a short recovery window in between, players may constantly lose part of their sleep during the season, which may impact their health and wellbeing over a longer term, especially for those players who sleep more than average. Further investigations should monitor more athletes for longer periods of time and aiming to identify the best strategy to increase sleep quantity and quality for athletes during the entirety of a season and in particular for matches played overseas.

Sleep is usually considered to have a large impact on response to training (Åkerstedt & Nilsson, 2003; Robey et al., 2013; Walters, 2002) and wellbeing (Chennaoui et al., 2015; Juliff et al., 2015; Walters, 2002). Sleep disruption may also affect athletes' performance (Halson, 2014b; Juliff et al., 2015; Reilly & Edwards, 2007). However, consistent with previous reports (Fullagar, Duffield, Skorski, Coutts, et al., 2015) Chapter 7 reported that, despite being substantially disrupted after travel, sleep had only a trivial to small negative acute effect on players' wellness, training response and performance.

Chapter 7 showed that training load changes when teams travel overseas, with an overall substantial reduction in external and internal load, which may also have influenced match performance (Foster et al., 1996) and athletes' wellness (Gastin et al., 2013). However, teams try to reduce the stress of travel on players modifying training when overseas (Fowler, Duffield, Waterson, et al., 2015). As both internal and external load tended to return to baseline upon return, changes in training response appear to be related to periodization more than travel effects or sleep disruption.

Chapter 7 also showed a limited impairment in wellness when teams travelled home after a period spent overseas to compete. A possible explanation is that well-being is complex and multidimensional (Camfield & Skevington, 2008) and the combined effect of multiple variables, including 'home-sickness', being in a non-familiar environment and match factors (Fowler, Duffield, Howle, et al., 2015) had a larger impact on wellness than jet lag and sleep disruption. However, the reduction in perceived wellness whilst overseas was clear and substantial. As athletes perform at their best when they feel well (Gastin et al., 2013) and are less prone to injury (Fowler, Duffield, Waterson, et al., 2015), the reduction in wellness following travel may have a negative impact on players' performance and general health. A reduction in general mood or other psychological functions are considered as a risk factor for injury in young and elite athletes (Galambos, Terry, Moyle, & Locke, 2005; Johnson & Ivarsson, 2011). Similarly, excessive training load, and potentially overtraining, are also considered as a potential risk factor for injury (Halson & Jeukendrup, 2004; Meeusen et al., 2013). However, the connection between psychological and physical well-being and their mutual influence on athletes' general health and risk of injury is still largely unclear. Furthermore, it is not clear whether repeated acute disruptions to wellness such as those when travelling, may accumulate over time, potentially resulting in an increased risk of injury impacting an athlete's career. Professional athletes are exposed to multiple stressors and travelling athletes have to face extra stress whenever they travel to compete. As discussed in Chapter 5, a shift toward a more holistic approach is required as psychological and emotional well-being may be as important as biological health in maintaining or improve health and performance of athletes, especially following travel. Further studies should implement a holistic approach to understand the effects of trans-meridian travel on sleep, training response and well-being of athletes and their reciprocal interaction and impact on athletes' performance and general health.

8.4: Key findings/Practical applications

8.4.1: Study 1: Out of your zone? 21 years of travel and performance in Super Rugby

Key Findings:

1. Throughout the first 21 years of Super Rugby, there was a substantial impairment of performance following the longest flights and greatest time zones shifts, although there was a gradual reduction of the impairment;
2. The major contributor to this performance impairment was the away-match disadvantage more than travel fatigue and jet lag.

Practical Applications:

1. Teams in Super Rugby are successfully dealing with long-haul travel and should now focus on reducing the effects of the away-match disadvantage.

Limitations:

1. The retrospective nature of the study limited the access to detailed information on the travel agenda of the teams. As such, some valuable information on the changes on the effects of travel on match outcomes over years may be missing.

