Effects of International and Domestic Air Travel on Team Sport Performance and Recovery

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Certificate of Authorship

I, Peter Fowler,

“hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma at Charles Sturt University or any other educational institution, except where due acknowledgment is made in the thesis *Effects of International and Domestic Air Travel on Team Sport Performance and Recovery*. Any contribution made to the research by colleagues with whom I have worked at Charles Sturt University or elsewhere during my candidature is fully acknowledged.

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Signature: ___________________________ Date: 12th November 2014
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Publications


Abbreviations

AEST  Australian Eastern Standard Time
ANOVA Analysis of Variance
   AU  Arbitrary Units
   BM  Body Mass
Bpm  Beats Per Minute
   CD  Cluster of Differentiation
   CI  Confidence Intervals
CMJ  Countermovement Jump
CON  Control
DLMO Dim Light Melatonin Onset
DOM  Domestic Air Travel
DVT  Deep Venous Thrombosis
   ES  Effect Size
EW₁  East or West Travel across < 2 time-zones
EW₂  East or West Travel across 2 time-zones
F₁O₂ Fraction of Inspired Oxygen
GABA Gamma-Aminobutyric Acid
GMT  Greenwich Mean Time
GPS  Global Positioning Satellite
HIR  High-Intensity Running
HR  Heart Rate
HRex Heart Rate During Exercise
HRmax Maximum Heart Rate
HRR  Heart Rate Recovery
HSD Honestly Significant Difference
INT  International Air Travel
   INT Intervention
LIA  Low-Intensity Activity
LIJMU Liverpool John Moores University
   LT  Local Travel
   NS  North or South Travel
PSG  Polysomnography
RESTQ Recovery-Stress Questionnaire for Athletes
sRPE Session Rating of Perceived Exertion
   Tₗmin Body Temperature Minimum
   TE  Typical Error
USG  Urine Specific Gravity
VHIR Very-High Intensity Running
VO₂max Maximal Oxygen Consumption
   vs.  Versus
YYIR₁ Yo-Yo Intermittent Recovery Level 1 Test
Symbols and Units

< Less than
> Greater Than
≤ Less Than or Equal To
≥ Greater Than or Equal To
↑ Increased
↓ Decreased
↔ No Change
= Equals
± Plus or Minus
~ Approximately
x Multiplied By
% Percentage
°C Degrees Celsius
cm Centimetre
dB Decibel
g Gram
h Hour
Hz Hertz
kg Kilogram
kJ Kilojoule
km Kilometre
lux Illuminance
m Meter
mg Milligram
min Minute
ml Millilitre
nm Nanometer
S Second
µW Microwatt
W Watt
Y Year
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Abstract

The present thesis examined the effects of simulated international and domestic air travel, together with the impact of practical interventions for international travel, on the recovery of performance, in conjunction with physiological and perceptual responses, as related to team sport performance and recovery.

Study one examined the effects of simulated domestic (5 h) and international (24 h) air travel, compared to a control condition, on team sport performance recovery in 10 physically active males. Specifically, the prolonged exposure to mild hypoxia, cramped conditions and cabin noise, together with the schedule (stopover, meal composition and timings, and lighting changes) typically experienced on a commercial flight were simulated. The results indicated that sleep disruption during international air travel may subsequently exacerbate physiological and perceptual fatigue ($P<0.05$) and suppress intermittent-sprint performance ($P<0.05$). Conversely, domestic air travel had negligible effects on sleep, fatigue or intermittent-sprint performance ($P>0.05$).

Study two assessed the impact of domestic air travel ($\leq 5$ h flight duration and $\leq 2$ h change in time-zones) on competition performance (match outcome and key performance indicators), in addition to physiological and perceptual responses before and after matches in six male professional football (soccer) players. Data was collected from 12 matches, which included six home and away matches against the same four teams, to account for the effect of opposition quality on match outcome. More points were accrued and technical and tactical performance was superior during home compared to away matches ($P<0.05$). However, the findings suggested that
whilst domestic air travel may temporarily augment perceptual fatigue prior to competition \((P<0.05)\), it has no significant effects on sleep patterns, hydration or recovery \((P>0.05)\). Therefore, other factors are likely to explain the improved competition performance observed at home compared to away.

Study three examined the effects of match location (home vs. away) and competition phase (early vs. late season) on training loads, wellness and injury rates following competitive matches in 18 male professional football players. The findings suggest that during the late competition phase, players’ recovery time following matches may be slower \((P<0.05)\) and their ability to cope with training and competition demands could be reduced \((P<0.05)\). However, no effects of match location were evident during this phase of the season \((P>0.05)\), which suggests repeated away travel had negligible cumulative effects.

Lastly, study four assessed the efficacy of artificial bright light and sleep hygiene interventions at enhancing the recovery of team sport performance following simulated international (24 h) air travel in 13 physically active males. The results indicated that sleep disruption during international air travel may suppress lower-body power as a result of increased perceptual fatigue \((P<0.05)\) and reduced motivation \((P<0.05)\). However, whilst sleep hygiene recommendations may attenuate sleep disruption \((P=0.06)\) and travel-related fatigue \((P<0.05)\), no effects were observed on the recovery of team sport physical performance, including jump, 20 m sprint and intermittent-sprint performance \((P>0.05)\).
Collectively, these findings demonstrate that the demands of international air travel may reduce sleep quantity during travel, which could subsequently exacerbate physiological fatigue and suppress team sport physical performance due to increased perceptual strain. Though minimising this sleep disruption through sleep hygiene recommendations may attenuate travel-related fatigue, post-travel intermittent-sprint performance was unaffected. In contrast, domestic air travel is unlikely to impact team sport performance and hence, the tendency for teams to perform better at home compared to away may relate more to situational variables, territoriality, tactics and athlete psychological state. Furthermore, neither acute nor longitudinal effects of domestic air travel were evident on player recovery following competition.
Chapter One
Introduction
Overview

In the present professional era, elite team sport competitions take place all over the world with great regularity. Thus, international air travel can be a frequent necessity, which can require travel times of up to and greater than 24 h. As a result, travel and the associated demands are an additional stress imposed on professional players’ competition and training schedules (Leatherwood & Dragoo, 2012; Schwellnus et al., 2012; Thompson et al., 2013). Additionally, professional teams often organise pre-season training camps overseas, to utilise warm-weather or altitude in order to accelerate physiological training adaptations (Buchheit et al., 2013a; Buchheit et al., 2013b; Reilly, Waterhouse, & Edwards, 2005). Accordingly, the ability to tolerate and recover from international air travel is potentially important for ensuing training or competition success.

Furthermore, during the competition phase of the season, frequent domestic travel to and from away matches is a necessity for many team sports, including football (soccer) (Bishop, 2004; Goumas, 2014; McGuckin, Sinclair, Sealey, & Bowman, 2014). Due to the geographical size of countries such as Australia, domestic air travel of up to and greater than 5 h may be required for away competition (Richmond et al., 2007; Smith, Efron, Mah, & Malhotra, 2012; Winter, Hammond, Green, Zhang, & Bliwise, 2009). Moreover, in between domestic competition for their club, players’ schedules may often involve travel to training camps and/or to compete for their national team. As a result of these demanding schedules, there is often little time between travel and ensuing competition or training (Carling, Le Gall, & Dupont, 2012). In order for specific guidelines to be provided to players to assist them with these demands, a comprehensive
understanding of the effects of international and domestic air travel on the recovery time line of team sport specific performance is required.

**International air travel**

**Effects on physical performance**

A thorough understanding of the effects of international air travel on physical performance for team sports remains to be obtained for several reasons (Leatherwood & Dragoo, 2012). Firstly, research strictly assessing the effects of a single episode of international air travel on subsequent physical performance is limited (Leatherwood & Dragoo, 2012). Reduced grip strength is commonly reported following long-haul transmeridian air travel (Edwards et al., 2000; Lemmer, Kern, Nold, & Lohrer, 2002; Reilly, Atkinson, & Budgett, 2001). In contrast, inconsistent results have been reported for vertical jump performance, with a decrease (Chapman, Bullock, Ross, Rosemond, & Martin, 2012) and no change (Lagarde et al., 2001) previously demonstrated following international air travel, together with no change in maximal-sprint performance (Bullock, Martin, Ross, Rosemond, & Marino, 2007). These conflicting findings emphasise the second reason, which is the equivocal effect of international air travel on physical performance. This could be a result of the varying degrees of success by which study designs have controlled for the multitude of confounding factors that affect sports performance (Leatherwood & Dragoo, 2012; Reilly & Waterhouse, 2009). However, it may also be explained by the inter-individual variation in responses to the different durations and directions of travel, due to age, flexibility of sleeping habits, time of arrival and previous travel experience (Waterhouse et al., 2002), and/or variance in the type, sensitivity, timing and frequency of the physical performance tests conducted (Bullock et al., 2007; Lagarde et al., 2001).
As the process of travel includes many variables, the third reason for this limited understanding is the predominance of studies investigating the effects of jet-lag and alterations in circadian rhythms on physical performance. Consequently, few studies have isolated the impact of the demands of air travel, including prolonged exposure to mild hypoxia (Coste, Van Beers, & Touitou, 2009; Muhm et al., 2007), sleep disruption (Takahashi, Nakata, & Arito, 2002), hypohydration (Simons & Krol, 1996) and activity restriction (Silverman & Gendreau, 2009) on team sport physical performance (Leatherwood & Dragoo, 2012). Lastly, the majority of the literature is based on performance measures that are questionably related to team sport physical performance, such as grip strength or performance of one particular muscle group (Leatherwood & Dragoo, 2012). Whilst these measures may assist with the logistics of testing the performance of athletes around travel, they have limited ecological relevance to most team sports, which require prolonged bouts of intermittent-sprint activity (Coutts, Quinn, Hocking, Castagna, & Rampinini, 2010). Accordingly, the effects of international air travel, including circadian rhythm disruption and the demands of travel per se, on the recovery time line of team sport specific performance remains to be investigated.

**Physiological and perceptual effects**

*Jet-lag*

When multiple time-zones are rapidly crossed during international air travel, a loss of synchrony occurs between the endogenous circadian rhythms and external cues of the new time-zone (Waterhouse, Reilly, Atkinson, & Edwards, 2007). Whilst at first circadian rhythms retain their habitual rhythms of the place of departure, external cues, particularly natural light, promote the adaptation of circadian rhythms to align with the new time-zone (Forbes-Robertson et al., 2012).
As a result, body temperature (Lemmer et al., 2002; Reilly et al., 2001; Waterhouse et al., 2002) and hormonal circadian rhythms (Bullock et al., 2007; Lemmer et al., 2002; Pierard et al., 2001), along with the sleep-wake cycle (Beaumont et al., 2004) are disrupted. These changes induce the detrimental symptoms of jet-lag (Forbes-Robertson et al., 2012; Reilly et al., 2007a; Waterhouse et al., 2007), such as increased fatigue, reduced alertness and negative mood states (Reilly et al., 2007a), all of which are likely to suppress physical performance (Reilly et al., 2007a; Reilly & Waterhouse, 2009; Reilly et al., 2005).

However, determining the underlying mechanisms of travel induced performance reductions is problematic. For instance, while it is possible for studies to control for environmental factors that influence circadian rhythms such as light, activity and diet, it is difficult to control for those that display circadian rhythms of their own, such as the sleep-wake cycle (Reilly & Waterhouse, 2009). Consequently, it is often unclear whether a decline in physical performance following long-haul transmeridian air travel is due to a shift in circadian rhythms or sleep deprivation (Leatherwood & Dragoo, 2012). Indeed, a significant reduction in sleep quantity and quality has been reported following long-haul transmeridian air travel (Beaumont et al., 2004; Takahashi et al., 2002). Since sleep loss is associated with negative effects on mood states and motivation (Skein, Duffield, Edge, Short, & Mundel, 2011), international air travel may have an effect on physical performance via such mechanisms (Leatherwood & Dragoo, 2012).
Travel fatigue

Symptoms of travel fatigue, which may include lethargy, irritability and headaches, are induced by the demands of air travel (Waterhouse, Reilly, & Edwards, 2004). Causes of travel fatigue may include the prolonged exposure to mild hypoxia, cramped conditions and cabin noise (Forbes-Robertson et al., 2012; Reilly et al., 2007a; Waterhouse et al., 2007), and/or the disruption of routines as a result of travel, such as eating and sleeping patterns (Reilly, Waterhouse, Burke, & Alonso, 2007b; Smith, Ciacciarelli, Serzan, & Lambert, 2000). Though symptoms of jet-lag tend to be more severe and longer lasting than those of travel fatigue, both occur following long-haul transmeridian air travel and may compromise physical performance (Forbes-Robertson et al., 2012; Reilly et al., 2007a; Waterhouse et al., 2007). However, the separation of their individual effects is difficult in field-based environments.

Consequently, limited data exists for the effects of international air travel per se on integrated physiological and perceptual responses and their subsequent effects on team sport physical performance. Due to the aforementioned travel demands, it is purported that sleep during long-haul air travel is likely to be fragmented at best (Forbes-Robertson et al., 2012). Therefore, sleep loss during and following long-haul transmeridian air travel may reduce physical performance. However, further research is required utilising objective methods of sleep monitoring. Furthermore, the effects of long-haul international air travel on physiological stress markers, such as heart rate responses to exercise, cortisol and immune function are yet to be determined, along with their subsequent impact on team sport physical performance.
Interventions

Despite the previously reported detrimental effects of long-haul transmeridian air travel on physical performance (Chapman et al., 2012; Reilly et al., 2001), a paucity of interventions has been confirmed as beneficial to travelling athletes. Instead, based on an understanding of chronobiology from laboratory-based experiments (Czeisler et al., 1989; Deacon & Arendt, 1996; Revell, Arendt, Terman, & Skene, 2005), generic recommendations have been published to promote the resynchronisation of circadian rhythms and thus, minimise the negative effects of jet-lag following international air travel in athletes (Arendt, 2009; Forbes-Robertson et al., 2012; Reilly et al., 2007a). However, it is unclear whether or not these recommendations have any effect on the recovery of physical performance following travel. For example, to accelerate the resynchronisation of the sleep-wake cycle following long-haul transmeridian air travel, previous recommendations propose that during travel, sleep should be scheduled according to when it is night at the destination, and must be avoided when it is daytime at the destination (Reilly & Edwards, 2007; Waterhouse et al., 2004). However, no research studies have attempted to implement such recommendations during travel and observe the ensuing effects on sleep quantity and quality, together with the recovery of physical performance following travel, particularly in team sport athletes.

In contrast, numerous studies have investigated the use of specific pharmacological interventions including caffeine, short-acting benzodiazepine hypnotics and melatonin (Beaumont et al., 2004; Edwards et al., 2000; Reilly et al., 2001), in addition to behavioural interventions such as artificial bright light exposure and exercise (Gronfier, Wright, Kronauer, Jewett, & Czeisler, 2004; Thompson et al., 2013; Yamanaka et al., 2010) to accelerate the resynchronisation of
circadian rhythms following long-haul transmeridian air travel. Considering the unwanted side-effects (Beaumont et al., 2004; Reilly et al., 2001) and medical concerns over the use of many pharmacological interventions, scheduled exposure to bright light is currently advocated as the most appropriate and effective method of adjusting circadian rhythms in athletes (Forbes-Robertson et al., 2012). Consequently, the commercial availability of portable artificial bright light sources, such as light boxes and light glasses, as a treatment for jet-lag has recently increased. Whilst evidence suggests these devices may adjust circadian rhythms in well controlled studies (Lack, Bramwell, Wright, & Kemp, 2007; Wright, Lack, & Kennaway, 2004), their effectiveness at enhancing the recovery of physical performance following transmeridian air travel is limited (Boulos et al., 2002), particularly in elite team sport athletes (Thompson et al., 2013). Furthermore, as sleep disruption is likely during (Takahashi et al., 2002; Waterhouse et al., 2002) and following (Beaumont et al., 2004; Takahashi et al., 2002) long-haul transmeridian air travel, which may itself reduce ensuing physical performance (Reilly & Edwards, 2007; Skein et al., 2011), sleep interventions that minimise this disruption may also enhance performance recovery, though this remains to be investigated.

**Domestic air travel**

**Effects on competition performance**

Short-haul domestic air travel is one of a myriad of factors purported to affect match outcome (Goumas, 2014; Pollard, 2008) and the tendency for teams to perform better at home compared to away, often referred to as the home advantage (Goumas, 2014; Pollard, 2008). Hence, it is frequently highlighted by the media, coaching staff and players as an explanation for poor away match performances (Du Preez & Lambert, 2009). As further evidence, crossing a greater
number of time-zones during domestic air travel for away matches has been correlated with reduced competition performance (Bishop, 2004; Goumas, 2014; Winter et al., 2009). Moreover, the time of competition appears to be influential, with teams gaining an advantage if competition occurs closer to the time of peak physical performance (Leatherwood & Dragoo, 2012). However, home advantage is difficult to separate from reductions in team sport physical performance related to domestic air travel, as situational variables, such as match location, match status and opposition quality (Lago, Casais, Dominguez, & Sampaio, 2010), together with territoriality (Neave & Wolfson, 2003), tactics, and the expectancy to perform worse away from home (Nevill & Holder, 1999) also influence match outcome.

Similar to international air travel research, there is a prevalence of studies that have investigated the effects of alterations in circadian rhythms, rather than the demands of domestic air travel per se on team sport performance. Indeed, only two studies have investigated the effects of the demands of domestic air travel on technical and tactical performance indicators and team sport physical performance measures (McGuckin et al., 2014; Richmond et al., 2007). During away compared to home matches, professional rugby league players performed more tackles and covered less distance (McGuckin et al., 2014), whereas no differences in match statistics, including time between possessions and team assists, were evident in professional Australian Football League players (Richmond et al., 2007). Moreover, no change in grip strength or lower-body power was reported following short-haul air travel (McGuckin et al., 2014). Given this limited and equivocal data, the effects of the demands of domestic air travel on the recovery time line of team sport specific performance also remain to be understood.
Effects on recovery

Team sport competition involves numerous physically demanding activities and thus, induces acute fatigue and physical performance decrements (Coutts et al., 2010; Duthie, Pyne, & Hooper, 2003; Nédélec et al., 2013). A progressive return to pre-match state occurs during the recovery process, but can take more than 72 h (McLean, Coutts, Kelly, McGuigan, & Cormack, 2010; Nédélec et al., 2013). Given the limited time between matches and subsequent training and competition, various recovery procedures are commonly used to regain optimal physical performance faster (Nédélec et al., 2013). Due to domestic competition schedules, short-haul air travel is often a necessity the day after an away match, particularly in Australia, where large distances are travelled by away teams (Goumas, 2014). Time lost to travel and the ensuing disruption of routines and training schedules may inhibit the use of recovery interventions and therefore, the recovery process following away matches could be impeded. However, as yet, no data exists on the acute effects of post-competition travel on recovery specific to team sport athletes.

Furthermore, the magnitude of travel completed by professional teams throughout a season can be substantial. For example, in Australian domestic competitions, teams are required to travel up to ~3500 km across ≤ 2 time-zones following matches (Goumas, 2014; McGuckin et al., 2014; Richmond et al., 2007). Therefore, it has been proposed that frequent travel throughout a season may result in the summation of acute intangible effects of travel (Samuels, 2012). However, as yet there is no evidence to support this hypothesis. Moreover, since travel is often a requirement for teams the day after an away match, ensuing training loads and recovery may be disrupted, which in turn could reduce player preparedness and thus, increase the risk of injury (Gastin,
Meyer, & Robinson, 2012). Considering the proposed accumulation of travel fatigue (Samuels, 2012), it could be anticipated that reduced player preparedness and thus, a greater risk of injury may be present following away matches in the latter half of the season. However, to date no studies have investigated the longitudinal effects of frequent travel on training loads, recovery and injury in team sports.

**Statement of the Problem**

Both international and domestic air travel is an additional stress frequently imposed on elite team sport athletes training and competition schedules (Leatherwood & Dragoo, 2012; Schwellnus et al., 2012; Thompson et al., 2013). Whilst these demands may have a detrimental impact on physical performance (Chapman et al., 2012; Reilly et al., 2001), information regarding the effects of international and domestic air travel on team sport specific performance is limited (Leatherwood & Dragoo, 2012). Consequently, an insufficient understanding of the effects of international and domestic air travel on physical performance and underlying mechanisms currently exists, and thus, evidence-based, practical guidelines for team sport athletes and coaches to implement around travel are limited and generic. This problem arises from the majority of previous research utilising performance measures that are not ecologically valid for team sports. An improved understanding of the timeline of recovery for team sport specific performance following international and domestic air travel, would allow practitioners to make informed decisions regarding the scheduling of travel around competition for optimal performance. Furthermore, considering the proximity of travel to competition and magnitude of travel completed by professional teams across a season, investigations into the acute and longitudinal effects of air travel on recovery are warranted.
The limited understanding of the underlying mechanisms of international air travel effects on physical performance results from difficulty in isolating individual factors in field-based environments and therefore, limited research into the effects of the demands of international air travel. As a result, current travel strategies are largely based on an understanding of the theory of chronobiology, rather than the specific effects of air travel on team sport specific performance. For example, it is recommended that athletes allow a sufficient number of days following international air travel for recovery to facilitate peak performance (Reilly et al., 2007a). However, this is not practical advice for professional team sport athletes, as due to their demanding schedules, there is often little time between travel and ensuing training or competition (Carling et al., 2012). Furthermore, current interventions that are sound in theory and have efficacy in laboratory-based research are often ineffective in the real world with professional team sport athletes (Thompson et al., 2013). Consequently, coaches and athletes still generally rely on their own preference or general, intuitive recommendations for travel arrangements.

**Research Aims and Hypotheses**

The present thesis is comprised of four studies examining the effects of international and domestic air travel on physical performance, physiological and perceptual responses, together with the efficacy of practical interventions at improving physical performance recovery following travel. More specifically, this thesis aims to examine the effects of (simulated) long- and short-haul air travel on team sport specific performance, and establish the potential physiological and perceptual responses that affect performance outcomes in order to develop
interventions for field-based use. In turn it is hoped that these interventions may benefit team
sport athletes within the constraints of travel, competition and training demands.

**Study One - Performance recovery following simulated air travel**

**Aims**

1. Examine the effects of exposure to the demands of simulated air travel (mild hypoxia and
cramped conditions) for different durations (24 h international and 5 h domestic) on the
recovery of team sport specific physical performance.

2. Determine the physiological and/or perceptual responses to simulated international air travel
as related to performance outcomes.

**Hypotheses**

1. Exposure to the demands of simulated air travel for 24 h will have a greater impact on the
recovery of team sport specific physical performance compared to 5 h.

2. Greater disruption of physiological and perceptual responses would occur during and
following 24 h of simulated air travel compared to 5 h.

**Study Two - Acute effects of domestic air travel on performance and recovery**

**Aims**

1. Determine the acute effects of short-haul air travel (≤ 8 h air travel time with ≤ 2 h change in
time-zones) on match outcome and technical and tactical performance indicators during
competition in football.

2. Establish the acute effects of short-haul air travel on sleep, hydration and perceptual fatigue.
3. Investigate whether short-haul air travel following competition impedes physiological and perceptual recovery.

**Hypotheses**

1. Detrimental physiological and perceptual effects will be observed following short-haul air travel prior to competition. Therefore, during away compared to home matches, worse technical and tactical performance will be evident, resulting in inferior match outcomes.

2. Adverse effects of short-haul air travel on sleep, hydration and perceptual fatigue will impede player recovery following competition.

**Study Three - Longitudinal effects of domestic air travel on recovery**

**Aims**

1. Examine the separate and interactive effects of match location (home vs. away) and competition phase (early vs. late season) on training loads, player wellness and injury prior to and following competitive football matches.

**Hypotheses**

1. Due to frequent travel demands, in the late competition phase, reduced training loads and player wellness, and increased injury rates will be identified following away compared to home matches.
Study Four - Interventions for international air travel

Aims

1. Examine the effects of exposure to the demands of simulated international air travel on the recovery of team sport specific physical performance.

2. Determine the physiological and/or perceptual responses to simulated international air travel as related to performance outcomes.

3. Investigate the efficacy of scheduled exposure to a portable artificial bright light source alongside sleep hygiene recommendations during and following travel at enhancing performance recovery.

Hypotheses

1. The demands of simulated international air travel will suppress team sport physical performance. However, the combined intervention will attenuate this reduction.

Limitations

- In studies one and four, the participant cohort of healthy physically active males may restrict the results being generalised to other populations. For example, it may not be plausible to make comparisons with the male professional Australian football players in studies two and three given their greater physical performance capabilities. Consequently, caution should be applied when using the results from studies one and four to interpret the findings of studies two and three, and vice versa.
• Though it was planned to conduct a study investigating the effects of *actual* international air travel on performance, physiological and perceptual responses, this unfortunately did not occur in time due to logistical reasons. Though considerable effort was made to ensure air travel was simulated meticulously in studies one and four, the effects of actual international air travel are likely to be greater due to factors such as the hypobaric cabin pressure and disruption of circadian rhythms.

• Core body temperature, dim light melatonin onset (DLMO) and urinary 6-sulphatoxymelatonin are considered as appropriate markers of circadian rhythms (Arendt, 2009). Therefore, measurement of one of these markers in studies one and four would have indicated whether the simulated change in time-zones and light-dark cycle, along with the artificial bright light intervention were effective at adjusting circadian rhythms. However, due to logistical reasons and costs associated with the collection and analyses of these markers, this was not possible.

• Assessments of countermovement jump (CMJ) performance were conducted in studies one and four as an indicator of neuromuscular function. Furthermore, a two- and four-choice reaction time test was performed in study four as an indicator of simple reaction time. However, these measures may not accurately reflect the specific movement and decision making requirements of team sport training and competition.

• Participants were required to record dietary intake and physical activity, replicating the 24 h prior to each testing session during studies one and four. Although these were monitored throughout, total compliance is difficult to control.
• Data collection was conducted in field-based settings during studies two and three with professional Australian football players. This setting prevents total control of all external variables and restricts some measures.

• Given studies two and three each only involved players from one team, it should be noted that the findings may only be a reflection of these particular two teams and their associated travel demands.

**Delimitations**

• In addition to the prolonged exposure to mild hypoxia and inactivity that has formed previous simulations of air travel (Coste et al., 2009; Muhm et al., 2007), in study one and four, the simulation of international air travel included the flight schedule (stopover, meal composition and timings, and lighting changes), seating arrangement, cramped conditions and cabin noise, together with a simulated change in time-zones and light-dark cycle. Therefore, the present thesis includes the most comprehensive simulation of international air travel to date.

• Though it was not possible to measure the aforementioned markers of circadian rhythms, salivary cortisol was measured in study one, which is a good indicator of physiological stress and has previously been utilised as a supplementary marker of circadian rhythms (Beaumont et al., 2004; Coste et al., 2004; Pierard et al., 2001).

• While a CMJ protocol may not reflect the specific movement demands of team sport training and competition, it does provide a measurement of contractile function at a given time point that would likely interrelate.

• Participants were requested to abstain from caffeine, alcohol and additional strenuous activity for 24 h before, during and 24 h following all trials.
• Data collection throughout studies one and four were conducted in a controlled laboratory environment.

• Data collection times were standardised throughout to avoid diurnal variances.
Chapter Two
Literature Review
Overview

The review of the literature aims to present a clear explanation of the current understanding of the effects of both international and domestic air travel on physical performance, with particular reference to team sport athletes. In addition, the potential physiological and perceptual mechanisms explaining these performance responses, together with the efficacy of interventions at improving the recovery of physical performance following travel will be clarified. Lastly, the literature will be critically reviewed throughout to identify key findings and directions for future research. In order to accomplish these aims, differences between the aetiology of travel fatigue and jet-lag will be discussed first, as they are likely to affect physical performance through different pathways (as presented in Figure 2.1). Following which, the effects of international air travel on physical performance will be presented. Given that the demands of international air travel are likely to induce symptoms of both jet-lag and travel fatigue, their causes and relationship with physical performance specific to team sports will be discussed, with particular reference to sleep disruption. Furthermore, a ‘travel management program’ of pre-, during and post-travel interventions will be outlined, concentrating on pharmacological and behavioural methods of adapting circadian rhythms and considering which may be more appropriate for use with team sport athletes. Lastly, given the magnitude of domestic air travel completed by professional teams to and from away matches throughout a season, its effects on competition performance and physiological and perceptual recovery will be discussed, in addition to whether the use of interventions is worthwhile.
Figure 2.1. Conceptual overview of the different mechanisms through which travel fatigue and jet-lag may affect physical performance.
Travel fatigue

The symptoms of travel fatigue are a consequence of the demands of long distance air travel *per se*; specifically, the plane cabin environmental and atmospheric conditions, the stressors associated with the process of travel and the disruption of normal routines (Reilly et al., 2007a; Waterhouse et al., 2007; Waterhouse et al., 2004). Symptoms of travel fatigue include, but are not limited to, general fatigue, confusion, irritability and headaches (Waterhouse et al., 2007; Waterhouse et al., 2004). However, it is proposed that following a sufficient night’s sleep these symptoms often cease (Waterhouse et al., 2007; Waterhouse et al., 2004). More explicit causes of travel fatigue include prolonged sitting in cramped conditions, which may reduce flexibility and mobility, induce deep venous thrombosis (DVT) (Cesarone et al., 2003; Waterhouse et al., 2007; Waterhouse et al., 2004), and together with noise from the plane engines and other passengers, may disrupt sleep during long-haul international air travel (Forbes-Robertson et al., 2012; Waterhouse et al., 2002).

In addition, the dry cabin air and low hypobaric pressure may cause dehydration (Hamada et al., 2002; Reilly et al., 2007b), and the reduced quality of the cabin air could impair immune function following prolonged exposures (Coste, Van Beers, Bogdan, & Touitou, 2007a; Schwellnus et al., 2012). Furthermore, such prolonged exposure to mild hypoxia may reduce oxygen saturation (Geertsema, Williams, Dzendrowskyj, & Hanna, 2008), have a detrimental impact on sleep (Coste et al., 2009) and exacerbate physiological stress (Coste, Beers, Bogdan, Charbuy, & Touitou, 2005) and perceptual fatigue (Coste, Van Beers, & Touitou, 2007b; Muhm et al., 2007). A final consequence of travel involves the perceived stress associated with delays and embarking and disembarking formalities, such as checking in, baggage claim and security
and customs clearance, which often result in negative perceptual states (Reilly et al., 2007a; Waterhouse et al., 2007). Of greater consequence to team sport athletes is the disruption to habitual eating and sleeping patterns, both of which are integral to optimal preparation and recovery (Reilly et al., 2007b; Waterhouse et al., 2007; Waterhouse et al., 2004).

**Jet-lag**

The symptoms of jet-lag occur following long distance air travel eastward or westward across time zones and tend to be more severe and longer lasting than those of travel fatigue (Reilly et al., 2007a). One of the main reported symptoms is poor sleep, especially delayed sleep onset and early awakening after eastward and westward flights, respectively (Beaumont et al., 2004; Forbes-Robertson et al., 2012; Takahashi et al., 2002). Since sleep disruption as a consequence of jet-lag can subsequently induce other detrimental symptoms, jet-lag is classified as a disorder of the sleep-wake cycle by the World Health Organisation (Forbes-Robertson et al., 2012; World Health Organization, 2004). Consequently, other jet-lag symptoms may include; poor performance at physical and mental tasks; negative perceptual changes, such as increased fatigue and irritability; decreased concentration, and gastrointestinal disturbances, together with decreased interest in eating (Reilly et al., 2007a; Waterhouse et al., 2007; Waterhouse et al., 2004).

The circadian regulator of human function, often referred to as the ‘body clock’, is located within the suprachiasmatic nuclei situated at the base of the hypothalamus (Arendt, 2009; Forbes-Robertson et al., 2012; Waterhouse et al., 2004). Input to the regulatory centre is provided from the retina (photic signals) and other regions of the brain (non-photic signals) (Arendt, 2009;
Forbes-Robertson et al., 2012; Waterhouse et al., 2004). The body clock affects circadian rhythms in body temperature, hormone release, sleep and activity (Forbes-Robertson et al., 2012; Reilly et al., 2007a; Waterhouse et al., 2004). Typically the endogenous (rhythms in body temperature and hormone release) and exogenous (sleep and activity) components of the body clock are in synchrony. For example, waking is promoted in the morning by inhibition of melatonin secretion, which causes vasoconstriction of blood vessels and a subsequent increase in body temperature, along with the alerting effects of the environment and activity. Conversely, together with the dark environment and inactivity, sleep onset is induced in the evening through melatonin secretion, which causes vasodilation of blood vessels and an ensuing reduction in body temperature (Cajochen, Kräuchi, & Wirz-Justice, 2003; Wyatt, Cecco, Czeisler, & Dijk, 1999). Circadian rhythms are internally generated rhythms that persist in the absence of external cues (Forbes-Robertson et al., 2012). The sleep-wake cycle is the most identifiable circadian rhythm, with activity and sleep associated with the hours of daylight and darkness, respectively (Reilly, Atkinson, & Waterhouse, 1997). The circadian rhythm in body temperature, with a peak and nadir in the late afternoon and early morning, respectively, is considered to be a reliable indicator of the phase of the body clock (Reilly et al., 1997).

Circadian rhythms occur in many physiological functions, and regardless of causality, such rhythmical fluctuations may also be evident in physical performance (Figure 2.2) (Drust, Waterhouse, Atkinson, Edwards, & Reilly, 2005; Reilly & Waterhouse, 2009). Specifically, previous research has identified rhythms in physiological systems that demonstrate responsiveness to exercise, including metabolism and circulation, physical performance, such as strength and aerobic and anaerobic power, and sport-specific performance, for example, cycling.
and running time trials, and football and tennis skills (Drust et al., 2005; Reilly & Waterhouse, 2009). In addition to these rhythms, significant associations between circadian rhythms in 200 m swimming time trial performance and alignment with core body temperature and psychological variables have been reported (Figure 2.3). Such relationships could reflect parallel suprachiasmatic nuclei regulation of physical performance, body temperature and mood, and may provide evidence for an endogenous rhythm in physical performance itself or factors that affect it (Kline et al., 2007). However, the view that circadian rhythms in physical performance exist has also been criticised due to limits on the frequency of measurements that can be conducted throughout the day (Waterhouse et al., 2007). Specifically, due to the potential influence of fatigue on subsequent performance, it is far more difficult to measure sport-specific performance repeatedly compared to other physiological circadian rhythms (Waterhouse et al., 2007). Moreover, considering sports performance is multi-factorial (Figure 2.4), further research is required to confirm and quantify the impact of circadian rhythm regulation (Drust et al., 2005; Reilly & Waterhouse, 2009).
**Figure 2.2.** Conceptual overview of the biological circadian clock in humans (Smolensky & Lamberg, 2001).
Figure 2.3. Relationship between body temperature and 200 m swim performance circadian rhythms (Kline et al., 2007).
Figure 2.4. Outline of the factors affecting sports performance (Reilly & Waterhouse, 2009).
Symptoms of jet-lag result from the loss of synchrony between the endogenous and exogenous components of the body clock (Waterhouse et al., 2007). Though this typically occurs when time-zones are rapidly crossed during air travel (Waterhouse et al., 2004), symptoms of jet-lag have also been noted following simulated time-zone changes in the laboratory, highlighting that unlike travel fatigue, jet-lag is not caused solely by the demands of travel (Waterhouse et al., 2007). Following transmeridian air travel, the body’s circadian rhythms at first retain their habitual rhythms of the place of departure. However, external factors in the new environment, particularly the time of sunrise and onset of darkness, act as zeitgebers (time-givers) and promote resynchronisation of the body clock to align with the new time-zone (Forbes-Robertson et al., 2012).

It is proposed that symptoms are worse the greater the number of time-zones crossed and if travelling east rather than west (Waterhouse et al., 2004). Indeed, rates of resynchronisation are estimated as half a day per hour of the time difference westwards, or 1 day per hour of the time difference eastwards (Forbes-Robertson et al., 2012). The predicted faster rate of resynchronisation following westward travel is based on an understanding of chronobiology, which indicates it is easier for the body clock to adapt to a phase delay following westward travel, compared to a phase advance after eastward travel (Forbes-Robertson et al., 2012). However, it has also been discovered that individual organs and cells have their own circadian clocks, and that differences exist in their rates of resynchronisation following travel. Consequently, inter-individual variation may exist for jet-lag symptoms and their severity, together with the rate of resynchronisation of the body clock following transmeridian air travel (Forbes-Robertson et al., 2012).
Therefore, if an endogenous rhythm in physical performance does exist, following travel across multiple time-zones, it would be expected that; (1) performance would fluctuate over the course of the day, exhibiting both a nadir and a peak; (2) a deterioration of the typical performance rhythm of a morning nadir and a late afternoon peak would occur, followed by a slow rate of resynchronisation; (3) eastward travel would induce more of a detrimental effect on performance compared to westward travel, due to difficulties in resynchronisation following a phase advance compared to a phase delay; and (4) performance will be reduced outside of its circadian peak ‘window’ (Leatherwood & Dragoo, 2012).

**International air travel**

Although international air travel is relative to the departure location and destination, for the present thesis and from an Australian perspective, international travel refers to travel times of up to and greater than 24 h across multiple time-zones. As a result, both symptoms of travel fatigue and jet-lag are likely to be more severe and longer lasting following international compared to domestic air travel, which for the present thesis is referred to as air travel of ≤ 5 h across ≤ two time-zones. Given elite team sport competitions frequently occur all over the world, international air travel is an additional stress imposed on professional players’ competition and training schedules (Leatherwood & Dragoo, 2012; Schwellnus et al., 2012; Thompson et al., 2013). Additionally, professional teams often organise pre-season training camps overseas to utilise warm-weather or altitude in order to accelerate physiological training adaptations (Buchheit et al., 2013a; Buchheit et al., 2013b; Reilly et al., 2005). Moreover, in between domestic competition for their club, players’ schedules will often involve international travel to training camps and/or to compete for their national team. Consequently, in order for practical, evidence-
based guidelines to be provided to players to assist them with these demands, a comprehensive understanding of the effects of international air travel on team sport physical performance, along with the underlying mechanisms is required.

**Effects on physical performance**

Substantial logistical issues and cost are associated with conducting research into the effects of an episode of international air travel on performance, physiological and perceptual responses, particularly in elite athletes. Consequently, there are limited field-based studies on the effects of international air travel in relation to sports performance (Leatherwood & Dragoo, 2012). Regardless of these issues, reduced grip strength has been detected following 12 h of eastward air travel across eight time-zones (Lemmer et al., 2002), together with nine and 10 h of westward air travel across five and six time-zones in elite gymnasts (Lemmer et al., 2002; Reilly et al., 2001). Though, in contrast to the assumption that eastward travel has a greater impact on performance compared to westward travel, no differences in grip strength were reported between 12 h of eastward travel across eight time-zones and 10 h of westward travel across six time-zones (Lemmer et al., 2002). However, considering only four participants completed travel in both directions and the large inter-individual variation reported in travel induced physiological responses (Lemmer et al., 2002), it is unsurprising that no differences in grip strength were evident. Moreover, this is the only study to date that has compared the response of a physical performance to both eastward and westward travel, thus further research is required to substantiate these findings.
Due to its convenience, hand grip strength is a common measure of the circadian rhythm in muscle performance (Reilly et al., 2001), especially given it can be administered frequently over the course of a day without eliciting undue fatigue (Drust et al., 2005). Whilst a test exhibiting these characteristics is preferable when assessing circadian rhythms in physical performance (Drust et al., 2005), the ecological validity of hand grip strength to performance in team sport training and competition is questionable. Accordingly, jump performance, which is still relatively non-fatiguing and time efficient to assess, but more specific to actions performed in certain team sports, may be a more appropriate measure. In elite skeleton athletes, reduced velocity and power eccentric utilisation ratios, box drop jump flight time and contact time to flight time ratio, squat jump velocity and power, and countermovement jump height were observed in the first two days following 24 h of eastward transmeridian air travel across 15 time-zones (Chapman et al., 2012). These results suggest that both skeletal muscle contractile and neuromuscular function, and therefore, jump performance are adversely affected by long-haul transmeridian air travel (Chapman et al., 2012). Conversely, no change in 30 m sprint performance was identified in the same participant population in response to the same travel demands (Bullock et al., 2007). Similarly, minimal disruptions to squat jump height and power output during a 15 s multiple jump test were reported following 10 h of eastward air travel across seven time-zones (Lagarde et al., 2001). Hence, these contrasting results may be due to differences in travel demands, including the duration and distance of travel, and/or the sensitivity, type and timing of physical performance measures, making meaningful comparisons between studies difficult. Thus, further research with varying travel demands, but similar modes and timing of physical performance assessments, is warranted.
Despite this research, a thorough understanding of the effects of international air travel on team sport physical performance is yet to be obtained for numerous reasons (Leatherwood & Dragoo, 2012). First, research thoroughly examining the effects of a single episode of travel on subsequent physical performance is limited. For example, this was the primary focus of only two of the five aforementioned studies. Secondly, the current conclusions regarding the effects of international travel on sports performance are based on studies utilising measures that are questionably related to performance in training or competition for team sport athletes. This includes, grip strength or performance of one particular muscle group not specific to the dynamic movement demands of team sports, such as squat jump performance (Leatherwood & Dragoo, 2012). For example, though grip strength was the only performance outcome, Lemmer et al. (2002) speculated that the data indicated that if athletes are required to travel across six time-zones for competition, they should arrive at least two weeks in advance in order to overcome jet-lag prior to competition. Moreover, whilst these measures may assist with the logistics of testing athletes around competition and travel, they have limited ecological relevance to most team sports, which require prolonged bouts of intermittent-sprint activity (Coutts et al., 2010). Lastly, previous research has utilised athletes from specific sports, such as gymnastics and skeleton, as participants (Bullock et al., 2007; Lemmer et al., 2002; Reilly et al., 2001). Therefore, it may be inappropriate to generalise results from these studies to team sport athletes.

Methodological limitations have also limited the performance outcomes of previous research. In particular, logistical difficulties associated with organising air travel research with a population of elite athletes has resulted in small sample sizes (n = 4-8). Consequently, it is possible that performance measures have remained unchanged following travel due to type II error (Bullock,
Cox, Martin, & Marino, 2009). Further limitations, some of which may again be due to
understandable logistical difficulties, include no pre-travel baseline measures or a control group
that didn’t travel for comparison to post-travel data. Moreover, the type, sensitivity, timing and
frequency of performance measures vary between studies. In particular, performance is
sometimes only measured once per day (Bullock et al., 2007; Chapman et al., 2012) compared to
multiple times in other studies (Edwards et al., 2000; Lemmer et al., 2002; Reilly et al., 2001).
The importance of measuring performance at different times of the day following travel across
multiple time-zones has been highlighted (Figure 2.5) (Reilly et al., 2001). For example, whilst
on the first day following long-haul transmeridian air travel, grip and leg strength were highest in
the morning and lowest in the late afternoon (Reilly et al., 2001), on subsequent days,
performance circadian rhythms resembled the typical morning nadir and late afternoon peak
(Drust et al., 2005; Reilly et al., 2001; Reilly & Waterhouse, 2009). Hence, as highlighted in
Figure 2.5, the timing of measurement may affect results and conclusions, and therefore, could
explain the differences in performance outcomes between studies. Lastly, the measurement error
associated with some short-duration performance assessments may be greater than the
underlying circadian rhythms in performance, which could mask potential detrimental effects of
long-haul transmeridian air travel on strength or power (Bullock et al., 2007).
Figure 2.5. The diurnal variation in leg strength following 9 h of westward air travel across five time-zones (Reilly et al., 2001).
In spite of the limitations of previous research, distinguishing any aspect of travel as a cause for deterioration of physical performance is challenging and met with a variety of understandable methodological issues (Leatherwood & Dragoo, 2012). Thus, the equivocal effects of international air travel on physical performance reported to date may be a result of the varying degrees of success by which study designs have controlled for the multitude of confounding variables that affect performance (Figure 2.4) (Leatherwood & Dragoo, 2012). The conflicting and lack of effects of travel on performance may also be explained by the inter-individual variation in responses to travel, as a result of differences in age, time of arrival and previous travel experience (Waterhouse et al., 2002). For instance, no effect of travel on grip strength or lower-body power may have been observed by Lagarde et al. (2001), as they utilised a non-homogenous participant population, which included men and women with an age range of 20 - 48 y. Lastly, athletes have been reported to exhibit a more positive mood profile than non-athletes and are generally more extroverted. Therefore, it is possible that they may be able to cope or are familiar with the demands of travel more so than non-athletes, which may assist with explaining the different findings between studies involving different participant populations (Bullock et al., 2007).

As the process of travel involves many variables, the final reason identified for the limited understanding of the effects of international air travel on physical performance is the predominance of studies investigating the impact of jet-lag and alterations in circadian rhythms. Therefore, studies isolating the effects of the demands of air travel, including sleep disruption, dehydration and activity restriction, and the subsequent impact on physical performance are scarce (Leatherwood & Dragoo, 2012). Consequently, further research is required to analyse the
effects of these demands and not just the influence of jet-lag or alterations in circadian rhythms. To date, the limited long-haul international air travel research literature presents a mixture of findings, without a readily discernible or coherent conclusion. Collectively, the limitations of previous research indicate that in order to establish an improved understanding of the effects of international air travel on team sport physical performance, future research needs to include; (1) a main aim/outcome of the effects of air travel on team sport performance; (2) measures that are sensitive, but also ecologically valid; and (3) greater control for confounding variables, pre-travel baseline measures, a control group that doesn’t travel, performance measures in the morning and afternoon, and a homogenous participant population.

**Physiological and perceptual effects**

Due to the demands of long distance air travel and the loss of synchrony between the endogenous and exogenous components of the body clock, adverse physiological and perceptual symptoms of both travel fatigue and jet-lag are likely to occur following long-haul transmeridian air travel (Reilly et al., 2007a; Waterhouse et al., 2007; Waterhouse et al., 2004). An understanding of these detrimental physiological and perceptual symptoms, including their aetiology and association with reductions in physical performance, could guide the development of interventions to assist athletes with overcoming travel demands. However, as will be discussed in the following sections, from the current research literature, it is difficult to determine the exact causes of jet-lag and travel fatigue symptoms, along with the mechanisms through which they may impact physical performance.
Jet-lag

Circadian rhythms

Following international transmeridian air travel, endogenous physiological circadian rhythms at first retain their habitual rhythms of the place of departure, whereas external cues, particularly the light-dark cycle, are aligned with the destination time (Arendt, 2009; Forbes-Robertson et al., 2012; Reilly et al., 2007a). Whilst these external cues promote the gradual resynchronisation of endogenous circadian rhythms, until they are fully aligned with the destination time, jet-lag symptoms persist (Arendt, 2009; Forbes-Robertson et al., 2012; Reilly et al., 2007a). Thus, in theory, the greater the number of time-zones crossed, the larger the misalignment between endogenous circadian rhythms and external cues, and hence, the longer it takes for them to align (Arendt, 2009; Forbes-Robertson et al., 2012; Reilly et al., 2007a). Despite the theoretical rate of realignment following travel of half a day per hour of the time difference westwards, or one day per hour of the time difference eastwards (Forbes-Robertson et al., 2012), the reality of post-travel outcomes, as will be discussed later, often means this is not always as evident as expected (Arendt, 2009; Waterhouse et al., 2000; Waterhouse et al., 2002).

It is well documented that endogenous circadian rhythms exist for the cardiovascular, respiratory, endocrine and nervous systems, together with body temperature and metabolism, all of which demonstrate responsiveness to exercise stimuli (Drust et al., 2005; Reilly & Waterhouse, 2009). To date, predominantly endocrine (Bullock et al., 2007; Lemmer et al., 2002; Pierard et al., 2001) and body temperature (Edwards et al., 2000; Lemmer et al., 2002; Reilly et al., 2001) responses to single episodes of international air travel have been investigated. This is likely due to the ease of measurement and association with rhythms in the sleep-wake cycle
and/or physical performance (Drust et al., 2005; Wyatt et al., 1999), along with the fact they exhibit a strong diurnal rhythm, which makes them appropriate indicators of the phase of the body clock (Bullock et al., 2009). Indeed, until all endogenous circadian rhythms adjust to the new time-zone, physical performance may be suppressed (Figure 2.6) (Reilly & Edwards, 2007). Therefore, as discussed below, the aforementioned physiological responses to long-haul transmeridian air travel can highlight the rate of circadian rhythm adaptation, which is likely to be associated with the rate of physical performance recovery (Reilly & Edwards, 2007).

Disruptions in the rhythmic patterns of body temperature, along with melatonin and cortisol concentrations have been observed in the days following international transmeridian air travel (Lemmer et al., 2002; Pierard et al., 2001). Specifically, a phase-advance in the body temperature nadir was evident after 10 h of westward air travel across six time-zones, and a phase-delay was reported following 12 h of eastward air travel across eight time-zones in elite gymnasts (Lemmer et al., 2002). Moreover, these disturbances were present on both day one and 11 after travel, though these were the only days on which measurements were collected (Lemmer et al., 2002). Compared to pre-travel, increased salivary melatonin concentrations were reported in the morning (07:00) for 10 days following 11 h of eastward transmeridian air travel across seven time-zones, with the largest increase observed on day five (Pierard et al., 2001). In addition, reduced salivary cortisol concentrations were reported at a standardised time for nine days following travel, with the largest reduction observed on day three (Pierard et al., 2001). Considering the role of melatonin and body temperature in waking and sleep onset (Cajochen et al., 2003; Waterhouse et al., 2007; Wyatt et al., 1999), and cortisol in energy metabolism (Kindermann et al., 1982), together with the association between circadian rhythms in body
temperature and physical performance (Kline et al., 2007), these disruptions may also impact the sleep-wake cycle and in turn, physical performance following travel.

**Figure 2.6.** A schematic illustration of the rate of adjustment of key circadian rhythms following international air travel (Reilly & Edwards, 2007).
However, there are significant between-study variations in the magnitude and duration of these circadian rhythm disruptions, with some studies reporting disruptions on only the first day following travel (Bullock et al., 2009; Reilly et al., 2001), whilst others have observed disturbances for up to 11 days post-travel (Beaumont et al., 2004; Lemmer et al., 2002). Though this could be due to differences in travel demands, it is also likely a result of methodological differences. For instance, between-study variation exists in measurement frequency, including the number of days data was collected for following travel, which ranges from three (Lemmer et al., 2002) to 13 (Beaumont et al., 2004; Pierard et al., 2001) and the number of measures each day, which varies from one (Pierard et al., 2001) to 10 (Lemmer et al., 2002). Studies with greater measurement frequency are obviously more likely to detect sensitive changes in circadian rhythms following travel, though this needs to be balanced with logistical constraints (Reilly et al., 2001). Indeed, studies that have reported interactions between the post-travel day and time of day highlight the importance of multiple measures throughout the day when assessing changes in circadian rhythms following travel (Bullock et al., 2009; Reilly et al., 2001).

Furthermore, the majority of the aforementioned studies have utilised elite athletes as participants (Bullock et al., 2009; Lemmer et al., 2002; Reilly et al., 2001). Whilst this is an advantage in terms of being able to translate the findings to such a specific, and often neglected, population (Leatherwood & Dragoo, 2012), it is also a limitation as it results in low participant numbers, increases the chance of missing data due to training and competition demands and thus, increases the variability of the results. For example, in the study by Lemmer et al. (2002), due to the limited number of samples available, statistical analysis was not performed on all data. Therefore, similar to the literature available on the effects of international air travel on physical
performance, the timing of various measurements may impact results and conclusions, and therefore, could explain the differences in physiological responses between studies.

Lastly, comparing results between studies to establish conclusions on the effects of long-haul transmeridian air travel on endogenous physiological circadian rhythms, is further complicated by the inter-individual variation in responses to travel, as a result of differences in age, flexibility of sleeping habits, time of arrival and previous travel experience (Waterhouse et al., 2002; Waterhouse et al., 2007). For example, significant inter-individual variation in the disruption of body temperature circadian rhythms to 24 h of westward air travel across 10 time-zones was observed, with 50 - 69 % phase-delays, 20 - 38 % phase-advances and 11 - 19 % unchanged (Edwards et al., 2000). Collectively, these results suggest that disruptions in melatonin, cortisol and body temperature circadian rhythms are likely to occur following international transmeridian air travel, which may impact the sleep-wake cycle and/or physical performance. However, making meaningful comparisons between previous research studies is again difficult due to methodological variation. Therefore, further research involving a similar frequency and timing of measurements, and participant populations is required to determine the effects of varying travel demands on the magnitude and duration of circadian rhythm disruptions.

Sleep-wake cycle

As previously described, sleep is easiest to initiate when body temperature is reduced or at its lowest and most difficult when body temperature is increased or at its highest (Waterhouse et al., 2007; Wyatt et al., 1999). Waking is the opposite of sleep onset as it occurs when body temperature is rising or is increased (Waterhouse et al., 2007; Wyatt et al., 1999). Therefore,
when circadian rhythms are disrupted following long-haul transmeridian air travel, sleep is difficult to initiate and maintain (Waterhouse et al., 2007). Hence, one of the main reported symptoms of jet-lag is sleep disruption, which can subsequently induce other detrimental physiological and perceptual symptoms (Forbes-Robertson et al., 2012) as highlighted in Figure 2.1. Therefore, an understanding of the specific impact of international transmeridian air travel on the sleep-wake cycle is important. Though this has been studied extensively in aircrews (Lamond, Petrilli, Dawson, & Roach, 2006; Petrilli, Roach, Dawson, & Lamond, 2006; Roach, Darwent, & Dawson, 2010), to date, minimal studies involving passengers, or more specifically, team sport athletes have been conducted (Beaumont et al., 2004; Takahashi et al., 2002).

Significant disruptions of sleep architecture were reported following 11 h of eastward transmeridian air travel across seven time-zones via the use of electroencephalography (EEG) measurements (Beaumont et al., 2004). Specifically, during the first night following travel, a greater duration of slow-wave sleep occurred at the expense of rapid eye movement sleep (Beaumont et al., 2004). Indeed, rapid eye movement sleep tends to be predominant at the end of the night, but, due to a phase advance of sleep rhythms, participants woke earlier prior to obtaining the optimal duration of rapid eye movement sleep (Beaumont et al., 2004). Moreover, overall sleep architecture was normalised from day five following travel (Beaumont et al., 2004). The only other study that has investigated the effects of transmeridian air travel on sleep in passengers, reported reduced sleep quantity and quality, and earlier sleep onset and waking through wrist actigraphy in the three days following 10 - 14 h eastward air travel across 8 - 11 time-zones (Figure 2.7) (Takahashi et al., 2002). Furthermore, though sleep onset and waking were delayed for five days following 11 - 12 h westward air travel across 7 - 8 time-zones, no
effect on sleep quantity or quality was evident (Takahashi et al., 2002). Though these results suggest that eastward air travel may have more of a detrimental impact on the sleep-wake cycle, they should be interpreted carefully, as data for each flight direction were not balanced, with differences in the number of participants and travel demands (duration and number of time-zones crossed) (Takahashi et al., 2002). Together these data indicate sleep disruption is likely following international transmeridian air travel. However, given the limited number of studies conducted with passengers, further research is necessary to determine the effects of various travel demands on the magnitude of these disruptions, together with the ensuing effects on passengers’ recovery following travel.
Figure 2.7. Sleep duration, mean activity during sleep, time awake after sleep onset and total nap time before, during, and after 10 - 14 h eastward and 11 - 12 h westward air travel (Takahashi et al., 2002).
Symptoms
The disruption of circadian rhythms and/or the sleep-wake cycle following international transmeridian air travel subsequently induces the detrimental symptoms of jet-lag (Reilly et al., 2007a; Waterhouse et al., 2007; Waterhouse et al., 2004). These symptoms include, negative perceptual changes, such as increased fatigue and irritability, and decreased motivation and concentration, together with gastrointestinal disturbances, all of which are likely to impact performance in physical and/or cognitive tasks (Reilly et al., 2007a; Waterhouse et al., 2007; Waterhouse et al., 2004). Previously, the assessment of jet-lag symptoms involved a visual analogue scale to determine the perceived level of jet-lag experienced, with the decision as to what exactly constituted jet-lag left to the individual (Arendt, Aldhous, & Marks, 1986). However, the Liverpool John Moores University (LJMU) jet-lag questionnaire was developed to include other symptoms associated with jet-lag, including sleep, fatigue, concentration, motivation, irritability and gastrointestinal disturbances, as these symptoms do not adjust at the same rate as each other or jet-lag following international transmeridian air travel (Waterhouse et al., 2000). For example, the symptoms with a strong endogenous component, such as sleep and fatigue, have a stronger link with jet-lag and thus a different rate of adaptation compared to those with a weaker endogenous component, such as food intake (Waterhouse et al., 2007). Subsequently, the LJMU jet-lag questionnaire has been commonly used in the literature to assess subjective jet-lag ratings following international air travel (Bullock et al., 2007; Waterhouse et al., 2002).
Compared to pre-travel, subjective jet-lag ratings were significantly increased for seven days following 24 h of eastward air travel across 14 time-zones in elite skeleton athletes (Bullock et al., 2007). Similarly, increased jet-lag symptoms were reported in non-athletes for six days following travel of the same duration and direction across 10 time-zones (Waterhouse et al., 2002). Though no differences in motivation and concentration were evident following air travel in elite athletes (Bullock et al., 2007), Waterhouse et al. (2002) observed a significant reduction in the same measures during the initial four days following travel in non-athletes. Whilst this emphasises the importance of assessing other symptoms associated with jet-lag, it also indicates the potential difference in responses of athletes and non-athletes to air travel. Specifically, the lack of change in motivation was attributed to the competitive environment in which elite athletes often function in (Bullock et al., 2007). Conversely, subjective jet-lag symptoms were only reported on the first three days following 9 h of westward transmeridian air travel across five time-zones in elite gymnasts (Reilly et al., 2001). Though collectively these data imply subjective jet-lag may be prolonged following eastward compared to westward air travel, it could also be a result of differences in travel duration (24 h vs. 9 h) and hence, number of time-zones crossed (14 and 10 vs. five).

Furthermore, symptoms of jet-lag are purported to demonstrate circadian rhythms and thus, exhibit within-day and inter-individual variation following travel (Waterhouse et al., 2000; Waterhouse et al., 2002). Specifically, jet-lag symptoms may vary between individuals due to differences in age, flexibility of sleeping habits, time of arrival and previous travel experience (Waterhouse et al., 2002). Throughout the day, subjective jet-lag symptoms are strongly associated with the level of perceptual fatigue assessed at the same time (Waterhouse et al.,
In contrast, food intake has been shown to have a weak association with subjective jet-lag and doesn’t vary with the time of day (Waterhouse et al., 2000). Moreover, soon after waking, jet-lag has a strong positive association with difficulty in getting to sleep and premature waking for the particular sleep period just ended (Waterhouse et al., 2000). Conversely, in the middle of the day, estimates of jet-lag have no association with sleep, whilst jet-lag assessed immediately prior to bed is positively correlated with sleep latency and earlier waking for the sleep period about to occur (Waterhouse et al., 2002). Hence, not only does this again signify the importance of measuring multiple jet-lag symptoms several times per day, but also taking this into consideration when comparing studies with different jet-lag assessment times and participant populations.

In contrast, few studies have investigated the effects of international transmeridian air travel on mood states, particularly in elite athletes or in relation to physical performance. Surprisingly, mood states improved following 12 h of eastward and westward air travel across four time-zones in competitive swimmers (O’Connor et al., 1991). However, this unexpected result may be explained by the high training loads completed by the swimmers leading into travel and thus, their pre-flight mood state was significantly disturbed compared to baseline (O’Connor et al., 1991). Considering the proposed differences in the psychological states of athletes and non-athletes (O’Connor et al., 1991), together with the detrimental impact of negative mood states on team sport physical performance (Skein et al., 2011), further research is warranted into the effects of international air travel on mood states, utilising measures such as the Brunel Mood Scale (Galambos, Terry, Moyle, Locke, & Lane, 2005) or the Recovery-Stress Questionnaire for Athletes (Kellmann, Altenburg, Lormes, & Steinacker, 2001).
Collectively, results from the research literature suggest that the disruption of circadian rhythms and/or sleep-wake cycle, as a result of long-haul transmeridian air travel, induce the ensuing detrimental symptoms of jet-lag, which in turn, may cause the reductions in physical performance discussed earlier (Reilly et al., 2007a; Waterhouse et al., 2007; Waterhouse et al., 2004). Furthermore, it is proposed that the magnitude and duration of jet-lag symptoms are affected by the direction and distance of travel (Arendt, 2009; Forbes-Robertson et al., 2012; Reilly et al., 2007a). However, this is difficult to ascertain from the present literature, as to the authors knowledge, there is no research with an appropriate study design and given the differences in the frequency and timing of measures, along with participant populations, it is tenuous to make comparisons between studies. For example, in the study by Lemmer et al (2002), circadian rhythm disruptions were compared following eastward and westward flights that differed in duration and the number of time-zones crossed. In addition, since the number of participants involved in eastward travel was too small, no statistical comparisons were made between data from the eastward and westward flights (Lemmer et al., 2002).

Moreover, while it is possible for studies to control for the environmental factors that influence circadian rhythms such as light, activity and diet, it is difficult to control for those that display independent circadian rhythms, such as the sleep-wake cycle (Reilly & Waterhouse, 2009). Consequently, it is often unclear whether jet-lag symptoms and a subsequent decline in physical performance following long-haul transmeridian air travel are due to circadian rhythm disruptions, or sleep deprivation as a result of interruptions to the sleep-wake cycle (Leatherwood & Dragoo, 2012). However, it is likely that it is a combination of the two, with reduced alertness, increased fatigue and negative mood states during the day following long-haul
transmeridian air travel partly attributed to the presence of night time physiology (i.e. the nadir of body temperature and peak of melatonin secretion) and partly to sleep deprivation (Arendt, 2009; Waterhouse et al., 2007).

Lastly, the majority of studies have investigated singular physiological or perceptual responses to travel, with little or no relation to performance measures, especially team sport physical performance. As a result, to the author’s knowledge, there are no studies that have associated the disruption of circadian rhythms and/or the sleep-wake cycle with the detrimental symptoms of jet-lag and in turn, reductions in physical, let alone team sport performance. For example, Lemmer et al (2002) stated in the discussion of the results that blood pressure and oxygen supply to organs are of utmost importance for optimal performance in competition and that the elite athlete participants in the study were unable to reach optimal performance due to the effects of travel on blood pressure and heart rate. However, neither sport specific performance or blood pressure and heart rate during exercise were assessed, only grip strength. Furthermore, though effects of 11 h of eastward air travel across seven time-zones on the disruption of circadian rhythms, the sleep-wake cycle and physical performance were investigated at the same time in the same group of participants, data were reported separately (Beaumont et al., 2004; Lagarde et al., 2001; Pierard et al., 2001). Therefore, further research is required into the effects of international transmeridian air travel on integrated performance, physiological and perceptual responses, in order to improve the current understanding of the aetiology of the symptoms of jet-lag and the association with reductions in physical performance.
Travel fatigue

As previously outlined, the symptoms of jet-lag are caused by the misalignment of endogenous circadian rhythms to external cues, resulting in disruptions to the sleep-wake cycle following international transmeridian air travel (Figure 2.1). Further the magnitude and duration of these symptoms is theoretically affected by the direction (east vs. west) and distance (number of time-zones crossed) of travel (Arendt, 2009; Forbes-Robertson et al., 2012; Reilly et al., 2007a). Conversely, symptoms of travel fatigue are a result of the demands of air travel, including the environmental and atmospheric conditions of the cabin, together with the stressors and disruptions to routine associated with travel (Figure 2.1) (Waterhouse et al., 2004). However, to date, the majority of studies have focused on the detrimental effects of jet-lag and thus, research isolating the effects of travel fatigue is limited (Leatherwood & Dragoo, 2012).

Whilst this may be due to a lack of research investigating the effects of long-haul international air travel north or south with minimal change in time-zones, it is also a result of the difficulty in separating the effects of travel fatigue from jet-lag in a field based environment. Indeed, the similarities in the outcomes of jet-lag and travel fatigue are highlighted in Figure 2.1. Consequently, several studies have attempted to address this by simulating long-haul air travel in the laboratory (Coste et al., 2004; Coste et al., 2009; Muhm et al., 2007). Specifically, these studies have been conducted in a hypobaric chamber and involved prolonged seated exposure (≤ 20 h) to the maximum altitude the cabin is pressurised to during actual long-haul commercial flights (2440 m). However, to isolate the effects of prolonged hypoxic exposure, other demands of air travel, such as the cramped conditions, cabin noise and flight schedule (stopovers, meal times, lighting changes) were not simulated.
During 20 h of hypobaric, hypoxic exposure at 2440 m, oxygen saturation decreased by 4.4 (3.9 - 4.9) % (Muhm et al., 2007), which is similar to the reduction (3.9 (2.6 - 5.2) %) observed in response to pressurised cabins of 1689 (1200 - 2300) m during actual international air travel (Geertsema et al., 2008). Reductions in oxygen saturation may augment physiological stress, requiring compensatory increases in cardiac output and ventilation rate, and therefore, energy expenditure and body temperature (Savourey, Launay, Besnard, Guinet, & Travers, 2003). Indeed, greater physiological stress was evident during and following 8 h of hypobaric hypoxic exposure at 2440 m, as indicated by the elevated plasma cortisol concentrations and sympathetic activity (Coste et al., 2005). Moreover, increased body temperature was observed during and following the same duration and magnitude of hypoxic exposure (Coste et al., 2009), together with a reduction in the plasma melatonin peak concentration during the first ensuing night (Coste et al., 2004). Considering that reduced melatonin concentration in conjunction with increased body temperature initiates waking (Waterhouse et al., 2004), prolonged hypoxic exposure may affect sleep quantity and/or quality. Indeed, Coste et al. (2009) observed a significant positive correlation between body temperature and sleep onset latency. However, reductions in sleep quantity and quality were only observed following hypobaric hypoxia equivalent to 3660 m (Coste et al., 2009), which suggests exposure to lower levels of hypoxia during actual air travel may not have as great an impact on sleep. Despite the theoretical link of hypoxia, sleep and performance outcomes, these relationships remain speculative and are yet to be substantiated.

Together, the aforementioned findings indicate that prolonged exposure to mild hypoxia during air travel may have an acute detrimental physiological effect. However, there is also evidence to suggest it may have an additional impact on circadian rhythms (Coste et al., 2009). Specifically,
a phase-delay in the body temperature nadir was observed following 8 h of hypobaric hypoxic exposure at 2440 m, which subsequently reduced sleep quality during the second night after exposure (Coste et al., 2009). In addition to its physiological effects, hypoxic exposure may also induce negative perceptual responses (Coste et al., 2007b; Muhm et al., 2007). Specifically, increased symptoms of acute mountain sickness, including greater fatigue and muscular discomfort, along with reduced alertness were observed during both 8 h and 20 h of hypobaric hypoxic exposure at 2440 m (Coste et al., 2007b; Muhm et al., 2007). However, greater symptoms were evident at higher altitudes (3660 m) and therefore, considering commercial flight cabins are pressurised to a maximum altitude of 2440 m (Geertsema et al., 2008), reduced perceptual symptoms may be observed during actual air travel. Regardless, these data suggest that prolonged exposure to mild hypoxia during air travel may contribute to post-flight fatigue and symptoms of jet-lag in the absence of time-zones being crossed. Although such conclusions may have implications for team sport physical performance, as yet, this relationship remains to be substantiated and was not reported in any of these studies.

In addition to the mild hypoxia, other atmospheric conditions that may induce negative physiological responses include the dry and reduced quality cabin air (Reilly et al., 2007b; Waterhouse et al., 2007; Waterhouse et al., 2004). In particular, the drying of the respiratory epithelium, re-circulated air and close contact with other travellers may increase the risk of upper-respiratory tract infections as a result of international air travel (Schwellnus et al., 2012). No effects of 8 h of hypobaric hypoxic exposure at 2440 m were observed on markers of cellular (CD4 and CD8 lymphocyte count) or humoral (plasma immunoglobulin A, G and M levels) immunity (Coste et al., 2007a), which suggests that factors other than the mild cabin hypoxia are
likely to influence immune function. In contrast, outbound international air travel across greater than five time-zones was associated with a significant 2 - 3 fold increase in the incidence of illness in professional rugby union players (Schwellnus et al., 2012). However the incidence of illness following return travel was similar to baseline, which indicates that the risk of illness may not be directly related to travel, but factors associated with the destination (Schwellnus et al., 2012). Though not measured, the authors speculated this could include environmental conditions, such as temperature, humidity, climate, altitude and pollution, food and/or exposure to different cultures, populations and pathogens, especially if there is a large contrast from the place of departure (Schwellnus et al., 2012). However, before firm conclusions can be made, further research is required to investigate the effects of a single episode of international air travel on markers of immune function during and following travel, including T cell counts and immunoglobulin levels to indicate both the cellular and humoral immune responses and thus, risk of infection (Gleeson, 2007). Furthermore, though also yet to be determined, athletes may be at an increased risk of infection during international air travel compared to non-athletes, particularly if they have completed an intensive training block prior to travel, which can compromise immune function (Gleeson, 2007).

There is some evidence to suggest that a further detrimental consequence of the low cabin humidity may be an increased loss of moisture via respiration, leading to gradual and unperceived hypohydration (Hamada et al., 2002; Reilly et al., 2007a). For example, participants exposed to an 8 h simulated flight at an altitude of 2440 m and a relative humidity of 8 - 10 % exhibited increased plasma and urine osmolality, and urine specific gravity (Simons & Krol, 1996). Conversely, no effect of 24 h of eastward transmeridian air travel across 15 time-zones
was observed on urine specific gravity in elite skeleton athletes (Bullock et al., 2007). Of further consequence, and although less likely in elite athletes who have fewer risk factors (Cesarone et al., 2003), hypohydration during travel may also increase the risk of DVT due to haemoconcentration and hyperviscosity (Silverman & Gendreau, 2009). Given the contrasting findings, further research is required to confirm the effects of international air travel on hydration status; especially the duration for which hypohydration may be present post-travel. However, in reality this is likely to be relatively transient following adequate fluid consumption and dependent on the duration of exposure to the low cabin humidity. Consequently, compared to the detrimental effects of other travel demands, the longevity of hypohydration is probably of less concern.

Furthermore, ‘economy class syndrome’ i.e. prolonged sitting in cramped conditions during long-haul air travel is also a risk factor for DVT (Cesarone et al., 2003; Hamada et al., 2002; Silverman & Gendreau, 2009), with a greater occurrence reported to occur in non-aisle seating where passengers tend to move less (Silverman & Gendreau, 2009). Reduced blood flow to, greater swelling of, and increased discomfort in the lower extremities may occur as a result of prolonged immobility and/or dehydration during long-haul air travel (Cesarone et al., 2003; Hamada et al., 2002; Silverman & Gendreau, 2009). However, further research utilising ultrasound or plethysmography is warranted to determine the true extent and time line of recovery of these variables post-travel, especially as they may impact subsequent physical performance. Moreover, not only is it likely that team sport athletes will lose training days as a consequence of long-haul international air travel, but the enforced prolonged inactivity may also reduce mobility and/or flexibility, which although speculative, may reduce athlete preparedness.
for competition. However, to date, no studies have investigated the impact of international air travel on training loads and team sport athlete wellness leading into competition compared to at home.

During travel, the quality, quantity and timing of food intake is often controlled by the airline, together with opportunities to adequately hydrate, consequently, athletes may fail to meet their specific nutritional requirements during travel (Reilly et al., 2007b). In particular, palatability of the second meal during long-haul flights may be reduced (Waterhouse, Kao, Edwards, Atkinson, & Reilly, 2006), which could be due to eating during the night (body clock time) or feeling tired after waking from sleep (Reilly et al., 2007b). Furthermore, the food offered by airlines tends to be low in volume and fibre, and may not meet athlete’s nutritional needs in terms of energy, carbohydrate or protein content (Reilly et al., 2007b). However, to date, there are no studies that have investigated the effects of a single episode of international air travel on energy and macronutrient intake in athletes or non-athletes. Lastly, the stressors associated with travel, including stopovers, delays and embarking and disembarking formalities, such as checking in, baggage claim and security and customs clearance, are proposed to have a detrimental impact on mood states (Reilly et al., 2007a; Waterhouse et al., 2007). However, not only is it difficult to isolate the effects of these specific travel demands, as yet, there are negligible studies that have assessed the effects of the demands of international air travel on mood states (O'Connor et al., 1991). Regardless, all travel involves some or all these factors, which may add to the cumulative detrimental effects of the demands of travel outlined in Figure 2.1.
Collectively these findings indicate that in addition to the detrimental symptoms of jet-lag, the demands of air travel *per se* are also likely to induce significant physiological and perceptual disruptions, which may in turn have a detrimental impact on physical performance (Figure 2.1). However, similar to those studies investigating the effects of jet-lag, the majority of the aforementioned research has investigated singular physiological or perceptual responses to the demands of air travel, with little or no relation to performance measures relevant to team sport athletes. Therefore, further research into the effects of international air travel, either north or south with minimal change in time-zones or under simulated, controlled conditions on team sport physical performance measures in conjunction with physiological and perceptual responses is warranted to improve the current understanding of the effects of travel fatigue.

*Sleep disruption*

As discussed earlier, due to the disruption of circadian rhythms and the sleep-wake cycle, reduced sleep quantity and quality is likely following long-haul transmeridian air travel (Beaumont et al., 2004). Specifically, often sleep disruption occurs due to delayed sleep onset and waking following westward and eastward travel, respectively (Takahashi et al., 2002). Moreover, this sleep disruption may be associated with certain jet-lag symptoms, including elevated daytime sleepiness and fatigue, and reduced concentration (Beaumont et al., 2004; Waterhouse et al., 2000). For example, in conjunction with reduced sleep quantity and quality, a suppression of daytime activity was detected through wrist actigraphy (Beaumont et al., 2004; Takahashi et al., 2002), along with greater perceived sleepiness (Beaumont et al., 2004) following international transmeridian air travel. Furthermore, evidence suggests that following 24 h of eastward air travel across 10 time-zones, the level of jet-lag in the morning is inversely
associated with waking time and therefore, alertness 30 min post-waking (Waterhouse et al., 2000). Greater fatigue and reduced concentration during the daytime was also associated with increased jet-lag, with the level of fatigue the strongest predictor of jet-lag (Waterhouse et al., 2000). Consequently, the magnitude of sleep disruption following international air travel may impact the level of jet-lag.

Depending on departure and destination locations, travel times of up to and greater than 24 h can be enforced by long-haul international air travel, and consequently, both phases of the sleep-wake cycle are likely to be encompassed, regardless of the time of departure. Therefore, in addition to disturbed sleep following international transmeridian air travel, as a result of the loss of synchrony between the endogenous and exogenous components of the body clock (Reilly et al., 2007a; Waterhouse et al., 2007; Waterhouse et al., 2004), sleep disruption may also occur during travel due to the demands of air travel (Forbes-Robertson et al., 2012). For instance, commercial international flight schedules, especially the timing of stopovers, meals and cabin lighting changes may disrupt sleep as they could enforce waking during the sleep phase of the sleep-wake cycle. In addition, the time of departure and arrival may impact the amount of sleep deprivation and ensuing severity of jet-lag symptoms (Waterhouse et al., 2002). Specifically, a travel schedule that results in a shorter interval between the last full sleep period before the flight and the first one at the destination may result in fewer jet-lag symptoms than a schedule with a longer interval (Waterhouse et al., 2002).
Evidence from the aforementioned series of simulated air travel studies suggests that prolonged exposure to mild hypoxia may also reduce sleep quantity and quality (Coste et al., 2009). The cabin noise from the engines and fellow travellers during air travel is also likely to affect sleep, considering that noise levels of 80 dB are typical on a commercial flight (Ozcan and Nemlioglu 2006) and sleep is likely to be disrupted if surrounding environmental noise is above 65 dB (Ozcan and Nemlioglu 2006). Lastly, the cramped conditions in economy class force passengers to attempt to sleep in a seated instead of a typical prone or supine position, with negligible leg room and head support. Therefore, along with the travel schedule, the conditions encountered during travel, including the mild hypoxia and noise levels, together with the seating and cramped conditions, and their impact on sleeping position, may have a significant impact on sleep.

However, to date, few studies have quantified sleep quantity and quality in passengers, especially athletes, during long-haul international air travel (Takahashi et al., 2002; Waterhouse et al., 2002).

Reduced sleep quantity was detected via actigraphy during 10 - 14 h eastward (1.5 ± 2.1 h) and 11 - 12 h westward (1.4 ± 2.4 h) international air travel (Figure 2.7) (Takahashi et al., 2002), and through self-report diaries during 24 h eastward (4.0 (2.0 - 5.0) h) international air travel (Waterhouse et al., 2002). Hence, it appears that sleep disruption may occur during long-haul international air travel, though given the limited data available, further research is required to confirm this. The difference between the homeostatic and circadian regulation of sleep and the impact that they may have on sleep following long-haul international air travel should also be considered. As previously mentioned, the circadian rhythm of sleep is regulated by the internal body clock. Conversely, the homeostatic process reflects the pressure for sleep that builds up
during sustained wakefulness (Sargent, Darwent, Ferguson, Kennaway, & Roach, 2012). Results from previous research indicate that following a period of sleep deprivation, the homeostatic pressure for sleep is high, which can override the circadian drive for wakefulness (Sargent et al. 2012). Therefore, considering sleep loss is likely during long-haul international travel, the homeostatic drive for sleep is likely to be high the first night following arrival at the destination, which may override any circadian influence on sleep. Consequently, it may not be until the second night following arrival, after the homeostatic drive for sleep has returned to normal, that any disruption to sleep due to circadian misalignment is observed. However, given the limited number of studies that have assessed the impact of long-haul international travel on sleep architecture, further research is necessary to substantiate this.

Acute sleep deprivation has been reported to initiate a physiological stress response from the sympathetic nervous system and the hypothalamic pituitary adrenal axis, resulting in greater sympathetic activity and cortisol concentrations at rest (Meerlo, Sgoifo, & Suchecki, 2008). Furthermore, adverse physiological effects of sleep deprivation have been observed during exercise, including a reduction in maximal heart rate (HR) (Chen, 1991), peak oxygen consumption (Chen, 1991; Plyley, Shephard, Davis, & Goode, 1987) and peak ventilation (Plyley et al., 1987). Lastly, following partial sleep deprivation of 2.5 h sleep per night, which is similar to the reduced sleep quantity reported during international air travel (Takahashi et al., 2002; Waterhouse et al., 2002), adverse effects on mood states were evident, with an increase in anger, depression, confusion, fatigue and tension, and reduced vigour (Sinnerton & Reilly, 1992). As discussed below, due to the detrimental physiological and perceptual consequences of
acute sleep deprivation, a number of studies have reported a decline in ensuing physical performance (Table 2.1) (Reilly & Edwards, 2007; Reilly & Piercy, 1994; Skein et al., 2011).

Following partial sleep deprivation of 3 h sleep per night, no significant effect on maximal strength was observed (Reilly & Piercy, 1994). However, greater perceived fatigue and vigour were reported prior to exercise, together with an elevated rating of perceived exertion during 20 sub-maximal repetitions of a strength training exercise (Reilly & Piercy, 1994). Therefore, whilst individuals may be able to overcome the adverse effects of sleep loss in single maximal efforts, diminished performance in sustained exercise bouts may occur, which could be due to reduced motivation to continue to perform at high intensities (Reilly & Edwards, 2007). Indeed, following 30 h of sleep deprivation an increase in perceptual stress prior to exercise, with participants reporting themselves to be less alert, energetic and lively, and more fatigued, subsequently had a negative effect on pacing strategies and reduced intermittent-sprint performance (Skein et al., 2011). Though, the reduction in maximal voluntary contractile force and muscle glycogen concentration observed is also likely to have contributed to the decline in performance (Skein et al., 2011). Regardless, these findings suggest that if sleep disruption were to occur during and following international air travel, there may be an ensuing detrimental impact on physiological and perceptual responses and therefore, reduced physical performance. However, to date, no studies have measured sleep quantity and quality during and following international air travel in conjunction with performance, physiological and perceptual responses deemed relevant to the demands of training and competition in team sports.
Table 2.1. Classification of sports affected by sleep loss (Reilly & Edwards, 2007).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Sports</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-aerobic, high vigilance</td>
<td>Sailing, road cycling, aiming sports</td>
<td>Errors ↑</td>
</tr>
<tr>
<td>Moderate aerobic, high concentration</td>
<td>Field sports, team games, court games</td>
<td>Decision-making ↓</td>
</tr>
<tr>
<td>High aerobic, gross skills</td>
<td>Running 3000 m, swimming 400 m</td>
<td>Marginal</td>
</tr>
<tr>
<td>Mixed aerobic–anaerobic</td>
<td>Combat sports, swimming, middle distance running</td>
<td>Power ↓</td>
</tr>
<tr>
<td>Anaerobic</td>
<td>Sprints, power events</td>
<td>Marginal</td>
</tr>
<tr>
<td>Multiple anaerobic efforts</td>
<td>Jumping events, weight-training</td>
<td>Fatigue ↑</td>
</tr>
</tbody>
</table>

Interventions

As previously outlined, the demands of long-haul transmeridian air travel, combined with the detrimental consequences of jet-lag, may induce adverse physiological (Coste et al., 2009; Pierard et al., 2001) and perceptual (Bullock et al., 2007; Muhm et al., 2007) responses, in addition to sleep disruption (Beaumont et al., 2004; Takahashi et al., 2002), which could suppress physical performance (Chapman et al., 2012; Reilly et al., 2001). Consequently, interventions to overcome these individual or collective effects would be advantageous for travelling team sport athletes, as they could assist with reducing travel-induced disruptions that may affect training and/or preparation for competition.

Following long-haul transmeridian air travel, external cues referred to as zeitgebers (time-givers), are reported to gradually resynchronise endogenous circadian rhythms (Forbes-Robertson et al., 2012). Though natural light is the strongest of these external cues, exercise,
meal timing and exogenous melatonin also contribute to resynchronisation (Arendt, 2009; Forbes-Robertson et al., 2012). Jet-lag symptoms persist until the circadian rhythms are aligned with the external cues of the destination, which theoretically takes approximately one day per time-zone crossed (Forbes-Robertson et al., 2012). Whilst it has been recommended that athletes allow a sufficient number of days in a new time-zone for the body clock to fully adjust prior to competition (Reilly et al., 2007a), this is often not plausible due to training and competition schedules. As a result, travel often occurs relatively close, prior to and/or following competition. Moreover, a faster rate of adaptation to a new time-zone would reduce the duration of jet-lag symptoms and therefore, the possible suppression of physical performance (Arendt, 2009). Consequently, improving the rate of adaptation, which is the goal of the majority of travel interventions (Arendt, 2009), within the logistics of travel would be beneficial for team sport athletes.

All zeitgebers affect the body clock according to a phase response curve, which indicates the direction and magnitude of a phase shift in a given circadian rhythm depending on the time the zeitgeber is applied (Figure 2.8) (Arendt, 2009). For instance, whilst light exposure in the early evening and morning may produce a phase delay and advance in the body clock, respectively, this is reversed for exogenous melatonin administration (Waterhouse et al., 2007). Moreover, the cross over point between advances and delays is close to the core temperature minimum and the melatonin maximum, with the largest phase-shifts observed closest to this point (Figure 2.9) (Arendt, 2009; Waterhouse et al., 2007). Whilst there is some evidence to suggest that light exposure or melatonin administration at these specified times may induce phase-shifts in circadian rhythms in well controlled laboratory studies (Eastman, Gazda, Burgess, Crowley, &
Fogg, 2005; Revell et al., 2006; Samel et al., 1991), in reality the process is more complicated in field settings.

Figure 2.8. Human phase response curves to bright light and melatonin. Upward arrow signifies the average dim light melatonin onset (DLMO), the rectangle indicates the average sleep schedule and the triangle specifies the estimated time of the body temperature minimum (Arendt, 2009).
Figure 2.9. Phase-shifts of circadian rhythms produced by light, melatonin ingestion and exercise at different times during the day. Dim light melatonin onset (DLMO), and the body temperature minimum ($T_{\text{min}}$) are highlighted, with the green shaded area and horizontal black bar indicating the typical range of $T_{\text{min}}$ and sleep period, respectively (Waterhouse et al., 2007).
Specifically, as a result of the inter-individual variation in phase response curves and thus, the timing of the temperature minimum and melatonin maximum, the use of generic interventions is questionable (Waterhouse et al., 2007), the specifics of which will be discussed in more detail later. Furthermore, if these interventions were to be utilised following long-haul transmeridian air travel, the timings of exposure/administration would have to be adjusted each day based on the rate of adaptation of circadian rhythms (Waterhouse et al., 2007). However, inter-individual variation exists for this too (Waterhouse et al., 2002). Lastly, since light inhibits the release of melatonin, if the two interventions are inadvertently administered at the same time, a degree of antagonism in their phase shifting effects is likely (Waterhouse et al., 2007). Consequently, to date there are no randomised control trials that have assessed the effectiveness of light exposure and/or melatonin administration at alleviating jet-lag symptoms and improving the recovery of team sport physical performance following an episode of international air travel.