8.4.2: Study 2: The longest journeys in Super Rugby: 11 years of travel and performance indicators

Key Findings:

1. Over the monitored 11 years of competition, despite changes in rules to increase safety of players as they become stronger and faster, the game shifted toward a more offensive and physically demanding style;
2. Throughout the monitored period, the changes in KPIs suggest an impairment of performance following eastward long-haul travel across multiple time zones, while performance did not change or slightly improved following westward travel;
3. As the impairment was more substantial for KPIs requiring high intensity efforts, fatigue related to jet lag and in match fatigue are suggested to be the major contributors to this performance impairment.

Practical Applications:

1. Teams in Super Rugby should focus on implementing adequate recovery strategies to reduce the effects of travel.

Limitations:

1. The retrospective nature of the study limited the access to detailed information on the travel agenda of the teams. As such, some valuable information on the changes on the effects of travel on KPIs over years may be missing.

8.4.3: Study 3: The road goes ever on and on-A socio-physiological analysis of travel related issues in Super Rugby

Key Findings:

1. Teams are concerned that travel and jet lag may have a negative impact on players' performance. Fatigue and sleep disruption after travel are considered to affect training response and subsequent match performance;
2. Teams are currently using one or more strategies to cope with the effects of travel and jet lag. These strategies can be broken into two general practices, namely in-flight management and arrival/return strategies once on the ground at the destination;

3. The decision for a particular strategy is based on a mix of anecdotal evidence, practice and literature evidence. However, common sense, experience and expertise are considered as a more valid and reliable source of information than literature and they seem to be at the basis of every intervention used;
4. There are two different approach to travel issues: an individualised clinical approach and a more holistic approach that considers other factors such as group dynamics and team culture.

Practical Applications:

1. There is not a final solution to address all travel related issues. However, a shift toward a more holistic approach is required as psychological and emotional well-being may be as important as biological interventions in controlling the negative effects of travel on players' performance and well-being.

8.4.4: Study 4: Travel and match related changes in sleep of Super Rugby players

Key Findings:

1. Travel fatigue, jet lag and a disruption of the normal sleep habit (sleeping in a non-familiar environment and sharing room with a team-mate) induce sleep disruption in Super Rugby players when overseas;
2. Matches have also a negative effect on players' sleep. Given the hectic schedule of Super Rugby, with matches played every week and a short recovery in between, players may constantly lose part of their sleep during the season;
3. Players' individual responses suggest different sensitivity to travel fatigue and jet lag or difference between individual compliance to travel strategies.

Practical Applications:

1. Over an entire season, rugby players experience chronic sleep deprivation that has the potential to affect their health and wellbeing. Teams should aim to identify the best strategy to increase sleep duration for athletes during the entirety of a season and in particular for matches played overseas; especially for those that sleep more than average.

Limitations:

1. A number of associations between variables, including players' age and travel effects, have not been included. Further studies should include those associations to fully understand the effects of travel and matches on the sleep of Super Rugby players.

8.4.5: Study 5: The effects of matches and travel on Super Rugby players' wellness training and performance. Is sleep the key?

Key Findings:

1. After travel, despite being disrupted, sleep had only a trivial to small negative effect on players' wellness, training response and performance;
2. Travel across time zones had a substantial negative effect on players' wellness. As this effect was less evident after travelling home, the combined effect of multiple factors, including 'home-sickness', being in a non-familiar environment and match factors may have a larger impact on wellness than sleep disruption and travel;
3. Teams tend to modify training when overseas to reduce the stress of travel on players. As both internal and external load tended to return to baseline upon return, changes in training load appears to be related to periodization more than to a travel and sleep disruption effect;
4. The effects of trans-meridian travel on KPIs were mostly unclear and trivial for both directions of travel, which is in in contrast with previous reports supporting the popular idea that travel fatigue and jet lag are the main factors accounting for the effects of travel on performance.

Practical Applications:

1. Teams should implement strategies to improve the well-being of their athletes, especially when overseas, as reduction in wellness may affect player's performance and general health;
2. At least in rugby, KPIs should be integrated with information related to the portion of the field where they occurred and information about team's occupation of the territory in order to clearly detect changes in performance both in general and after travel.

Limitations:

1. As no intervention was undertaken, the results of the study may be somewhat limited. For instance, it was not possible to separate the pure effect of travel per se from the effects mediated by the different interventions applied by the teams;
2. A number of associations between variables, including players' age and travel effects, have not been included. Further studies should include those associations to fully understand the effects of travel on Super Rugby players' wellness training and performance.

Chapter 9: Conclusions

Continuous long-haul travel influenced team performance over the first 21 years of Super Rugby. The away-match disadvantage is likely to be the main cause of these negative effects on match outcomes, whilst the increased physical demand of the game and fatigue related to long-haul travel are suggested to have a larger impact on players' individual performance when overseas.

Travel had a clear detrimental effect on players' sleep. However, sleep disturbances had only a limited impact on rugby players' performance and wellness. Although the effects on performance are largely unclear, trans-meridian travel had a substantial negative impact on the well-being of athletes, which may have a negative impact on their general health.

Travel variables are too many to control and therefore there is not a final solution to address all travel related issues. However, psychological and emotional well-being may take primacy over physiological wellness as team culture and cohesion may be as important as biological interventions in controlling the negative effects of travel on players' performance and well-being. However, the reduction in the effects of travel over time suggests that teams in Super Rugby are somewhat successfully dealing with long-haul travel. The findings of this thesis can be of interest for all the coaches and supporting staff in sports that require international travel to compete.

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Appendices

Appendix A: Consent form (Chapter 5)

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:
We would like to invite you to be a part of a study that aims to discover which strategies (if any) are currently applied to cope with the effect of travel within the Super Rugby teams.

CERTIFICATION BY SUBJECT

I, Mr.
of

certify that I am at least 18 years old and that I am voluntarily giving my consent to participate in the study: **"An analysis of the current practice for coping with the effects of travel and jet-lag in professional Rugby Union**" being conducted at Victoria University by: Prof Andrew Stewart.

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by Mr. Michele Lo and that I freely consent to participation involving the below mentioned procedures:

- Semi-structured interview

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way. I understand that the interview will be audio recorded.

I have been informed that the information I provide will be kept confidential.

I authorize/don't authorize the researcher to record the interview.

Signed:

Date:

Any queries about your participation in this project may be directed to the researcher

Prof Andrew Stewart
Ph: (+61) 03 9919 5200
E-mail: andrew.stewart@vu.edu.au

If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email Researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

Appendix B: Information to participants (Chapter 5)

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled "**An analysis of the current practice for coping with the effects of travel and jet-lag in professional Rugby Union"**

This project is being conducted by a student researcher Mr. Michele (Mick) Lo as part of a PhD study at Victoria University under the supervision of Prof Andrew Stewart from the College of Sport and Exercise Science and The Institute of Sport, Exercise and Active Living (ISEAL).

Project explanation

To achieve the best level of performance when required is the key to success in sport. Performance is complex and can be influenced by physiological (e.g. training), psychological (e.g. mood) and external factors (e.g. the weather). Frequent air travel is a common feature in sport. Air travel can affect performance due to travel fatigue and jet lag. Fatigue is a state of exhaustion after a period of mental or physical exertion. This state induces a decrease of the capacity to work and respond to stimuli. Travel fatigue is the summation of physiological, psychological and environmental factors. Travel fatigue occurs after a single trip and accumulates over time. Jet-lag is a disorder caused by an alteration of the circadian rhythms. These rhythms are the daily pattern of all human functions and systems. Jet-lag occurs after rapid travel across time zones due to a change in the external cues that drive such rhythms. The extent to which travel and jet-lag can affect performance is still uncertain. Yet, athletes and teams are using a number of strategies to avoid the negative effects of travel. The efficacy of such strategies, however, is still unclear. The aim of the study is to discover which strategies, if any, are used to cope with the effects of travel and jet-lag in rugby union. In particular, the strategies used by the teams competing in the Super Rugby will be investigated.