A further complication is the decision on whether or not to attempt to resynchronise circadian rhythms to the new time-zone following international air travel. For short stays (1-2 days), attempts to resynchronise the body clock are not recommended (Forbes-Robertson et al., 2012). Instead, individuals are encouraged to stay on home time and schedule important events at the time of maximum alertness in the departure time-zone (Forbes-Robertson et al., 2012). However, this is logistically difficult in an applied setting, given it is not possible to adjust competition times to suit team sport athletes, hence, the use of hypnotics (e.g. melatonin and benzodiazepines) and stimulants (e.g. caffeine) are advocated to reduce sleep deprivation and maintain alertness and performance (Forbes-Robertson et al., 2012; Waterhouse et al., 2007).
For longer stays (≥ 4 - 5 days) light exposure and/or exogenous melatonin administration are recommended to promote adaptation of circadian rhythms prior to departure and upon arrival to alleviate jet-lag symptoms (Arendt, 2009; Forbes-Robertson et al., 2012). Promotion of sleep and maintenance of daytime alertness through hypnotics and stimulants respectively is also proposed to manage jet-lag symptoms (Waterhouse et al., 2007). Indeed, a ‘travel management program’, which is a comprehensive approach to the management of jet-lag and travel fatigue that includes pre-, during and post-travel periods, has been advocated for longer stays (Samuels, 2012). Considering that team sport athletes travelling overseas to attend training camps or for competition are likely to stay for longer than 1-2 days, the literature for interventions that could be included in a ‘travel management program’ will be discussed in the following sections, with respect to the research evidence and in particular, the practicality for use with professional sports teams.

An understanding of the principles of chronobiology has resulted in the publication of generic recommendations to reduce the effects of international air travel (Figure 2.10) and promote adaptation of circadian rhythms to the new time-zone (Reilly et al., 2007a). However, there are few randomised control trials that have assessed the effectiveness of these recommendations at alleviating jet-lag symptoms and improving the recovery of team sport physical performance following an episode of international air travel. Moreover, similar to the aforementioned literature regarding the effects of international air travel, there is a predominance of research that has investigated the impact of interventions on the adaptation of circadian rhythms and jet-lag symptoms. Therefore, information regarding the effectiveness of various interventions at reducing the demands of air travel *per se* and travel fatigue is limited. Consequently, there
remains a paucity of evidence-based interventions that have been translated into recommendations to be of practical benefit to team sport athletes when travelling internationally.

**Advice**

*Before the journey*
- Plan the journey well in advance
- Try to arrange for any stopover to be comfortable
- Be clear about documentation, inoculations, visas, etc.
- Make arrangements for activity at your destination

*During the flight*
- Take some roughage (e.g. apples) to eat
- Drink plenty of water or fruit juice; avoid tea, coffee, and alcohol

*On reaching your destination*
- Relax with a non-alcoholic drink
- Take a shower
- Take a brief nap, if feeling exhausted

**Figure 2.10.** Current recommendations for reducing the detrimental effects of international air travel (Reilly et al., 2007a).
Pre-travel

It is proposed that the most effective way to avoid jet-lag is through pre-adjustment or adapting circadian rhythms to the new time-zone prior to arrival at the destination (Arendt, 2009; Forbes-Robertson et al., 2012; Samuels, 2012). Indeed, pre-adjustment using light exposure and/or melatonin administration has been successfully achieved in laboratory settings (Deacon & Arendt, 1996; Eastman et al., 2005; Revell et al., 2006). For example, a 9 h phase-delay in core body temperature and melatonin (6-sulphatoxymelatonin) circadian rhythms, together with the sleep-wake cycle were observed in response to 9 h of bright light exposure (1000 lux) per day for 3 days, with a 3 h delay in exposure each day (Deacon & Arendt, 1996). However, a phase-shift this large is unlikely to be feasible in the general population, let alone among elite team sport athletes, as it would encroach too much on a conventional lifestyle, and thus training schedules, prior to travel (Waterhouse et al., 2007). A smaller and more practical 1.9 h phase-advance in the DLMO, which gives an indication of the melatonin circadian rhythm, was achieved through gradually advancing the sleep schedule for 2 h per day for 3 days, together with intermittent bright light exposure for 3.5 h (4 x 0.5 h pulses of 5000 lux separated by 0.5 h in normal room light of < 60 lux) upon awakening (Eastman et al., 2005). Furthermore, the phase-advance in the DLMO achieved by the aforementioned protocol was increased to 2.5 h and 2.6 h through the addition of 0.5 mg and 3 mg of melatonin, respectively, administered in the afternoon according to the melatonin phase response curve (Revell et al., 2006).

Whilst these smaller phase-shifts require less demanding pre-adjustment protocols and are therefore more practical, given that the time-zone difference following long-haul transmeridian air travel is likely to be much greater than the 2-3 h phase-shifts induced, interventions to
promote the adaptation of circadian rhythms would still be required following travel. Furthermore, inadvertent exposure to other zeitgebers, particularly bright light could cause phase-shifts in the opposite direction to the one intended (Forbes-Robertson et al., 2012). Therefore, it remains unclear whether pre-adjustment would be effective in the field, where accidental exposure to bright light is much more likely to occur than under controlled laboratory conditions. In fact, to date no randomised control trials have assessed the effectiveness of pre-adjustment at alleviating jet-lag symptoms and improving the recovery of physical performance following an episode of international air travel, where it is presumed that strict compliance would also be required during travel to maintain the phase-shifts induced. Lastly, due to the stringent compliance required and limitations to normal daily behaviour, it would be very difficult to adjust team sport athletes training, eating and sleeping times, without causing large disruptions to their preparation prior to travelling overseas for competition (Forbes-Robertson et al., 2012). Whether these disruptions to optimal training outweigh the need to induce phase-shifts prior to travel is a question that remains unanswered. Moreover, it is often the case, especially for national teams, that the coach and sports medicine/sports science staff has limited contact with the athletes prior to travel. Thus, considering the strict compliance required, this may be another reason why pre-adjustment is not often practical for use with team sport athletes.

Previous research suggests that the severity of jet-lag symptoms may depend on the travel schedule (Waterhouse et al., 2002). Specifically, individuals with a travel schedule that resulted in a shorter interval between their last full sleep period before the flight and their first one at the destination reported fewer jet-lag symptoms than those whose schedule resulted in a longer interval (Waterhouse et al., 2002). Therefore, when booking flights, selecting a schedule that
minimises the duration between full sleep periods at home and the destination may be an effective strategy for reducing jet-lag symptoms (Waterhouse et al., 2002). Moreover, considering the sleep loss that occurs during (Takahashi et al., 2002) and following (Beaumont et al., 2004) travel, it has been suggested that an emphasis should be placed on sleep prior to travel in order to ensure individuals do not begin travel in a sleep deprived state (Samuels, 2012). Indeed, sleep extension (a minimum of 10 h in bed each night) may be effective at increasing sleep quantity, enhancing physical and cognitive performance, together with improving alertness and mood states (Mah, Mah, Kezirian, & Dement, 2011). However, evidence suggests that sleep extension only assists with recovery and not ‘protection’ from sleep disruption (Van Dongen, Maislin, Mullington, & Dinges, 2003) and therefore, sleep extension is unlikely to have additional benefits over ensuring good sleep habits prior to travel. Regardless, again there are no randomised control trials that have assessed the effectiveness of these strategies at alleviating jet-lag symptoms and improving the recovery of physical performance following an episode of international air travel. Therefore, based on the current research evidence, there are no pre-travel interventions that would be recommended for use with team sport athletes.

*During travel*

General recommendations exist for during travel that are proposed to reduce the impact of the demands of air travel and reduce the disruption of circadian rhythms and the sleep-wake cycle following travel (Reilly et al., 2007a). First, on boarding the flight, individuals are advised to set their watches and begin to live (eat and sleep) in agreement with the local time at the destination (Reilly et al., 2007a). In addition, it is advocated that fluid consumption should be increased above that normally expected, whilst avoiding diuretics, such as coffee, tea and alcohol, as the
dry cabin air may cause hypohydration (Simons & Krol, 1996). Lastly, to alleviate joint and muscle stiffness, and reduce the risk of DVT, periodic activity, such as walking and light stretching exercises, is recommended approximately every two hours, along with wearing appropriate compression stockings (Reilly et al., 2007a). Whilst these recommendations are based on an understanding of the principles of chronobiology and the demands of air travel, there is negligible evidence to support their efficacy at reducing travel fatigue and jet-lag symptoms, together with improving the recovery of team sport physical performance following international air travel.

The low sleep quantities (2 - 4 h) previously reported during international air travel (Takahashi et al., 2002; Waterhouse et al., 2007), together with the detrimental effects of sleep deprivation on performance, physiological and perceptual responses (Meerlo et al., 2008; Reilly & Piercy, 1994; Skein et al., 2011), suggests interventions to minimise sleep disruption during travel are of importance. It is currently recommended that sleep should be scheduled during travel according to when it is night at the destination, and must be avoided when it is daytime at the destination, otherwise circadian rhythms will remain aligned with the time-zone of the place of departure (Reilly & Edwards, 2007; Waterhouse et al., 2004). However, these guidelines may be difficult to implement in practice, as during travel circadian rhythms and the sleep-wake cycle will still be aligned with the departure time-zone. Consequently, passengers could be attempting to sleep during travel when the circadian rhythms in melatonin and body temperature are inducing the physiological state for waking, and endeavouring to stay awake when these rhythms are promoting sleep onset. Therefore, short-acting sleeping pills (e.g. benzodiazepines) have been advocated as a solution to counteract this problem (Arendt, 2009), though, this may have the
potential to increase the risk of DVT during travel as a result of prolonged immobility (Samuels, 2012).

Consequently, the use of behavioural interventions to improve sleep quantity and quality during travel may be more favourable (Samuels, 2012). Indeed, the following behavioural interventions have recently been proposed to facilitate sleep during travel. First, a comfortable environment should be created by using a neck pillow and the use of electronic devices should be minimised (Samuels, 2012). Further, eye masks, earplugs and/or noise cancelling headphones could be used to aid rest and relaxation and prevent overstimulation (Samuels, 2012). Utilising sleep hygiene recommendations similar to these (i.e. minimising light and noise) was reported to increase sleep quantity and improve perceptual recovery following intensive training in highly-trained tennis players (Duffield, Murphy, Kellett, & Reid, 2013). However, it remains to be determined whether increasing comfort and following sleep hygiene recommendations during travel can minimise the sleep debt accrued and subsequently, alleviate travel fatigue symptoms to improve performance recovery following international air travel. Regardless, the limited number of interventions advocated for use during travel is likely a result of the lack of research into and therefore, an insufficient understanding of the demands of air travel.

*Post-Travel*

As previously discussed, there is currently negligible scientific evidence from field-based studies to support the use of interventions prior to and during international air travel in order to alleviate jet-lag symptoms and improve the recovery of physical performance following travel. In addition, considering team sport athletes training and competition demands, the practicality of
utilising some of these interventions, particularly pre-adjustment, is limited. In contrast, there is a plethora of research on the use of interventions following travel to resynchronise circadian rhythms, which has delivered promising findings (Beaumont et al., 2004; Lack et al., 2007; Lagarde et al., 2001). In particular, the following interventions may be utilised post-travel; bright light in conjunction with exercise to adjust circadian rhythms, melatonin to promote sleep and adjust circadian rhythms, short-acting benzodiazepine hypnotics to promote sleep and caffeine to maintain daytime alertness (Waterhouse et al., 2007). Therefore, the efficacy and practicality of administering pharmacological agents (caffeine, benzodiazepines and melatonin) compared to modifying behaviour (timing of light exposure, exercise and meals) to alleviate jet-lag symptoms and improve the recovery of physical performance in team sport athletes following international air travel will now be discussed.

**Pharmacological interventions**

Caffeine

Due to the psychostimulant properties of caffeine, it has been reported as an effective ergogenic aid (Burke, 2008) and to assist in the maintenance of alertness and performance following sleep deprivation (Lagarde et al., 2000). As such, it may be effective at combating the sleep loss that occurs as a consequence of long-haul international air travel. In a double-blind, randomised, placebo-controlled study, following 10 h of eastward air travel across seven time-zones, the effects of separately administered caffeine and melatonin (to be discussed later) on the adaptation rate of circadian rhythms, the sleep-wake cycle and physical performance, were investigated and published in three separate manuscripts (Beaumont et al., 2004; Lagarde et al., 2001; Pierard et al., 2001). Due to its stimulatory properties, 300 mg of slow-release caffeine
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was administered at 08:00 local time for five days following travel. The dose was administered as a slow-release form to prolong plasma concentrations, which may enhance the overall effectiveness compared to a fast-acting solution (Lagarde et al., 2001). Moreover, as caffeine can modify the endogenous secretion of melatonin by the pineal gland, slow-release caffeine may also have an effect on circadian rhythms (Lagarde et al., 2001; Pierard et al., 2001).

Compared to baseline, an increase in grip strength was observed on the first four mornings (07:00 local time) following travel in the caffeine trial, whereas a reduction was reported in response to a placebo (Lagarde et al., 2001). Moreover, compared to baseline in the placebo trial, salivary cortisol concentrations were reduced in the morning (07:00 local time) on days 2 - 9 and salivary melatonin concentrations were increased at the same time on days 3 - 5 following travel (Pierard et al., 2001). In contrast, reductions in cortisol levels were only observed up to day five, whilst no differences in melatonin concentration were evident following the use of caffeine (Pierard et al., 2001). Furthermore, resynchronisation of the body temperature nadir began on day three and five in the caffeine and placebo trials, respectively (Beaumont et al., 2004).

Therefore, these findings suggest that slow-release caffeine may have a chronobiotic effect (enhance the adaptation of circadian rhythms) following long-haul (10 h) transmeridian air travel (Beaumont et al., 2004; Pierard et al., 2001).

Daytime activity, measured via actigraphy, was reduced until day six post-travel in the placebo trial compared to pre-travel. However, with caffeine ingestion, it was increased for the five days post-travel (Beaumont et al., 2004). Although such findings suggest that caffeine may reduce daytime sleepiness, it also had some adverse side effects on objective and subjective sleep
quantity and quality, including a reduction in sleep duration, increased sleep latency and wakefulness after sleep onset, an earlier waking time and increased difficulty waking (Beaumont et al., 2004). It was postulated that this could have resulted from the slow-release properties of the caffeine, as despite being administered at 08:00 local time, salivary caffeine was still elevated above the level required for effectiveness at 22:00 local time (Beaumont et al., 2004). Moreover, improved sleep quantity and quality were reported after the treatment ceased, which highlights the sleep loss that occurred during the five days that caffeine was ingested (Beaumont et al., 2004) and is an important reminder of the potential unwanted side effects of a pharmaceutical interventions for team sport athletes.

Considering the sleep loss that occurs following long-haul transmeridian air travel as a result of circadian rhythm disruptions (Beaumont et al., 2004) and the impact it may have on ensuing physical performance (Skein et al., 2011), the benefits of slow-release caffeine may be outweighed by its detrimental effects on sleep. Moreover, given the importance of sleep for recovery from training and competition in athletes (Halson, 2013), it is unlikely that a pharmacological agent known to reduce sleep quantity and quality would be recommended for use in athletes undertaking high training loads. Consequently, further research is required with various doses and forms of caffeine to determine which is optimal for improving recovery from international air travel, without the negative effects on sleep. For instance, it is unclear whether the fast-acting solution of caffeine would have the same effects as the slow-release form, as although it is reported to temporarily alleviate fatigue (Waterhouse et al., 2007), it is unlikely to have the same chronobiotic effect (Lagarde et al., 2001). Lastly, 2-3 mg·kg⁻¹ of fast-acting caffeine is commonly used by athletes ~ 1 h prior to training and competition for its ergogenic
effects (Burke, 2008). Whilst the ingestion of fast-acting caffeine prior to training and competition could help to overcome the detrimental impact of international air travel on physical performance (Chapman et al., 2012; Edwards et al., 2000), to date, there are no studies that have investigated its influence.

Benzodiazepines

Benzodiazepines enhance the effect of the neurotransmitter gamma-aminobutyric acid (GABA) at the GABA<sub>A</sub> receptor, resulting in sedative and hypnotic (sleep-inducing) properties (Rush & Griffiths, 1996). Therefore, in theory, short-acting benzodiazepine hypnotics may attenuate the effects of international air travel through a hypnotic effect and/or a chronobiotic effect; whereby improving sleep quantity and quality could subsequently increase daytime alertness and accelerate the adaptation rate of the sleep-wake cycle following travel (Reilly et al., 2001).

Indeed, both a hypnotic and chronobiotic effect of a benzodiazepine (triazolam) were reported in a double-blind, placebo-controlled study, consisting of an 8 h phase-delay of the sleep-wake and dark-light cycles to simulate westward transmeridian air travel (Buxton, Copinschi, Van Onderbergen, Karrison, & Van Cauter, 2000). Compared to a placebo, 0.5 mg of triazolam, administered immediately prior to bed for four days following the phase-shift, increased the duration of rapid eye movement, non-rapid eye movement and slow-wave sleep (hypnotic effect) and accelerated the resynchronisation of the sleep-wake cycle, as indicated by the time of sleep onset and awakening, together with the cortisol circadian rhythm (chronobiotic effect) (Buxton et al., 2000). However, only six participants were involved in this study and thus, given the low statistical power and lack of performance outcomes, further research is required to confirm these effects.
Conversely, no effect of 10 mg of a short-acting benzodiazepine hypnotic (temazepam) administered immediately prior to bed for three days following 9 h of westward air travel across five time-zones was observed on performance, physiological or perceptual responses, compared to a placebo (Reilly et al., 2001). It was speculated that because subjective sleep quality following travel was better than expected, due to the proposed mechanism of action, effects of short-acting benzodiazepine hypnotics are likely to be greater with larger sleep disturbances (Reilly et al., 2001). Moreover, benzodiazepines may have residual effects on sleep timing, alertness and psychomotor performance and therefore, to avoid any detrimental side effects on training and/or competition performance, it is imperative the timing and dose is correct if administering to athletes (Forbes-Robertson et al., 2012; Reilly et al., 2001). However, the methodology of the aforementioned studies suggests, at present, there is limited consensus on the type, dose and timing of benzodiazepine administration. Moreover, adverse side effects, including sleep problems, memory impairment and negative mood states, may be associated with the chronic use of benzodiazepines. Lastly, negligible field-based studies have assessed the effects of benzodiazepines on the recovery of physical performance following international air travel and therefore, athletes are currently advised to avoid such supplementation (Forbes-Robertson et al., 2012).

Melatonin

Endogenous melatonin is synthesised from serotonin in the pineal gland and forms part of the system that regulates the sleep-wake cycle by chemically causing drowsiness and lowering body temperature (Atkinson, Drust, Reilly, & Waterhouse, 2003). Similar to benzodiazepines, melatonin may also negate the effects of international air travel through hypnotic and/or
chronobiotic pathways (Edwards et al., 2000). Based on the melatonin phase response curve, exogenous administration in the evening may induce a phase-advance in circadian rhythms, whereas administration in the morning could induce a phase-delay (Waterhouse et al., 2007). In the aforementioned double-blind, randomised, placebo-controlled, field-based study (Beaumont et al., 2004; Lagarde et al., 2001; Pierard et al., 2001), 5 mg of melatonin was administered orally by participants in accordance with previous recommendations (Arendt & Deacon, 1997), corresponding to 18:00 local time on the departure day and during the flight, and at local bed time (22:00 - 23:00) for four days on arrival (Arendt & Deacon, 1997). Melatonin prevented the reduction in grip strength observed in the placebo trial (Lagarde et al., 2001) and similar to slow-release caffeine, salivary cortisol returned to baseline levels four days earlier compared to the placebo (Pierard et al., 2001). Moreover, the resynchronisation of the oral temperature nadir was fastest in the melatonin trial, taking only two days post-travel (Beaumont et al., 2004). In contrast to slow-release caffeine, melatonin improved sleep quantity and quality, but did not alleviate daytime sleepiness (Beaumont et al., 2004). It was speculated that this was due to the participants being sleep deprived, as they were prevented from sleeping on the flight, rather than a residual hypnotic effect, as melatonin concentrations were similar in the morning of both the melatonin and placebo trials (Beaumont et al., 2004). These findings highlight the importance of conducting field-based investigations, given that research into the efficacy of melatonin in the laboratory is conducted on well rested individuals (Samel et al., 1991), which may alter the effects outlined above (Beaumont et al., 2004). Furthermore, the findings of the aforementioned studies indicate that melatonin may improve the recovery of physical performance following international air travel through both a hypnotic and chronobiotic effect.
In contrast, no effects of melatonin were observed on grip strength, subjective jet-lag symptoms or the adaptation rate of the body temperature circadian rhythm, in a study utilising the same administration protocol (Arendt & Deacon, 1997) following 24 h of eastward air travel across 10 time-zones in sports scientists visiting Australia for business (Edwards et al., 2000). In fact, melatonin had neither a hypnotic or chronobiotic effect, given that no differences in the ease of getting sleep or number of wake episodes were reported compared to a placebo. Further, only 20 - 38% of participants’ circadian rhythms shifted in the correct direction (phase-advance), with 50 - 69% adapting by a phase-delay, and 11 - 19% remaining unchanged (Edwards et al., 2000). Similar variance in phase-shifts has been reported in well controlled, laboratory-based studies examining the efficacy of exogenous melatonin following simulated time-zone changes (Samel et al., 1991). This may be a consequence of the inter-individual variation in melatonin phase response curves and thus, differences in the rates and direction of circadian rhythm adaptation to a generic timing and dose of melatonin administration (Arendt, 2009). The implications of this for future research directions will be discussed later. Moreover, in contrast to the aforementioned studies that reported both a hypnotic and chronobiotic effect of melatonin (Beaumont et al., 2004; Pierard et al., 2001), the daily routine of participants was not standardised (Edwards et al., 2000). If bright light exposure and melatonin administration occur at the same time, opposing effects on circadian rhythms are likely, as bright light inhibits the release of melatonin (Waterhouse et al., 2007). Consequently, the busy schedules of the participants following travel and hence, the uncontrolled exposure to bright light, was identified as a possible reason that no beneficial effects were observed (Edwards et al., 2000).
However, considering team sport athletes’ busy training and competition schedules, the findings of Edwards et al. (2000) may have greater ecological validity. Indeed, in 12 elite biathletes, negligible effects of 5 mg of melatonin, administered at 22:00 local time, were observed on subjective sleep quality and the resynchronisation of the body temperature circadian rhythm following 8 h of eastward transmeridian air travel across eight time-zones (Manfredini, Manfredini, Fersini, & Conconi, 1998). However, no placebo group or measures of physical performance were included in this study and thus, further research is required to determine the efficacy of melatonin administration at alleviating jet-lag symptoms and improving the recovery of sport-specific performance following international air travel in athletes. Regardless, these findings indicate that avoidance of bright light at specific times may be integral to improving the effectiveness of melatonin. Moreover, though there is some encouraging evidence supporting the use of melatonin to attenuate the negative effects of international air travel (Beaumont et al., 2004; Herxheimer & Petrie, 2002; Pierard et al., 2001), since many countries still have restrictions on its purchase and use, current recommendations are that it should be administered with caution in athletes (Forbes-Robertson et al., 2012; Waterhouse et al., 2007).

*Behavioural interventions*

Since caffeine may negatively impact sleep (Beaumont et al., 2004), benzodiazepines may have residual effects on alertness (Reilly et al., 2001) and many countries restrict the use of melatonin (Forbes-Robertson et al., 2012), behavioural modification, especially the timing of light exposure and exercise, is currently recommended over pharmacological interventions in an attempt to enhance circadian rhythm adaptation in athletes following international air travel (Forbes-
Consequently, the efficacy of behavioural interventions will now be discussed.

Bright light

Based on the phase response curve to light (Figure 2.8) (Czeisler et al., 1989), the timing of light exposure required to induce phase-shifts in circadian rhythm can be estimated. In fact, promoting and restricting exposure to natural sunlight at specific times may be the simplest travel intervention, as no specialist equipment is required (Forbes-Robertson et al., 2012). It is proposed that following westward transmeridian air travel, light exposure should be sought in the evening and avoided in the morning, whereas the opposite is required after travelling eastwards (Figure 2.9) (Forbes-Robertson et al., 2012; Waterhouse et al., 2007). However, as yet, no randomised control trials have assessed the efficacy of these general recommendations and exposure to natural sunlight is not always possible. For instance, compared to bright sunlight (~110,000 lux), the light intensity is significantly reduced on an overcast day (~1000 - 2000 lux) and/or if light exposure is required at sunrise or sunset (~400 lux). Consequently, artificial bright light may be used to supplement natural light exposure.

As previously mentioned, a 9 h phase-delay in circadian rhythms was achieved in the laboratory through 9 h of bright light exposure (1000 lux) per day for three days (Arendt et al., 1986). However, it is unlikely that artificial bright light exposure of this duration would be feasible with the general population following travel, let alone elite athletes, as it would encroach too much on a conventional lifestyle and therefore, training schedules (Waterhouse et al. 2007). In another laboratory-based study, comparable phase-delays in rectal temperature and plasma melatonin
circadian rhythms were observed in response to both continuous (6.5 h of 9,500 lux) and intermittent (6 x 15 min 9,500 lux pulses) artificial bright light exposure (Gronfier et al., 2004). These findings suggest that if the intensity of artificial bright light is increased, it could be possible to reduce exposure time, which would enhance the feasibility of implementing this intervention in an applied setting. Conversely, the timing of exposure, which was in the middle of the night ~3.5 h prior to the body temperature minimum (Gronfier et al., 2004), reduces its applicability to an applied setting. Therefore, in an attempt to increase the practicality of artificial bright light exposure, research interest into the development of portable artificial bright light sources, including light boxes and light glasses has recently increased (Forbes-Robertson et al., 2012). Though broad-spectrum white light has typically been used for artificial bright light interventions, researchers have recently reported that circadian rhythms are more responsive to shorter wavelength (blue to green) than longer wavelength (yellow and red) light (Wright et al., 2004). Whilst evidence suggests that artificial blue light devices may be able to adjust circadian rhythms with shorter (2 h) and more practical exposure times (Lack et al., 2007; Wright et al., 2004), to date, limited field-based studies have investigated their efficacy at alleviating jet-lag symptoms and enhancing the recovery of team sport physical performance following transmeridian air travel (Thompson et al., 2013).

In a randomised control trial, the efficacy of exposure to a light box (~2500 lux) for 45-60 min per day, for four consecutive days following 7 h of eastward air travel across five time-zones, was examined in elite female football players (Thompson et al., 2013). Artificial bright light exposure occurred at the time of day predicted to advance circadian rhythms and was delayed each day based on an estimate of the rate of circadian rhythm adaptation (Waterhouse et al.,
Negligible effects were observed on jet-lag symptoms and grip strength, together with the resynchronisation of the body temperature circadian rhythm. It was speculated that no effect of artificial bright light exposure occurred due to the large inter-individual variation in the severity of jet-lag symptoms and rate of adaptation of circadian rhythms (Thompson et al., 2013), which is a widespread issue associated with implementing generic interventions (which will be discussed in further detail later). Moreover, several compromises were required to implement the intervention with a group of elite team sport athletes, including sharing light boxes, reducing the duration of light exposure due to team commitments and the inability to control incidental sunlight exposure and exercise, which may have masked the effects of the intervention (Thompson et al., 2013). Lastly, whilst participants in the intervention group were restricted to their room for the artificial bright light exposure, no limitations were placed on the control group. Hence, the control group may have inadvertently been exposed to natural sunlight at the same times the intervention group were exposed to artificial bright light (Thompson et al., 2013).

Together, these findings highlight the level of control required for bright light exposure to be effective, which may reduce the feasibility of use with team sport athletes in field-based environments.

A limitation of the use of light boxes is that daily routines are disrupted whilst using them. Given team sport athletes demanding training and competition schedules, the use of artificial bright light emitting glasses may be more practical. Furthermore, avoidance of bright light using glasses with filters, may circumvent the problems of light avoidance (Sasseville, Paquet, Sévigny, & Hébert, 2006). Consequently, research is warranted into the efficacy of artificial
bright light emitting and light blocking glasses at alleviating jet-lag symptoms and enhancing the recovery of team sport physical performance following transmeridian air travel.

Sleep

As previously outlined, the disruption of habitual sleep patterns is likely to occur during (Takahashi et al., 2002) and following (Beaumont et al., 2004) long-haul international air travel, as a result of the demands of air travel per se (Coste et al., 2009) as well as disruption of circadian rhythms and the sleep-wake cycle (Waterhouse et al., 2007). Furthermore, the sleep debt accrued is likely to induce detrimental physiological (Meerlo et al., 2008) and perceptual (Reilly & Piercy, 1994; Skein et al., 2011) effects, which may suppress ensuing physical performance (Skein et al., 2011). Though sleep medication, such as short-acting benzodiazepine hypnotics and melatonin, has been advocated as a solution to this problem (Arendt, 2009), in addition to the ethical issues associated with the long-term use of prescription drugs (Forbes-Robertson et al., 2012), they may also induce unwanted side-effects, particularly for elite athletes (Reilly et al., 2001). Consequently, non-pharmacological interventions may be a better option for improving sleep quantity and quality during and following international air travel in athletes (Samuels, 2012).

Given the recent emphasis on the importance of sleep for elite athletes (Halson, 2013; Samuels, 2008), sleep education and the use of sleep hygiene recommendations have been recommended (Halson, 2013; Samuels, 2008). Specifically, strategies for improving sleep include ensuring a cool, quiet and dark environment, which eye masks and earplugs may assist with, especially during travel, minimising the use of electronic equipment 1 h prior to sleep and avoiding caffeine
approximately 4-5 h prior to sleep (Halson, 2013). Considering that utilising sleep hygiene recommendations similar to these increased sleep quantity and improved perceptual recovery following intensive training in highly-trained tennis players (Duffield et al., 2013), they may also be effective at reducing sleep disruption during and following international air travel. Therefore, further research is warranted into the efficacy of sleep hygiene recommendations at improving sleep quantity and quality during and following international air travel, especially when there are disruptions to circadian rhythms in body temperature and melatonin, which regulate sleep (Waterhouse et al., 2007).

Exercise

Since the phase response curve for exercise may be similar to the one for light, theoretically early morning exercise may induce phase-delays in circadian rhythms, whilst early evening exercise could result in phase-advances (Atkinson, Edwards, Reilly, & Waterhouse, 2007; Forbes-Robertson et al., 2012). However, the research evidence is conflicting, with both morning and evening exercise reported to induce a phase-delay in the plasma melatonin circadian rhythm during well controlled laboratory-based studies (Buxton, Lee, L'Hermite-Balériaux, Turek, & Van Cauter, 2003; Yamanaka et al., 2010). Moreover, the phase-delays observed have been as minimal as 30 min (Buxton et al., 2003), phase-advances have proved difficult to obtain (Atkinson et al., 2007) and the exercise utilised in such studies is relatively prolonged, for example, 2 x 2 h sessions per day (Yamanaka et al., 2010). Furthermore, based on chronobiological principles, exercise may need to be conducted at a time of low activity, such as during the night, to induce phase-shifts in circadian rhythms (Barger, Wright, Hughes, & Czeisler, 2004; Forbes-Robertson et al., 2012). Accordingly, exercise may not be a practical
intervention for circadian rhythm adaptation following transmeridian air travel, with further research still required to determine the optimal mode, intensity, duration and frequency of exercise (Atkinson et al., 2007). Lastly, considering the similarities in the phase response curves for exercise and light, it could be appropriate for athletes to combine outdoor training sessions with appropriately timed light exposure following international transmeridian air travel (Forbes-Robertson et al., 2012), which will be discussed in the following section. However, as exercise in the aforementioned laboratory-based studies was conducted under very dim light, in order to separate the phase-shifting effects of exercise from those of bright light, if they were to be scheduled at the same time, the interactive effects are currently unknown (Waterhouse et al., 2007).

Combined interventions

Once again, based on chronobiological principles and phase response curves, theoretically, compared to the aforementioned exposure to just one zeitgeber, the appropriate timing of exposure to two or more zeitgebers could have a cumulative effect and therefore, accelerate the rate of adaptation of circadian rhythms following long-haul transmeridian air travel (Forbes-Robertson et al., 2012). Considering the phase response curves for light and exercise may be similar, combining appropriately timed bright light exposure with outdoor activity is a strategy that has been frequently advocated to enhance adaptation to a new time-zone (Reilly et al., 2007a). For instance, to promote the phase-advance in circadian rhythms required after travelling in an eastward direction, outdoor exercise and thus, light exposure in the afternoon is recommended, whereas individuals are advised to avoid light and exercise in the morning (Reilly et al., 2007a). Furthermore, as presented in Figure 2.11, recent literature reviews have provided
examples of ‘zeitgeber exposure schedules’ for various travel scenarios (Arendt, 2009; Forbes-Robertson et al., 2012). Specifically, these schedules detail the precise timing of bright light exposure, exercise and melatonin administration required to induce a phase delay or advance in circadian rhythms depending on the travel direction (Arendt, 2009; Forbes-Robertson et al., 2012). However, similar to many of the aforementioned interventions, whilst a combination of zeitgebers is sound in theory and has been successful in shifting circadian rhythms in laboratory-based studies (Revell et al., 2006), negligible effects have been observed in field-based environments (Cardinali et al., 2002).

Figure 2.11. Adaptation strategies for both eastward and westward transmeridian air travel. Grey panels indicate night, white panels indicate daylight. White ellipses show sleep and wake onset times, and black ellipses show meal times (Forbes-Robertson et al., 2012).
To date, only one study has attempted to assess the efficacy of combining bright light exposure, exercise and melatonin administration on the resynchronisation of circadian rhythms following long-haul transmeridian air travel (Cardinali et al., 2002). Specifically, the study examined the effects of daily outdoor exercise in the morning (08:00 - 11:00) and afternoon (13:00 - 16:00), in addition to 3 mg of melatonin, administered 30 min prior to bed time, on the resynchronisation of the sleep-wake cycle following 24 h of westward air travel across 12 time-zones in 22 elite male football players (Cardinali et al., 2002). The mean resynchronisation rate of the sleep-wake cycle was two days, which was reported to be significantly different from the estimated circadian rhythm adaptation rate of six days (Cardinali et al., 2002). However, in addition to having no control group, compared to pre-travel, no changes in the subjective assessment of the sleep-wake cycle (time to bed and time awake) were reported following travel, which contradicts the aforementioned finding of a faster resynchronisation rate. Furthermore, based on the phase response curve for light (Czeisler et al., 1989), bright light exposure in the morning and afternoon are likely to have opposing effects on circadian rhythms, as light in the morning induces as phase-advance, whereas light in the afternoon may cause a phase-delay (Waterhouse et al., 2007). Therefore, the results of this study are difficult to interpret and hence, based on current evidence, the use of combined pharmacological and behavioural interventions for resynchronising circadian rhythms following international air travel cannot be recommended. However, further research is warranted with regards to the ability to alleviate jet-lag symptoms and improve the recovery of physical performance following long-haul transmeridian air travel.
In summary, whilst the majority of the aforementioned interventions have efficacy in laboratory-based studies (Arendt et al., 1986; Buxton et al., 2003; Eastman et al., 2005), effectiveness in field-based research and thus, an applied setting remains uncertain (Cardinali et al., 2002; Manfredini, Manfredini, & Conconi, 2000; Thompson et al., 2013). Whilst this may be a result of the limited number of field-based studies conducted to date (Cardinali et al., 2002; Lagarde et al., 2001; Thompson et al., 2013), it could also be a consequence of the inter-individual variation that exists in the direction and rate of circadian rhythm adaptation following simulated and actual time-zone changes (Arendt, 2009), which will be discussed in the following section. Furthermore, it has been suggested that in order to improve the effectiveness of these interventions in applied settings, they may need to be more demanding and intrusive (Thompson et al., 2013). However, this would reduce the practicality and feasibility of utilising these interventions in athlete populations (Thompson et al., 2013) and therefore, further research is required to find a balance between the effectiveness and invasiveness of interventions.

**Individual variability**

Applying a generic intervention to a specific participant population assumes that there is an average direction and rate of circadian rhythm adaptation to a new time-zone (Arendt, 2009). However, in reality, the rate of adaptation differs between variables within the same individual and between individuals for any given variable, together with inter-individual variation in the direction of adaptation (advance or delay) (Arendt, 2009; Waterhouse et al., 2002). Furthermore, inter-individual variation exists in phase response curves and hence, for the relationship between the timing and the effect of specific zeitgebers on circadian rhythms (Forbes-Robertson et al., 2012). Therefore, responses to the aforementioned interventions will also vary between
individuals. This explains why even in well controlled laboratory-based experiments, when a generic intervention is applied, significant inter-individual variation in the rate and direction of circadian rhythm adaptation occurs (Arendt, 2009; Samel et al., 1991). Consequently, generic interventions are even less likely to be effective in field-based studies, with greater confounding factors, such as accidental exposure to zeitgebers at inappropriate times (Thompson et al., 2013).

However, the alternative, which is to individualise interventions, is also complicated. In theory, the timing of exposure to zeitgebers should be based on individual phase response curves and subsequently adjusted based on individual rates and directions of circadian rhythm adaptation following travel (Forbes-Robertson et al., 2012; Waterhouse et al., 2007). However, this requires an instantaneous circadian rhythm phase-marker, which currently does not exist (Arendt, 2009). The rate of adaptation can be estimated from chronobiological principles (1 h per day when advancing circadian rhythms and 2 h per day when delaying them) or an individual’s body temperature minimum and/or sleep timings (Forbes-Robertson et al., 2012; Waterhouse et al., 2007). However, the practicality of individualising interventions with athletes, particularly those in team sports, is questionable. For example, due to team commitments, such as training, meal and meeting times, it would be difficult to have individualised bright light exposure schedules, as highlighted in the study conducted by Thompson et al (2012), where football players were required to share light boxes. Therefore, whilst further research into the possibility of individualising interventions is warranted, currently, generic interventions are more feasible for use with athletes.
Domestic air travel

Frequent domestic travel to and from away matches is a necessity for professional teams throughout a season, though the magnitude of travel demands varies between countries and competitions (Goumas, 2014; Pollard, 1986; Winter et al., 2009). Due to the geographical size of countries such as Australia and North and South America, large distances are travelled by away teams for domestic competition (Goumas, 2014). For example, in Australian professional team sport competitions, Western Australian teams are required to frequently travel eastward via air for up to 5 h or 3500 km, across two time-zones to the east coast of Australia, where the majority of teams are based (Richmond et al., 2007). Hence given the regional concerns, a majority of research studies on domestic-based travel and sport have been conducted in either Australia or America (Bishop, 2004; Goumas, 2014; Winter et al., 2009) as these competitions are ideal for investigating domestic air travel effects on team sport performance.

Effects on match outcome

The tendency for teams to perform better at home compared to away, referred to as the home advantage, has consistently been reported in domestic competitions from a range of team sports (Clarke, 2005; Gomez, Pollard, & Luis-Pascual, 2011; Goumas, 2014), even though the reasons for this remain ambiguous (Nevill & Holder, 1999). In addition to domestic air travel, situational variables such as match location and status, and opposition quality (Lago et al., 2010), together with territoriality (Neave & Wolfson, 2003), tactics, and the expectancy to perform worse away from home (Nevill & Holder, 1999) have been identified as the factors most likely to affect match outcome. Moreover, three specific components of travel are thought to provide an advantage to the home team; the disruption of familiar routines, fatigue from travelling and the
distance travelled, which may also be inversely associated with crowd support (Smith et al., 2000). In particular, the disruption of familiar routines is the main aspect of travel thought to influence competition performance (Smith et al., 2000). For example, it is speculated that the home team may have physiological and psychological advantages over their opposition because they are able to reside at home rather than in an unfamiliar hotel, can sustain a regular sleep pattern as sleep is not affected by travel demands and/or jet-lag, and can maintain normal diet and eating practices (Smith et al., 2000).

Several studies have attempted to determine whether travel is a major factor behind reduced away competition performance in team sports, though to date the evidence is equivocal (Nevill & Holder, 1999). For example, separating travel effects through regression analyses on performance data from team sports has revealed that parameters such as distance travelled and number of time-zones crossed may account for only 1 - 2% of the variance in match outcome (Smith et al., 2000). However in other studies, crossing a greater number of time-zones during domestic air travel for away matches has been significantly correlated with reduced competition performance (Bishop, 2004; Goumas, 2014; Winter et al., 2009). Furthermore, as the time of optimum physical performance is similar to the late afternoon peak in body temperature (Drust et al., 2005), athletes travelling west to east across time-zones for afternoon competition may not perform optimally as their body clock time will be closer to morning time, where the body temperature circadian rhythm will be closer to its nadir and physical performance is reduced (Drust et al., 2005; Leatherwood & Dragoo, 2012). Similarly, athletes travelling east to west across time-zones may have a disadvantage in late afternoon competition given their body clock time will be nearer to bed time, where, as a result of the circadian rhythms in body temperature
and melatonin, the physiological state required for sleep onset is induced (Cajochen et al., 2003; Leatherwood & Dragoo, 2012; Wyatt et al., 1999). Hence, along with the number of time-zones crossed, the time of competition and direction of travel may also influence match outcome (Leatherwood & Dragoo, 2012).