What will I be asked to do?

As a participant you will be interviewed via Skype. The questions will be related to the strategies applied in your team to cope with the effects of travel and jet-lag. The interviews will take approximately 30 minutes. All interviews will be recorded and transcribed to be analysed. To protect your privacy and your identity, during the interview, instead of your name, a numeric code will be used.

What will I gain from participating?

The result of this study will be used to investigate the efficacy of the strategies used to cope with the effects of travel and jet-lag on performance. Report will be provided to you and your team on an individual basis, completely confidential from the other teams. Reports will contain information that can be used by you and your team to enhance performance.
Such information can help you and your team to be better equipped to manage travel or confirm the accuracy of your on-going intervention. The information provided is likely to increase the chance of match success for your team.

How will the information I give be used?

The information collected will be analysed following transcription of the audio records. A general inductive content analysis will be adopted for the analysis. Such approach is based on the identification of themes and categories that emerge directly from the quotes of the interviews. Your participation is voluntary. You can refuse to be part of the project. Your decision will not affect you in any way. You are also allowed to withdraw at any point, without giving any reason and without any consequences. Any information obtained in this research project that can identify you will remain confidential and will only be used for research purposes. It will only be disclosed with your permission, except as required by law. Data will be used in scientific publications and/or presentations. Information will be provided in such a way that you cannot be identified, except with your permission. The data will be reported as average of the entire group and as individuals.

What are the potential risks of participating in this project?

There are no relevant risks involved if you decide to participate in this study. The interview will be immediately interrupted under your request if you feel discomfort or being affected by the questions in any way. You are also allowed to withdraw at any point and without giving any reason. All possible measures will be used during the interview to increase your comfort and reduce any possible risk.

Janet Young, a VU psychologist will be available at any point to help you in solving any psychological issue. Janet contact details are:
Ph: +61 3 9919 4762; E-mail: janet.young@vu.edu.au.

Who is conducting the study?

College of Sport and Exercise Science, Institute of Sport, Exercise and Active Living (ISEAL), Victoria University

Prof Andy Stewart	Ph: (+61) 03 9919 5200 E-mail: andrew.stewart@vu.edu.au
A/Prof Rob Aughey	Ph: (+61) 03 9919 6329 E-mail: robert.aughey@vu.edu.au
Dr Lauren Banting	Ph: (+61) 03 9919 4771 E-mail: lauren.banting@vu.edu.au
Mr Michele Lo	Ph: (+61) 0435 410 492 E-mail: michele.lo@live.vu.edu.au

Any queries about your participation in this project may be directed to the Chief Investigator listed above.
If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

Appendix C: Consent form (Chapter 6 and 7)

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:
We would like to invite you to be a part of a study that aims to discover the effects of travel on performance of professional rugby union teams and players.

CERTIFICATION BY SUBJECT

I, Mr.
of

certify that I am at least 18 years old and that I am voluntarily giving my consent to participate in the study: **"An analysis of the effects of travel and their influence on team and rugby union player performance"** being conducted at Victoria University by: Prof Andrew Stewart.

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by: Mr. Michele Lo and that I freely consent to participation involving the below mentioned procedures:

- Sleep screening
- Training load screening
- Mood screening
- Performance assessment
- Injury record

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I authorize/don't authorize the researcher to take photo or videos during the study. I have been informed that these photos and videos will be used in scientific meetings and conference presentations.

I have been informed that the information I provide will be kept confidential.

Signed:

Date:

Any queries about your participation in this project may be directed to the researcher

Prof Andrew Stewart
Ph: (+61) 03 9919 5200
E-mail: andrew.stewart@vu.edu.au

If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email Researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

Appendix D: Information to participants (Chapter 6 and 7)

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled "**An analysis of the effects of travel and their influence on team and rugby union player performance".**

This project is being conducted by a student researcher Mr. Michele (Mick) Lo as part of a PhD study at Victoria University under the supervision of Prof Andrew Stewart from the College of Sport and Exercise Science and The Institute of Sport, Exercise and Active Living (ISEAL).

Project explanation

To achieve the best level of performance when required is the key to success in sport. Performance is complex and can be influenced by physiological (e.g. training), psychological (e.g. mood) and external factors (e.g. the weather). Frequent air travel is a common feature in sport. Air travel can affect performance due to travel fatigue and jet lag. Fatigue is a state of exhaustion after a period of mental or physical exertion. This state induces a decrease of the capacity to work and respond to stimuli. Travel fatigue is the summation of physiological, psychological and environmental factors. Travel fatigue occurs after a single trip and accumulates over time. Jet-lag is a disorder caused by an alteration of the circadian rhythms. These rhythms are the daily pattern of all human functions and systems. Jet-lag occurs after rapid travel across time zones due to a change in the external cues that drive such rhythms. The extent to which travel and jet-lag can affect performance is still uncertain. This study employs a quantitative design to discover the effects of travel and jet-lag on players' response to training and match performance. The study will be conducted during the 2016 season. You and your team will be monitored during the matches played home, away and away overseas. Monitoring will include sleep, training load and mood analysis and a record of the injury rate. All data will be related to your response to training and to the outcome of performance based on notational analysis.

What will I be asked to do?

As a participant, you will be monitored during the 2016 Super Rugby season. You will be monitored for a 7 days period in vicinity of the matches. Monitoring will include measurements which are part of your normal training and match routine (training load, performance and injury) and measurements specific for the study (sleep and mood). We required and got permission to use the data already collected by your team and to collect the research specific data. In particular, monitoring will include:

- **Sleep screening**: Sleep is considered the best available strategy to recover for athletes. Air travel can affect sleep. The changes in sleep will be measured to assess their influence on your training response, mood and performance. To measure sleep, you will be requested to wear an activity monitor and to complete a sleep diary. Activity monitors are devices shaped as wrist watches commonly used to monitor sleep. You will be asked to wear the device all day, excluding training, matches and shower to monitor night sleep and naps. You will be also asked to report on a sleep diary the beginning and the end of each sleep period, the numbers of awakenings and to rate the quality of your sleep.

- **Training load screening**: Training load is a combination of external and internal load. External load is a measure of the physical work you perform during training and matches. Internal load is your response to these stimuli. An important aspect of internal load is wellness, a measure of the quality of your life. Training load will be collected, as normal routine on your team, to assess the influence of travel on your training response. External load data will be collected using accelerometer units. You are probably familiar with the use of such units which are currently used by your team to assess externa load. The units are small and located in a manufactured bib you have to wear under your jersey. Internal load will be measured using the sRPE scale and the wellness questionnaire. At the end of each session you will be asked to complete the sRPE. You will also be asked to complete a wellness questionnaire. You are probably familiar with both tools which are currently used by your team to assess internal load. Monitoring training load is a common practice in team sport. Your team is currently collecting training load data and you are probably familiar with this methodology.
- **Mood screening**: An appropriate mood state is considered as a key factor to enhance performance. The changes in mood after travel will be measured to assess their influence on your performance. To assess mood, you will be asked to complete the POMS-A questionnaire. The POMS-A is considered a valid and useful tool to self-rate athletes' performance. The questionnaire has to be completed three days before the match, the day before and during match day. You have to complete the questionnaire every evening at the same time.
- **Performance assessment**: Performance can be negatively affected by travel. Your performance, as well as your team performance, will be rated by a member of the coaching staff as normal routine. Performance will be evaluated using notational analysis. Such approach is based on the study of a number of performance indicators. For the purpose of this study, the indicators used to assess individual players will be tackles, carries and passes. The number and outcome of these actions will be marked. For the team, the indicators analysed will be the number of tries scored, the amount of penalties conceded and the final result of the match (win, lost, draw). Your team is currently rating you and your team performance in a similar way so you are probably familiar with such analysis.
- **Injury record**: Injuries are frequent in collision sport such as rugby union. A record of the injury occurred during the season will be collected by the medical staff of your team. The data will be collected to identify whether travel can be considered a risk factor for injury. All information collected will be used for research purpose. Data will be only made available to the researchers. Your team is currently monitoring your health and injury so you are probably familiar with this screening.