In the highest national football competition in Australia (A-League), a strong positive correlation between home advantage and the number of time-zones crossed by away teams was observed, with home advantage increasing by 20% with each time-zone crossed (Goumas, 2014). Moreover, no association of distance or direction travelled with home advantage was reported, which suggests jet-lag, rather than travel fatigue, could be a reason behind reduced away team performance. However, a limitation of this study was the relatively small number of matches involving away teams that had crossed more than two time-zones, as this is not a regular occurrence in the A-League. During a season in the highest national netball competition in Australia, a point’s difference (difference at home - difference away) was calculated for pairs of games where teams played each other both home and away (Bishop, 2004). No significant differences were observed in the point’s difference between pairs of games where teams travelled for the away match; locally for less than one hour (LT); ~ 1000 - 2000 km, north or south without a time-zone change (NS); ~ 1000 - 2500 km, east or west with a < 2 h time-zone change (EW\(_1\)); or ~ 4000 km, east or west across 2 time-zones (EW\(_2\)). However, a large effect was evident for the point’s difference when EW\(_2\) was compared to LT. Furthermore, a significant difference was reported for points scored away between NS and EW\(_2\), and for points scored at home compared with away for EW\(_2\) (Figure 2.12).
Figure 2.12. Points difference (home margin - away margin) for each pair of games for each of the four groups of travel (Bishop, 2004).
In American Major League Baseball, when a match involved a team that had travelled across three time-zones, the three hour circadian advantage and disadvantage associated with the home and away team, respectively, resulted in a winning percentage of 61% for the home team compared to 42% for the away team (Figure 2.13) (Winter et al., 2009). Furthermore, it was reported that the probability of the home team winning depended on whether the away team had travelled east, and that the home team could expect to score 1.24 (0.79 - 1.69) more runs than usual when this occurred (Recht, Lew, & Schwartz, 1995). Collectively these findings imply that domestic air travel across time-zones may have a negative impact on competition performance and that west coast teams in Australia and America have the double handicap of playing their away games after travelling east across time-zones. However, no physical performance, physiological or perceptual responses were measured in conjunction with competition performance in these studies and therefore, despite the aforementioned evidence based on ‘scoreboard performance’, there is yet to be any verification that travel affects competition performance.
Figure 2.13. Home team winning percentage under relative circadian advantage/disadvantage (Winter et al., 2009).
As evidence of the above concept, previous research has also reported a home advantage in countries with negligible travel demands (distance travelled and number of time-zones crossed), such as England (Pollard, 1986) and Spain (Gomez et al., 2011). Thus, in addition to domestic travel, other factors are likely to influence competition performance (Lago et al., 2010; Neave & Wolfson, 2003; Nevill & Holder, 1999). Indeed, it is suggested that the media, coaches and athletes are more supportive of domestic travel effects than the research literature (Smith et al., 2000). Evidence for a ‘belief effect’ is provided by studies which have identified that coaches and athletes believe that the team’s chances of winning are greater at home compared to away, and that travel prior to a match is one of the main reasons for this (Bray & Widmeyer, 2000; Gayton, Broida, & Elgee, 2001). In addition, both team and individual self-efficacy has been reported to be greater at home compared to away (Bray, Jones, & Owen, 2002). Given greater self-efficacy is associated with increased effort and determination, teams may be able to produce the additional effort required to maintain a lead or come back from a losing position at home, something that may be missing when playing away (Bray et al., 2002). Moreover, considering self-efficacy is affected by past experience, it is proposed that the opposition may also influence psychological states as well as match location (Bray et al., 2002). That said, such theories are rather speculative and lack quantifiable evidence for their effect on competition performance.

The effects of travel on home advantage may even be a social construct and thus, sociological rather than psychological (Smith et al., 2000). It has been suggested that during the prolonged time teams spend together when travelling, they are likely to discuss travel, its associated disruptions and resulting fatigue, which may result in the belief that these factors are more important than they actually are (Smith et al., 2000). Together, results from these studies suggest
that domestic travel is one of a multitude of factors that affect competition performance. In addition, the underlying mechanisms of domestic travel effects may be a combination of physiological, psychological and sociological consequences. Therefore, it is challenging to design studies that control for numerous confounding factors, whilst simultaneously detecting the effects of travel (Smith et al., 2000). For example, team ability is often not taken into account in analyses. Good teams win a higher percentage of their games both at home and away, which may be because they adapt to travel effects better than poorer teams. Thus, team ability may suppress any potential influence of travel (Smith et al., 2000). Therefore, further research is required with study designs that control for confounding factors such as team ability and thus, isolate the effects of domestic travel on integrated performance, physiological and perceptual measures related to competition performance in team sports.

**Effects on key performance indicators and physiological and perceptual responses**

Except for the aforementioned evidence of reduced away competition performance, limited information exists on team sport specific performance at home compared to away. Indeed, only two studies have reported physical performance, physiological and perceptual responses prior to competition and key performance indicators during away matches following domestic air travel (≤ 5 h and ≤ 2 time-zones) compared to at home (McGuckin et al., 2014; Richmond et al., 2007). Professional rugby league players performed more tackles and covered less distance during away compared to home matches, which may indicate greater tactical and technical dominance by the opposition in away matches (McGuckin et al., 2014). However, in contrast, no differences in individual player match statistics, including time between possessions and team assists (kicks, handballs, tackles, shepherds, spoils and knock-on’s) per total minutes played were evident
between home and away matches in professional Australian Football League players (Richmond et al., 2007). Though, coach’s ratings of players’ game performance were higher at home compared to away (Richmond et al., 2007). In addition, no differences in grip strength or squat jump performance were observed on the day prior to or the day of each match at home compared to away (McGuckin et al., 2014). However, whilst grip strength and squat jump tests may be quick and convenient, and therefore, assist with the logistics of testing athletes surrounding travel and competition, they have limited ecological relevance to most team sports, which require prolonged bouts of intermittent-sprint activity (Coutts et al., 2010). Moreover, it could be that the measurement error associated with these short-duration performance assessments is greater than the level of the fatigue induced by short-haul air travel.

Collectively these findings indicate that the tendency for teams to perform better at home compared to away is unlikely to be a result of domestic air travel affecting physical performance during competition. However, in one of the aforementioned studies data was only collected from four consecutive alternating home and away matches against different opposition (McGuckin et al., 2014). Therefore, opposition quality could have had a major bearing on tactical and technical performance, along with match outcome, masking any potential effects of domestic air travel. As a result of these limitations and the minimal data available, further research involving pairs of games, where teams play each other both at home and away, is required to attempt to control for the effects of opposition quality on match outcome and substantiate the impact of domestic air travel on key performance indicators and sport specific performance measures.
Since the disruption of normal sleep patterns may impair physical performance (Skein et al., 2011) and travel across time-zones has the potential to reduce sleep quantity and quality (Beaumont et al., 2004), detrimental effects of repeated domestic air travel across time-zones on sleep has been suggested as a potential cause of reduced away competition performance (Richmond et al., 2007). However, compared to at home, no differences in actigraphy measures (sleep duration and efficiency, number of wake episodes and mean wake duration) were observed on the night prior to competition following eastward air travel of up to 5 h or 3500 km, across two time-zones (Richmond et al., 2007). Despite no difference in objective measures of sleep, perceived sleep quality was reported to be reduced on the night prior to competition (Richmond et al., 2007). Furthermore, correlations between all sleep variables and indicators of match performance were small and non-significant (Richmond et al., 2007). These results may indicate that the demands of short-haul air travel for away matches in Australian team sport competitions may be insufficient to induce substantial sleep disturbances. However, given the limited data available and the importance of sleep for optimal physical performance (Halson, 2013), further research is warranted into the effects of domestic air travel on objective sleep measures.

In agreement with the aforementioned reduction in perceived sleep quality (Richmond et al., 2007), following air travel of 3.1 ± 1.2 h south across no time-zones, negative perceptual states, assessed through the daily analyses of life demands for athletes, together with reduced alertness were evident on the day prior to competition compared to a similar time at home (McGuckin et al., 2014). Specifically, worse than normal responses for tiredness, need for a rest, boredom, irritability, general weakness and running nose were identified, which suggests that symptoms of
travel fatigue were present following domestic air travel. Together, these data imply that the underlying mechanisms of domestic air travel effects on match outcome are, if any, likely to be perceptual rather than physiological. Due to the relatively short duration of domestic air travel ($\leq 5$ h and $\leq 2$ time-zones), these negative perceptual effects are probably a result of the stressors associated with the process of travel and the disruption of normal routines, rather than the plane cabin environmental and atmospheric conditions (Figure 2.1). For example, a reduction in subjective, but not objective sleep quality following domestic air travel suggests that sleeping in unfamiliar surroundings may have a greater impact compared to physiological effects of travel (Richmond et al., 2007). That said, perceptual responses were similar prior to competition on match day at home compared to away (McGuckin et al., 2014; Richmond et al., 2007). Therefore it is unlikely the aforementioned negative perceptual states affected match outcome.

Considering the negligible impact of domestic air travel *per se* on physical performance, physiological and perceptual responses (McGuckin et al., 2014; Richmond et al., 2007), by default, the impact of other situational variables is a more plausible explanation of reduced away competition performance, especially given match location and opposition quality may influence team tactics and therefore, technical and tactical performance indicators (Lago et al., 2010). However, whilst speculative and difficult to detect, the sum of minor effects of travel related disruptions on individual athletes may have a cumulative impact on team sport competition performance (Richmond et al., 2007). Therefore, given the limited research to date (McGuckin et al., 2014; Richmond et al., 2007), further investigations are necessary to confirm the impact of domestic air travel on sleep quantity and quality, perceptual responses and ensuing team sport specific performance.
Effects on recovery

As a result of domestic team sport competition schedules, domestic air travel is often a necessity for professional teams the day after an away match, which is typically the largest physical load of the training week. This is particularly evident in Australia and North and South America, where large distances are travelled by away teams for competition (Goumas, 2014). Team sport competition involves numerous physically demanding activities and thus, induces acute fatigue and physical performance decrements (Coutts et al., 2010; Duthie et al., 2003; Nédélec et al., 2013). A progressive return to pre-match state occurs during the recovery process, but this may take more than 72 h (McLean et al., 2010; Nédélec et al., 2013). Given the limited time between matches and subsequent training and competition, various recovery procedures are commonly used to regain optimal performance faster (Nédélec et al., 2013). However, as domestic air travel may induce minor acute physiological and perceptual stress (McGuckin et al., 2014; Richmond et al., 2007; Waterhouse et al., 2004), and the disruption of routines could inhibit the use of recovery interventions, the recovery process following away matches may be impeded. Moreover, evidence suggests that due to the time lost as a result of travel the day after an away match, the periodisation of training loads in the days leading into subsequent competition is likely to be altered compared to following a home match (Kelly & Coutts, 2007). Together with impeded recovery, this could reduce player wellness and readiness to perform and thus, increase the risk of injury (Gastin et al., 2012). Hence, acute detrimental effects of domestic air travel on recovery and training may have a negative impact on preparation for subsequent competition.
Considering the acute intangible effects of domestic air travel and the need for frequent travel to and from away matches throughout a competitive season for professional teams (Goumas, 2014; McGuckin et al., 2014; Richmond et al., 2007), it has been proposed that travel fatigue may accumulate during the season (Samuels, 2012). For example, throughout a 27 week season, professional football teams in Australia are required to travel up to 5 h or 3500 km by air, 26 times (Goumas, 2014). Therefore, it could be hypothesised that the acute minor effects of domestic air travel on perceptual responses, together with potential disruptions to recovery and training may be exacerbated across a season, resulting in reduced athlete preparedness and thus, increased injury risk in the late compared to the early competition phase. However, to date, no studies have investigated the effects of post-competition travel on the acute recovery timeline or whether the summation of acute intangible effects of domestic travel throughout a season impact player readiness to perform and/or injury incidence. Given the importance of recovery for subsequent physical performance, and the limited preparation time between matches and ensuing training or competition, this is an area that requires further investigation.

**Interventions**

With domestic air travel reported to have a detrimental impact on match outcome (Bishop, 2004; Goumas, 2014; Winter et al., 2009), psychological states such as self-efficacy (Bray et al., 2002) and perceptual responses (McGuckin et al., 2014; Richmond et al., 2007), the implementation of evidence-based, practical interventions to attenuate these effects in team sport athletes is worthwhile. However, to date, only generic recommendations on how to overcome travel fatigue are available for athletes (Figure 2.10) (Reilly et al., 2007a; Waterhouse et al., 2007). Moreover, no studies have investigated the effects of these recommendations on the incidence of travel
fatigue symptoms and recovery of sport specific performance following domestic air travel. The provision of these generic recommendations is likely a result of the limited understanding of the effects of domestic air travel on sport specific performance and associated mechanisms, together with the impact of return travel on athlete recovery. Accordingly, an improved understanding, through studies investigating the effects of outbound and return domestic air travel on integrated performance, physiological and perceptual measures related to competition performance, could lead to the development of more detailed, evidence-based domestic travel guidelines for team sport athletes.

**Summary**

The demands of international air travel *per se*, combined with the loss of synchrony between endogenous circadian rhythms and external cues following travel, may induce adverse physiological (Beaumont et al., 2004; Coste et al., 2009; Pierard et al., 2001) and perceptual (Bullock et al., 2007; Muhm et al., 2007; Waterhouse et al., 2000) responses, which could in turn, suppress physical performance (Chapman et al., 2012; Edwards et al., 2000; Reilly et al., 2001). In addition, evidence from laboratory-based research indicates both pharmacological (Arendt et al., 1986; Buxton et al., 2000; Samel et al., 1991) and behavioural (Eastman et al., 2005; Gronfier et al., 2004; Yamanaka et al., 2010) interventions can induce phase-shifts in circadian rhythms and hence, theoretically attenuate these detrimental effects. Though, due to potential side effects (Beaumont et al., 2004; Reilly et al., 2001), behavioural interventions are currently preferred over pharmacological aids for use with travelling athletes (Forbes-Robertson et al., 2012). However, to date, negligible field-based studies have examined; (1) the recovery of team sport specific performance; or (2) the efficacy of behavioural interventions, particularly
bright light exposure, at enhancing recovery following international air travel. Furthermore, limited research exists on the impact of international air travel demands on team sport specific performance, measured in conjunction with physiological and perceptual markers of fatigue. As a result, few evidence-based interventions are available to attenuate these demands, especially the disruption of sleep patterns (Takahashi et al., 2002). Therefore, further research is warranted into the effects of the demands of international air travel on the recovery of team sport specific performance, together with the development of behavioural interventions to reduce the impact of these demands in team sport athletes.

The tendency for teams to perform better at home compared to away has consistently been reported in domestic competitions from a range of team sports (Bishop, 2004; Goumas, 2014; Richmond et al., 2007). Whilst domestic air travel is believed to provide an advantage to the home team (Smith et al., 2000), evidence suggests that, as a result of lower demands compared to international air travel, it may cause negligible physiological and perceptual disruptions (McGuckin et al., 2014; Richmond et al., 2007). However, given the limited and equivocal data, further research into the effects of domestic air travel on technical and tactical performance indicators during matches, in conjunction with physiological and perceptual responses would enhance the current understanding of the impact of domestic air travel on competition performance. Furthermore, considering domestic air travel is often a necessity for professional teams the day after an away match and the importance of recovery for subsequent physical performance, further research is warranted into whether domestic air travel impedes player’s physiological and perceptual recovery.
Chapter Three
Study One

Effects of simulated domestic and international air travel on
sleep, performance and recovery for team sports

Based on the publication;

Abstract

Aims: Examine the effects of simulated air travel on team sport physical performance. Methods: In a randomised crossover design, ten physically active males completed a simulated 5h domestic flight (DOM), 24h simulated international travel (INT), and a control trial (CON). The mild hypoxia, seating arrangements and activity levels typically encountered during air travel were simulated in a normobaric, hypoxic altitude room. Physical performance was assessed in the afternoon of the day before (D-1 PM) and in the morning (D+1 AM) and afternoon (D+1 PM) of the day following each trial. Mood states and physiological and perceptual responses to exercise were also examined at these time points, whilst sleep quantity and quality were monitored throughout each condition. Results: Sleep quantity and quality were significantly reduced during INT compared with CON and DOM (P<0.01). Yo-Yo Intermittent Recovery level 1 test performance was significantly reduced at D+1 PM following INT compared with CON and DOM (P<0.01), where performance remained unchanged (P>0.05). Compared to baseline, physiological and perceptual responses to exercise, and mood states were exacerbated following the INT trial (P<0.05). Conclusions: Attenuated intermittent-sprint performance following simulated international air travel may be due to sleep disruption during travel and the subsequent exacerbated physiological and perceptual markers of fatigue.
Introduction

Air travel is an additional stress frequently imposed on elite athletes’ competition and training schedules. Whilst domestic air travel of up to 5 h may be required for ‘away’ competition, particularly for athletes in America and Australia (Richmond et al., 2007; Winter et al., 2009), international air travel to major sporting competitions or training camps can take up to and greater than 24 h (Bullock et al., 2007; Lemmer et al., 2002; Reilly et al., 2001). Reduced physical performance (Chapman et al., 2012; Lemmer et al., 2002; Reilly et al., 2001), adverse changes in physiological variables, including sleep (Beaumont et al., 2004; Bullock et al., 2007; Lemmer et al., 2002) and exacerbated mood states, such as increased subjective fatigue (Reilly et al., 2001; Waterhouse et al., 2002) have been reported following international transmeridian air travel. Conversely, negligible effects of domestic air travel have been identified on these variables (McGuckin et al., 2014; Richmond et al., 2007). However, as yet the integration of performance, physiological and perceptual measures, related to intermittent-sprint activities and thus, training and competition in team sports are yet to be obtained following either domestic or international air travel.

From the limited information available, the effects of domestic air travel on exercise performance appear to be minimal, with no changes in grip strength or squat jump performance detected following travel of up to 5 h without changes in time-zones (McGuckin et al., 2014). Consequently, further research is required to confirm the effects of domestic air travel, with and without changes in time-zones, on physical performance measures. In contrast, a reduction in grip strength has consistently been observed following eastward and westward international transmeridian air travel (Edwards et al., 2000; Lemmer et al., 2002; Reilly et al., 2001).
Conflicting results have been reported for jump performance, with a decrease (Chapman et al., 2012) and no change (Lagarde et al., 2001) previously demonstrated following 18 h and 10 h of eastward international air travel, respectively. Moreover, no change in 30 m sprint performance was identified following 18 h of eastward international air travel (Bullock et al., 2007). These equivocal findings may relate to the inter-individual variation in responses to the duration and direction of travel (Waterhouse et al., 2002), together with the type, sensitivity, timing and frequency of the tests conducted (Bullock et al., 2007; Lagarde et al., 2001). Furthermore, whilst the predominance of grip strength and jump tests as physical performance measures may assist with testing logistics, they have limited ecological relevance to most team sports, which require prolonged bouts of intermittent-sprint activity (Coutts et al., 2010).

When multiple time-zones are rapidly crossed during air travel, body temperature (Lemmer et al., 2002; Reilly et al., 2001; Waterhouse et al., 2002) and hormonal circadian rhythms (Bullock et al., 2007; Lemmer et al., 2002; Pierard et al., 2001), along with the sleep-wake cycle (Beaumont et al., 2004) are disrupted. These changes induce the detrimental physiological and perceptual symptoms of jet-lag (Forbes-Robertson et al., 2012; Reilly et al., 2007a; Waterhouse et al., 2007). In contrast, the adverse physiological and perceptual symptoms of travel fatigue are a result of the demands of travel per se, including prolonged exposure to mild hypoxia, cramped conditions and sleep disruption (Forbes-Robertson et al., 2012; Reilly et al., 2007a; Waterhouse et al., 2007). Symptoms of jet-lag and travel fatigue have also been observed following prolonged exposure to mild hypoxia for up to 20 h (Coste et al., 2005; Coste et al., 2009; Muhm et al., 2007). However, separating the effects of jet-lag and travel fatigue is difficult in field-based environments and the combined effects of all the aforementioned travel demands are yet to
be determined under simulated, controlled conditions. Increased physiological and perceptual fatigue may reduce team sport performance following air travel. However, as the majority of research reports singular physiological or perceptual responses, with little relation to the physical performance demands of team sports, this is yet to be conclusively determined. Therefore, further research is required to clarify the physiological and perceptual responses to the demands of travel under simulated, controlled conditions and the subsequent impact on intermittent-sprint performance.

Consequently, the purpose of the present study was to investigate the effects of simulated domestic and international travel demands, including prolonged exposure to mild hypoxia, cramped conditions and change in time-zones, on the recovery of team sport physical performance and physiological and perceptual fatigue.

**Methods**

**Participants**

Ten healthy physically active males were recruited to participate in the present study; mean (95 % confidence intervals, CI); age 23.9 (22.2-25.6) y, body mass 79.2 (72.8-85.6) kg and estimated \( \dot{V}O_{2\text{max}} \) 52.8 (50.4-55.2) ml\cdot min\(^{-1}\) (Bangsbo, Iaia, Krustrup, 2008). Participants were free of sleep disorders and did not consume large doses of caffeine or alcohol. In addition, participants were non-smokers, medication free, and had not undertaken shift work or any long-haul transmeridian flights in the month prior to the study. Participants’ compliance with the study’s inclusion and exclusion criteria was determined from a general health questionnaire and an interview with a member of the research team. Prior to the commencement of the study,
participants were informed of any associated risks and provided verbal and written informed consent. The study was approved by the institutional Human Research Ethics Committee.

**Experimental Design**

Following a minimum of two familiarisation sessions, participants completed three trials in a randomised order. The trials included; (1) a simulated 5 h domestic flight (DOM), similar to travel from Sydney to Perth, Australia; (2) 24 h of simulated international travel (INT), consisting of a 9 h and 13 h flight separated by a two hour stopover, replicating the demands of travel from Sydney, Australia to London, England; and (3) a control trial (CON) during which no simulated air travel was completed, but participants still reported to the laboratory (Figure 3.1).

Collection of baseline performance, physiological and perceptual data occurred at a standardised time in the afternoon (16:00 Australian Eastern Standard Time, AEST) of the day prior to each trial (D-1 PM), followed 24 h later by the commencement of the simulated travel or CON trial, termed the day of travel (DT). Physiological and perceptual data were obtained immediately pre, during, and post simulated air travel, and at the same time points throughout the CON trial. Performance, physiological, and perceptual measures were again obtained at standardised times (09:00 and 16:00 AEST) in the morning (D+1 AM) and afternoon (D+1 PM) of the day following the simulated travel and CON trial. This corresponded to 23:00 and 06:00 London time in the INT trial (Figure 3.1). Whilst these times attempted to standardise for the diurnal variation in physical performance (Drust et al., 2005), it is acknowledged that competition the day after international travel is unlikely. Therefore, the absence of measures on ensuing days is recognised as a limitation of the present study.
Figure 3.1. Schematic outline of the study design illustrating the timing of performance, physiological and perceptual data collection, and the duration of the three conditions; simulated domestic air travel (DOM), simulated international air travel (INT) and no simulated air travel (CON).
Data were collected over three consecutive days (Monday to Wednesday) for the DOM and CON trials, and four consecutive days for the INT trial (Monday to Thursday). On each day during the DOM and CON trial, participants slept according to night time AEST (i.e. 22:00 to 07:00) at home and were free to choose their own bed and wake times. Conversely, on the days of travel in the INT trial (Tuesday and Wednesday), participants slept on the simulated flight in a hypoxic altitude room (refer to ‘simulated travel’ section), and were free to choose their own sleep times. Moreover, on the day following the simulated travel in the INT trial (Thursday), participants slept at home, where their bed and wake times were standardised according to the destination time (London), which corresponded to 10:30 to 15:00 AEST (between the morning and afternoon performance testing at 09:00 and 16:00 AEST). This was following 18 h of forced wakefulness between the end of the simulated INT travel (Wednesday 16:00 AEST) and the end of D+1 AM testing (Thursday 10:00 AEST) (refer to ‘simulated travel’ section). Following the D+1 PM testing in the INT trial, participants sleep schedule returned to normal (i.e. participants slept according to night time AEST at home and were free to choose their own bed and wake times). Each trial was separated by one week to ensure adequate recovery time. Physical activity and nutritional intake were documented 24 h prior to the first trial and replicated for all subsequent trials. Participants abstained from caffeine, alcohol and additional strenuous activity for 24 h before, during and 24 h following all trials.

**Simulated Travel**

Participants completed the DOM and INT trials as a group in a normobaric, hypoxic altitude room (Kinetic Performance Technologies, Canberra, Australia), with no exposure to natural light. The simulated altitude (2093 (2076-2110) m) via nitrogen dilution, temperature (20.2
(19.6-20.8) °C) and seating arrangement replicated what is typically encountered during an actual commercial flight (Hamada et al., 2002; Muhm et al., 2007). The chairs used (Cycloid Vibration Therapy Chair, Niagara, Meadowbrook, Australia) had a pitch and width of 117 and 90 cm, respectively. The fraction of inspired oxygen ($F_{O_2}$) during simulated travel was 0.17 (0.16-0.18) %, as is representative of the $F_{O_2}$ during actual airline travel (Coste et al., 2009). Activity was regulated to simulate the activity patterns of passengers during an actual commercial flight. Specifically, participants were permitted to watch movies, read, listen to music or play handheld computer and card games, but remained seated at all times other than when using the bathroom (located in the adjacent room). Furthermore, lighting was dimmed (36 (18-54) lux) and raised (113 (103-123) lux), and meals/fluid were served to participants according to a typical commercial flight schedule. Specifically, a main meal similar in content and packaging to standard airline food was provided 30 min into the simulated DOM travel, and 30 min and 6.5 h into the first leg, and 30 min and 10.5 h into the second leg of the simulated INT travel. Additional fluid was offered at 2.5 h during the simulated DOM travel and 2.5 h, 4 h and every subsequent hour during both legs of the simulated INT travel. Nutritional intake was documented by participants throughout all trials via dietary recall, which was analysed using nutrient analysis software (FoodWorks®, Xyris Software Pty Ltd, Kenmore Hills, Australia). Please refer to Appendix C for photographic examples of the simulated travel environment.

The hypoxic room, within which the simulated travel was completed, formed part of an altitude house. During the INT trial, all natural light and external influences were blocked out of the house. To simulate the change in time-zones, all clocks in the testing area were altered to show the destination time (London, England) from the beginning of the first leg of travel to the end of
the trial. During the two hour stopover, participants exited the house and were permitted to move around freely in normoxia, as they would at a stopover destination during actual travel. Furthermore, when the simulated INT travel was completed at 16:00 AEST on day three, the corresponding time in London was 06:00. Therefore, to simulate a morning arrival in London, participants were required to remain awake overnight (AEST) in the altitude house with the lights on (164 (131-197) lux). However, it is acknowledged as a limitation that this does not represent normal daylight. During this time, participants were permitted to move around freely in normoxia and were provided with breakfast, lunch, and dinner according to London time. During the CON trial, measures were obtained at the same time points, however participants were not required to complete any simulated travel. Instead, participants were permitted to complete a normal sedentary day and only reported to the laboratory when measurements were required. Whilst recorded, food and fluid intake were not controlled during this time period.

**Experimental Procedures**

**Physical performance**

Prior to the collection of physical performance data, a warm-up consisting of the 5´-5´ test (Buchheit, Voss, Nybo, Mohr, & Racinais, 2011), involving 5 min of standardised sub-maximal exercise and 5 min seated recovery, followed by 10 min of general whole body movements was completed (Taylor, Cronin, Gill, Chapman, & Sheppard, 2010). All performance testing sessions were performed on an enclosed synthetic running track in temperate conditions. Participants completed a countermovement jump (CMJ) test (Taylor et al., 2010), followed by the Yo-Yo Intermittent Recovery level 1 test (YYIR1) (Krustrup et al., 2003), to assess neuromuscular and intermittent-sprint performance, respectively. Jump height, peak power, and peak velocity for the
concentric phase of the CMJ were measured using a linear position transducer (GymAware, Kinetic Performance Technologies, Canberra, Australia) sampling at 50 Hz, attached to a 1.5 m long, 0.5 kg aluminium bar held firmly across the shoulders during each jump. The typical error (TE) of these measures in the present study was 1.8 (1.4-2.5) cm, 420 (328-584) W and 0.15 (0.12-0.21) m·s\(^{-1}\) respectively. During the YYIR1, performance was determined by total distance covered at the point of volitional exhaustion, which has been identified as a reliable measure of team sport physical performance (Krstrup et al., 2003) and had a TE of 145 (113-202) m in the present study.

**Physiological measures**

Participants’ sleep was monitored using self-report diaries and wrist activity monitors (ReadiBand™, Fatigue Science, Honolulu, Hawaii) for two days prior to, during and two days following each trial. In studies that involve data collection from multiple participants simultaneously over consecutive nights, activity monitors are typically preferred over polysomnography (PSG), the gold standard for monitoring sleep, because they are portable, non-invasive and operate remotely without an attendant technician. Validation studies comparing wrist activity monitors with PSG report high correlations for sleep duration \((r=0.84-0.89)\) (Weiss, Johnson, Berger, & Redline, 2010). Using customised manufacturers software (Sleep Analyser, Fatigue Science, Honolulu, Hawaii) data from the activity monitors was used in conjunction with information from the sleep diaries to determine participants’ quantity and quality of sleep. Sleep during both legs of the simulated INT travel was summed and is reported under the day of travel (DT) in Table 3.1.
Oxygen saturation was recorded whilst seated with a pulse oximeter (Nonin 4000 Avant Bluetooth Pulse Oximeter, Nonin, North Plymouth, MN) for 10 min immediately prior to, continuously throughout, and for 10 min immediately following the simulated DOM and INT travel, and at matched time points during the CON trial. Additional readings were recorded for 10 min at 2.5 h and 5 h after the simulated INT travel and at the same time during the CON trial. Data was subsequently downloaded using device specific software and a mean oxygen saturation value was obtained at specific time points (Figure 3.1). To assess urine specific gravity (USG), a midstream urine sample was collected immediately prior to all performance testing sessions, immediately before and after the simulated DOM and INT travel, and at matched time points during the CON trial (Refractometer 503, Nippon Optical Works, Co., Tokyo, Japan). Given that confounding factors, such as diet, can affect the reliability of USG as a measure of hydration status (Shirreffs & Maughan, 1998), caution was applied when interpreting the results from samples that were not of the first void (urination) of the morning following an overnight fast.

To obtain an indication of lower-limb muscle swelling, mid-thigh and mid-calf girths were measured (Lufkin®, Apex Tool Group, Apex, NC) in duplicate at the same time points as USG, except for prior to the performance tests at baseline. Measurement sites were standardised based on those previously described for the mid-thigh and mid-calf (Norton et al., 1996). Heart rate (HR) was measured (Polar Team², Polar Electro, Kempele, Finland), continuously throughout the 5´-5´ and YYIR1 tests, and was analysed using customised manufacturers software (Polar Team System 2, Polar Electro, Kempele, Finland). Heart rate during (HRex) and recovery (HRR) following the 5´-5´ test (Buchheit et al., 2011), and maximum HR (HRmax) during the YYIR1
was recorded. The TE for HRex and HRR in the present study was 5 (4-7) beats per minute (bpm) and 9 (7-13) bpm, respectively.

**Saliva collection and analysis**

Saliva samples were collected via passive drool immediately upon and 30 min post-waking and immediately prior to bed, one day prior to (D-1), the day(s) of (DT) and one (D+1) day following the simulated travel and CON trial. For all collections, participants remained seated and refrained from ingesting any fluid for 10 min prior. Participants were instructed to swallow and then, whilst making minimal orofacial movement, dribble saliva into a sterile vial for a minimum of three minutes or until one millilitre was collected. Saliva samples were sealed and stored in a -20°C freezer until analysed. Cortisol concentration was determined according to the manufacturer’s instructions provided in the respective assay kits (ELISA, Demeditec Diagnostics, Kiel, Germany), by enzyme-linked immunosorbent assay, and using a microplate reader (VICTOR³, PerkinElmer Inc, Waltham, MA) and associated software (WorkOut 2.5, Dazdaq Ltd, Brighton, England). Intra-assay coefficients of variation were less than 5 % for all analyses.

**Perceptual measures**

The Brunel Mood Scale (Galambos et al., 2005) was used to assess mood states before and after all performance testing sessions. Perceived whole-body fatigue and muscle soreness were also assessed on a Likert scale (Hooper, Mackinnon, Howard, Gordon, & Bachmann, 1995) at the aforementioned time points. Approximately 30 min after the completion of the physical
performance tests, a session rating of perceived exertion (sRPE) (Foster, Daines, Hector, Snyder, & Welsh, 1996) and physical feeling (Hardy & Rejeski, 1989) were obtained from participants.

Statistical Analysis

Data are presented as mean (95% CI). The TE of measurement was determined using a commercially available Excel spreadsheet for calculations of reliability (http://www.sportsci.org/resource/stats/xrely.xls). For YYIR1 and CMJ performance, and mid-calf and mid-thigh girth, the effect of time and trial was assessed by fitting a linear mixed model to the absolute change from baseline. For all other variables, a linear mixed model was fitted to the raw data. Specifically, time and trial, and their interaction were fitted as fixed effects to determine whether there was a difference in the effect of trial over time. In addition, participant and trial (within participant) were fitted as random effects to account for the possible correlation within participants and within trial within participants. Statistical significance was accepted at $P<0.05$. Where a significant effect was observed, a Tukey HSD post-hoc test was used to determine differences between means. Analyses were performed using JMP statistical software (JMP Pro v 10.0, SAS, Cary, NC).

Results

Physical performance

No significant differences were observed between trials in YYIR1 performance at D+1 AM ($P>0.05$). However, participants covered significantly less distance at D+1 PM following the INT trial compared to the DOM and CON trials ($P<0.01$; Figure 3.2). No significant differences were detected between trials for CMJ height, peak power or peak velocity ($P>0.05$; Figure 3.2).
Figure 3.2. Effect of simulated air travel on intermittent-sprint and neuromuscular performance. Mean change from baseline (95% CI) in the YYIR1 (A) and CMJ height (B), peak power (C) and peak velocity (D) in the morning (D+1 AM) and afternoon (D+1 PM) of the day following the CON (white diamond), DOM (grey square) and INT (black circle) trials.*Significantly different to CON (P<0.01). †Significantly different to DOM (P<0.01). Grey shaded area indicates typical error of the measure.
Physiological measures

Sleep duration and efficiency were significantly reduced, and the duration of awakenings was significantly greater during the INT trial compared with the first night following the DOM and CON trials ($P<0.01$; Table 3.1). No significant differences existed between trials for sleep latency or number of awakenings ($P>0.05$). Oxygen saturation was significantly lower during the DOM and INT trials compared with the CON trial ($P<0.05$; Figure 3.3). Furthermore, oxygen saturation remained significantly suppressed immediately following the second leg of the INT trial, when compared with the same time point in the CON trial ($P<0.05$). Compared to pre-travel, USG was significantly lower post-travel, in the DOM (1.023 (1.019-1.027) vs. 1.012 (1.010-1.014); $P<0.05$) and INT (1.020 (1.016-1.024) vs. 1.008 (1.006-1.010); $P<0.01$) trials. However, there were no significant differences between trials ($P>0.05$). Change in mid-calf girth was significantly greater post-travel in the INT compared to the CON trial ($P<0.05$; Table 3.2). Conversely, change in mid-calf girth was significantly lower at D+1 PM, following the INT trial compared with the CON trial ($P<0.05$). Compared to baseline, mid-thigh girth was significantly greater immediately following the INT trial and at D+1 AM ($P<0.05$; Table 3.2). However, there were no significant differences between trials ($P>0.05$).
Table 3.1. Mean (95% CI) for sleep volume and quality for the CON, DOM and INT trials for the two days prior to travel (D-2 and D-1), the day of travel (DT) and the two days following travel (D+1 and D+2).

<table>
<thead>
<tr>
<th></th>
<th>D-2</th>
<th>D-1</th>
<th>DT</th>
<th>D+1</th>
<th>D+2</th>
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<tr>
<td><strong>Sleep duration (h)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>7.2 (6.2 - 8.2)</td>
<td>7.1 (6.3 - 7.9)</td>
<td>6.7 (5.8 - 7.6)</td>
<td>7.6 (6.7 - 8.5)</td>
<td>7.0 (6.3 - 7.7)</td>
</tr>
<tr>
<td>DOM</td>
<td>7.1 (5.8 - 8.4)</td>
<td>6.9 (6.0 - 7.8)</td>
<td>6.7 (5.9 - 7.5)</td>
<td>6.6 (6.0 - 7.2)</td>
<td>7.6 (6.4 - 8.8)</td>
</tr>
<tr>
<td>INT</td>
<td>6.4 (5.5 - 7.3)</td>
<td>6.9 (5.7 - 8.1)</td>
<td>2.5 (1.7 - 3.3)*</td>
<td>12.6 (11.2 - 14.0)**</td>
<td>5.6 (4.0 - 7.2)</td>
</tr>
<tr>
<td><strong>Sleep latency (min)</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CON</td>
<td>27 (14 - 40)</td>
<td>26 (12 - 40)</td>
<td>12 (9 - 15)</td>
<td>17 (11 - 23)</td>
<td>18 (12 - 24)</td>
</tr>
<tr>
<td>DOM</td>
<td>14 (13 - 15)</td>
<td>16 (7 - 25)</td>
<td>17 (8 - 26)</td>
<td>18 (7 - 25)</td>
<td>16 (10 - 22)</td>
</tr>
<tr>
<td><strong>Sleep efficiency (%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>80 (70 - 90)</td>
<td>82 (75 - 89)</td>
<td>86 (78 - 94)</td>
<td>83 (77 - 89)</td>
<td>83 (75 - 91)</td>
</tr>
<tr>
<td>DOM</td>
<td>82 (70 - 94)</td>
<td>83 (77 - 89)</td>
<td>85 (77 - 93)</td>
<td>86 (78 - 92)</td>
<td>85 (78 - 92)</td>
</tr>
<tr>
<td>INT</td>
<td>81 (73 - 89)</td>
<td>82 (75 - 89)</td>
<td>55 (45 - 65)*</td>
<td>87 (82 - 93)</td>
<td>81 (71 - 91)</td>
</tr>
<tr>
<td><strong>Number of awakenings</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>5 (2 - 8)</td>
<td>4 (2 - 6)</td>
<td>4 (2 - 6)</td>
<td>3 (1 - 5)</td>
<td>5 (2 - 8)</td>
</tr>
<tr>
<td>DOM</td>
<td>4 (0 - 8)</td>
<td>4 (2 - 6)</td>
<td>3 (1 - 5)</td>
<td>4 (2 - 6)</td>
<td>5 (2 - 8)</td>
</tr>
<tr>
<td>INT</td>
<td>4 (1 - 7)</td>
<td>4 (2 - 6)</td>
<td>4 (2 - 6)</td>
<td>5 (3 - 7)</td>
<td>4 (1 - 7)</td>
</tr>
<tr>
<td><strong>Duration of awakenings (min)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>14 (6 - 22)</td>
<td>10 (5 - 15)</td>
<td>7 (4 - 10)</td>
<td>11 (5 - 17)</td>
<td>13 (9 - 17)</td>
</tr>
<tr>
<td>DOM</td>
<td>8 (2 - 14)</td>
<td>9 (7 - 11)</td>
<td>11 (8 - 14)</td>
<td>9 (4 - 14)</td>
<td>10 (7 - 13)</td>
</tr>
<tr>
<td>INT</td>
<td>9 (3 - 15)</td>
<td>11 (8 - 14)</td>
<td>29 (18 - 40)**</td>
<td>9 (5 - 13)</td>
<td>6 (3 - 9)</td>
</tr>
</tbody>
</table>

*Significantly different to CON (P<0.01). †Significantly different to DOM (P<0.01).
Figure 3.3. Physiological responses to simulated air travel. Mean (95% CI) oxygen saturation (A) and salivary cortisol concentration (B) for the CON (dotted line and white diamond), DOM (solid grey line and square) and INT (solid black line and circle) trials. Salivary cortisol concentration was measured immediately upon and 30 min post-waking (W), and immediately prior to bed (Bed) on the day before (D-1), the day of (DT) and the day after (D+1) each trial. †Significantly different from in the morning on D-1 and DT in the INT trial (P<0.05). ✝DOM significantly different to CON (P<0.01). ♯INT significantly different to CON (P<0.05).
Table 3.2. Mean change from baseline (95% CI) in lower body limb girths for the CON, DOM and INT trials, immediately post-travel (Post-Travel) and the morning (D+1 AM) and afternoon (D+1 PM) of the day after travel.

<table>
<thead>
<tr>
<th></th>
<th>Post-Travel</th>
<th>D+1 AM</th>
<th>D+1 PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-calf girth (cm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>-0.2 (-0.4, 0.0)</td>
<td>-0.4 (-0.6, -0.2)</td>
<td>-0.1 (-0.3, 0.1)</td>
</tr>
<tr>
<td>DOM</td>
<td>-0.1 (-0.3, 0.1)</td>
<td>-0.5 (-0.6, -0.4)</td>
<td>-0.4 (-0.5, -0.3)</td>
</tr>
<tr>
<td>INT</td>
<td>0.3 (0.1, 0.5)*</td>
<td>-0.3 (-0.5, -0.1)</td>
<td>-0.6 (-0.9, -0.3)*</td>
</tr>
<tr>
<td>Mid-thigh girth (cm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>-0.2 (-0.5, 0.1)</td>
<td>-0.3 (-0.6, 0.0)</td>
<td>-0.1 (-0.4, 0.2)</td>
</tr>
<tr>
<td>DOM</td>
<td>-0.2 (-0.5, 0.1)</td>
<td>-0.3 (-0.6, 0.0)</td>
<td>-0.2 (-0.7, 0.3)</td>
</tr>
<tr>
<td>INT</td>
<td>0.1 (0.0, 0.2)†</td>
<td>0.0 (-0.2, 0.2)†</td>
<td>-0.3 (-0.6, 0.0)</td>
</tr>
</tbody>
</table>

*Significantly different to D+1 PM (P<0.05). †Significantly different to CON (P<0.05)
Compared to baseline (148 (140-156) bpm), HRex was significantly increased at D+1 AM (156 (147-165) bpm); $P<0.05$ and D+1 PM (158 (149-167) bpm); $P<0.01$ following the INT trial. There were no significant differences between trials for HRex, and no significant effects of time or trial, or associated interaction for HRR and HRmax ($P>0.05$). As no significant differences were observed between immediately upon and 30 min post-waking salivary cortisol concentrations ($P>0.05$), a mean of the two values was calculated and analysed. A significant diurnal variation was apparent, with increased values identified in the morning and reduced values in the evening ($P<0.01$; Figure 3.3). Moreover, following the INT trial, cortisol concentrations were significantly lower in the morning on D+1 compared with D-1 and DT ($P<0.05$). However, there were no significant differences between trials ($P>0.05$).

**Perceptual measures**

Compared to baseline, whole-body fatigue was significantly greater at D+1 AM ($P<0.01$) and D+1 PM ($P<0.05$) following the INT trial, which was significantly different to the CON trial at D+1 AM ($P<0.05$; Table 3.3). Muscle soreness was significantly increased at D+1 PM following the DOM trial compared to baseline ($P<0.01$), though this was not significantly different to the INT or CON trial ($P>0.05$). There were no significant differences between trials for anger and confusion ($P>0.05$), though compared to baseline, anger was significantly greater at D+1 AM ($P<0.01$) and confusion was significantly greater at D+1 AM ($P<0.01$) and PM ($P<0.05$) following the INT trial. Depression ($P<0.05$) and fatigue ($P<0.01$) were both significantly greater at D+1 AM following the INT trial compared with the DOM and CON trials. Compared to baseline, vigour was significantly lower at D+1 AM following the INT trial ($P<0.05$).

Compared to baseline (5.9 (4.7-7.1), sRPE was significantly greater at D+1 AM (8.2 (6.2-7.2))
and D+1 PM (7.8 (7.0-8.6) following the INT trial ($P<0.05$). Physical feeling was significantly lower following the INT trial at D+1 AM (-2.8 (-4.3, -1.3) and D+1 PM (-2.5 (-3.6, -1.4) compared to baseline (0.8 (-0.2, 2.4) ($P<0.05$).

**Nutrition**

Energy (kJ) intake was significantly greater ($P<0.05$) on the day of travel during the INT trial (17,180 (16,187-18,173) kJ) compared with the CON trial (13,274 (11,112-15,463) kJ). Carbohydrate intake (g/kg BM) was also significantly greater ($P<0.01$) on the day of travel during the INT trial (6.4 (5.8-7.0) g/kg BM) compared with the DOM (4.2 (3.8-4.6) g/kg BM) and CON (3.8 (3.0-4.6) g/kg BM) trials. No other significant differences existed between trials for energy (kJ), carbohydrate, protein, or fat (g/kg BM) intake ($P>0.05$).
<table>
<thead>
<tr>
<th></th>
<th>D-1 PM</th>
<th>D+1 AM</th>
<th>D+1 PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole-body fatigue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>2.3 (1.7 - 2.9)</td>
<td>3.0 (2.3 - 3.7)</td>
<td>3.4 (2.4 - 4.4)</td>
</tr>
<tr>
<td>DOM</td>
<td>3.3 (2.5 - 4.0)</td>
<td>4.3 (3.7 - 4.9)</td>
<td>4.4 (3.9 - 4.9)</td>
</tr>
<tr>
<td>INT</td>
<td>3.2 (2.4 - 4.0)</td>
<td>5.0 (4.0 - 6.0) $^g$</td>
<td>4.6 (3.9 - 5.3) $^f$</td>
</tr>
<tr>
<td>Muscle soreness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>2.3 (1.7 - 2.9)</td>
<td>1.9 (1.4 - 2.4)</td>
<td>3.7 (3.0 - 4.4)</td>
</tr>
<tr>
<td>DOM</td>
<td>2.6 (1.9 - 3.3)</td>
<td>3.2 (2.8 - 3.6)</td>
<td>4.6 (3.9 - 5.3) $^f$</td>
</tr>
<tr>
<td>INT</td>
<td>2.9 (2.0 - 3.8)</td>
<td>3.4 (2.7 - 4.1)</td>
<td>4.1 (3.2 - 5.0)</td>
</tr>
<tr>
<td>Anger</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>0.8 (0.0 - 1.6)</td>
<td>0.7 (0.0 - 1.4)</td>
<td>0.6 (0.0 - 1.2)</td>
</tr>
<tr>
<td>DOM</td>
<td>1.8 (0.2 - 3.4)</td>
<td>0.7 (0.0 - 1.4)</td>
<td>0.2 (0.2 - 0.6)</td>
</tr>
<tr>
<td>INT</td>
<td>0.2 (0.0 - 0.4)</td>
<td>3.1 (1.5 - 4.7) $^g$</td>
<td>1.6 (0.0 - 3.2)</td>
</tr>
<tr>
<td>Confusion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>0.8 (0.0 - 1.6)</td>
<td>0.7 (0.0 - 1.4)</td>
<td>0.4 (0.0 - 0.8)</td>
</tr>
<tr>
<td>DOM</td>
<td>0.8 (0.1 - 1.5)</td>
<td>0.1 (0.0 - 0.2)</td>
<td>0.2 (0.0 - 0.4)</td>
</tr>
<tr>
<td>INT</td>
<td>0.0 (0.0 - 0.0)</td>
<td>2.4 (0.5 - 6.3) $^g$</td>
<td>1.6 (0.1 - 3.7) $^f$</td>
</tr>
<tr>
<td>Depression</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>0.8 (0.0 - 1.6)</td>
<td>0.6 (0.0 - 1.2)</td>
<td>0.4 (0.0 - 0.8)</td>
</tr>
<tr>
<td>DOM</td>
<td>0.9 (0.0 - 1.8)</td>
<td>0.7 (0.0 - 1.4)</td>
<td>0.8 (0.0 - 1.6)</td>
</tr>
<tr>
<td>INT</td>
<td>0.2 (0.0 - 0.4)</td>
<td>3.1 (1.2 - 5.0) $^g$ $^{**}$</td>
<td>0.9 (0.0 - 1.8)</td>
</tr>
<tr>
<td>Fatigue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>3.1 (0.9 - 5.3)</td>
<td>3.7 (1.2 - 6.2)</td>
<td>6.1 (4.1 - 8.1)</td>
</tr>
<tr>
<td>DOM</td>
<td>4.8 (2.5 - 7.1)</td>
<td>6.7 (4.2 - 9.2)</td>
<td>8.4 (6.1 - 10.7)</td>
</tr>
<tr>
<td>INT</td>
<td>2.4 (1.5 - 3.3)</td>
<td>13.4 (12.7 - 14.1) $^{g**}$</td>
<td>10.1 (8.0 - 12.2)</td>
</tr>
<tr>
<td>Tension</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>0.6 (0.0 - 1.3)</td>
<td>0.3 (0.3 - 0.6)</td>
<td>1.0 (0.1 - 1.9)</td>
</tr>
<tr>
<td>DOM</td>
<td>1.6 (0.7 - 2.5)</td>
<td>1.1 (0.2 - 2.0)</td>
<td>1.7 (0.8 - 2.6)</td>
</tr>
<tr>
<td>INT</td>
<td>1.1 (0.0 - 2.2)</td>
<td>2.0 (0.4 - 3.6)</td>
<td>0.8 (0.0 - 1.6)</td>
</tr>
<tr>
<td>Vigour</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>6.9 (4.6 - 9.2)</td>
<td>6.3 (3.6 - 9.0)</td>
<td>5.7 (3.4 - 8.0)</td>
</tr>
<tr>
<td>DOM</td>
<td>7.0 (4.8 - 9.2)</td>
<td>4.7 (2.9 - 6.5)</td>
<td>4.8 (3.0 - 6.6)</td>
</tr>
<tr>
<td>INT</td>
<td>6.4 (4.6 - 8.2)</td>
<td>1.9 (0.5 - 3.3) $^g$</td>
<td>4.1 (2.7 - 5.5)</td>
</tr>
</tbody>
</table>

**Table 3.3.** Mean (95% CI) mood states for the CON, DOM and INT trials, prior to performance testing in the afternoon of the day before travel (D-1 PM) and the morning (D+1 AM) and afternoon (D+1 PM) of the day after travel. $^g$Significantly different to baseline ($P<0.05$). $^f$Significantly different to CON ($P<0.05$). $^*$Significantly different to DOM ($P<0.05$).
Discussion

The present study examined the effects of exposure to mild hypoxia and cramped conditions during simulated domestic and international air travel, together with a simulated change in time-zones following international air travel, on team sport physical performance. Sleep quantity and quality, and oxygen saturation were reduced during, and intermittent-sprint performance was suppressed following simulated INT travel. In contrast, physiological and performance measures were unaffected by simulated DOM travel, which only had a minor effect on perceived muscle soreness. Sleep disruption during and subsequent exacerbated physiological and perceptual fatigue following INT travel may explain the decrement observed in intermittent-sprint performance.

Given the effects of air travel on performance specific to the physical demands of team sports are yet to be determined, a notable finding of the present study was the reduction of intermittent-sprint performance in the afternoon (AEST) of the day following simulated INT travel. Whilst this corresponded to 06:00 London time, where physical performance would typically be at its nadir (Drust et al., 2005), it is unlikely that circadian rhythms were changed in the present study. Therefore, reductions in performance are likely to have resulted from other stressors associated with the simulated INT travel, particularly sleep disruption and associated fatigue. Indeed, between the commencement of the simulated INT travel (Tuesday 16:00 AEST) and the performance tests in the morning (Thursday 09:00 AEST) and afternoon (Thursday 16:00 AEST) of the day following travel, participants obtained only 2.5 (1.7 - 3.3) h of sleep in 41 h and 6.3 (5.3 - 7.3) h of sleep in 48 h, respectively. Previous research reports that greater durations of sleep disruption exacerbate reductions in cognitive performance (Van Dongen et al., 2003).
Accordingly, the greater duration of sleep disruption prior to the performance tests in the afternoon may explain the larger reduction in intermittent-sprint performance compared to the morning in the present study.

Whilst YYIR1 performance was reduced following INT travel, no significant effects on lower-body power were detected. Conflicting results exist in the literature, with some research reporting no change (Bullock et al., 2007; Lagarde et al., 2001) and others a reduction (Chapman et al., 2012) in lower-body power following international transmeridian air travel. These contrasting findings may be a result of the inter-individual variation in responses to the duration and direction of travel (Waterhouse et al., 2002), along with the type, sensitivity, timing and frequency of the tests conducted (Bullock et al., 2007; Lagarde et al., 2001). These factors could help explain the findings of the present study, especially given the relatively large TE observed for CMJ peak power and velocity. A reduction in YYIR1 performance with minimal change in CMJ performance, suggests the suppression of intermittent-sprint ability may not relate to reduced contractile function following prolonged travel, but to other physiological or perceptual mechanisms. Moreover, no change in CMJ or intermittent-sprint performance was identified following simulated DOM travel. To date, only one other investigation has reported the effects of domestic air travel on physical performance, highlighting no change in grip strength or lower-body power (McGuckin et al., 2014). However, given the limited information available, further research is required to confirm this.
Limited research exists on the effects of domestic and international air travel on the quality and quantity of sleep in passengers. Thus, another notable finding from the present study was the reduction in sleep quantity and quality observed during INT travel. However a limitation of the present study is that the amount and quality of sleep obtained by the participants was assessed using wrist activity monitors rather than PSG. PSG is considered to be the gold-standard for monitoring sleep in laboratory based studies because it measures the depth of an individual’s sleep. However, in studies such as the present one, where PSG was unavailable and the primary measure was sleep duration rather than sleep depth, activity monitors are a reasonable alternative. Similarly low sleep quantities (2-5 h) have previously been self-reported by passengers during international transmeridian air travel (Waterhouse et al., 2002), with environmental factors, such as comfort (Waterhouse et al., 2007; Waterhouse et al., 2004) and exposure to mild hypoxia (Coste et al., 2004) purported as contributors to sleep disruption. Interestingly, the magnitude of the reduction in oxygen saturation observed during simulated air travel in the present study was similar to values previously reported during actual air travel (Geertsema et al., 2008). Moreover, oxygen saturation may have remained suppressed immediately following INT compared to CON, due to the prolonged duration of INT travel and thus, exposure to mild hypoxia, though further research is required to confirm this observation. Reduced subjective sleep quality has previously been reported following domestic air travel (Richmond et al., 2007). Considering no effects of DOM travel were evident for objective sleep quantity or quality in the present study, domestic air travel per se may not affect sleep patterns. Instead, sleeping in unfamiliar surroundings may explain the aforementioned reduction in perceived sleep quality (Richmond et al., 2007).
Maintaining wakefulness in a state of sleep debt requires increased sympathetic activation, particularly if physically challenged (Meerlo et al., 2008). Since an increase in sympathetic activity is associated with elevated cardiovascular activity (Meerlo et al., 2008), this may explain the increase in HR detected during a standardised sub-maximal exercise bout, in the morning and afternoon of the day following simulated INT travel. Given the present study is the first to report such responses, further research is required to confirm elevated sympathetic activity resulting from prolonged travel. Reduced cortisol concentrations have been identified in response to acute sleep deprivation, which may be related to increased fatigue and sleepiness, and decreased physical and mental activity (Meerlo et al., 2008). In the present study, reduced cortisol levels were evident in the morning of the day following simulated INT travel, where fatigue and sleepiness were high, and physical and mental activity were low. A reduction in cortisol concentration in conjunction with an increase in sub-maximal HR responses could imply an increase in physiological fatigue following simulated INT travel. This may explain why during the YYIR1, HRmax did not differ, but distance covered was reduced, perceived exertion was increased and physical feeling was worse. However, further research is required to confirm these findings.

In the morning of the day following simulated INT travel, greater perceived anger, confusion, depression and fatigue were observed, in addition to reduced vigour. Restricted sleep has previously been demonstrated to have comparable effects on these mood states (Sinnerton & Reilly, 1992). Furthermore, whilst time to volitional exhaustion was reduced, perceived exertion was increased and physical feeling was worse during intermittent-sprint exercise in the afternoon of the day following simulated INT travel. Previous research suggests that whilst individuals can
overcome the effects of sleep loss to complete explosive/short duration exercise, they are unable to maintain performance in sustained or repeated exercise bouts (Reilly & Edwards, 2007). Such findings imply difficulty in maintaining the motivation to perform at a high intensity (Reilly & Edwards, 2007), which is supported by observations of reduced tolerance to exercise following sleep loss (Skein et al., 2011), which includes the present study. Therefore, increased perceptual fatigue prior to and during exercise may have contributed to the suppression of intermittent-sprint performance detected following simulated INT travel in the present study. Increased perceptual fatigue has also been reported following domestic air travel (McGuckin et al., 2014). Whilst an increase in perceived muscle soreness was observed following simulated DOM travel in the present study, this was not significantly different from the other trials, indicating only a minor effect and that actual domestic travel may have a greater impact on perceptual responses.

During travel it is recommended that passengers increase fluid consumption to counteract the dry cabin air and unperceived dehydration (Reilly et al., 2007a), and wear compression stockings to prevent edema and DVT (Cesarone et al., 2003). However, these generic recommendations are based on a limited amount of generalised evidence (Samuels, 2012). In the present study there were no differences between trials in hydration status. However, one of the major limitations of the present study was that the humidity during simulated travel was 61 %. This is significantly greater than the 13 % recorded during actual international air travel, which has been reported to have a detrimental impact on hydration (Hamada et al., 2002). In addition, mid-calf girth was significantly increased immediately after the simulated INT travel. This suggests acute muscle swelling may have occurred, which is similar to the observations of previous studies (Cesarone et al., 2003; Hamada et al., 2002). Other limitations to acknowledge include the small sample
size, together with the inability to simulate the mild hypobaric pressure and reduced air quality experienced on a commercial flight (Muhm et al., 2007), which may increase hypohydration and muscle swelling.

In conclusion, a reduction in intermittent-sprint performance was observed following simulated international air travel. Results imply this may be due to sleep disruption during travel and subsequent physiological and perceptual fatigue. Conversely, simulated domestic air travel had only a minor effect on perceived muscle soreness. Thus, from a practical perspective, practitioners should consider implementing interventions that aim to attenuate sleep disruption during international air travel. Further research is required into the effects of actual domestic and international air travel on team sport physical performance, including the impact of circadian rhythm disruptions and the longitudinal, rather than acute, post-travel recovery timeline.
Chapter Four
Study Two

Effects of domestic air travel on technical and tactical performance and recovery in soccer

Based on the publication;

Abstract

Aims: Examine the effects of short-haul air travel on competition performance and subsequent recovery. Methods: Six male professional Australian football players were recruited to participate in the study. Data was collected from 12 matches, which included six home and away matches against the same four teams. Together with the outcome of each match, data was obtained for team technical and tactical performance indicators and individual player movement patterns. Furthermore, sleep quantity and quality, hydration and perceptual fatigue were measured two days prior to, the day of, and two days following each match. Results: Greater competition points were accumulated (P>0.05; d=1.10) and fewer goals were conceded (P>0.05; d=0.93) in home compared to away matches. Furthermore, greater shots on goal (P>0.05; d=1.17), and corners (P>0.05; d=1.45), and fewer opposition shots on goal (P>0.05; d=1.18) and corners (P<0.05; d=2.32) occurred, alongside reduced total distance covered (P>0.05; d=1.19) and low-intensity activity (P<0.05; d=2.25) during home compared to away matches. However, whilst oxygen saturation was significantly lower during compared with pre and post outbound and return travel (P<0.01), equivocal differences in sleep quantity and quality, hydration and perceptual fatigue were observed prior to and following competition away compared to home. Conclusions: These results suggest that compared to short-haul air travel, other factors including situational variables, territoriality, tactics and athlete psychological state are more important in determining match outcome. Furthermore, despite the potential for disrupted recovery patterns, return travel did not impede player recovery or perceived readiness to train.
Introduction

Short-haul air travel is one of a myriad of factors purported to affect match outcome in football (Goumas, 2014; Pollard, 2008) and in particular, the tendency for teams to perform better at home compared to away, referred to as the home advantage (Goumas, 2014; Pollard, 2008). Hence, it is frequently highlighted by the media, coaching staff and players as an explanation for poor away match performances (Du Preez & Lambert, 2009). However, limited data exist to support this perception, with few studies, particularly in football, reporting the acute effects of short-haul air travel on physical performance, physiological and perceptual responses and ensuing match outcome or technical and tactical performance indicators (McGuckin et al., 2014; Richmond et al., 2007). Of further concern is the potential impact of travel on post-match recovery, considering that many domestic football competition schedules require short-haul air travel the day after an away match. However, the effects of post-competition travel on recovery are yet to be determined.

Following short-haul air travel, symptoms of travel fatigue may include lethargy, confusion and headaches (Waterhouse et al., 2004), resulting from the conditions encountered during travel. This includes, exposure to mild hypoxia (Coste et al., 2007b), cramped conditions with restricted activity (Reilly et al., 2007a; Waterhouse et al., 2004), and disruption of routines, such as eating and sleeping patterns (Reilly et al., 2007b; Smith et al., 2000). However, to date, only two studies have reported acute effects of short-haul air travel on integrated physical performance, physiological and perceptual responses, and ensuing match outcome and technical and tactical performance indicators (McGuckin et al., 2014; Richmond et al., 2007). Though adverse effects on psychological state and perceived sleep quality were identified the day prior to competition in
professional rugby league and Australian Football League players, respectively, subsequent effects on physical, technical and tactical performance during competition were equivocal (McGuckin et al., 2014; Richmond et al., 2007). Therefore, further research is required to establish whether short-haul air travel *per se* affects match outcome, as opposed to other factors, including, situational variables, such as match location, match status and opposition quality (Lago et al., 2010), and territoriality (Neave & Wolfson, 2003), tactics, and the expectancy to perform worse away from home (Nevill & Holder, 1999).

Competitive football matches involve a large number of physically demanding activities and thus, induce acute fatigue and physical performance decrements (Nédélec et al., 2013). A progressive return to pre-match state occurs during the recovery process, but this may take more than 72 h (Nédélec et al., 2013). Given the limited time between matches and subsequent training and competition, various recovery procedures are commonly used to regain optimal performance faster (Nédélec et al., 2013). However, due to domestic football competition schedules, short-haul air travel is often a necessity the day after an away match, particularly in north and south America, and Australia, where large distances are travelled by away teams (Goumas, 2014). As conditions during air travel may induce acute physiological and perceptual stress (Coste et al., 2007b; Waterhouse et al., 2004), and the disruption of routines can inhibit the use of recovery interventions, the recovery process following away matches could be impeded. However, as yet, no data exists on the effects of post-competition travel on recovery.
Therefore, the purpose of the present study was to investigate the acute effects of short-haul air travel on physiological and perceptual measures prior to and following, and technical and tactical performance indicators during competition in elite Australian football players. It was hypothesised that short-haul air travel would have an acute negative impact on physiological and perceptual responses, which would result in worse technical and tactical performance during competition, match outcome and ensuing recovery.

**Methods**

**Participants**

Six male professional Australian football players were recruited to participate in the present study; mean (95% confidence intervals, CI); age 23.4 (19.9-25.9) y, body mass 78.0 (72.3- 83.7) kg, height 182.8 (178.4-187.2) cm. The players were representatives of a professional team located in North Queensland, Australia, and competed in the highest Australian national football competition (A-League). Due to the team’s location, players were required to undertake short-haul air travel for all away matches. The players volunteered to participate and, prior to the commencement of the study, were informed of any associated risks and provided verbal and written informed consent. The study was approved by the institutional Human Research Ethics Committee.

**Experimental Design**

Following familiarisation with all experimental measures and procedures, due to selection in the team and the competition structure and schedule, data was collected from the players for 12 matches during the 2010/2011 A-League season, which included six home and away matches...
against the same four teams. Mean (95% CI) match time (AEST) was 18:50 (17:45-19:55) and 17:17 (15:15-19:19) for the home and away matches, respectively. Measures were obtained two days prior to (Pre 1 and Pre 2), the day of (Match Day) and two days following (Post 1 and Post 2) each match. Accordingly, to account for the effect of opposition quality on match outcome, the present study was a within-subject, cross-over design, which allowed the comparison of measures against the same opposition for both home and away matches. Mean (95% CI) air travel time and distance for the six away matches was 5.3 (3.1-7.5) h and 3759 (2453-5065) km, respectively. Direction of outbound and return travel was south and north to Melbourne, Victoria, west and east across two time-zones to Perth, Western Australia, and east and west across two time-zones to Wellington, New Zealand, respectively. Whilst outbound travel occurred one day prior to matches in Melbourne, the team travelled two days prior to matches in Perth and Wellington. Return travel always occurred one day following each away match.

**Experimental Procedures**

**Key performance indicators**

For the 12 matches included in analyses, match outcome and technical and tactical performance indicators were obtained post-match from a freely accessible game statistics website (www.footballaustralia.com.au/aleague/matchcentre). All website data is provided by OPTA Sportsdata (*OPTA Client System*, OPTA Australia, Sydney, NSW), which has been reported to have a high level of inter-operator reliability (*kappa value* = 0.94) (Liu, Hopkins, Gómez, & Molinuevo, 2013). Specifically, standardised typical errors and intra-class correlation coefficients varied from 0.00 to 0.37 and 0.88 to 1.00, respectively for shots on goal, corners, opposition corners and fouls (Liu et al., 2013). During each match, total distance covered (m),
mean speed (m/min) and the distance covered (m) in three pre-defined categories (Coutts & Duffield, 2010); low-intensity activity (LIA; <14.4 km.h\(^{-1}\)); high-intensity running (HIR; >14.5 km.h\(^{-1}\)); and very-high intensity running (VHIR; >20 km.h\(^{-1}\)) were determined via 1-Hz Global Positioning Satellite (GPS) devices (SPI elite, GPSports, Canberra, Australia). For each match, players wore the same individually assigned device between the scapulae in a customised harness and data was subsequently analysed using device specific software (Team AMS, GPSports, Canberra, Australia). Match load (arbitrary units; AU) was calculated for each player by multiplying their respective playing duration (min) and session rating of perceived exertion (sRPE) given, on a scale from zero (nothing at all) to 10 (maximal), approximately 30 min following each match (Foster et al., 1996). At the same time, players rated their physical feeling during each match on a scale of -5 (very bad) to 5 (very good) (Hardy & Rejeski, 1989), and the morning after each match, player performance was subjectively assessed by the same member of coaching staff on a scale from one (very poor) to 10 (excellent).

Physiological measures

Sleep patterns were assessed using actigraphy watches (ReadiBand™, Fatigue Science, Honolulu, Hawaii) worn on players’ non-dominant wrist, two days prior to, the day of and two days following each match. Actigraph records were subsequently analysed using customised manufacturers software (Sleep Analyser, Fatigue Science, Honolulu, Hawaii) for quantity and quality of sleep. In field-based studies that involve data collection from multiple participants simultaneously over consecutive nights, activity monitors are typically preferred over PSG, the gold standard for monitoring sleep, because they are portable, non-invasive and operate remotely without an attendant technician. Validation studies comparing wrist activity monitors with PSG
report high correlations for sleep duration ($r=0.84$-$0.89$) (Weiss et al., 2010). Hydration status was also assessed at the same time points. Specifically, participants provided a midstream urine sample upon awakening, which was subsequently analysed for urine specific gravity (USG) using a visual scale urine refractometer (Refractometer 503, Nippon Optical Works, Co., Tokyo, Japan). For each away match, oxygen saturation was recorded whilst seated with a pulse oximeter (Nonin 4000 Avant Bluetooth Pulse Oximeter, Nonin, North Plymouth, MN) immediately prior to, halfway through and immediately following outbound and return travel. Values were recorded after stabilisation of the reading.

*Perceptual measures*

Perceived sleep quality, stress, fatigue and muscle soreness were assessed on a scale (Hooper et al., 1995) of one (very, very good/very very low) to seven (very, very bad/very very high), and perceived sleepiness was assessed on a scale (Hoddes, Dement, & Zarcone, 1972) of one (feeling active/alert/wide awake) to eight (asleep) two days prior to, the day of and two days following each match. To assess players’ stress-recovery balance, the Recovery-Stress Questionnaire for Athletes (RESTQ-19 Sport) (Kellmann et al., 2001) was completed at the same time points. In addition, fatigue and sleepiness were recorded immediately prior to and immediately following outbound and return travel.

*Statistical Analysis*

Data for each player was only included in analyses if playing duration was ≥60 min in both the home and away match against the same opposition. Data are presented as mean (95% CI). One-way analysis of variance (ANOVA) was used to determine differences between home and away
matches for all key performance indicators, and differences between pre and post outbound and return travel in perceived fatigue and sleepiness. A one-way ANOVA with repeated measures was used to identify differences between pre, during and post outbound and return travel in oxygen saturation. A linear mixed model was used for analyses of all other physiological and perceptual measures. Specifically, time and location (home vs. away), and their interaction were fitted as fixed effects to determine whether there was a difference in the effect of location over time. In addition, player and location (within player) were fitted as random effects to account for the possible correlation within players and within location within players. For all analyses, where a significant effect was observed ($P<0.05$), a Tukey HSD post-hoc test was used to determine differences between means. Analyses were performed using JMP statistical software (JMP Pro v 10.0, SAS, Cary, NC). Furthermore, standardised effect size (Cohen’s $d$) analysis was used to interpret the magnitude of differences between home and away matches. Due to the substantial amount of statistical analyses performed, only large effect sizes (ES; $d>0.90$) are reported.

**Results**

**Key performance indicators**

No significant differences were identified between home and away for match outcomes ($P>0.05$). However large ES indicated greater points accrued (1.0 vs. 0.3; $P=0.21$; $d=1.10$) and fewer goals conceded (1.5 vs. 2.2; $P=0.47$; $d=0.93$) at home compared to away. Whilst number of opposition corners was significantly greater in away compared to home matches ($P=0.02$; Table 4.1), no significant differences were evident for any other technical and tactical performance indicators ($P>0.05$). Large ES suggested greater shots off target ($d=1.18$), shots on goal ($d=1.17$), and corners ($d=1.45$), with fewer opposition shots on goal ($d=1.18$) or corners
(d=2.32) occurring at home compared to away. No significant differences in coach subjective ratings of player performance were observed between home (7.2 (6.9-7.5)) and away (7.6 (7.1-8.0)) matches ($P>0.05$). Low-intensity activity and total distance covered were significantly ($P=0.001$; $d=2.25$) and almost significantly ($P=0.06$; $d=1.19$) greater, respectively, in away compared to home matches (Table 4.2). No significant differences were evident between home and away matches for high-intensity running, very-high intensity running, match load or physical feeling (0.1 (-1.1 - 1.2) vs. 0.6 (-0.3 - 1.4)) ($P>0.05$).
Table 4.1. Mean (95% CI) technical and tactical performance indicators from six home and six away matches.

<table>
<thead>
<tr>
<th></th>
<th>Possession (%)</th>
<th>Shots on target</th>
<th>Shots off target</th>
<th>Shots on goal</th>
<th>Opposition shots on goal</th>
<th>Corners</th>
<th>Opposition corners</th>
<th>Fouls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home</td>
<td>49 (45-52)</td>
<td>5 (2-8)</td>
<td>9 (6-12)</td>
<td>14 (11-17)</td>
<td>7 (3-11)</td>
<td>4 (0-7)</td>
<td>12 (8-16)</td>
<td></td>
</tr>
<tr>
<td>Away</td>
<td>48 (45-51)</td>
<td>5 (2-7)</td>
<td>7 (4-10)</td>
<td>11 (8-14)</td>
<td>16 (8-24)</td>
<td>4 (2-6)</td>
<td>8 (5-11)</td>
<td>12 (9-14)</td>
</tr>
</tbody>
</table>

*Significantly different to away matches (P<0.05). *Large ES for difference to away matches (d>0.90)
Table 4.2. Mean (95% CI) physical demands from six home and six away matches.

<table>
<thead>
<tr>
<th></th>
<th>Distance (m)</th>
<th>Work rate (m/min)</th>
<th>LIA (m)</th>
<th>HIR (m)</th>
<th>VHIR (m)</th>
<th>sRPE</th>
<th>Match load (AU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home</td>
<td>10620</td>
<td>111</td>
<td>8340</td>
<td>2280</td>
<td>519</td>
<td>7.6</td>
<td>688</td>
</tr>
<tr>
<td>Away</td>
<td>11128</td>
<td>115</td>
<td>8953</td>
<td>2175</td>
<td>461</td>
<td>8.1</td>
<td>720</td>
</tr>
<tr>
<td></td>
<td>(10730-11527)</td>
<td>(110-121)</td>
<td>(8665-9241)</td>
<td>(1947-2403)</td>
<td>(325-597)</td>
<td></td>
<td>(664-776)</td>
</tr>
</tbody>
</table>

*Significantly different to away matches (P<0.01). aLarge ES for difference to away matches (d>0.90).
Physiological measures

No significant differences existed between home and away matches for any sleep measure ($P>0.05$; Figure 4.1). However, large ES indicated that sleep latency was greater ($d=0.99$) and variance from mean bed time was earlier ($d=2.46$), away compared to home on Pre 2 and Pre 1, respectively. Moreover, variance from mean bed time was earlier ($d=0.90$) and sleep latency ($d=1.34$), and duration ($d=1.95$) were greater on Post 1 away compared to home. On Post 2, variance from mean bed time was earlier ($d=1.51$), and sleep duration ($d=1.40$), and both number and duration ($d>1.20$) of wake bouts were greater at home compared to away. Furthermore, variance from mean bed time was significantly later on Match Day compared to Pre 1 for away matches ($P=0.02$; Figure 4.1). Sleep duration was significantly reduced on Match Day compared to Pre 1 ($P=0.001$) and Post 1 ($P=0.005$) for away matches, and compared to Pre 1 ($P=0.001$) and Post 2 ($P=0.04$) for home matches (Figure 4.1). No significant effects of time were identified for sleep latency, sleep efficiency and number or duration of awakenings ($P>0.05$; Figure 4.1) No significant differences between home and away matches were evident for USG ($P>0.05$; $d<0.90$; Figure 4.2). Oxygen saturation was significantly lower during, compared with pre and post outbound and return travel ($P<0.01$; $d>0.90$; Table 4.3); however, no significant differences were identified during outbound compared with during return travel ($P>0.05$; $d<0.90$).
**Figure 4.1.** Effect of time and location on sleep volume and quality. Mean (95% CI) variance from mean bed time (A), sleep duration (B), sleep latency (C), sleep efficiency (D), number of awakenings (E) and duration of awakenings (F) for home (dashed line and white circle) and away (solid black line and square) matches. *Significantly different to Pre 1 (Away) (P<0.05). †Significantly different to Pre 1 (Home) (P<0.05). ‡Significantly different to Post 1 (Away) (P<0.05). ††Significantly different to Post 2 (Home) (P<0.05). aLarge ES for difference between home and away (d>0.90).
Figure 4.2. Effect of time and location on hydration status. Mean (95% CI) urine specific gravity for home (dashed line and white circle) and away (solid black line and square) matches.
Table 4.3. Mean (95% CI) for physiological and perceptual measures collected pre, during and post outbound and return travel for six away matches.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Time</th>
<th>Outbound Travel</th>
<th>Return Travel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen Saturation (%)</td>
<td>Pre</td>
<td>97.9 (97.5-98.3)</td>
<td>97.8 (97.4-98.2)</td>
</tr>
<tr>
<td></td>
<td>During</td>
<td>95.0 (94.4-95.6)*</td>
<td>94.4 (93.9-95.0)*</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>98.2 (97.7-98.6)</td>
<td>97.7 (97.3-98.1)</td>
</tr>
<tr>
<td>Fatigue</td>
<td>Pre</td>
<td>3.8 (3.3-4.2)</td>
<td>4.3 (3.7-5.0)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>4.2 (3.5-4.8)</td>
<td>4.2 (3.4-5.0)</td>
</tr>
<tr>
<td>Sleepiness</td>
<td>Pre</td>
<td>3.1 (2.3-3.9)</td>
<td>4.1 (3.2-5.0)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>4.3 (3.8-4.9)*</td>
<td>4.2 (3.4-5.0)</td>
</tr>
</tbody>
</table>

*Significantly different to pre and post travel (P<0.01). #Large ES for difference to Pre (d>0.90).
Perceptual measures

No significant differences existed between home and away matches for any perceptual measure ($P>0.05$; Figure 4.3). However, large ES indicated fatigue was greater away compared to home on Pre 1 (d=1.26), and stress (d=0.97) and muscle soreness (d=1.11) were greater at home compared to away on Post 1. Sleep quality and stress-recovery balance were significantly lower on Match Day compared to Pre 1 for home and away matches ($P<0.01$), and compared to Pre 2 for home matches ($P<0.05$). Stress and sleepiness were significantly higher at Post 1 compared to Match Day ($P<0.01$) and Pre 1 ($P<0.05$) for home matches. Furthermore, sleepiness was almost significantly greater post compared with pre outbound travel ($P=0.09$; d=1.32; Table 4.3). A significantly greater level of fatigue was observed at Post 1 compared with all other time points for home matches ($P<0.05$) and compared with Match Day ($P=0.0007$) and Pre 2 ($P=0.007$) for away matches. Fatigue was also significantly greater at Post 2 compared with Match Day for away matches ($P=0.03$). Muscle soreness was significantly greater at Post 1 compared with all other time points for home matches ($P<0.001$) and compared with all other time points except Post 2 for away matches ($P<0.001$). Furthermore, muscle soreness was significantly greater at Post 2 compared with Pre 2 ($P=0.02$), Pre 1 ($P=0.003$) and Match Day ($P=0.0006$) for away matches and compared with Pre 1 ($P=0.001$) and Match Day ($P=0.0002$) for home matches.
Figure 4.3. Effect of time and location on perceptual responses. Mean (95% CI) perceived sleep quality (A), stress (B), fatigue (C), muscle soreness (D), stress-recovery (E) and sleepiness (F) for home (dashed line and white circle) and away (solid black line and square) matches. *Significantly different to Pre 1 (Away) ($P<0.05$). †Significantly different to Pre 1 (Home) ($P<0.05$). ‡Significantly different to Pre 2 (Home) ($P<0.05$). §Significantly different to Pre 1 and Match Day (Home) ($P<0.05$). ¶Significantly different to all other time points (Home) ($P<0.05$). ††Significantly different to Pre 2 and Match Day (Away) ($P<0.05$). ‡‡Significantly different to Match Day (Away) ($P<0.05$). *Large ES for difference between home and away ($d>0.90$).
**Discussion**

The present study examined effects of short-haul air travel, with minimal or no change in time-zones, on match outcome, technical and tactical performance during and sleep, hydration and perceptual fatigue before and after competition in elite Australian football players. Though a reduction in oxygen saturation was identified during short-haul air travel, it appeared to have negligible effects on ensuing competition performance and post-match recovery, as equivocal differences in sleep quantity and quality, hydration and perceptual measures were observed at home compared to away. However, in contrast, more points were accrued, fewer goals were conceded and technical and tactical performance was superior, resulting in reduced physical demands at home compared to away. Therefore, compared to short-haul air travel, other factors including situational variables such as match location, match status and opposition quality (Lago et al., 2010), and territoriality (Neave & Wolfson, 2003), tactics, and the expectancy to perform worse away from home (Nevill & Holder, 1999), may be of greater importance in determining match outcome. However, it is recognised that the small sample size and number of games that data was collected from is a limitation of the present study, restricting the generalisability of the results to other teams or travel demands.

Due to the myriad of factors influencing match outcome, isolating the effects of travel is complex, and requires control of numerous confounding variables (Pollard, 2008). A recent study confirmed a home advantage exists in the highest Australian national football competition (A-League) and reported a strong positive association with the number of time-zones crossed during travel (Goumas, 2014). However, given the logistical issues, limited data exists detailing the travel effects on integrated physical performance, physiological and perceptual responses,
and ensuing competition performance. Indeed, only two studies have attempted to isolate effects of short-haul air travel on key performance indicators during competition (McGuckin et al., 2014; Richmond et al., 2007). Whilst professional rugby league players performed more tackles and covered less distance (McGuckin et al., 2014), no differences in game statistics, including time between possessions and team assists, were evident in professional Australian Football League players, during away compared to home matches (Richmond et al., 2007). In the present study, more points were accrued and fewer goals were conceded, in addition to greater shots on goal and corners and fewer opposition shots on goal and corners in home compared to away matches. Not only does this support the finding that teams tend to perform better at home compared to away in the A-League (Goumas, 2014), it could also explain the greater distance covered, particularly in low-intensity activity during away compared to home matches. Specifically, with greater tactical dominance by the opposition during away matches, greater movement tracking the ball and/or opposition players is required (Lago et al., 2010; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007). Furthermore, evidence suggests that an expectancy to perform worse away from home, may result in a change in tactics which in turn can alter physical performance demands compared to home matches (Lago et al., 2010). However, despite greater distance covered, no difference in match load was evident, possibly resulting from the similar high-intensity running and very-high intensity running distance observed in away compared to home matches.

The conflicting results between studies for the aforementioned key performance indicators could be due to the different sports analysed and/or the plethora of factors that influence match outcome, including the ability and tactics of the team analysed and the opposition, which have an
interactive effect (McGuckin et al., 2014; Nevill & Holder, 1999). Whilst the present study attempted to control for some of these factors by analysing ‘pairs’ of matches against the same teams at home and away, previous research has compared performance in consecutive home and away matches against different opposition (McGuckin et al., 2014), where opposition quality could impact the results. Consequently, further research is required with larger data sets and across multiple sports, teams and seasons to conclusively determine the effects of travel on specific match outcomes.

Physiological consequences of air travel may include reduced oxygen saturation (Muhm et al., 2007) and sleep quality (Coste et al., 2009), as observed during and following prolonged exposure to mild hypoxia. Oxygen saturation was reduced during both outbound and return travel in the present study, similar to previously reported values (Geertsema et al., 2008; Muhm et al., 2007). However, given the relatively short-duration of air travel time (5.3 (3.1-7.5) h) in the present study and that values returned to normal immediately post-travel, the impact of the small reduction in oxygen saturation on match preparation is likely to be minimal. In addition, disruption of routine upon arrival, for example, residing in an unfamiliar environment, rather than at home, may impact sleep (Smith et al., 2000). Results from the present study suggest that players tended to go to bed earlier the night before away compared to home matches. This could be because players and coaching staff reside together in a hotel for away matches, whereas players are left to their own practices when at home. Moreover, players have reduced family and/or social commitments while away, which could result in greater time available for sleep. However, whilst players were in bed earlier, this didn’t result in greater sleep duration, which may suggest players took longer to fall asleep the night prior to away matches. A potential
explanation for this finding could be that players are required to share hotel rooms whilst away and are therefore residing in an unfamiliar environment compared to at home.

In addition, players slept for longer the day after away compared to home matches in the present study. Given that return travel occurred the day after each away match, this finding suggests that players slept for longer at home the first night following return travel. However, rather than an effect of travel, a more plausible explanation for this finding could be differences in the training schedule following home compared to away matches. Specifically, whilst training tended to occur in the morning on Post 2 following home matches, since return travel occurred on Post 1 following away matches, players were given the day off on Post 2, which would have resulted in greater time available for sleep. Previously, no differences in actigraphy-derived sleep measures were observed in Australian Football League players the night before competition, though, players perceived their sleep quality to be better at home compared to away (Richmond et al., 2007). Consequently, these results suggest that short-haul air travel has equivocal effects on sleep patterns. Furthermore, anecdotal evidence suggests that athletes who compete at night, as is often the case in football, have difficulties with sleep following competition (Halson, 2013). Thus, a novel finding of the present study was the reduction in sleep quantity and perceived sleep quality observed in elite football players following both home and away matches. Given the physically demanding nature of competitive football matches (Nédélec et al., 2013) and the recent emphasis placed on the importance of sleep (Halson, 2013), further research is warranted for recovery purposes (Duffield et al., 2013).
Conditions during air travel, particularly prolonged exposure to mild hypoxia, cramped conditions and activity restrictions, can induce acute increases in perceptual fatigue and muscular discomfort (Coste et al., 2007b; Muhm et al., 2007; Waterhouse et al., 2004). Indeed, inferior psychological states and greater perceived sleepiness have previously been reported immediately post travel in Australian rugby league players, travelling similar routes to those in the present study (McGuckin et al., 2014). Yet since these perceptual effects subsided prior to competition the following day, it is unlikely they were present during competition and therefore, impacted performance. In the present study, greater perceived sleepiness was evident immediately post compared to pre outbound travel and perceptual fatigue was increased one day prior to competition away compared to home. However, no differences were evident between home and away matches for perceived stress, fatigue and muscle soreness on match day. These findings confirm those of the aforementioned research and suggest that while short-haul air travel may acutely increase perceptual fatigue, it is unlikely to affect competition performance.

Considering these effects on fatigue and the fact that short-haul air travel is often a necessity the day after an away match (commonly the largest physical load of the training week), post-competition recovery may be impeded. However, results from the present study suggest that on the day following competition, perceived stress and muscle soreness were greater at home compared to away. This is surprising considering that less distance was covered during home compared to away matches, though the crowd, tactics and environment may also be a factor. Given the importance of recovery for subsequent performance and the limited preparation time until ensuing training and competition, further investigation is required to confirm these findings.
In conclusion, more points were accrued, fewer goals were conceded and technical and tactical performance was superior, resulting in reduced physical demands during competition at home compared to away. Furthermore, while domestic air travel may acutely increase perceptual fatigue, equivocal effects on sleep quantity and quality and perceptual responses were observed. These results indicate that compared to short-haul air travel, other situational variables (Lago et al., 2010) could have a greater impact on match outcome, and that return travel did not impede player recovery. However, it should be noted that travel fatigue could be cumulative and may accrue over the course of a season. As such, research into the longitudinal effects of short-haul air travel is warranted.
Chapter Five
Study Three

Effects of regular away travel on training loads, recovery and injury rates in professional Australian soccer players

Based on the publication;

Abstract

Aims: Examine the acute and longitudinal effects of regular away travel on training loads (TL), player wellness and injury surrounding competitive soccer (football) matches. Methods: Eighteen male professional football players, representing a team competing in the highest national competition in Australia, volunteered to participate in the study. Training loads, player wellness and injury incidence, rate, severity and type, together with the activity at the time of injury were recorded on the day prior to, the day of and for four days following each of the 27 matches of the 2012/2013 season. This included 14 home and 13 away matches, further subdivided based on the mid-point of the season into early (1-13) and late competition (14-27) phases. Results: Whilst TL were significantly greater on day 3 at home compared to away during the early competition phase (p=0.03), no other significant effects of match location were identified (p>0.05). Total TL and mean wellness over the six days surrounding matches, and TL on day 3 were significantly reduced during the late compared to the early competition phase at home and away (p<0.05). Though not significant (p>0.05), training missed due to injury was 60 and 50 % greater during the late compared to the early competition phase at home and away, respectively. Conclusions: No significant interactions between match location and competition phase were evident during the late competition phase, which suggests away travel had negligible cumulative effects on the reduction in player wellness in the latter half of the season.
**Introduction**

Frequent short-haul air travel for away matches is necessary for soccer teams during the season (Goumas, 2014). Despite these travel demands, few studies detail acute travel effects on player wellness (McGuckin et al., 2014; Richmond et al., 2007). Whilst short-haul air travel may temporarily augment perceptual fatigue (McGuckin et al., 2014), negligible effects on physiological and performance responses are reported (McGuckin et al., 2014; Richmond et al., 2007). It is proposed that frequent travel during the season may result in the accumulation of these minor acute effects (Samuels, 2012), though as yet there is no evidence to support this hypothesis. Since travel is often required the day of or day following away matches, subsequent training loads (TL) and recovery may be disrupted, reducing player wellness and increasing injury risk (Gastin et al., 2012). Given the proposed accumulation of travel related fatigue (Samuels, 2012), these effects may be augmented following away matches in the latter half of the season. However to date, no studies have investigated the effects of frequent travel during a season on TL, recovery and injury in football.