Your participation is voluntary and you will be able to withdraw at any time without consequences.

What will I gain from participating?

The findings from the present study can provide evidence of the effects of travel on performance. The participation to this study may enhance your performance and health reducing the effects of travel fatigue and jet-lag. Reports will be provided to you and your team. Reports will contain useful information for you and your coaches.

How will the information I give be used?

Reports will be provided to coaching, medical and fitness staff of your team. The reports will show your individual and team data. The aim of this project is to provide a level of understanding to coaching and medical staff on the effects of travel in terms of training response and performance. Monitoring your response to training and travel can potentially increase your performance, reduce the risk of injury and enhance your health and well-being. The information will be provided to your team at the end of the season. As such, the information provided will not impact upon team selection for the matches. Furthermore, many of the information are currently collected and used by your team. Your participation is voluntary. You can refuse to be part of the project. Your decision will not affect you in any way. You are also allowed to withdraw at any point, without giving any reason and without any consequences.
Excluding the reports, any other information obtained in this research project that can identify you will remain confidential and will only be used for research purposes. It will only be disclosed with your permission, except as required by law. Data will be only used in scientific publications and/or presentations. Information will be provided

in such a way that you cannot be identified, except with your permission. The data will be reported as average of the entire group and as individuals. We may ask your permission to take some photos or videos during the study. These photos and videos will be used in scientific meetings and conference presentations.

What are the potential risks of participating in this project?

Rugby union is a contact sport that involves frequent impacts. Playing rugby union is inherently risky. The main risk is injury. The air travel required to reach the venues where you will play also involves risks. Participation to this study is not increasing any of these risks. All the methodologies used for collecting data are low risk. However, unforeseen or unknown risks can manifest during the data collection. These risks will be addressed according to their nature. To enhance your safety, researchers and team members will attain CPR and First Aid certifications. During the study, potential injury will be managed by the medical and rehabilitation staff of your team.

You can feel stress or anxiety related to participation to this study. You may also fell under pressure because of your performance and training assessment. All possible measures will be used to increase your comfort. Part of the methodology is based on procedures already used by your team. A familiarization will be done prior the beginning of the study for all the new procedures (mood and sleep monitoring). Result will be given only to coaching, medical and fitness staff. The other players will not being aware of your results. When the results of the research are made available to publication, data will be de-identified to avoid the possibility of identify your results.

Your participation is voluntary. You can refuse to be part of the project. Your decision will not affect you in any way. You are also allowed to withdraw at any point, without giving any reason and without any consequences. Janet Young, a VU psychologist will be also available at any point to help you in solving any psychological issue. Janet contact details are: Ph: +61 3 9919 4762; E-mail: janet.young@vu.edu.au.

Who is conducting the study?

College of Sport and Exercise Science, Institute of Sport, Exercise and Active Living (ISEAL), Victoria University

Prof Andy Stewart	Ph: (+61) 03 9919 5200 E-mail: andrew.stewart@vu.edu.au
A/Prof Rob Aughey	Ph: (+61) 03 9919 6329 E-mail: robert.aughey@vu.edu.au
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Mr. Michele Lo	Ph: (+61) 0435 410 492 E-mail: michele.lo@live.vu.edu.au

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