Effects of short-haul air travel (≤ 5 h) on performance, physiological and perceptual responses are equivocal (McGuckin et al., 2014; Richmond et al., 2007). Whilst greater perceived fatigue, worse mood states and reduced subjective sleep quality were identified following short-haul air travel in professional athletes, no effects on strength and power or objective sleep quantity were reported (McGuckin et al., 2014; Richmond et al., 2007). The magnitude of travel completed by professional teams during a season can be substantial. For example, during the competitive season, football teams in Australia are required to travel 26 times (including outbound and return), covering up to 3500 km during each respective flight. Consequently, acute travel effects
may be exacerbated in the late compared to the early competition phase, potentially resulting in reduced player wellness. However, the longitudinal effects of travel throughout a season on player recovery and wellness in football are unknown.

In-season, precise control of TL is required to maintain training adaptations achieved during pre-season and minimize the risk of non-functional overreaching and musculoskeletal injuries (Coutts, Reaburn, Piva, & Rowsell, 2007; Gabbett & Jenkins, 2011; McLean et al., 2010). However, periodisation of TL is often complicated by competition and travel schedules, along with the limited time between matches (Kelly & Coutts, 2007). As a result of travel the day of or day after an away match, the time lost, disruption of normal routines, and acute fatigue may hinder the recovery process. Therefore, compared to after a home match, the prescription of TL in the days leading into subsequent competition may be congested in order to maintain the weekly training dose, which in conjunction with impeded recovery, could reduce player wellness and increase injury risk (Gastin et al., 2012). Moreover, repeated travel throughout the season may augment these disruptions and thus, increase injury risk in the late compared to the early competition phase. However, longitudinal effects of travel throughout a season on injury incidence in football are yet to be reported.

Therefore, the purpose of the present study was to examine the acute and longitudinal effects of regular away travel through assessing the separate and combined effects of match location (home vs. away) and competition phase (early vs. late) on TL, player wellness and injury prior to and following competitive football matches.
Methods

Participants

Eighteen male professional Australian football players representing a team competing in the highest national competition (A-League), participated in the present study; mean (95% confidence intervals, CI); age 26.4 (24.7-28.1) y, height 168.8 (165.4-172.2) cm and body mass 72.11 (69.32-74.90) kg. At the time of data collection, players were participating in 3-5 sport-specific field-based training sessions, 1-2 recovery sessions, and 1 competitive match per week. Due to the location of opposing teams, players were required to undertake short-haul air travel for all but three away matches, where they travelled via road. All players volunteered to participate and prior to the commencement of the study, were informed of any associated risks and provided verbal and written informed consent. The study was approved by the institutional Human Research Ethics Committee.

Experimental Design

Following familiarisation with all experimental measures and procedures, data was collected from players for 27 matches during the 2012/2013 A-League season. This included 14 home and 13 away matches against nine opposition teams, which were further subdivided, based on the mid-point of the season, into early (1-13) and late competition (14-27) phases. Though measures were obtained daily as part of the clubs normal training monitoring, only data collected on the day prior to (day -1), the day of (match day) and for four days following (day 1, 2, 3 and 4) each match, from players who’s match duration was ≥ 60 min, were used for analyses. Thus, the total data points analysed was approximately 1,620 (10 players per match*27 matches*6 days). This specific time frame was selected as travel occurred either one or two days prior to away matches,
and the recovery timeline from competitive football matches is reported to be 72-96 h (Dupont et al., 2010; Nédélec et al., 2013). Consequently, effects of travel on the post-match recovery timeline and thus, player wellness leading into subsequent competition could be defined. Mean (95% CI) travel time and distance for air and road travel to away games was 2.3 (1.3-3.3) h and 1476 (621-2453) km, and 1.1 (0.4-1.8) h and 92 (22-162) km respectively. Direction of air travel was north and south across no time zones or east and west across two time zones.

**Experimental Procedures**

*Training loads and wellness*

Training loads (AU) were calculated by multiplying each player’s training session or match duration (min) by their session rating of perceived exertion (sRPE) provided approximately 30 min following each training session or match (Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004). A questionnaire based on previous recommendations (Hooper et al., 1995) was used to assess players’ fatigue, sleep quality, muscle soreness, stress levels and mood on a Likert scale from 1 to 5, in 0.5 point increments. Overall wellness was determined by summing the five scores (McLean et al., 2010). Player wellness has been reported to be sensitive to changes in TL in an applied setting (Buchheit et al., 2013a; McLean et al., 2010) and a useful indicator of athlete recovery and fatigue (McLean et al., 2010). The questionnaire was completed approximately 60 min prior to each training session and match.


Injury

The definitions of injury used in the present study follow those recommended by the Injury Consensus Group of the FIFA Medical Assessment and Research Center (Fuller et al., 2006) and are similar to those used in previous studies (Bengtsson, Ekstrand, & Hägglund, 2013; Dupont et al., 2010). Specifically, an injury was defined as any physical complaint sustained by a player during a match or training that led to the player being unable to take full part in future matches or training. All injuries were diagnosed by a full-time team physiotherapist, with the player considered to remain injured until the physiotherapist cleared them for participation in full training or matches. The time lost as a result of injury was calculated by the number of training sessions and matches missed. Injury exposure was calculated by multiplying the number of players by the session duration, and injury rate was determined by dividing the total number of injuries by the overall injury exposure, and expressed per 1000 training hours (Dupont et al., 2010; Gabbett & Jenkins, 2011). Injuries were also classified according to their type (non-contact or contact) and the activity at the time of injury (training or match) (Dupont et al., 2010; Gabbett & Jenkins, 2011). In addition, incidence of modified training, where a player completed a different session to the rest of the team, and no training, as a result of either excessive fatigue or injury was calculated. Absence arising from illness was not included in the study. Given the proposed association between reduced air quality in plane cabins and impaired immune function (Schwellnus et al., 2012; Waterhouse et al., 2004) this is acknowledged as a limitation.
Statistical Analysis

Unless substituted as a result of injury, data for each player was only included in analyses if match playing duration was ≥ 60 min. For all analyses, differences between match location (home vs. away), during the full season and early and late competition phases, and differences between competition phase (early vs. late) at home and away, were assessed separately. Data are presented as mean (95% CI), except for injury count data (Table 1). A generalized linear model, with poisson distribution and log link function, was used to examine differences in injury incidence, rate, severity and type, and the activity at the time of injury. Two-way analysis of variance (ANOVA) was used to determine the effects of match location and competition phase, and their interaction on total TL and mean wellness over the six days surrounding each match. A linear mixed model was used to identify differences in TL and wellness on each individual day surrounding each match. Specifically, time and match location (home vs. away), and time and competition phase (early vs. late), and their interaction were fitted separately as fixed effects to determine whether there was a difference in the effect of match location or competition phase over time. In addition, player and match location (within player) or player and competition phase (within player) were fitted separately as random effects to account for the possible correlation within players, within location within players or within competition phase within players. Where a significant effect was observed (P<0.05), a post-hoc test (Tukey HSD) was used to determine differences between means. Analyses were performed using JMP statistical software (JMP Pro v10.0, SAS, Cary, NC).
**Results**

No significant differences existed between match location or competition phase for injury incidence, rate, severity, type or the activity at the time of injury ($P>0.05$; Table 5.1). Though not significantly different due to the low total number of injuries, training missed was 60 and 50% greater during the late compared to the early competition phase at home ($P=0.09$) and away ($p=0.44$), respectively. Modified training was significantly greater following home compared to away matches by 77 and 60% during the early competition phase ($P=0.04$) and full season ($P=0.02$), respectively. Total TL and mean wellness were significantly greater during the early compared to the late competition phase, ($P<0.05$; Table 5.2). However, there was no significant effect of match location or interaction between match location and competition phase ($P>0.05$).

No significant effects of match location or competition phase, or interaction was detected for match load ($P>0.05$; Table 5.2), together with no significant differences in match duration between home early competition (86 (84-88) min), home late competition (87 (85-89) min), away early competition (88 (86-90) min) and away late competition (87 (85-89) min) ($P>0.05$).
Table 5.1. Effects of match location and competition phase on incidence, severity and type of injuries.

<table>
<thead>
<tr>
<th></th>
<th>Home Early Competition</th>
<th>Home Late Competition</th>
<th>Away Early Competition</th>
<th>Away Late Competition</th>
<th>Season</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury Incidence</td>
<td>3</td>
<td>4</td>
<td>7</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Injury Rate</td>
<td>7.1</td>
<td>12.0</td>
<td>9.2</td>
<td>6.8</td>
<td>7.6</td>
</tr>
<tr>
<td>Training Missed</td>
<td>11</td>
<td>27</td>
<td>38</td>
<td>11</td>
<td>33</td>
</tr>
<tr>
<td>Matches Missed</td>
<td>4</td>
<td>6</td>
<td>10</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Contact Injuries</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Non-contact Injuries</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Training Injuries</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Match Injuries</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Modified Training</td>
<td>13*</td>
<td>12</td>
<td>25#</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>No Training</td>
<td>6</td>
<td>5</td>
<td>11</td>
<td>1</td>
<td>8</td>
</tr>
</tbody>
</table>

*Significantly different to Away Season (P<0.05). *Significantly different to Away Early Competition (P<0.05).
Table 5.2. Mean (95\% CI) match load, total training load and mean wellness prior to, during and following each match at home and away and during the early competition and late competition phases.

<table>
<thead>
<tr>
<th></th>
<th>Match Load (AU)</th>
<th>Total Training Load (AU)</th>
<th>Mean Wellness (AU)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Home</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early Competition</td>
<td>738 (711, 765)</td>
<td>1900 (1696, 2104)</td>
<td>19.0 (18.8, 19.2)</td>
</tr>
<tr>
<td>Late Competition</td>
<td>732 (707, 757)</td>
<td>1603 (1405, 1801)</td>
<td>18.5 (18.3, 18.7)*</td>
</tr>
<tr>
<td><strong>Away</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early Competition</td>
<td>765 (726, 804)</td>
<td>1815 (1513, 2117)</td>
<td>18.8 (18.4, 19.2)</td>
</tr>
<tr>
<td>Late Competition</td>
<td>731 (696, 766)</td>
<td>1657 (1379, 1935)</td>
<td>18.5 (18.1, 18.9)</td>
</tr>
</tbody>
</table>

*Significantly different to early competition (P<0.05).
Table 5.3 provides a general description of the training schedule, along with mean TL on each individual day surrounding home and away matches. During the early competition phase, TL tended to be greater on day 2 ($P=0.09$) and were significantly greater on day 3 ($P=0.03$) at home compared to away (Figure 5.1). Furthermore, during the early compared to the late competition phase, TL were significantly greater on day 3 at home ($P<0.01$; Figure 5.2) and away ($P=0.01$; Figure 5.2). Wellness was significantly reduced on day 1, 2, 3 and 4 compared to day -1 and match day. Furthermore, wellness was significantly greater on day 2 compared to day 1 over the full season and during the early and late competition phases at both home and away ($P<0.05$). On day 3 compared to day 2, wellness was significantly greater at home and away over the full season, at home during the early competition phase and away during the late competition phase ($P<0.05$).
Table 5.3. General description of training content and mean (95% CI) training load on the day prior to, the day of and four days following each match at home and away.

<table>
<thead>
<tr>
<th></th>
<th>Day -1</th>
<th>Match Day</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Home</strong></td>
<td>Tactical</td>
<td>Match + Recovery</td>
<td>Day Off</td>
<td>Recovery (Pitch) + Yoga</td>
<td>Tactical</td>
<td>Conditioning + Gym</td>
</tr>
<tr>
<td></td>
<td>147 (117-177)</td>
<td>721 (691-751)</td>
<td>0</td>
<td>90 (60-120)</td>
<td>465 (435-495)</td>
<td>373 (343-403)</td>
</tr>
<tr>
<td><strong>Away</strong></td>
<td>Tactical</td>
<td>Match</td>
<td>Recovery + Travel</td>
<td>Day Off</td>
<td>Tactical</td>
<td>Conditioning + Gym</td>
</tr>
<tr>
<td></td>
<td>132 (102-162)</td>
<td>744 (714-774)</td>
<td>0</td>
<td>24 (0-48)</td>
<td>421 (391-451)</td>
<td>411 (381-441)</td>
</tr>
</tbody>
</table>
Figure 5.1. Effect of match location on mean (95% CI) training load and wellness during the full season (A and B), and early competition (C and D) and late competition (E and F) phase. †Significantly different to away ($P<0.05$). *Significantly different to Day -1 and Match Day (Home) ($P<0.05$). ‡Significantly different to Day -1 and Match Day (Away) ($P<0.05$). §Significantly different to previous time point (Home) ($P<0.05$). ¶Significantly different to previous time point (Away) ($P<0.05$).
Figure 5.2. Effect of competition phase on mean (95% CI) training load and wellness at home (A and B), and away (C and D). †Significantly different to the late competition phase ($P<0.05$). ‡Significantly different to Day -1 and Match Day (Early Competition) ($P<0.05$). §Significantly different to Day -1 and Match Day (Late Competition) ($P<0.05$). ¶Significantly different to previous time point (Early Competition) ($P<0.05$). ‡Significantly different to previous time point (Late Competition) ($P<0.05$).
**Discussion**

The present study examined the acute and longitudinal effects of regular away travel on TL, player wellness and injury prior to and following matches, in a professional Australian football team during a season of the A-League. Increased TL were evident following home compared to away matches during the early competition phase. Whilst this suggests travel following away matches may affect the weekly distribution of TL in the first half of the season, given no differences in wellness were identified following home compared to away matches, it is unlikely this was a result of travel impeding recovery. Moreover, reduced TL and wellness, and increased injury severity were evident in the late compared to the early competition phase. These results may imply that in the latter half of the season, players’ recovery time following matches was slower and their ability to cope with the demands of training and competition were diminished. However, no differences were present at home compared to away during the late competition phase, which suggests away travel *per se* had a negligible impact on the reduction in player wellness in the latter half of the season.

Differences in the weekly distribution of TL were detected following home compared to away matches in the early competition phase. Conversely, no differences in weekly TL were reported between home and away matches in professional rugby league players (McGuckin et al., 2014). However, as the recovery period from one match and preparation for subsequent competition are likely to affect TL in the first and second half of the week, respectively, separating the effects of home and away matches on weekly TL is difficult. TL was measured one day prior to, the day of and for four days following each match in the present study as a more effective way of isolating the acute effects of travel, though it is possible this was not fully achieved. As a result of losing a
day to travel following away matches, differences in training schedules were evident on day 1 and 2 post-match at home compared to away. Time lost due to travel makes it difficult to prescribe the TL required to optimize training responses between matches, which may impact preparation for ensuing competition. Moreover, reduced TL on day 3 following both home and away matches, and reduced total TL over the six days surrounding each match were reported in the late compared to the early competition phase. These results may imply that in the latter half of the season players’ recovery time following matches was slower, which required TL to be adjusted accordingly by the coaching staff, through reducing the training duration and/or intensity. However, no differences in TL were evident between home and away matches during the late competition phase, which suggests the cumulative effects of travel had a negligible impact on TL.

Similar to previous findings (Gastin et al., 2012; McLean et al., 2010), wellness returned to baseline levels within four days following matches in the present study. This is also comparable to previous reports that recovery of performance, physiological and perceptual responses requires 72-96 h following competitive football matches (Nédélec et al., 2013). Consequently, wellness may be a simple and effective method of monitoring post-match recovery in football. However, no differences in wellness were evident between home and away matches in the present study. In contrast, greater perceived fatigue, worse mood states and reduced subjective sleep quality have been identified one day prior to away matches in professional athletes (McGuckin et al., 2014; Richmond et al., 2007). Regardless, this is the first study to assess the effects of match location on the recovery of wellness following competitive football matches and thus, further research is required to confirm these findings. Conversely, reduced mean wellness over the six days
surrounding each match was evident in the late compared to the early competition phase. Together with the aforementioned reduction in TL, this implies that during the latter half of the season, players’ recovery time following matches was slower, their ability to cope with training and competition demands was reduced and consequently, their preparedness for ensuing training and competition may have been diminished. Whilst this could indicate an accumulation of fatigue throughout the season, no differences in wellness were observed at home compared to away during the late competition phase, which suggests factors other than travel per se influenced player wellness in the latter half of the season. Moreover, as increased wellness has previously been reported over the course of an Australian Football League season (Gastin et al., 2012), further research is required with larger data sets across multiple sports, teams and seasons to conclusively determine the longitudinal effects of travel on wellness.

In five out of the eight seasons since the beginning of the present format of the A-League, the team with the least injuries has finished top of the table (Professional Footballers Australia, 2013). Consequently, injury prevention is of upmost importance, with an understanding of the timing of peak injury incidence the fundamental first step in this process (Ekstrand, Hägglund, & Waldén, 2011). Increased training missed as a result of injury was evident in the late compared to the early competition phase for both home and away matches. This indicates greater injury severity in the late competition phase, which may be a result of the aforementioned reduction in player wellness, given its previous association with increased injury risk (Gastin et al., 2012). However, no differences in any injury measure were observed at home compared to away, which further suggests away travel had negligible effects on recovery and injury rates in professional football players. In contrast to previous research that reports teams in European professional
football can expect approximately 50 injuries per season (Bengtsson et al., 2013), only 13 injuries were reported during the season in the present study. This is likely due to the greater number of games played per week in Europe compared to Australia, and therefore, research is warranted into the longitudinal effects of travel on injury risk, when more than one game is played per week.

In conclusion, acute effects of travel on the distribution of TL were observed following matches in the early competition phase. However, no other differences between home and away matches were detected for TL, player wellness or injury. Instead, reduced TL and wellness, along with increased training missed due to injury were identified during the late compared to the early competition phase. These findings suggest recovery time following matches was prolonged and thus, preparedness for ensuing training and competition may have been diminished in the latter half of the season. Whilst this may indicate an accumulation of travel-related fatigue throughout the season, results from the present study imply that away travel had negligible effects on the reduction in player wellness observed during the latter half of the season. However, it is acknowledged that factors other than the competition phase could augment travel effects, including congested fixture schedules and increased travel during pre-season for training camps and friendly matches, when TL are also greater. Therefore, further research is warranted into the interaction between these factors and the magnitude of travel effects. Furthermore, as the present study only involved players from one team, it should be noted that the findings may only be a reflection of this particular team and their associated travel demands. Indeed, there are teams within Australian domestic competitions with greater travel demands, particularly those based in
Western Australia or New Zealand (Goumas, 2014). Therefore, further research involving larger data sets from multiple teams with a range of travel demands is required.
Chapter Six
Study Four

Effects of sleep hygiene and artificial bright light interventions on recovery from simulated international air travel

Based on the publication;

Abstract

Aims: Despite the reported detrimental effects of international air travel on physical performance, a paucity of interventions have been scientifically tested and confirmed to benefit travelling athletes. Consequently, the aim of the present study was to examine the effects of sleep hygiene and artificial bright light interventions on physical performance following simulated international travel. Methods: In a randomized crossover design, thirteen physically active males completed 24-h of simulated international travel with (INT) and without (CON) the interventions. The mild hypoxia and cramped conditions typically encountered during commercial air travel were simulated in a normobaric, hypoxic room. Physical performance, subjective jet-lag symptoms and mood states were assessed in the morning and evening on the day prior to and for two days post-travel. Sleep quantity and quality were monitored throughout each trial. Results: Sleep duration was significantly reduced during travel in both trials ($P<0.01$), though total sleep duration during and following travel was almost significantly greater ($P=0.06$) in INT (17.0 (16.2-17.8) h) compared to CON (15.7 (14.9-16.5) h). Maximal-sprint and countermovement jump ($P<0.05$), but not Yo-Yo Intermittent Recovery level 1 test ($P>0.05$) performance, were significantly reduced the evening of day 1 and 2 post-travel, with no differences between trials ($P>0.05$). Furthermore, vigour was significantly greater ($P=0.04$) the morning of day 2 in INT (5.3 (3.9-6.7)) compared to CON (2.8 (1.4-4.2)), and subjective jet-lag symptoms and mood states were significantly worse on day 2 in CON only ($P<0.05$). Conclusions: Whilst reducing travel-induced sleep disruption may attenuate travel fatigue, no improvements in the recovery of physical performance were apparent.
Introduction

For many elite team sport athletes, frequent international air travel is required for competition or training camps. However, given the decline in physical performance reported following international travel (Chapman et al., 2012; Reilly et al., 2001), performance during training and competition, as is often required within days of arrival, may be reduced. Such decrements are purported to result from the detrimental symptoms of jet-lag and travel fatigue, including disruptions to circadian rhythms and sleep, together with negative mood states (Forbes-Robertson et al., 2012; Leatherwood and Dragoo, 2012; Reilly et al., 2007). Though behavioural (Thompson et al., 2013) and pharmacological (Lagarde et al., 2001; Reilly et al., 2001) interventions may attenuate jet-lag symptoms, and thus improve athlete preparedness following travel, limited scientific recommendations currently exist for reducing travel fatigue in athletes (Reilly et al., 2007; Waterhouse et al., 2007). Considering sleep disruption has previously been reported during and following transmeridian air travel (Takahashi et al., 2002), which is likely a result of the demands of air travel per se and altered circadian rhythms, respectively (Forbes-Robertson et al., 2012; Takahashi et al., 2002), interventions focused on these factors may be important. However, since the time line of recovery for team sport physical performance following international travel is yet to be determined, the effects of such interventions for team sports is currently unknown.

Symptoms of jet-lag result from the loss of synchrony between the endogenous (circadian rhythms in body temperature and hormone release) and exogenous (sleep and activity) components of the body clock, which occurs after rapidly crossing multiple time zones during transmeridian air travel (Forbes-Robertson et al., 2012; Reilly et al., 2007; Waterhouse et al.,
2007). Conversely, travel fatigue symptoms are induced by the demands of air travel *per se*, including the mild hypoxia, cramped conditions, cabin noise and associated sleep disruption. Though symptoms of jet-lag tend to be more severe and longer lasting than those of travel fatigue, both may result in compromised physical performance (Forbes-Robertson et al., 2012; Reilly et al., 2007; Waterhouse et al., 2007). However, the separation of their individual effects is often difficult in field-based environments (Leatherwood and Dragoo, 2012). Whilst a decline in grip strength and countermovement jump (CMJ) performance has been observed following transmeridian air travel (Chapman et al., 2012; Reilly et al., 2001), others have reported no change in squat jump and maximal-sprint performance (Bullock et al., 2007; Lagarde et al., 2001). These equivocal findings may relate to differences in the type, sensitivity, timing and frequency of testing (Bullock et al., 2007; Lagarde et al., 2001). Furthermore, whilst the predominance of grip strength and jump tests as performance measures may assist with the logistics of testing athletes around travel and competition, they have limited ecological relevance to team sports, which require prolonged bouts of intermittent-sprint activity.

Despite the detrimental effects of transmeridian air travel on physical performance (Chapman et al., 2012; Reilly et al., 2001), a paucity of interventions have been confirmed as beneficial for travelling athletes. Given the disruption of habitual sleep patterns is likely to occur during and following long-haul international air travel (Takahashi et al., 2002), which may reduce physical performance itself (Reilly and Edwards, 2007; Skein et al., 2011), sleep hygiene recommendations that minimize this disruption may enhance performance recovery following international travel. Specific strategies include minimizing the use of electronic equipment prior to sleep and ensuring a cool, quiet and dark environment (Halson, 2013). Though these strategies
are advocated to improve sleep in elite athletes (Halson, 2013), it remains to be investigated as to whether they are effective at minimizing sleep disruption during and following international travel. Moreover, the correct timing of exposure to bright light is currently purported to be the most effective method of adjusting circadian rhythms (Forbes-Robertson et al., 2012). Consequently, the commercial availability of portable artificial bright light sources as a treatment for jet-lag has recently increased. Whilst evidence suggests these devices can adjust circadian rhythms (Wright et al., 2004), their effectiveness at enhancing the recovery of physical performance for team sports following transmeridian air travel is limited (Thompson et al., 2013).

Therefore, the purpose of the present study was to investigate the effects of the demands of simulated international air travel *per se* and a simulated change in time zones on the recovery of team sport physical performance. Furthermore, the efficacy of sleep hygiene recommendations alongside an artificial bright light intervention on performance recovery was assessed.

**Methods**

**Participants**

Thirteen, healthy, physically active males were recruited to participate in the present study; mean and 95% confidence intervals (CI); age 24.3 (19.6-29.0) y, body mass 73.8 (69.3-78.3) kg and estimated \( \dot{V}O_2 \text{max} \) 52.3 (50.4-54.2) ml·kg\(^{-1}\)·min\(^{-1}\) (Bangsbo et al. 2008). Participants were free of sleep disorders and did not consume large doses of caffeine or alcohol. In addition, participants were non-smokers, medication free, and had not undertaken shift work or any long-haul transmeridian flights in the month prior to the study. Participants’ compliance with the study’s
inclusion and exclusion criteria was determined from a general health questionnaire and an interview with a member of the research team. At the time of testing, participants reported completing three or more physical training sessions per week, including sport-specific, cardiovascular and resistance training. However, it is recognized as a limitation of the present study that the participants were not all highly-trained team sport athletes, which may restrict the generalisability of the results. Prior to the commencement of the study, participants were informed of any associated risks and provided verbal and written informed consent. The study was approved by the institutional Human Research Ethics Committee.

**Experimental design**

Following a minimum of two familiarization sessions with all experimental measures and procedures, including a detailed account of the simulated travel protocol, participants completed two trials in a randomized cross-over design. Each trial involved 24 h of simulated international travel, including 10 h and 12 h flights separated by a two hour ‘stopover’, thus, replicating the demands of travel from Sydney, Australia to London, England via Hong Kong. Trials were standardized and differed only by whether the artificial bright light and sleep hygiene interventions were utilized (INT) or not (CON). Collection of performance, physiological and perceptual data occurred in the morning at 08:00 and evening at 18:00, Australian Eastern Standard Time (AEST) on the day prior to travel, and in the morning at 07:00 and evening at 19:00 AEST for two days post-travel, which corresponded to 21:00 and 09:00 Greenwich Mean Time (GMT, London, England) (Figure 6.1). These specific times were selected to align with previous research (Reilly et al., 2001; Thompson et al., 2013) and to standardize for the diurnal variation in physical performance (Drust et al., 2005).
Data were collected over five consecutive days for both trials. Specifically, in both conditions, the experimental protocol consisted of 1 x 24 h day of baseline, 2 x 24 h days of simulated international travel, and 2 x 24 h days of forced de-synchrony (simulated time-zone change). On the baseline day (Monday) participants slept according to AEST (i.e. 22:00 to 07:00 h) at home and were free to choose their own bed and wake times, though were encouraged to obtain a minimum of 8 h sleep. Time in bed on the baseline day for both trials is reported in Table 6.1. On the two days of simulated travel (Tuesday and Wednesday), participants slept on the simulated flight in a hypoxic altitude room (refer to ‘simulated air travel’ section), and were free to choose their own sleep times. However, during the INT trial participants were encouraged to sleep whenever possible (refer to ‘interventions’ section). Lastly, on the two forced de-synchrony days (Thursday and Friday), participants slept in an altitude house, where their bed and wake times were standardised according to GMT, which corresponded to 09:30 to 18:00 AEST (between the morning and afternoon performance testing at 07:00 and 19:00 AEST). The time in bed for these two days is again displayed in Table 6.1. Each trial was separated by a minimum of one week to ensure adequate recovery. Physical activity and dietary and fluid intake were documented 24 h prior to the first trial and replicated for the subsequent trial. Participants abstained from caffeine, alcohol and additional strenuous activity for 24 h before and during each trial.
Figure 6.1. Schematic outline of the study design illustrating the timing of performance, physiological and perceptual data collection, and the timing of exposure to artificial bright light in the INT trial. Light and dark grey shaded areas indicate light exposure (02:00 - 05:00 AEST) and avoidance (05:00 - 08:00 AEST), respectively.
Simulated air travel

The INT and CON groups completed the simulated travel in separate normobaric, hypoxic altitude rooms (Kinetic Performance Technologies, Canberra, ACT, Australia), where the simulated altitude via nitrogen dilution (2377 (2366-2388) m), temperature (20.8 (20.3-21.3) °C) and seating arrangement replicated what is typically encountered during a commercial flight (Geertsema et al., 2008). An inability to regulate the humidity meant it was 48.7 (46.1-52.3) % during travel. Converted bus seats with head and arm rests, and the ability to recline, were used to simulate plane seats. The seats were arranged in a similar configuration to a commercial flight, had a height, width and pitch of 110 cm, 45 cm, and 85 cm, respectively, and were set in the upright position for the first and last 30 min of each flight during ‘take-off’ and ‘landing’. The fraction of inspired oxygen during travel was 0.17 (0.16-0.18) %, which is representative of the fraction of inspired oxygen during actual airline travel (Coste et al., 2009). Activity patterns were regulated to ensure simulation of airplane travellers, and lighting was dimmed (27 (20-34) lux) and raised (114 (93-135) lux), and meals and fluid were served according to a typical commercial flight schedule. Please refer to Appendix C for photographic examples of the simulated travel environment.

Meals similar in content and packaging to standard airline food were provided 1 h into and 2.5 h from the end of each leg of the simulated travel, whilst additional fluid was provided every two hours during each flight. Nutritional intake was documented by participants throughout all trials via dietary recall, which was analyzed using nutrient analysis software (FoodWorks®, Xyris Software Pty Ltd, Kenmore Hills, Australia). No significant differences existed between the INT and CON trials ($P<0.05$) for energy (KJ) and carbohydrate, protein, or fat intake (g/kg BM). To
simulate engine noise levels in the cabin during a commercial flight, air blowers (Side Channel Blower SE0120, BUSCH, Broadmeadows, VIC, Australia) were positioned in each room so that the noise level where participants sat was 80 decibels (Ozcan & Nemlioglu, 2006). During the two hour stopover, participants exited the altitude room and were permitted to move around freely in normoxia.

**Simulated time-zone change**

The hypoxic rooms in which the simulated travel was completed formed part of an altitude house. Natural light and external influences were blocked out of the house throughout each trial. From the beginning of the simulated travel, all clocks were altered to show the destination time (GMT, London, England). In addition, on completion of the simulated travel, participants’ light-dark cycles and thus, eating and sleeping patterns were changed to London time for the rest of the trial. In an attempt to simulate day time in London, participants were required to remain awake overnight AEST in the altitude house with the lights on (167 (100-234) lux). However, it is acknowledged as a limitation that this doesn’t represent normal daylight. During this time participants were permitted to move around freely in normoxia and were provided with breakfast, lunch, and dinner according to London time. To simulate night time in London, participants slept in the altitude house during the day time AEST. To allow sufficient time for sleep, compared to baseline, testing commenced an hour earlier in the morning (07:00 vs. 08:00 AEST) and an hour later in the evening (19:00 vs. 18:00 AEST). In order to limit potential exposure to incidental natural light, participants wore wrap-around sunglasses (Contractor Smoke Safety Glasses, Dewalt, Melbourne, Australia) when moving between the altitude house and the enclosed synthetic running track, where the performance tests were conducted and all
natural light was blocked out. Since testing began at 07:00, participants continued to wear the wrap-around sunglasses until 08:00 during the INT trial, in accordance with the timings of light exposure and avoidance detailed below.

**Interventions**

During the simulated travel, participants in the INT group were provided with noise cancelling headphones (Sennheiser HD 280 Pro, Sennheiser, Chatswood, Australia), a sleep mask (Sweet Dreams Eye Mask, Dream Essentials, Paradise Point, Australia) and a neck pillow (Traveller’s Pillow, Therapeutic Pillow International, Cheltenham, Australia), and were instructed to sleep whenever possible. This aimed to increase comfort and the likelihood of sleep, since reduced sleep quantities have previously been reported during long-haul transmeridian air travel (Takahashi et al., 2002). Furthermore, participants’ exposure to and avoidance of light was controlled during simulated travel. Specifically, artificial bright light emitting glasses (Re-Timer™, Bedford Park, SA, Australia) and wraparound sunglasses (Contractor Smoke Safety Glasses, Dewalt, Melbourne, Australia) were used from 02:00 - 05:00 and 05:00 - 08:00 AEST, respectively (Figure 6.1). This specific timing of light exposure was derived from previous research on the phase response curve to light (Czeisler et al., 1989), which suggests that light exposure prior to and light avoidance following the circadian nadir in body temperature, which typically occurs at 05:00 in healthy young adults (Duffy, Dijk, Klerman, & Czeisler, 1998), can induce a phase delay in circadian rhythms. Hence, the light exposure intervention aimed to assist with aligning the participants’ body clock to the new simulated time zone (GMT). Conversely, no assistance or advice was provided to the CON group, who self-selected their sleep patterns during the simulated travel. When participants in the CON group were not sleeping they were
permitted to watch movies, read, listen to music or play handheld computer and card games, but remained seated at all times other than when using the bathroom (located in the adjacent room). In contrast, participants in the INT group were instructed to avoid electronic equipment when they were not sleeping, as previous research has reported that exposure to light, including electronic equipment, causes melatonin suppression and could therefore, potentially impact sleep (Wood, Rea, Plitnick, & Figueiro, 2013; Gooley et al., 2010).

Participants in the INT group continued to use the light glasses and wraparound sunglasses at the same times for two days post-travel, to assist with circadian rhythm resynchronization following the simulated change in time zones and light-dark cycle. Overall, participants were exposed to 506 lux of blue-green 500 nm dominant wavelength, UV-free light at 12 mm for 3 h per day for three days during the INT trial, with each eye receiving 230 µW/cm² at the corneal surface. Light glasses with similar specifications have previously been reported to induce phase-shifts in circadian rhythms (Wright et al. 2004). Sleep hygiene recommendations were also provided to participants during and for the two sleep periods following travel in the INT trial. These recommendations aimed to induce the physiological state required for sleep onset and were again based on evidence that exposure to excessive light and electronic stimuli causes melatonin suppression, which could potentially impact sleep (Wood et al., 2013; Gooley et al., 2010). Specifically, in the hour prior to bed, participant’s limited computer, TV and phone use and dimmed their bedroom lights. Cool (19.7 (19.1-20.3) C), quiet and dark conditions were ensured throughout the sleep period. In contrast, the CON group was instructed to maintain normal behaviour prior to bed and did not alter their room lighting or temperature. For both trials,
participants shared the same room with the same group and the INT and CON groups were in separate rooms.

**Experimental Procedures**

*Performance measures*

In a rested state prior to a warm-up, participants completed a two- and four-choice reaction time test (React, Australian Institute of Sport, Canberra, ACT, Australia). The typical error of these measures in the present study was 41 (32-62) ms and 31 (24-48) ms, respectively. Following the reaction time test, a warm-up consisting of the 5´-5´ test (Buchheit et al. 2011), involving 5 min of standardized sub-maximal exercise and 5 min seated recovery, followed by 10 min of general whole body movements was completed (Taylor et al. 2010). All performance testing sessions were performed in temperate conditions on an enclosed synthetic running track. Participants performed an unloaded and loaded (40 kg) CMJ test (Taylor et al. 2010), a 20 m sprint test and the Yo-Yo Intermittent Recovery level 1 (YYIR1) test (Krstrup et al. 2003), as these tests are commonly utilized to assess the physical performance levels of elite team sport athletes (Australian Institute of Sport 2000). Participants were blinded from their results in all performance tests until the end of the study, which included using a modified version of the YYIR1, with feedback regarding the level removed from the test audio mp3.

Jump height was measured using a linear position transducer (GymAware, Kinetic Performance Technologies, Canberra, ACT, Australia) sampling at 50 Hz. Performance of the unloaded and loaded CMJ tests involved participants holding either a 1.5 m long, 0.5 kg aluminium bar or a weighted Olympic bar (40 kg in total), respectively, firmly across the shoulders. The GymAware
unit was fastened to a frame overhead and during each jump the linear position transducer was attached to the centre of the bar from above. A minimum of 3 min recovery was provided between each set of jumps. The typical error for jump height from the unloaded and loaded jumps in the present study was 1.5 (1.1-2.1) cm and 1.0 (0.8-1.4) cm, respectively. Three maximal 20 m sprints were performed with a minimum of 3 min recovery between each. Splits were measured at 5 m and 20 m using a single-beam infrared timing gate system (Smartspeed™, Fusion Sport, Coopers Plains, QLD, Australia). The fastest 5 m and 20 m sprint time was selected for analyses, which had a typical error of 0.04 (0.03-0.06) sec and 0.08 (0.06-0.12) sec, respectively. During the YYIR1, performance was determined by total distance covered at the point of volitional exhaustion, which has been identified as a reliable measure of team sport physical performance (Krstrup et al. 2003) and had a typical error of 134 (104-203) m in the present study.

**Physiological measures**

Participants’ sleep was monitored using self-report diaries and wrist activity monitors (Philips Respironics, Bend, OR) worn on the same wrist during each trial for two days prior to, during and two days following the simulated travel. In studies that involve data collection from multiple participants simultaneously over consecutive nights, activity monitors are typically preferred over PSG, the gold standard for monitoring sleep, because they are portable, non-invasive and operate remotely without an attendant technician. Validation studies comparing wrist activity monitors with PSG report high correlations for sleep duration ($r=0.84-0.89$) (Weiss et al., 2010). According to methods previously described (Sargent, Halson, & Roach, 2014), data from the sleep diaries and activity monitors was used to determine when participants were awake and
asleep. The following dependent variables were derived; sleep duration (h): the amount of time spent in bed asleep; sleep efficiency (%): sleep duration expressed as a percentage of time in bed; and the number of wake bouts (Sargent et al., 2014). Total sleep duration (h) during the sleep hygiene intervention period was also calculated for each trial, by summating individual sleep durations from during-travel, day 1 and day 2.

Oxygen saturation was recorded whilst seated with a pulse oximeter (Nonin 4000 Avant Bluetooth Pulse Oximeter, Nonin, North Plymouth, MN) immediately prior to, 1 h after ‘take-off’, half-way through, 1 h prior to ‘landing’ and immediately following each leg of the simulated travel. To assess urine specific gravity, a midstream urine sample was collected and analyzed (Refractometer 503, Nippon Optical Works, Co., Tokyo, Japan) immediately prior to all performance testing sessions, and immediately before the first leg and after the second leg of the simulated travel. Heart rate was measured (Polar Team², Polar Electro, Kempele, Finland), continuously throughout the 5’-5’ test and was analyzed using customized manufacturers software (Polar Team System², Polar Electro, Kempele, Finland). Heart rate during and recovery following the test was calculated according to a method previously described (Buchheit et al., 2011). The typical error for these measures in the present study was 6 (4-9) beats per minute and 4 (3-6) beats per minute, respectively.

**Perceptual measures**

The Liverpool John Moore’s University jet-lag questionnaire (Waterhouse et al., 2000) was completed immediately prior to all performance testing sessions, and immediately before the first leg and after the second leg of the simulated travel. The questionnaire assessed participants’
subjective ratings of jet-lag and sleep, function, diet and bowel movement ratings on a visual analogue scale. Following a method previously outlined (Thompson et al., 2013), questionnaire data was pooled and summed into the above categories for analysis. The Brunel Mood Scale (Galambos et al., 2005) was also completed at the aforementioned time points to assess participants’ anger, confusion, depression, fatigue, tension and vigour. Lastly, approximately 30 min after the completion of the performance tests, a session rating of perceived exertion (Foster et al., 1996) and physical feeling (Hardy & Rejeski, 1989) were obtained from participants.

Statistical Analysis

Data are presented as means and 95% CI. The effect of time and trial was assessed by fitting a linear mixed model. Specifically, time and trial, and their interaction were fitted as fixed effects to determine whether there was a difference in the effect of trial over time. In addition, participant and trial (within participant) were fitted as random effects to account for the possible correlation within participants and within trial within participants. Where a significant effect was observed ($P<0.05$), a Tukey HSD post-hoc test was used to determine differences between means. All analyses were performed using JMP statistical software (JMP Pro v 10.0, SAS, Cary, NC).

Results

Performance measures

For reporting purposes, whilst the time of day at baseline refers to AEST, as a result of the simulated change in time zones and light-dark cycle, the two days following travel are referred to in GMT (Figure 6.1). No significant differences existed between conditions for any performance
measure ($P>0.05$) or over time for distance covered in the YYIR1 ($P>0.05$; Figure 6.2) or two- or four-choice reaction time ($P>0.05$; Figure 6.2). Compared to the evening baseline in CON and morning and evening baseline in INT, 5 m sprint time was significantly slower the evening of day 2 ($P>0.05$; Figure 6.2), and 20 m sprint time was significantly slower the evening of day 1 ($P>0.05$; Figure 6.2). Furthermore, 20 m sprint time was significantly slower the evening of day 2 compared to the morning and evening baseline in both trials ($P<0.05$). Whilst no significant differences were evident over time for loaded CMJ height, unloaded CMJ height was significantly reduced the evening of day 1 and 2 compared to the morning and evening baseline in the INT trial ($P>0.05$; Figure 6.2). Unloaded CMJ height was almost significantly reduced the evening of day 1 compared to the evening baseline in the CON trial ($P=0.08$).

**Physiological measures**

No significant differences existed between conditions for any physiological measure ($P>0.05$). Sleep duration was significantly reduced during travel compared to all other time points in both trials ($P<0.01$; Table 6.1), while total sleep duration was almost significantly greater during the INT compared with the CON trial ($P=0.06$). Perceived sleep quality was significantly worse during travel compared to all other time points in both trials ($P<0.01$; Table 6.1). Compared to baseline, perceived sleep quality was significantly and almost significantly better on day 1 ($P=0.03$) and day 2 ($P=0.06$), respectively, in the INT trial.
Figure 6.2. Effect of simulated international air travel and intervention on performance responses. Mean (95% CI) distance covered in the YYIR1 (A), 5 m sprint time (B), 20 m sprint time (C) unloaded and loaded CMJ height (D), and two- and four-choice reaction time (E) during the INT (solid black line and square) and CON (dashed line and white circle) trials. *Significantly different to the morning baseline (CON) ($P<0.05$). †Significantly different to the morning and evening baseline (INT) ($P<0.05$). ‡Significantly different to the morning and evening baseline ($P<0.05$).
Table 6.1. Effects of travel and intervention on sleep. Mean (95% CI) sleep volume and quality in the CON and INT trial, two days prior to (Baseline 1 and Baseline 2), during (During Travel) and two days following (Day 1 and Day 2) travel.

<table>
<thead>
<tr>
<th></th>
<th>Baseline 1</th>
<th>Baseline 2</th>
<th>During Travel</th>
<th>Day 1</th>
<th>Day 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bed Time (AEST)</td>
<td>22:00</td>
<td>22:00</td>
<td>N/A</td>
<td>09:30</td>
<td>09:30</td>
</tr>
<tr>
<td>Wake Time (AEST)</td>
<td>07:00</td>
<td>07:00</td>
<td>N/A</td>
<td>18:00</td>
<td>18:00</td>
</tr>
<tr>
<td>Time in Bed (h)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>7.7 (6.9, 8.5)</td>
<td>9.0 (8.3, 9.7)</td>
<td>N/A</td>
<td>8.1 (7.9, 8.3)</td>
<td>7.4 (7.0, 7.8)</td>
</tr>
<tr>
<td>INT</td>
<td>7.4 (6.6, 8.2)</td>
<td>9.3 (8.5, 10.0)</td>
<td>N/A</td>
<td>8.1 (7.9, 8.3)</td>
<td>7.9 (7.6, 8.2)</td>
</tr>
<tr>
<td>Sleep Duration (h)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>6.7 (5.9, 7.5)</td>
<td>7.8 (7.0, 8.6)</td>
<td>2.2 (1.4, 3.0)</td>
<td>7.1 (6.3, 7.9)</td>
<td>6.5 (5.7, 7.3)</td>
</tr>
<tr>
<td>INT</td>
<td>6.5 (5.7, 7.3)</td>
<td>8.1 (7.3, 8.9)</td>
<td>3.0 (2.2, 3.8)</td>
<td>7.3 (6.5, 8.1)</td>
<td>6.8 (6.0, 7.6)</td>
</tr>
<tr>
<td>Sleep Efficiency (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>CON</td>
<td>84.0 (78.9, 89.1)</td>
<td>85.9 (80.7, 91.1)</td>
<td>78.6 (73.5, 83.7)</td>
<td>85.9 (80.8, 91.0)</td>
<td>84.9 (79.8, 90.0)</td>
</tr>
<tr>
<td>INT</td>
<td>82.2 (77.3, 87.1)</td>
<td>83.0 (77.9, 88.1)</td>
<td>79.6 (74.4, 84.8)</td>
<td>88.0 (83.1, 92.9)</td>
<td>84.6 (79.5, 89.7)</td>
</tr>
<tr>
<td>Wake Bouts (#)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>24.8 (18.7, 30.9)</td>
<td>30.5 (24.2, 36.8)</td>
<td>8.7 (2.6, 14.8)</td>
<td>24.0 (17.9, 30.1)</td>
<td>23.9 (17.8, 30.0)</td>
</tr>
<tr>
<td>INT</td>
<td>23.7 (17.7, 29.7)</td>
<td>30.1 (24.0, 36.2)</td>
<td>10.5 (4.2, 16.8)</td>
<td>21.3 (15.3, 27.3)</td>
<td>21.4 (15.3, 27.5)</td>
</tr>
<tr>
<td>Perceived Sleep Quality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>3.7 (3.1, 4.3)</td>
<td>3.4 (2.8, 4.0)</td>
<td>5.6 (5.0, 6.2)</td>
<td>2.7 (2.1, 3.3)</td>
<td>3.5 (2.9, 4.1)</td>
</tr>
<tr>
<td>INT</td>
<td>3.6 (3.0, 4.2)</td>
<td>2.9 (2.3, 3.5)</td>
<td>5.5 (4.9, 6.1)</td>
<td>2.3 (1.7, 2.9)</td>
<td>3.5 (2.9, 4.1)</td>
</tr>
</tbody>
</table>

*Significantly different to all other time points (P<0.05). †Significantly different to Day 2 (CON) (P<0.05). *Significantly different to Baseline 1 and Day 2 (INT) (P<0.05). ‡Significantly different to During Travel (INT) (P<0.05). §Significantly different to Baseline 1 (P<0.05).
In the CON and INT trials, respectively, oxygen saturation was significantly reduced during travel (94.8 (94.0-95.6) % and 94.7 (93.9-95.5) %; \( P<0.01 \)) compared to immediately pre- (97.4 (96.6-98.2) % and 97.7 (96.9-98.5) %) and post-travel (98.2 (97.6-99.0) % and 98.7 (98.1-99.5) %). No significant differences existed in the heart rate response to sub-maximal exercise (5´-5´ test) between conditions. Interestingly, heart rate was significantly lower in the evening compared to the morning on day 2 in both trials (\( P<0.05 \); Table 6.2). Urine specific gravity was significantly lower the evening of day 1 compared to the morning baseline and pre-travel (\( P<0.01 \)), and the evening of day 2 compared to the morning baseline (\( P<0.05 \)) in both trials (Table 6.2).

**Perceptual measures**

Whilst vigour was significantly greater the morning of day 2 in the INT compared to the CON trial (\( P=0.04 \); Table 6.3), no other significant differences existed between conditions for any perceptual measure (\( P>0.05 \)). Compared to the morning and evening baseline, subjective jet-lag was significantly greater at all other time points and sleep ratings were significantly worse on day 1 in both trials (\( P<0.05 \); Figure 6.3). In contrast, sleep ratings were significantly better the morning of day 2 in the CON trial (\( P<0.05 \)) and the morning and evening of day 2 in the INT trial (\( P<0.05 \)). Function ratings were significantly worse the evening of day 1 compared to the morning and evening baseline in both trials (\( P<0.05 \); Figure 6.3). Additionally, function ratings were significantly worse the morning of day 1 and the evening of day 2 compared to baseline in the CON trial (\( P<0.05 \)). Conversely, in the INT trial, function ratings were almost significantly better the morning of day 2 compared to the morning of day 1 (\( P=0.09 \)) and evening of day 2.
Lastly, bowel movement ratings were significantly worse the evening of day 1 compared to the morning baseline in the CON trial ($P<0.01$; Figure 6.3).

No significant effects of time were identified for anger, depression or tension in either trial ($P>0.05$) and therefore, given the extent of the data already presented, no data is presented for these variables. Compared to baseline, confusion and fatigue were significantly greater the evening of day 1 and the evening of day 1 and 2, respectively, in both trials ($P<0.05$; Table 6.3). Moreover, fatigue was significantly greater the morning of day 1 compared to baseline in the CON trial ($P<0.05$). Vigour was significantly lower the evening of day 1 compared to pre-travel in the CON trial ($P<0.05$), and the morning baseline and pre-travel in the INT trial ($P<0.05$; Table 6.3). Lastly, compared to baseline, session rating of perceived exertion was significantly greater, and physical feeling was significantly worse, the evening of day 1 and 2 in both trials ($P<0.05$; Table 6.3).
Table 6.2. Effects of travel and intervention on physiological responses. Mean (95% CI) urine specific gravity (USG), together with heart rate during (HRex) and following (HRR) sub-maximal exercise in the CON and INT trials, one day (Baseline) and immediately prior to (Pre-Travel) travel, and immediately (Post-Travel) and three days following (Day 1, Day 2 and Day 3) travel.

<table>
<thead>
<tr>
<th></th>
<th>GMT</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Travel</td>
<td>Post-Travel</td>
<td>Day 1</td>
<td>Day 2</td>
<td>Day 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>08:00</td>
<td>21:00</td>
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<td>19:00</td>
<td>07:00</td>
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<tr>
<td>GMT</td>
<td>08:00</td>
<td>18:00</td>
<td>18:00</td>
<td>07:00</td>
<td>19:00</td>
<td>07:00</td>
<td>19:00</td>
<td></td>
</tr>
<tr>
<td>AEST</td>
<td>08:00</td>
<td>18:00</td>
<td>18:00</td>
<td>07:00</td>
<td>19:00</td>
<td>07:00</td>
<td>19:00</td>
<td></td>
</tr>
<tr>
<td>USG CON</td>
<td>1.021</td>
<td>1.012</td>
<td>1.020</td>
<td>1.013</td>
<td>1.008</td>
<td>1.015</td>
<td>1.010</td>
<td>1.016</td>
</tr>
<tr>
<td></td>
<td>(1.017, 1.025)</td>
<td>(1.008, 1.016)</td>
<td>(1.016, 1.024)</td>
<td>(1.009, 1.017)</td>
<td>(1.004, 1.012)</td>
<td>(1.011, 1.019)</td>
<td>(1.006, 1.014)</td>
<td>(1.012, 1.020)</td>
</tr>
<tr>
<td>USG INT</td>
<td>1.019</td>
<td>1.010</td>
<td>1.018</td>
<td>1.014</td>
<td>1.010</td>
<td>1.014</td>
<td>1.011</td>
<td>1.015</td>
</tr>
<tr>
<td></td>
<td>(1.015, 1.023)</td>
<td>(1.006, 1.014)</td>
<td>(1.014, 1.022)</td>
<td>(1.010, 1.018)</td>
<td>(1.006, 1.014)</td>
<td>(1.010, 1.018)</td>
<td>(1.007, 1.015)</td>
<td>(1.011, 1.019)</td>
</tr>
<tr>
<td>HRex (bpm) CON</td>
<td>156 (148, 164)</td>
<td>159 (151, 167)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>153 (145, 161)</td>
<td>160 (152, 168)</td>
</tr>
<tr>
<td>HRex (bpm) INT</td>
<td>158 (150, 166)</td>
<td>159 (151, 167)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>155 (147, 163)</td>
<td>160 (152, 168)</td>
</tr>
<tr>
<td>HRR (bpm) CON</td>
<td>62 (55, 69)</td>
<td>62 (55, 69)</td>
<td></td>
<td></td>
<td>68 (61, 75)</td>
<td>63 (56, 70)</td>
<td>63 (56, 70)</td>
<td>60 (53, 67)</td>
</tr>
<tr>
<td>HRR (bpm) INT</td>
<td>64 (57, 71)</td>
<td>63 (56, 70)</td>
<td></td>
<td></td>
<td>63 (56, 70)</td>
<td>58 (51, 65)</td>
<td>62 (55, 69)</td>
<td>59 (52, 66)</td>
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</tbody>
</table>

*Significantly different to Pre-Travel (P<0.05). †Significantly different to morning baseline (P<0.05). ††Significantly different to morning on day 2 (P<0.01).
Table 6.3. Effects of travel and intervention on perceptual responses. Mean (95% CI) sRPE, physical feeling and mood states, in the CON and INT trial, one day (Baseline) and immediately prior to (Pre-Travel) travel, and immediately (Post-Travel) and three days following (Day 1, Day 2 and Day 3) travel.

<table>
<thead>
<tr>
<th>Measure</th>
<th>GMT</th>
<th>Baseline</th>
<th>Pre-Travel</th>
<th>Post-Travel</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
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<tr>
<td></td>
<td>AEST</td>
<td>08:00</td>
<td>18:00</td>
<td>08:00</td>
<td>18:00</td>
<td>07:00</td>
<td>19:00</td>
</tr>
<tr>
<td>sRPE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CON</td>
<td>5.7 (4.7, 6.7)</td>
<td>6.3 (5.3, 7.3)</td>
<td>7.2 (6.2, 8.2)*</td>
<td>6.5 (5.5, 7.5)</td>
<td>7.2 (6.2, 8.2)*</td>
<td>6.4 (5.4, 7.4)</td>
<td></td>
</tr>
<tr>
<td>INT</td>
<td>5.6 (4.6, 6.6)</td>
<td>6.1 (5.1, 7.1)</td>
<td>6.9 (5.9, 7.9)*</td>
<td>6.4 (5.4, 7.4)</td>
<td>7.2 (6.2, 8.2)*</td>
<td>7.1 (6.1, 8.1)</td>
<td></td>
</tr>
<tr>
<td>Physical Feeling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>1.4 (0.2, 2.6)</td>
<td>0.3 (-0.9, 1.5)</td>
<td>-3.1 (-4.3, -1.9)</td>
<td>-0.5 (-1.7, 0.7)</td>
<td>-1.6 (-2.8, -0.4)</td>
<td>0.1 (-1.1, 1.3)</td>
<td></td>
</tr>
<tr>
<td>INT</td>
<td>0.1 (-1.1, 1.3)</td>
<td>0.7 (-0.5, 1.9)</td>
<td>-2.2 (-3.4, -1.0)</td>
<td>0.4 (-0.8, 1.6)</td>
<td>-2.2 (-3.4, -1.0)</td>
<td>-0.8 (-2.0, 0.4)</td>
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<tr>
<td>Confusion</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>0.4 (0.0, 1.4)</td>
<td>0.4 (0.0, 1.4)</td>
<td>0.6 (0.0, 1.6)</td>
<td>1.5 (0.5, 2.5)</td>
<td>1.9 (0.9, 2.9)*</td>
<td>1.2 (0.2, 2.2)</td>
<td>1.2 (0.2, 2.2)</td>
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<td>0.2 (0.0, 1.2)</td>
<td>0.6 (0.0, 1.6)</td>
<td>1.4 (0.4, 2.4)</td>
<td>2.3 (0.3, 3.3)*</td>
<td>0.7 (0.0, 1.7)</td>
<td>1.0 (0.0, 2.0)</td>
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<tr>
<td>Fatigue</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>2.8 (1.3, 4.3)</td>
<td>3.8 (2.3, 5.3)</td>
<td>3.0 (1.5, 4.5)</td>
<td>7.6 (6.1, 9.1)*</td>
<td>11.2 (9.7, 12.7)*</td>
<td>3.9 (2.4, 5.4)</td>
<td>7.8 (6.3, 9.3)*</td>
</tr>
<tr>
<td>INT</td>
<td>3.1 (1.6, 4.6)</td>
<td>3.8 (2.3, 5.3)</td>
<td>2.5 (1.0, 4.0)</td>
<td>5.6 (4.1, 7.1)</td>
<td>10.6 (9.1, 12.1)*</td>
<td>2.5 (1.0, 4.0)</td>
<td>6.5 (4.0, 8.0)*</td>
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<tr>
<td>Vigour</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>2.8 (1.0, 4.2)</td>
<td>3.2 (1.8, 4.6)</td>
<td>3.5 (2.1, 4.9)</td>
<td>2.5 (1.1, 3.9)</td>
<td>1.2 (0.0, 2.6)*</td>
<td>2.8 (1.4, 4.2)*</td>
<td>1.8 (0.4, 3.2)</td>
</tr>
<tr>
<td>INT</td>
<td>4.2 (2.8, 5.6)</td>
<td>3.4 (2.0, 4.8)</td>
<td>4.2 (2.8, 5.6)</td>
<td>2.5 (1.1, 3.9)</td>
<td>1.5 (0.1, 2.9)*</td>
<td>5.3 (3.9, 6.7)</td>
<td>2.6 (1.2, 4.0)</td>
</tr>
</tbody>
</table>

*Significantly different to INT (P<0.05). †Significantly different to morning and evening baseline (P<0.05). ‡Significantly different to pre-travel (P<0.05). §Significantly different to morning baseline and pre-travel (P<0.05).
Figure 6.3. Effect of simulated international air travel and intervention on subjective jet-lag symptoms. Mean (95% CI) subjective jet-lag (A), sleep ratings (B), function ratings (C), diet ratings (D) and bowel movement ratings (E) during the INT (solid black line and square) and CON (dashed line and white circle) trials. *Significantly different to the morning and evening baseline (P<0.05). †Significantly different to the morning and evening baseline (INT) (P<0.05). ‡Significantly different to the morning and evening baseline (CON) (P<0.05). §Significantly different to the morning baseline (CON) (P<0.01).
Discussion

The present study investigated the effects of simulated international air travel on the recovery of team sport physical performance. Moreover, the efficacy of sleep hygiene recommendations in conjunction with artificial bright light was assessed. Results suggest that sleep disruption during travel increased perceptual fatigue and reduced lower-body power, but had no effect on intermittent-sprint performance. Furthermore, reducing sleep disruption through sleep hygiene recommendations may attenuate travel fatigue, but had no effect on performance recovery. Whilst no effect of artificial bright light was observed, given the simulated travel environment, research into its efficacy at enhancing team sport physical performance recovery following actual transmeridian air travel is warranted.

Effects of simulated travel

Results from the present study indicate simulated air travel had negligible effects on intermittent-sprint performance, though further research involving actual international travel is required to confirm these findings. Conversely, slower sprint times were evident in the evening of day 1 and 2 post-travel, which is contrary to previously reported effects of transmeridian air travel on maximal-sprint performance (Bullock et al., 2007). Similar to previous research (Chapman et al., 2012), reductions in unloaded CMJ height were also evident in the evening of day 1 and 2 following travel. Considering sprint times and jump height were reduced in the evening GMT, which corresponded to the morning AEST, simulated travel may have augmented the performance reduction often observed in the morning compared to the evening (Drust et al., 2005). This could be a result of the simulated change in light-dark cycle, which meant that following simulated travel, wakefulness prior to testing in the morning AEST was greater than
normal. Though reduced eight-choice reaction time has previously been identified following transmeridian air travel (Reilly et al., 2001), there were no meaningful changes in two- or four-choice reaction time in the present study. Such findings may imply that long-haul air travel affects complex (decision making), but not simple (psychomotor speed) reaction time (Reilly et al., 2001). Whilst this may indicate that decision making could be affected during team sport training and competition following international air travel, further research utilizing more sport-specific reaction time measures, such as reactive agility, is required to substantiate this.

Sleep disruption is a detrimental consequence of long-haul air travel which is often emphasised (Forbes-Robertson et al. 2012; Reilly and Edwards 2007). Reduced sleep quantity and subjective sleep quality were observed during simulated travel in the present study. However a limitation of the present study is that the amount and quality of sleep obtained by the participants was assessed using wrist activity monitors rather than PSG. Though, in studies such as the present one, where PSG was unavailable and the primary measure was sleep duration rather than sleep depth, activity monitors are a reasonable alternative. Similarly low sleep quantities (2-5 h) have previously been reported during transmeridian air travel (Takahashi et al., 2002), with cramped conditions (Forbes-Robertson et al., 2012; Waterhouse et al., 2007), cabin noise (Ozcan & Nemlioglu, 2006) and mild hypoxia (Coste et al., 2004; Coste et al., 2009) thought to be the predominant causes. Previous research indicates acute effects of hypobaric hypoxic exposure on ensuing body temperature and melatonin concentrations may impact sleep (Coste et al., 2004; Coste et al., 2009). However, as greater physiological disturbances are induced by hypobaric compared to normobaric hypoxia (Savourey et al., 2003), an inability to simulate in-cabin hypobaric pressure is acknowledged as a logistical limitation of the present study. Moreover, it is
probable that cramped conditions and cabin noise also contributed to sleep disruption. For example, sleep is likely to be disrupted if noise levels are above 65 decibels (Ozcan & Nemlioglu, 2006), however, similar to a commercial flight (Ozcan & Nemlioglu, 2006), noise levels of 80 decibels were endured during simulated travel in the present study.

Sleep disruption can induce a physiological stress response (Meerlo et al., 2008) and therefore, maintaining wakefulness in a state of sleep debt may require increased sympathetic activation and hence, cardiovascular activity, particularly during exercise (Meerlo et al., 2008). In the present study, the heart rate response to sub-maximal exercise was unchanged following travel, which may suggest that sleep disruption did not induce substantial physiological stress. However, considering the present study is the first to report such findings and other physiological stress markers were not measured, further research is required to confirm this. Evidence suggests that as a result of the low cabin humidity during actual air travel, an increased loss of moisture via respiration may occur, resulting in hypohydration (Simons & Krol, 1996) which could impact subsequent exercise performance (Maughan, 2003). Therefore, given hydration status improved post-simulated travel, the inability to simulate low cabin humidity is acknowledged as a logistical limitation of the present study. Furthermore, as testing occurred at similar body clock times pre- and post-travel, the detrimental physiological consequences of jet-lag (Forbes-Robertson et al., 2012; Reilly et al., 2007; Waterhouse et al., 2007) are unlikely to have occurred. Though the lack of physiological markers of circadian rhythms in the present study, such as melatonin and body temperature, means this is difficult to ascertain. Instead, symptoms of travel fatigue which are predominantly perceptual (Reilly et al., 2007; Waterhouse et al., 2007) may have been present.
Subjective jet-lag following simulated travel was comparable to levels previously reported following transmeridian air travel (Reilly et al., 2001; Thompson et al., 2013). Furthermore, sleep and function ratings, which have a strong endogenous component and association with jet-lag (Waterhouse et al., 2007) were worse post-travel, whereas diet and bowel movement ratings, which have a weaker endogenous component (Waterhouse et al., 2007), were relatively unchanged. Accordingly, it is possible that jet-lag may have occurred following simulated travel in the present study. Indeed, the enforced change in the light-dark cycle would have resulted in the misalignment of the timing of external factors, such as sleep, with body clock time post-travel. Results from previous research indicate that following a period of sleep deprivation/forced wakefulness (similar to what occurred during simulated travel in the present study) the homeostatic pressure for sleep is high, which can override the circadian drive for wakefulness (Sargent et al., 2012). This could explain why on day 1 and 2, despite bed and wake times of 08:00 and 18:00 AEST, respectively, sleep duration was similar to baseline. Therefore, it is plausible that if the data collection period following simulated travel was extended beyond two days, greater sleep disruption may have occurred due to circadian misalignment. Consequently, in the present study, sleep loss during travel could have potentially masked any jet-lag following travel. Though again, the lack of physiological markers of circadian rhythms in addition to subjective jet-lag means this is difficult to ascertain.

Additionally, increased perceptual strain prior to and during exercise was evident following travel in the present study. Since restricted sleep has been associated with similar responses (Reilly & Edwards, 2007; Skein et al., 2011), it is likely that sleep disruption during simulated travel caused the reported increase in perceived fatigue. Together with reduced effects of
simulated travel on 5 m compared to 20 m sprint times and loaded compared to unloaded CMJ height, these results suggest that the decrease in lower-body power detected in the present study, may have been due to increased subjective fatigue and thus, reduced motivation rather than a decline in skeletal muscle contractile function. However, it must be recognized that without an explicit measure of skeletal muscle contractile function, such a conclusion cannot be confirmed in the present study.

**Effects of travel interventions**

Results from the present study suggest that the use of artificial bright light alongside sleep hygiene recommendations had no effect on performance recovery following simulated air travel. However, for the following reasons it was difficult to detect whether, if as intended, the artificial bright light intervention delayed circadian rhythms. Firstly, if, similar to previous research which utilised a comparable intervention (Wright et al., 2004), the artificial bright light intervention had been effective at delaying circadian rhythms by 45-60 min per day, the timing of performance testing post-travel would have occurred at a ‘worse’ body clock time in the INT compared to the CON trial. For example, it is plausible that on the morning of day 2, testing could have occurred at 07:00 and 04:00 body clock time in the CON and INT trials, respectively. Hence, performance would have been tested closer to the circadian nadir in body temperature (Duffy et al., 1998) in the INT trial, which has been associated with reduced performance (Kline et al., 2007). Therefore, an effect of artificial bright light on performance recovery may have been detected if testing was conducted at a more ‘optimal’ body clock time for the INT group and/or a less fatiguing test, such as grip strength, had been conducted more frequently. However, the ecological validity of the results would have been reduced, as the timing of performance testing
in the present study was based on when team sport athletes are most likely to train following long-haul air travel. Second, given that the delay in circadian rhythms would have only been a maximum of 3 h by day 2 (Wright et al., 2004), an effect of artificial bright light on performance recovery may have been detected if the recovery period had been extended beyond two days and therefore, body clock times were closer to the new simulated time-zone. Lastly, it is recognised as a limitation of the present study that in the absence of any physiological markers of circadian rhythms, such as core body temperature or melatonin, it is impossible to ascertain if a phase delay was induced by artificial bright light exposure.

Previous research also reports negligible effects of artificial bright light on performance recovery following transmeridian air travel (Thompson et al., 2013), which could be due to limited consensus on optimal protocols and/or further study limitations (Forbes-Robertson et al., 2012). For example, compared to the individual use of light glasses for 3 h per day in the present study, light boxes shared between two people for 45-60 min per day have previously been utilized (Thompson et al., 2013). Furthermore, considering bright light exposure at the wrong time may cause circadian rhythm shifts in the opposite direction (Gronfier et al., 2004), avoidance of incidental light at specific times is essential. Yet, previously no restrictions have been placed on exposure to additional light (Thompson et al., 2013). Consequently, further research is required to determine optimum protocols for utilising bright light to resynchronise circadian rhythms and study designs for assessing their effectiveness at enhancing performance recovery following transmeridian air travel in a practical, ecologically valid environment.
Total sleep duration was almost significantly greater in the INT trial, which suggests that assistance with comfort during travel and sleep hygiene recommendations may help with reducing the sleep debt accumulated from long-haul air travel. Despite increased sleep quantity during the INT trial, no subsequent effects on the recovery of performance or physiological fatigue were evident post-travel. Given the absence of supporting literature, further research into the efficacy of optimizing sleep hygiene on sleep during and following travel is required, especially when there are disruptions to circadian rhythms in body temperature and melatonin, which regulate sleep.

Increased jet-lag symptoms and perceptual fatigue, together with reduced vigour were evident following simulated travel in the CON trial, indicating that artificial bright light together with sleep hygiene recommendations may attenuate travel fatigue following long-haul air travel. Given the restorative effects of sleep on alertness following sleep restriction (Belenky et al., 2003), increased sleep quantity during the INT trial may explain these results. However, artificial bright light exposure has also been reported to increase alertness (Wright, Badia, Myers, & Plenzer, 1997), which suggests both interventions may have contributed to the reduced travel fatigue observed in the INT trial. Regardless, this small reduction in travel fatigue did not translate into enhanced recovery of physical performance following simulated travel and therefore, the interventions utilized in the present study are unlikely to enhance team sport physical performance following international air travel.
In conclusion, sleep disruption resulting from conditions during travel may have increased perceptual fatigue and suppressed lower-body power post-travel. Whilst attenuating sleep disruption through increased comfort during travel and sleep hygiene recommendations, together with the alerting effects of artificial bright light, may assist with reducing travel fatigue, no subsequent effect on the recovery of team sport physical performance was identified. Therefore, practitioners may consider utilizing interventions that minimize sleep disruption in combination with the alerting effects of artificial bright light in order to reduce travel fatigue following long-haul air travel. Conversely, the findings of the present study suggest that artificial bright light exposure had negligible effects on performance, physiological and perceptual responses following simulated travel. However, the authors acknowledge that the main limitation of simulating international air travel was that testing occurred at a similar body clock time pre- and post-travel. Moreover, the timing and frequency of performance testing, relatively short duration of the recovery period and lack of physiological markers of circadian rhythms, made detection of altered circadian rhythms difficult. Consequently, further research into the impact of artificial bright light exposure on circadian rhythm resynchronization and team sport physical performance recovery following actual transmeridian air travel is warranted. Though, a balance between practical application and the efficacy of artificial bright light interventions needs to be considered.
Chapter Seven
Discussion
Overview of the Thesis

The present thesis examined the effects of international and domestic air travel, together with the impact of practical travel-oriented interventions, on team sport performance. More specifically, the present thesis investigated: (1) the recovery of team sport specific physical performance following simulated international and domestic air travel; (2) the respective acute and longitudinal effects of frequent domestic air travel throughout a season on competition performance and recovery in football; and (3) the efficacy of artificial bright light and sleep interventions for enhancing the recovery of team sport specific physical performance following simulated international air travel. In relation to thesis aim (1), the effects of international (studies one and four) and domestic (study one) air travel on the recovery of intermittent-sprint ability and lower-body power were assessed under simulated, controlled conditions. Thesis aim (2) was subsequently addressed in the field, with the respective acute and longitudinal effects of domestic air travel investigated in studies two and three, respectively. Lastly, thesis aim (3) was examined in study four, where the efficacy of interventions aimed at reducing the detrimental effects of international air travel outlined in study one and thus, enhancing the recovery of team sport specific physical performance, was investigated.
Summary of the Major Findings

Study One - Performance recovery following simulated air travel

Aims

To examine the effects of simulated domestic (5 h) and international (24 h) air travel on the recovery of team sport specific physical performance.

Conclusions

Sleep disruption during international air travel may exacerbate physiological and perceptual fatigue and thus, suppress intermittent-sprint performance following 24 h of simulated travel. Conversely, simulated domestic air travel appears to have negligible effects on performance, physiological and perceptual responses.

Study Two - Acute effects of domestic air travel on performance and recovery

Aims

To determine the effects of short-haul air travel (≤ 8 h flight duration and ≤ 2 h change in time-zones) on match outcome, tactical and technical performance during, and physiological and perceptual responses before and after competitive football matches.

Conclusions

More points were accrued and technical and tactical performance was superior during home compared to away matches. Whilst domestic air travel may temporarily augment perceptual fatigue prior to competition, its effects on sleep quantity and quality, and hydration were
negligible. Therefore, other factors may be of greater importance in determining match outcome. Moreover, return travel did not impede players’ physiological or perceptual recovery.

**Study Three - Longitudinal effects of domestic air travel on recovery**

*Aims*

To assess the effects of match location (home vs. away) and competition phase (early vs. late season) on training load, player wellness and injury rates following competitive football matches.

*Conclusions*

Whilst short-haul air travel may affect training prescription in the days following competition, given no differences in player wellness were identified following home compared to away matches, it is unlikely this was a result of travel impeding recovery. Instead, this could be a result of the time lost to travel following away matches. Moreover, during the late competition phase, players’ recovery time following matches may be slower and their ability to cope with training and competition demands could be reduced. Whilst this may indicate an accumulation of travel-related fatigue throughout the season, given no effects of match location were evident during the late competition phase, these findings imply that frequent away travel had negligible effects on the reduction in player wellness observed during the latter half of the season.
Study Four - Interventions for international air travel

Aims
To further investigate the effects of simulated international air travel (24 h) on the recovery of team sport specific physical performance and assess the efficacy of sleep hygiene recommendations, along with artificial bright light exposure at enhancing performance recovery following travel.

Conclusions
Sleep disruption during international air travel may increase perceptual fatigue, and suppress lower-body power as a result of reduced motivation. Though sleep hygiene recommendations may attenuate sleep disruption and travel-related fatigue, no effects were observed on team sport physical performance recovery.

A summary of the major findings from the present thesis are included in Table 7.1. Specifically, the acute effects of simulated international air travel, along with simulated and actual domestic air travel on performance, physiological and perceptual responses are presented.
Table 7.1. Summary of the major findings from the present thesis.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Simulated INT</th>
<th>Simulated DOM</th>
<th>Actual DOM</th>
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<td>Study 1</td>
<td>Study 4</td>
<td>Study 1</td>
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<tr>
<td><strong>Performance</strong></td>
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<td>↔</td>
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<tr>
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<td>↔</td>
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<td>↔</td>
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<td>↔</td>
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<tr>
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<tr>
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<td>↔</td>
</tr>
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<td>↑</td>
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<td>↔</td>
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<tr>
<td>Fatigue</td>
<td>↑</td>
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<td>↔</td>
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<tr>
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<td>↔</td>
</tr>
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<td>↓</td>
<td>↓</td>
<td>↔</td>
</tr>
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<td>↔</td>
</tr>
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<td>Stress</td>
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↑ Increase, ↔ No change, ↓ Decrease, ↑↓ Equivocal (variable responses), *During international (INT) travel, ^Following domestic (DOM) travel. A blank space indicates not measured.
International air travel

Effects on team sport physical performance

Currently there is a limited understanding of the effects of international air travel on physical performance. This equivocal understanding stems from the majority of previous research utilising measures that lack the sensitivity to detect jet-lag and/or travel fatigue, and/or have a questionable relationship to team sport physical performance, and the difficulty associated with separating the effects of jet-lag from travel fatigue in field-based environments (Leatherwood & Dragoo, 2012). Consequently, the present thesis aimed to isolate the effects of travel fatigue on performance related to training and competition in team sports under simulated, controlled conditions. Therefore, the reduction of intermittent-sprint performance observed at 06:00 GMT on day two following simulated international air travel in study one (chapter three) is a novel finding. However, in contrast, following simulated international travel in study four (chapter six), no change in intermittent-sprint performance was observed. This discrepancy in results may be explained by differences in the aims and hence, methodologies implemented for each study.

Specifically, the aim of study one was to investigate the effects of the demands of simulated international air travel on team sport physical performance in the 24 h post-travel, compared to the demands of simulated domestic air travel and a control trial. Conversely, study four aimed to determine the impact of bright light and sleep hygiene interventions on the recovery of team sport physical performance in the 48 h following simulated international air travel and a simulated change in time-zones. Consequently, whilst participants’ in study one returned immediately to baseline circadian patterns following simulated international travel, a greater control of participant’s light-dark and thus, sleep-wake cycle occurred in study four. Moreover,
whilst performance testing occurred at 23:00 and 06:00 GMT following simulated travel in study one, in order to examine the effect of sleep hygiene recommendations on sleep quantity and quality following travel, testing times were set to 21:00 and 9:00 GMT in study four. As a result, sleep quantity between performance testing sessions was lower in study one (3.8 (3.6 - 4.0) h) compared to study four (7.1 (6.3 - 7.9) h). Given the restorative effects of sleep following sleep restriction (Belenky et al., 2003), the greater cumulative duration of wakefulness could explain the reduction in intermittent-sprint performance observed in study one, which was not observed in study four. Consequently, the discrepancies in these findings may actually highlight the importance of sleep following international air travel for the recovery of team sport physical performance.

Whilst results from study four imply that the demands of air travel and ensuing travel fatigue are unlikely to affect sleep quantity or quality following travel, previous research has reported disrupted sleep following actual transmeridian air travel (Beaumont et al., 2004; Takahashi et al., 2002). These disruptions of the sleep-wake cycle are suggested to result from altered melatonin and body temperature circadian rhythms (Cajochen et al., 2003; Wyatt et al., 1999). Specifically, waking is initiated in the morning by inhibition of melatonin secretion, which causes vasoconstriction of blood vessels and a subsequent increase in body temperature, along with the alerting effects of the environment and activity (Cajochen et al., 2003; Wyatt et al., 1999). Conversely, together with a dark environment and inactivity, sleep onset is induced in the evening through melatonin secretion, which causes vasodilation of blood vessels and an ensuing reduction in body temperature (Cajochen et al., 2003; Wyatt et al., 1999). On arrival at the destination following air travel across multiple time-zones, circadian rhythms retain their
habitual rhythms of the place of departure, whereas external cues, particularly the light-dark cycle, are aligned with the destination time (Forbes-Robertson et al., 2012). Therefore, the misalignment of melatonin and body temperature circadian rhythms and the sleep-wake cycle with the destination time is likely to cause sleep disruption following transmeridian air travel (Forbes-Robertson et al., 2012). Collectively, these findings suggest that if sleep is disrupted the first night following international air travel, performance related to team sport training and competition demands is likely to be reduced the following day. Furthermore, if this is the case, the more pronounced symptoms of jet-lag, such as disturbed sleep, together with elevated fatigue and negative mood states during the day (Waterhouse et al., 2000), are likely to have a greater impact on intermittent-sprint performance compared to travel fatigue. However, as yet, no studies have investigated the effects of actual international air travel, including the impact of circadian rhythm disruptions, on team sport specific performance.

To date, the majority of research studies have examined the impact of long-haul transmeridian air travel on grip strength or performance of a single muscle group, such as squat jump or CMJ performance (Leatherwood & Dragoo, 2012). Specifically, previous research has reported a reduction (Chapman et al., 2012) and no change (Lagarde et al., 2001) in vertical jump performance following 24 h and 10 h of eastward air travel across 15 and seven time-zones, respectively. Similar to these contradictory findings, no change and a reduction in jump performance were observed following simulated international air travel in study one and four, respectively. Moreover, whilst a reduction in maximal-sprint performance was evident following simulated travel in study four, it has been reported to remain unchanged following 24 h of eastward air travel across 15 time-zones (Bullock et al., 2007). Regardless, the reduction in jump
and maximal-sprint performance observed at 21:00 GMT on day one and two following simulated travel in study four, indicates that the demands of international air travel, including the prolonged exposure to mild hypoxia, cramped conditions and cabin noise, together with ensuing travel fatigue, could have a detrimental impact on lower-body power. Moreover, the restorative effects of one night’s sleep may not reverse this reduction. The potential underlying physiological and perceptual mechanisms, through which the demands of international air travel may impact physical performance, will be discussed later.

The contradictory findings from the majority of research conducted into the effects of international air travel on physical performance may be as a result of the variation in participant populations and travel demands (i.e. the direction and distance of travel). In addition, differences in the type, timing and frequency of performance measures restrict direct comparisons between studies. For example, the reduction in jump performance identified by Chapman et al. (2012) was attributed to a decline in skeletal muscle contractile function and neuromuscular performance. In particular, it was speculated that the reduction in lower-body power was attributed to crossing 15 time-zones and the ensuing alterations in circadian rhythms for body temperature and arousal, and thus muscular activity (Chapman et al., 2012). Therefore, jump performance may have remained unchanged following simulated travel in study one due to reduced travel demands and no alteration in circadian rhythms. Furthermore, Bullock et al. (2007) speculated that the reason they observed no change in maximal-sprint performance was because motivation remained unchanged in their elite athlete participant population, who due to their psychological profile may be able to cope with the demands of travel better than non-athletes. Whilst difficult to substantiate, a reduction in maximal-sprint performance following
simulated travel in study four may have been due to a reduction in motivation to perform maximally during testing in the lesser trained participant population.

Collectively these data provide novel insight into the effects of international air travel on physical performance, demonstrating potential intermediate (24 - 48 h) reductions in performance following travel. From a practical perspective, coaches should be aware of these potential reductions in physical performance, as training is often prescribed in the days immediately following long-haul international air travel. Specifically, training is regularly scheduled in an attempt to overcome the enforced sedentary behaviour and interruption of training schedules due to travel, and findings from the present thesis indicate that performance during these sessions may be sub-optimal. In study one, a reduction in intermittent-sprint performance, with minimal change in jump performance was observed, and in study four reduced effects of simulated international travel were reported on 5 m compared to 20 m sprint times and loaded compared to unloaded jump height. Together these findings suggest that the suppression of physical performance following simulated international air travel may not only relate to alterations in circadian rhythms and thus, reduced skeletal muscle contractile function and neuromuscular performance, but rather, other physiological and perceptual mechanisms to be discussed in the next section.

**Physiological and perceptual effects**

Due to the prolonged duration of international air travel, both phases of the sleep-wake cycle are often encompassed and therefore, an understanding of the resulting effects on sleep is important (Forbes-Robertson et al., 2012). Yet to date, limited research exists for the effects of
international air travel on the quantity and quality of passengers sleep (Takahashi et al., 2002). Consequently, a novel, though not unexpected finding of the present thesis was the reduced sleep quantity identified through actigraphy during 24 h simulated international air travel in studies one (2.5 (1.7 - 3.3) h) and four (2.2 (1.4 - 3.0) h). Similarly low sleep quantities have previously been detected in passengers via actigraphy during 10 - 14 h eastward (1.5 ± 2.1 h) and 11 - 12 h westward (1.4 ± 2.4 h) international air travel (Takahashi et al., 2002), and through self-report diaries during 24 h eastward (4.0 (2.0 - 5.0) h) international air travel (Waterhouse et al., 2002). Given sleep loss has been reported to induce a physiological stress response (Meerlo et al., 2008) and increase perceptual fatigue (Skein et al., 2011), such low sleep quantities are likely to impact ensuing physical performance, which will be discussed later.

Prior to discussing the effect of sleep loss on performance, an explanation of why sleep loss occurs during travel is of relevance. The conditions encountered during international air travel, especially the prolonged exposure to mild hypoxia (Coste et al., 2004), cramped conditions (Waterhouse et al., 2007; Waterhouse et al., 2004) and cabin noise (Ozcan & Nemlioglu, 2006) are purported as the main causes of sleep disruption. Previous research indicates acute effects of prolonged hypobaric hypoxic exposure on oxygen saturation, together with ensuing body temperature and melatonin concentrations may negatively affect sleep (Coste et al., 2004; Coste et al., 2009; Savourey et al., 2003). Specifically, a reduction in melatonin concentrations (Coste et al., 2004) and increase in body temperature (Coste et al., 2009) have been observed in response to 8 h of hypobaric hypoxic exposure at 2450 m, which is the physiological state required for waking rather than sleep onset (Waterhouse et al., 2004). Reductions in oxygen saturation during 24 h of normobaric hypoxic exposure at 2093 m and 2377 m in studies one (2.5
(1.9 - 3.1 %) and four (3.2 (2.7 - 3.7) %), respectively, were similar in magnitude to reductions (3.9 (2.6 - 5.2) %) observed in response to hypobaric hypoxic exposure at 1689 m during actual long-haul international air travel (Geertsema et al., 2008). However, the effects of melatonin concentrations and body temperature on sleep in the present thesis are unknown, as these measures would have required further disruption of participants sleep during travel, independent from the demands of travel. Furthermore, as larger physiological disturbances are induced by hypobaric compared to normobaric hypoxia (Savourey et al., 2003), the conditions during actual international air travel may induce greater physiological stress and hence, sleep disruption compared to the simulated conditions of the present thesis. Though, further research is required to confirm this hypothesis.

In addition to the prolonged mild hypoxic exposure, it is likely that the cramped conditions and cabin noise also contributed to sleep disruption during the simulated international travel in studies one and four. For instance, sleep is likely to be disrupted if noise levels are above 65 dB (Ozcan & Nemlioglu, 2006) and similar to a commercial flight (Ozcan & Nemlioglu, 2006), noise levels of 80 dB were endured during the simulated travel. However, reducing the impact of cabin noise through noise cancelling headphones did not significantly increase sleep quantity in study four. This implies that the seating and cramped conditions on a commercial flight may have a greater impact on sleep, especially in economy class where passengers attempt to sleep in a seated instead of a typical prone or supine position, along with negligible leg room and head support. Moreover, commercial international flight schedules, particularly the timing of stopovers, meals and changes in cabin lighting, which were simulated in studies one and four, are likely to disrupt sleep as they may enforce waking during the sleep phase of the sleep-wake
cycle. For example, similar to the demands of travel from Sydney, Australia to London, England via Hong Kong, a 2 h stopover occurred at 01:00 and 04:00 AEST during studies one and four, respectively. Therefore, the combination of the conditions encountered during travel, particularly the seating and cramped conditions, and their impact on sleeping position, together with the travel schedule may have caused the significant reduction in sleep quantity observed in the present thesis. However, it is difficult to separate each individual travel demand and thus, precisely quantify the magnitude of their impact on sleep during long-haul travel, though in reality these demands are never encountered in isolation.

Regardless of the causes of sleep loss, maintaining wakefulness in a state of sleep debt may require increased sympathetic activation, particularly during exercise (Meerlo et al., 2008). Accordingly, the reduction in sleep quantity during simulated international travel may explain the increased heart rate response to sub-maximal exercise observed in the morning and afternoon AEST on the day following travel in study one. To the author’s knowledge, the present thesis is the first to report elevated sympathetic activity as a consequence of sleep disruption during long-haul travel. Moreover, reduced cortisol levels were evident in the morning of the day following simulated travel in study one, which is similar to responses after acute sleep deprivation (Meerlo et al., 2008), and actual transmeridian air travel (Carruthers, Arguelles, & Mosovich, 1976). Reduced cortisol concentrations in conjunction with increased sub-maximal heart rate responses may indicate exacerbated physiological fatigue in the morning of the day following simulated international travel in study one. However, reduced intermittent-sprint performance was only observed in the afternoon, together with an increased heart rate response to sub-maximal exercise. Whilst elevated sympathetic activity may increase cardiovascular strain during exercise
and thus, explain why HRmax did not differ, while distance covered was reduced and perceptual strain was increased during the YYIR1, it is likely that other underlying mechanisms affected intermittent-sprint performance in study one. Furthermore, no change in the heart rate response to sub-maximal exercise or distance covered in the YYIR1 was observed in the morning or afternoon of the day following simulated travel in study four. Consequently, the reduction in sleep quantity during and following travel in study one, compared to only during travel in study four may have exacerbated physiological fatigue in the day following travel, which contributed to the suppression of intermittent-sprint performance.

Despite these results indicating elevated physiological fatigue following simulated international travel in study one, no change in jump performance was observed. Moreover, reductions in both jump and maximal-sprint performance were evident following simulated travel in study four, with no corresponding change in physiological responses. These findings could be explained by the different factors that affect intermittent-sprint performance compared to lower-body power. For instance, increased cardiovascular strain is unlikely to affect performance in explosive/short duration exercise. Instead, changes in neuromuscular performance measures, such as the voluntary force and evoked twitch properties of the knee extensors are more likely to mirror changes in lower-body power (Skein et al., 2011). However, due to logistical constraints these measures were not collected in the present thesis, which is recognised as a limitation. Furthermore, though again not measured, it has previously been speculated that alterations in body temperature and arousal circadian rhythms and thus, skeletal muscle contractile function and neuromuscular performance were responsible for the reduction in jump performance following 24 h of eastward air travel across 15 time-zones (Chapman et al., 2012). However,
considering testing in study four of the present thesis occurred at a similar body clock time pre-
and post-travel, alterations in circadian rhythms are unlikely to explain the suppression of lower-
body power. Instead, the detrimental effects of sleep disruption on perceptual responses may
clarify these findings.

Previous research suggests that following sleep loss, diminished performance in sustained
exercise bouts is likely, due to reduced motivation to continue to perform at high intensities
(Reilly & Edwards, 2007). This is supported by the finding that following sleep deprivation,
increased perceptual strain during exercise negatively affected pacing strategies and thus,
reduced intermittent-sprint performance (Skein et al., 2011). Similarly, in the afternoon (AEST)
of the day following simulated international travel in study one, increased perceptual fatigue and
strain, prior to and during exercise, respectively, coincided with a decline in intermittent-sprint
ability. The increased perceptual strain may have been a result of the aforementioned elevated
cardiovascular strain during exercise and suggests that reduced distance covered in the YYIR1
could be due to reduced motivation to reach maximal volitional exhaustion. Moreover, greater
perceptual fatigue and irritability, and reduced motivation were evident prior to attenuated jump
and maximal-sprint performance in the morning of day one and two following simulated
international travel in study four. Hence, these results further imply that reductions in physical
performance following long-haul international air travel may be due to increased subjective
fatigue and reduced motivation as a result of sleep disruption. Conversely, though an increase in
perceptual strain was again evident during exercise, no change in intermittent-sprint performance
was detected in study four. Consequently, the amalgamation of exacerbated physiological and
perceptual fatigue due to the greater cumulative duration of wakefulness prior to the performance
tests in the afternoon of the day following simulated travel, may explain why intermittent-sprint performance was reduced in study one, but not four.

Collectively, these results indicate that sleep disruption during long-haul international air travel, due to the cramped conditions and flight schedule, together with reduced sleep quantity following travel may increase physiological fatigue and thus, cardiovascular strain during exercise. In turn, this could augment perceptual strain, reduce the motivation to continue to perform at a high intensity and therefore, suppress intermittent-sprint performance. Moreover, increased perceptual fatigue and reduced motivation as a result of sleep loss during travel may also reduce jump and maximal-sprint performance. Therefore, by minimising sleep disruption during and following long-haul international air travel, it may be possible to attenuate subsequent physiological and perceptual fatigue and thus, reductions in physical performance. Thus, practitioners may consider implementing interventions that aim to attenuate sleep disruption during and following international air travel. However, further research into the development and implementation of effective interventions is required.

**Effect of interventions on the recovery of team sport physical performance**

Given the detrimental impact of sleep loss during and following international air travel on ensuing physical performance, the development of interventions to minimise sleep disruption as a consequence of travel is important. Previous recommendations propose that to accelerate the resynchronisation of the sleep-wake cycle following international transmeridian air travel, sleep should be scheduled during travel according to when it is night at the destination, and must be avoided when it is daytime at the destination (Reilly & Edwards, 2007; Waterhouse et al., 2004).
Whilst these recommendations are based on a comprehensive understanding of chronobiology and the impact of international transmeridian air travel on circadian rhythms (Arendt, 2009; Reilly et al., 2007a; Waterhouse et al., 2007), there is currently no research evidence to suggest they are effective at improving sleep following travel, particularly with physical populations. Furthermore, they may be difficult to implement in practice, as during travel circadian rhythms and the sleep-wake cycle will still be aligned with the departure time-zone. Consequently, passengers could be attempting to sleep during travel when the circadian rhythms in melatonin secretion and body temperature are initiating waking, and endeavouring to stay awake when these rhythms are inducing the physiological state required for sleep onset.

Results from both the present thesis and previous research (Forbes-Robertson et al., 2012; Takahashi et al., 2002; Waterhouse et al., 2002) suggest passengers may only obtain 2 - 4 h of reduced quality sleep during long-haul air travel. Accordingly, it may be more beneficial to attempt to maximise sleep during travel and therefore, attenuate the subsequent physiological and perceptual fatigue, and performance reductions observed in studies one and four. Moreover, findings of the present thesis suggest that the uncomfortable seating, together with the cabin noise and lighting, could be the predominant cause of sleep disruption during travel. Therefore, by increasing comfort and reducing noise and light, it may be possible to establish a more optimal sleep environment and increase sleep quantity during travel. Furthermore, previous research has also reported disrupted sleep following international air travel (Beaumont et al., 2004; Takahashi et al., 2002) and results from the present thesis suggest these disruptions may exacerbate physiological fatigue and suppress intermittent-sprint performance. Consequently, the use of sleep hygiene recommendations, which aim to induce the optimal physiological state
required for sleep onset following travel could be beneficial. However, to date, no studies have investigated the effects of sleep hygiene recommendations on sleep quantity and quality during and following international air travel.

Therefore, a further novel finding of the present thesis is that by increasing sleep quantity and subjective sleep quality during and following travel through assistance with comfort and sleep hygiene recommendations, such as reducing light and noise exposure, it may be possible to reduce symptoms of travel fatigue. Specifically, compared to baseline, increased tiredness and irritability, and reduced motivation were observed in the control trial following simulated international travel in study four. However, no effects on the subsequent recovery of lower-body power were identified, possibly due to the fact that over the three days during and following travel there was only a 1.3 (0.5 - 2.1) h difference in total sleep quantity between the intervention (17.0 (16.2 - 17.8) h) and control (15.7 (14.9 - 16.5) h) trials. As previous research has reported no change in explosive exercise performance following much greater sleep loss of 3 h per night for three nights, the current difference in sleep quantity may have been insufficient to result in performance differences (Reilly & Piercy, 1994).

Furthermore, sleep following actual transmeridian air travel is likely to be disrupted due to the misalignment of melatonin and body temperature circadian rhythms and the sleep-wake cycle with the destination time, resulting in delayed sleep onset and early awakening following eastward and westward flights, respectively (Beaumont et al., 2004; Forbes-Robertson et al., 2012; Takahashi et al., 2002). Since sleep disruption following travel is one of the major causes of jet-lag symptoms (Forbes-Robertson et al., 2012), and given no disruption of sleep was
evident in the control trial following simulated air travel, this may explain why increased sleep quantity in the intervention trial did not significantly reduce jet-lag symptoms. However, as discussed in chapter six, following sleep disruption during simulated air travel, the high homeostatic pressure for sleep may have overridden the circadian drive for wakefulness (Sargent et al., 2012). Therefore, it is plausible that if the data collection period following simulated travel was extended beyond two days, once the homeostatic drive for sleep was reduced, greater sleep disruption may have occurred due to circadian misalignment. Hence, as sleep is also likely to be disrupted following long-haul transmeridian air travel, potentially creating an even greater sleep debt and thus, prolonging the period of recovery, developing interventions to minimise sleep loss during travel is especially important.

Of all the behavioural (Boulos et al., 2002; Thompson et al., 2013) and pharmacological (Atkinson et al., 2001; Lagarde et al., 2001; Reilly et al., 2001) interventions purported to reverse the detrimental outcomes of jet-lag and travel fatigue, the evidence supporting planned exposure to natural and artificial bright light is most encouraging (Forbes-Robertson et al., 2012). Therefore, a number of recent literature reviews have provided examples of light exposure schedules for various travel scenarios (Arendt, 2009; Forbes-Robertson et al., 2012). These protocols are based on chronobiological principles derived from laboratory experiments on the circadian phase shifting effects of light (Czeisler et al., 1989). Specifically, these schedules detail the precise timing of light exposure and avoidance required to induce a phase delay or advance in circadian rhythms following westward or eastward travel, respectively (Forbes-Robertson et al., 2012). Consequently, the commercial availability of portable artificial bright light sources has increased. Whilst evidence suggests these devices can adjust circadian rhythms (Lack et al.,
2007; Wright et al., 2004), their effectiveness at enhancing the recovery of physical performance for team sports following transmeridian air travel is limited (Boulos et al., 2002; Thompson et al., 2013).

The scheduled use of artificial bright light glasses, at times required to induce a phase delay in circadian rhythms following simulated westward international air travel from Sydney, Australia to London, England, also had a negligible impact on the recovery of subjective jet-lag symptoms and team sport physical performance. If as intended, the bright light exposure had induced a phase delay in circadian rhythms, it was hypothesised that differences in performance between conditions would be observed, as testing would have occurred at different phases of the circadian rhythm in physical performance. However, it is plausible that negligible effects of artificial bright light exposure were observed for several reasons. First, the timing and frequency of performance measures is recognised as a limitation of study four. As discussed in chapter six, if the artificial bright light intervention had been effective at delaying circadian rhythms by 45-60 min per day (Wright et al. 2004), the timing of performance testing post-travel would have occurred closer to the circadian nadir in body temperature (Duffy et al. 1998) in the intervention trial, which has been associated with reduced performance (Kline et al. 2007). Therefore, an effect of artificial bright light on performance recovery may have been detected if testing was conducted at a more ‘optimal’ body clock time in the intervention trial and/or a less fatiguing test, such as grip strength, had been conducted more frequently, as with more regular measures it may have been possible to increase the sensitivity to detect differences between trials. However, given team sport athletes are only likely to train in the morning and/or afternoon of the days following travel, a greater frequency of performance measures may not have been ecologically
valid. Secondly, the simulated travel environment may have restricted the effectiveness of the intervention, given testing occurred at a similar body clock time pre- and post-travel, and thus jet-lag symptoms were not present and circadian rhythms in performance were unchanged. Lastly, there are numerous factors that could impact the effectiveness of artificial bright light exposure (Thompson et al., 2013). Specifically, incidental light exposure at the wrong time may cause phase-shifts in the opposite direction (Gronfier et al., 2004). Whilst light blocking glasses were utilised at specific times and minimal external light exposure was ensured throughout study four in an attempt to avoid this, it cannot be dismissed. Furthermore, not only does inter-individual variation exist for jet-lag symptoms and their severity, but also for rates of resynchronisation of the body clock and thus, responses to artificial bright light exposure following international air travel (Forbes-Robertson et al., 2012).

Together these data indicate that it may be possible to reduce travel fatigue symptoms following long-haul international air travel by increasing sleep quantity during and following travel through assistance with comfort and sleep hygiene recommendations. However, interventions that are more effective at minimising sleep loss as a consequence of travel may be required to enhance the recovery of team sport physical performance. Moreover, given sleep following actual transmeridian air travel is likely to be disrupted (Beaumont et al., 2004; Takahashi et al., 2002), further research into the effect of optimising sleep hygiene on the resynchronisation of the sleep-wake cycle following travel is required, especially when there are disruptions to circadian rhythms in body temperature and melatonin, which regulate sleep. Accordingly, there may still be a role for pharmacological interventions to assist with sleep during and following travel, though this remains to be substantiated. In contrast, based on the evidence from previous
research (Boulos et al., 2002; Thompson et al., 2013) and the present thesis, artificial bright light appears to be ineffective at augmenting the recovery of team sport physical performance and jet-lag symptoms following long-haul international air travel. However, given that in study four, the delay in circadian rhythms would have only been a maximum of 3 h by day 2 (Wright et al., 2004), an effect of artificial bright light on performance recovery may have been detected if the data collection period had been extended beyond two days and therefore, body clock times were closer to the new simulated time-zone. Furthermore, since inter-individual variation in the recovery of jet-lag symptoms and responses to artificial bright light exposure may exist (Forbes-Robertson et al., 2012), further research into the effectiveness and practicality of implementing individual rather than generic bright light exposure schedules is warranted.

**Domestic air travel**

**Effects on competition performance**

Domestic air travel is one of several factors purported to affect match outcome (Goumas, 2014; Pollard, 2008), which also includes situational variables, such as match location, match status and opposition quality (Lago et al. 2010), together with territoriality (Neave and Wolfson 2003) and the expectancy to perform worse away from home (Nevill and Holder 1999). The collection of these factors that may affect match outcome, together with the potential mechanisms through which domestic air travel may also affect competition performance are schematically presented in Figure 7.1.
Figure 7.1 A schematic outline of the factors, including domestic air travel, that may affect tactical and technical performance during competition, and thus, match outcome. The red and amber text indicates a detrimental effect and no change, respectively, identified in the present thesis and/or by previous research investigating domestic air travel effects on competition performance.
In study two (chapter four) of the present thesis, fewer points were accrued away compared to at home, which is similar to previous findings in the A-League competition, (Goumas, 2014), from which this current data was collected from, and other Australian team sport competitions (Bishop, 2004). Specifically, within the A-League, an inverse association between home advantage and the number of time-zones crossed exists, but not due to the distance travelled by away teams, which suggests jet-lag rather than travel fatigue may explain reduced competition performance by away teams (Goumas, 2014). However, only two teams in the A-League are required to cross greater than two times zones for away matches, who have historically finished in the bottom half of the table. Therefore, these findings are confounded by the relatively poor performance of these two teams and small number of matches included in the analyses that involved away teams crossing more than two time-zones (n = 42), compared to those crossing less than or equal to two time-zones (n = 723).

Moreover, the results are surprising given that larger travel distances are often associated with a greater number of time-zones crossed. Indeed, a greater point’s difference (difference at home - difference away) was observed for pairs of games where teams travelled ~ 4000 km east or west across two time-zones compared to locally for less than one hour in Australian netball competition (Bishop, 2004). In addition, fewer points were scored away compared to at home by teams that travelled across a greater number of time-zones and thus, for a greater distance (Bishop, 2004). Together with the results from study two, where the participating team travelled an average of 3760 km across less than or equal to two time-zones, these data indicate that together with jet-lag, travel fatigue may also have an impact on match outcome in Australian team sport competitions.
Given the time of optimum physical performance mirrors the late afternoon peak in body temperature (Drust et al. 2005), depending on the time of competition, jet-lag may have an impact on match outcome in Australian team sport competitions. For instance, teams from Western Australia travelling east across time-zones for afternoon competition on the east coast of Australia or in New Zealand, may not perform optimally since their body clock time will be closer to morning time (Leatherwood and Dragoo 2012). Conversely, teams from New Zealand or the east coast of Australia travelling west across time-zones to Western Australia, could have a disadvantage in late afternoon competition given their body clock time will be nearer to bed time (Leatherwood and Dragoo 2012). Therefore, teams may have an advantage if the time of competition is closer to their late afternoon peak in body temperature compared to the opposition. However, in reality the warm-up, crowd and thus, increase in body temperature and catecholamine’s prior to competition may negate any such advantage, though this remains to be substantiated. Moreover, for the majority of teams based on the east coast of Australia, including those who participated in studies two and three of the present thesis, a greater frequency of long distance air travel north or south is required and thus, symptoms of travel fatigue are more likely to have an impact on match outcome compared to jet-lag. Regardless, while the aforementioned studies have observed associations between reduced away competition performance and a greater number of time-zones crossed and/or distance travelled, it is unclear how domestic air travel may impact match outcome as other relevant measures, such as tactical and technical performance were not reported.
In study two of the present thesis, more goals were conceded, together with fewer shots on goal and corners, and greater opposition shots on goal and corners in away compared to home matches in professional Australian football players. These results indicate that reduced tactical and technical performance and/or greater opposition tactical and technical dominance may have occurred. In turn, such technical dominance by opposing teams may explain the greater distance covered by players, particularly in low-intensity activities, during away compared to home matches. Specifically, with greater tactical and technical dominance by the opposition, increased movement tracking the ball and/or opposition players may be required (Lago et al., 2010; Rampinini et al., 2007). In contrast, whilst professional rugby league players performed more tackles, they covered less distance during away compared to home matches (McGuckin et al., 2014). Furthermore, no differences were evident between home and away matches in individual player match statistics, including time between possessions and team assists (kicks, handballs, tackles, shepherds, spoils and knock-on’s) per total minutes played, in professional Australian Football League players (Richmond et al., 2007). These conflicting results may be explained by differences in the key performance indicators for these sports. For example, a reduction in distance covered together with a greater number of tackles performed in rugby league matches may indicate that the opposition were frequently on the attack, which required more defensive actions and thus, fewer meters gained.

Despite the obvious presence of travel as a factor, worse tactical and technical performance and/or greater opposition tactical and technical dominance during away matches may actually be a result of an expectancy to perform worse away from home. Specifically, it has been reported that both coaches and athletes believe the team’s chances of winning are less and thus, both team
and individual self-efficacy may be reduced during away compared to home matches (Bray et al., 2002; Bray & Widmeyer, 2000). Moreover, considering self-efficacy is affected by past experience, it is proposed that the opposition may also influence psychological states as well as match location (Bray et al., 2002). Consequently, changes in tactics may occur depending on the match location and/or opposition quality. However, the physical performance, physiological and perceptual responses to domestic air travel that were investigated in the present thesis may also have an impact and are yet to be discussed.

**Effects on team sport physical performance**

Whilst increased total distance covered and low intensity activity were observed in away compared to home matches in study two, no differences in high-intensity running or very-high intensity running distance were reported. Though the distance covered at various speeds by elite football players may be dependent on match contextual factors, such as match status (whether the team is winning, losing or drawing), tactics and the opposition quality (Lago et al., 2010), these results may also suggest that in contrast to the hypotheses, away travel didn’t have a detrimental impact on the capacity for physical performance during competition. Similarly, no change in intermittent-sprint performance (YYIR1), as is associated with the physical demands of football (Krstrup et al., 2003), or lower-body power (CMJ) were observed in the morning or afternoon of the day following 5 h of simulated domestic air travel (study one). Furthermore, though not as ecologically valid, grip strength and squat jump performance were unchanged in professional rugby league players immediately and in the morning of the day following 2.5 (1.8 - 3.2) h of actual short-haul air travel (McGuckin et al., 2014). Together, these data imply that the environmental and atmospheric conditions during (simulated), in addition to the stressors and
disruption of routine (actual) as a result of domestic air travel may not have a negative impact on physical performance in team sport training or competition.

**Effects on physiological and perceptual responses**

The relative physiological stress imposed on an athlete during training or competition is referred to as the internal training load, which is also influenced by the athlete’s perceptual state (Impellizzeri et al., 2004). The session rating of perceived exertion (sRPE), which has been correlated with several physiological variables (Impellizzeri et al., 2004), is a common method used to quantify internal training load, through multiplying the whole training or match rating of perceived exertion by its duration (Foster et al., 1996). Despite greater physiological stress (total distance covered) in away matches, no differences in sRPE were evident between home and away matches in study two. This is also supported by the findings of study three (chapter five), where no differences in sRPE were identified between home and away matches in professional football players from a different A-League team. Such findings imply that domestic air travel may have negligible effects on internal physical loads from matches.

Greater reductions in oxygen saturation were observed during actual outbound (3.1 (2.4 - 3.8) %) and return (3.3 (3.0 - 3.6) %) domestic air travel in study two, compared to simulated domestic air travel in study one (1.9 (1.3 - 2.5) %). In theory these greater perturbations during actual travel could be due to the larger physiological disturbances induced by hypobaric compared to normobaric hypoxia (Savourey et al., 2003). For example, several deleterious physiological and perceptual effects have been reported in response to 8 h (Coste et al., 2004; Coste et al., 2007b, 2009) and 20 h (Muham et al., 2007) of hypobaric hypoxic exposure equivalent to 2438 m. These
include reduced sleep quality (Coste et al., 2009) as a result of alterations in the circadian rhythms of melatonin (Coste et al., 2004) and body temperature (Coste et al., 2009), along with increased perceptual fatigue and muscular discomfort, and reduced alertness (Coste et al., 2007b; Muhm et al., 2007). It is purported that these changes may explain the fatigue following long duration flights, even if no time-zones are crossed (Coste et al., 2004). However, during short-haul domestic air travel for away matches in Australian team sport competitions, it is unlikely that athletes would be exposed to these unfavourable cabin conditions for such prolonged periods, which suggests ensuing physiological and perceptual effects may be reduced. Specifically, the longest flight duration required for an away match in the A-League is 7 h between Western Australia and New Zealand. However, this is only a requirement for teams based in these two locations once or twice per season (depending on the competition schedule). Whilst teams based in Western Australia are frequently required to travel 5 h to the east coast of Australia, where the majority of teams are based, 1 - 3 h flights north and south are the normal travel demands faced by the rest of the competition.

No changes in sleep quantity or quality were detected via actigraphy in the two nights following 5 h simulated domestic air travel in study one. Furthermore, whilst actigraphy data indicated that players may have gone to bed earlier the night prior to matches away compared to at home, no significant detrimental effects of actual domestic air travel 5.3 (3.1 - 7.5) h were observed on sleep quantity and quality in study two. However, whilst players were in bed earlier, this didn’t result in greater sleep duration, which may suggest players took longer to fall asleep the night prior to away matches. Indeed, though statistical analyses revealed no differences, sleep latency was 36 (18 - 54) min vs. 26 (11 - 41) min the night before away compared to home matches. A
potential explanation for this finding could be that players are required to share hotel rooms whilst away and are therefore, residing in an unfamiliar environment compared to at home. These results are similar to the findings of previous research, which reported no significant differences in actigraphy derived sleep quantity or quality on the night prior to competition at home compared to away in professional Australian Football League players from a team based in Western Australia (Richmond et al., 2007). However, a reduction in subjective sleep quality was evident (Richmond et al., 2007), which suggests that whilst short-haul air travel may not affect sleep patterns, the disruption of normal routines and sleeping in unfamiliar surroundings may induce feelings of insufficient sleep. Moreover, no effects of short-haul domestic air travel were reported on hydration status in either study one or two of the present thesis. This may be particularly evident when club hydration practices are adhered to, including the provision and regular consumption of water and sports drinks. Considering the hypohydration induced by long-haul international air travel (Hamada et al., 2002), together with the deleterious physiological effects reported in response to prolonged exposure to mild hypoxia (Coste et al., 2004; Coste et al., 2009), these findings indicate that the duration of short-haul air travel for away matches in Australian team sport competitions may be insufficient to induce substantial physiological disturbances.

The relatively short duration of domestic travel may reduce the effects of the environmental and atmospheric conditions during travel on physiological responses. Therefore, the procedural demands surrounding domestic air travel and associated stressors and disruption of normal routines may have a greater impact on perceptual responses (Waterhouse et al., 2007; Waterhouse et al., 2004). For instance, though the flight for away competition may only be 1 - 5
h in duration, prior to the flight teams are required to travel to the airport to check in at a specified time, which is typically 90 min prior to boarding for group check-in. Following this, security clearance is necessary before waiting in the departure lounge for boarding, which is sometimes delayed. Once on the plane, take off is delayed until all passengers have boarded and a safety demonstration has been delivered. Following the flight teams are required to collect their baggage and then transfer to the hotel via road. As a result, even with short flight times, the whole process of away travel may encompass the majority of the day. During this time prolonged inactivity/sitting is required and a loss of access to usual and important foods, and eating practices may occur (Waterhouse et al., 2007; Waterhouse et al., 2004). Accordingly, travel to away matches could have a detrimental impact on mood states, increase perceptual fatigue and therefore, reduce player wellness.

Greater perceived muscle soreness was observed on the day following simulated domestic air travel in study one and increased perceived sleepiness and fatigue were evident immediately following outbound travel and on the day prior to away competition, respectively, in study two. These results are similar to previous reports of worse mood states and greater perceived fatigue and sleepiness immediately following travel in professional Australian rugby league players (McGuckin et al., 2014). The comparative findings may be a result of the team being based in the same location in Australia and thus, would have had similar travel routes and demands as the team that participated in study two. However, given that both studies found no difference in perceptual fatigue between home and away on match day (McGuckin et al., 2014), these perceptual effects appear to be temporary and hence, unlikely to affect player preparedness for competition. Collectively, these findings imply that short-haul domestic air travel may have
negligible effects on physiological responses and only short-term effects on perceptual fatigue. Hence, it is unlikely to affect physical, tactical and technical performance during competition and thus, match outcome. Therefore, other factors, including situational variables such as match location, match status and opposition quality (Lago et al., 2010), and territoriality (Neave & Wolfson, 2003), tactics, and the expectancy to perform worse away from home (Nevill & Holder, 1999), may be of greater importance in determining match outcome (Figure 7.1).

**Effects on post-competition recovery**

Competitive football matches involve a large number of physically demanding activities and thus, induce acute fatigue and physical performance decrements (Nédélec et al., 2013). A progressive return to pre-match state occurs during the recovery process, but this may take more than 72 h (Nédélec et al., 2013). Given the limited time between matches and subsequent training and competition, various recovery procedures are commonly used to regain optimal performance faster (Nédélec et al., 2013). However, due to domestic football competition schedules, short-haul air travel is often a necessity the day after an away match, particularly in Australia, where large distances are travelled by away teams (Goumas, 2014). Considering the aforementioned minor acute perceptual effects of short-haul air travel (McGuckin et al., 2014; Richmond et al., 2007) and that the disruption of normal routines by travel may inhibit the use of some recovery interventions, the recovery process following away matches could be impeded. However, results from study two suggest return travel did not impact players recovery, as perceived stress and muscle soreness were greater one day following home compared to away matches. This is somewhat surprising considering the reduced total distance covered during home compared to away matches, though may be a result of no difference in high-intensity or very-high intensity
running distance. Moreover, the crowd, tactics, environment and pitch condition may also affect these perceptual responses.

Increased training loads were evident on day two and three following home compared to away matches in the early competition phase in study three. Whilst this may indicate acute short-haul air travel affects on training prescription in the days following competition, given no differences in player wellness were identified in the four days following home compared to away matches, it is unlikely this is a result of travel impeding recovery. Instead, differences in training scheduling and prescription were evident on day one and two post-match at home compared to away, which is most likely to result from losing a day to travel following away matches. Time loss due to travel creates difficulties in prescribing the training loads required to optimise training responses between matches, which may further impact player preparedness for ensuing competition (Kelly & Coutts, 2007). Alternatively, it could be speculated that reduced training loads induced by travel may limit the ability to maintain sufficient training stimuli over prolonged periods if travel is overly regular. Together these findings suggest that domestic air travel per se had negligible effects on post-competition recovery for these specific teams based on the east coast of Australia. However, given the present thesis is the first to report such findings, and considering the importance of recovery for subsequent training and competition performance, further investigation is warranted, particularly for teams with extended or prolonged travel demands, such as those in Western Australia or New Zealand (Goumas, 2014).
The magnitude of travel completed by professional teams throughout a season can be substantial. For example, during a 27 week season, football teams in Australia are required to travel up to 3500 km by air, 26 times. Consequently, it has been proposed that the aforementioned minor acute travel-related fatigue may accumulate throughout the season (Samuels, 2012), which could result in reduced player wellness. However, to date there is no evidence to support this hypothesis. In study three, reduced training loads and player wellness were evident following matches in the late compared to the early competition phase. This implies that during the latter half of the season, players’ recovery time following matches was slower, their ability to cope with training and competition demands was reduced and consequently, their preparedness for ensuing training and competition may have been diminished. Moreover, increased training missed as a result of injury was evident in the late compared to the early competition phase for both home and away matches. This indicates greater injury severity in the late competition phase, which may be a result of the aforementioned reduction in player wellness, given its previous association with increased injury risk (Gastin et al., 2012). Collectively these data may indicate an accumulation of travel-related fatigue throughout the season. However, given no differences between home and away matches were detected for training loads, player wellness or injury during the late competition phase, it in fact suggests that away travel had negligible effects on the reduction in player wellness observed during the latter half of the season. That said, considering increased wellness has previously been reported over the course of an Australian Football League season (Gastin et al., 2012) and study three only involved players from one team, further research is required with larger data sets across multiple sports, teams and seasons to conclusively determine the longitudinal effects of domestic air travel on athlete recovery.
Conclusions

The findings presented in the current thesis demonstrate that whilst team sport specific physical performance is reduced following simulated international air travel, simulated and actual domestic air travel has negligible effects on performance, physiological and perceptual responses. Of note, the demands of simulated international air travel, including the prolonged exposure to mild hypoxia, cramped conditions and cabin noise appear to disrupt sleep during travel, which subsequently exacerbates physiological and perceptual fatigue. Consequently, physical performance may be suppressed as a result of reduced motivation rather than a decline in skeletal muscle contractile function. Though minimising this sleep disruption through sleep hygiene recommendations attenuated perceptual fatigue, the recovery of post-travel performance was unaffected. In contrast, the present thesis demonstrates that although simulated and actual domestic air travel may temporarily augment perceptual fatigue, it is unlikely to impact physical or competition performance and hence, the reported tendency for teams to perform better at home compared to away. Furthermore, neither acute nor longitudinal effects of actual domestic air travel were evident on player recovery or perceived readiness to train following competition. Importantly, these data indicate the impact of domestic and international air travel on team sport specific performance and present athletes with a practical means to reduce the impact of travel fatigue.
Chapter Eight
Summary and Conclusions
Summary and Conclusions

The present thesis examined the effects of simulated international, in addition to simulated and actual domestic air travel on performance, physiological and perceptual responses. Furthermore, the efficacy of practical travel interventions at enhancing performance recovery following simulated international air travel was assessed. The major conclusions drawn from the findings of the present thesis include:

- Both a reduction in intermittent-sprint performance with no change in lower-body power (study one), and a decline in lower-body power with no change in intermittent-sprint performance (study four) were observed following simulated international air travel. Though these results indicate that international air travel may attenuate team sport specific physical performance, they also highlight the inter-individual variation in travel induced responses, which is important to consider if generalising these results to populations other than physically active males.

- A reduction in sleep quantity and quality was consistently reported during simulated international air travel (studies one and four). Given that the prolonged exposure to mild hypoxia, cramped conditions and cabin noise, together with the schedule (stopover, meal composition and times, and lighting changes) typically encountered during a commercial flight formed the majority of the simulation, these findings suggest that sleep disruption during long-haul air travel is a result of the demands of air travel per se.

- Following simulated international travel, increased physiological (study one) and perceptual (study one and four) fatigue were evident prior to and during exercise. Therefore, it was concluded that sleep disruption during and exacerbated physiological and perceptual fatigue
following long-haul international air travel may suppress team sport specific physical performance.

- Reduced sleep quantity was also observed between performance testing sessions on day one following travel in study one (23:00 - 06:00 GMT) compared to study four (21:00 - 9:00 GMT). Given that no change in intermittent-sprint performance was observed in study four, these data could suggest that if sleep is disrupted the first night following international air travel, performance related to team sport training and competition demands is likely to be reduced the following day.

- Increasing sleep quantity during and following simulated international air travel through sleep hygiene recommendations reduced perceptual fatigue, but had no significant effect on physiological or performance responses following travel (study four). These results imply that reducing sleep disruption during long-haul air travel may attenuate subsequent travel fatigue, but is unlikely to impact the recovery of team sport specific performance. However, the impact of the intervention on sleep disruption was relatively small, therefore greater sleep quantity and quality during travel may result in enhanced recovery of team sport physical performance.

- Though an increase in perceived muscle soreness was evident following simulated domestic air travel, physiological and performance measures were unchanged (study one). Thus, the effects of short-haul air travel may be perceptual rather than physiological or performance related.
- Reduced alertness was observed immediately following actual domestic air travel and though perceived fatigue was increased one day prior to away competition compared to at home, no differences were evident on match day between home and away (study two). These results indicate that whilst domestic air travel may temporarily augment perceptual fatigue, it is unlikely to impact competition performance and hence, the reported tendency for teams to perform better at home compared to away (study two).

- Sleep duration was greater and perceived stress and muscle soreness were lower following short-haul air travel the day after away matches compared to at home (study two). Moreover, no differences in player wellness were detected in the four days following home compared to away matches (study three). Therefore, domestic travel following competition may not impede players’ physical recovery or perceived readiness to train.

- Reduced training loads and player wellness, along with increased training missed due to injury were identified during the late compared to the early competition phase (study three). Whilst this may indicate an accumulation of fatigue throughout the season, considering no differences in these measures were evident between home and away during the late competition phase, these findings demonstrate that regular domestic travel had a negligible impact on the reduction in player readiness to perform in the latter half of the season.
**Practical Applications**

The series of studies conducted for the present thesis have several novel outcomes. Whilst these require confirmation from and generate more considerations for future research, they also have a number of practical applications and deliver the following specific recommendations.

- Since long-haul travel enforces sedentary behaviour for prolonged periods and interrupts athletes training schedules, coaches often prescribe training sessions in the days following long-haul international air travel. However, they should be aware of potential intermediate (24 - 48 h) reductions in physical performance, which implies that during training sessions occurring within this time period, performance is likely to be sub-optimal.

- Implementing interventions that are effective at minimising sleep disruption during long-haul international air travel may attenuate subsequent physiological and perceptual fatigue and therefore, reductions in physical performance.

- Reducing sleep disruption through the following procedures, may be effective at attenuating symptoms of travel fatigue post long-haul international travel with minimal change in time-zones:

  **During Travel**

  - Since data from the present thesis suggests that sleep quantity and quality are significantly reduced during travel, sleep whenever possible in order to maximise the total sleep accumulated.

  - Utilise noise cancelling headphones, neck pillows and eye masks to increase comfort and create an improved environment for sleep onset.
- Combining these interventions with the identification of optimal sleep times (i.e. when its night time in the place of departure) may also be appropriate.

*Post Travel*

- Follow sleep hygiene recommendations to increase sleep quantity and quality (Halson, 2013). Specifically, in the hour prior to bed, limit the use of electronic equipment and dim bedroom lights. Ensure cool (19-21°C), quiet and dark conditions throughout the sleep period.

- Prior to away competition, instead of focusing on the negligible acute effects of domestic air travel on performance, physiological and perceptual responses, it may be more beneficial for practitioners to concentrate on mentally preparing athletes to believe playing away is not a disadvantage.

- Given that during the latter half of the season, players’ recovery time following matches may be slower and their ability to cope with training and competition demands could be reduced, increased emphasis should be placed on the use of adequate and appropriate recovery interventions following matches in the latter half of the season.
**Recommendations for Future Research**

It is acknowledged that there are still many unanswered questions regarding the effects of domestic air travel on performance, physiological and perceptual responses. However, along with previous research, data from the present thesis suggests that the demands and consequences of international air travel are much greater and thus, require more immediate research attention. Furthermore, though the series of studies that constitute the present thesis have attempted to address several unanswered questions within the area of international air travel and physical performance research, in addition to the questions generated by the innovative findings, many still remain.

1. The rate of adaptation of circadian rhythms is purported to be half a day and one day per time-zone crossed following westward and eastward transmeridian air travel, respectively (Forbes-Robertson et al., 2012; Reilly et al., 2007a). However, there is negligible data from studies with appropriate study designs to support this theory. Moreover, competition is unlikely to occur within the 1 - 2 days following international air travel. Therefore, further research into the longitudinal (1-2 weeks) post-travel recovery timeline for team sport specific physical performance following eastward compared to westward transmeridian air travel is warranted. Subsequently, guidelines would be available to assist coaches and athletes with the scheduling of travel around competition to facilitate optimal performance.

2. To the author’s knowledge, the present thesis is the first to report elevated heart rate responses to sub-maximal exercise following long-haul international air travel, which may suggest elevated sympathetic activity and physiological fatigue that could impact subsequent physical performance. Therefore, further research is required to confirm these findings.
Moreover, further research into the physiological consequences of the demands of international air travel *per se* is warranted, including changes in immune function, haematology and blood flow, and their association with ensuing physical performance. Effects on immune function may be particularly pertinent considering the recent observation of a greater incidence of illness in athletes following international transmeridian air travel (Schwellnus et al., 2012).

3. Current recommendations propose that to accelerate the resynchronisation of the sleep-wake cycle following international transmeridian air travel, sleep during travel should be scheduled according to when it is night at the destination, and must be avoided when it is daytime at the destination (Reilly et al., 2007a). However, as these recommendations may be difficult to implement in practice and considering significant reductions in sleep quantity and quality were reported during long-haul air travel in the present thesis, the effects of maximising sleep during travel were also investigated. While results suggest this may attenuate symptoms of travel fatigue following long-haul travel with minimal change in time-zones, further research is necessary to determine whether sleeping whenever possible during actual international air travel impedes the resynchronisation of the sleep-wake cycle post-travel.

4. Sleep following actual transmeridian air travel is likely to be disrupted due to the loss of synchrony between endogenous circadian rhythms and external cues (Beaumont et al., 2004). Consequently, further research into the efficacy of optimising sleep hygiene on the resynchronisation of the sleep-wake cycle following travel is required, especially when there are disruptions to circadian rhythms in body temperature and melatonin, which regulate sleep. Moreover, along with previous research (Thompson et al., 2012), the present thesis reported negligible effects of artificial bright light on performance recovery following
international air travel. In the present thesis, this could be due to the timing and frequency of performance testing, relatively short duration of the recovery period and lack of physiological markers of circadian rhythms, which made detection of altered circadian rhythms difficult. Accordingly, further research into the impact of artificial bright light exposure on circadian rhythm resynchronization and team sport physical performance recovery following long-haul transmeridian air travel is warranted. Though, a balance between practical application and the efficacy of artificial bright light interventions needs to be considered.

5. The inter-individual variation in travel induced responses is frequently highlighted in previous research (Waterhouse et al., 2000; Waterhouse et al., 2002). Therefore, further research with elite team sport athletes as participants is warranted to ensure recommendations based on research findings are specific to this population. In addition, research that further examines the determinants of individual responses to transmeridian air travel is worthwhile, as this may assist with identifying individuals at a greater risk of suffering from the detrimental symptoms of jet-lag. For example, research into the physiological predictors of ‘good’ and ‘bad’ responders to long-haul transmeridian air travel would be advantageous, as within a team sport environment, this would indicate which athletes require greater sports medicine/sports science support around travel. Moreover, as inter-individual variation in circadian rhythms is also apparent (Forbes-Robertson et al., 2012), generic interventions that aim to accelerate the resynchronisation of circadian rhythms following transmeridian air travel, such as scheduled exposure to bright light, are likely to induce varied responses. Consequently, further research is warranted into whether it is feasible to individualise these interventions for athletes around travel and competition.
Chapter Nine
References


Appendix A
Participant Information and Consent Forms
INFORMATION SHEET

Effects of simulated domestic and international air travel on physiological, perceptual, performance and recovery responses.

Thank you for expressing interest in this research. Please read and retain this information sheet. Should you have any questions regarding this study please do not hesitate to contact:

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Please note, we are recruiting healthy, male team sport athletes for this study

Information about the Research

- Contemporary elite athletes face an increased frequency and duration of air travel as part of their normal competition and training routines.
- The augmented travel-related demands placed on preparation for competition and recovery for subsequent competition raises issues over the effects of domestic and international airline travel on physiological, perceptual, performance and recovery responses in elite athletes.
- This study forms part of my PhD, which is titled “The effects of domestic and international travel on physiological, perceptual, performance and recovery responses, and interventions to attenuate these effects in athletes.”
- My other completed and planned studies are field-based and use professional athletes as participants. However, such a research setting can limit or prevent total control of all variables and may restrict some measures, as data collection and procedures are at the mercy of coaches, athletes and practicality.
- This study will be completed in the laboratory in the Department of Physiology at the Australian Institute of Sport (AIS), which will allow greater control of variables and a greater breadth of measures to be taken.
- As a result, we will gain a greater insight into the effects of domestic and international airline travel on physiological and perceptual responses, and ensuing effects on post-travel exercise performance and recovery.
- This is of particular interest considering the next Olympic Games will be held in London in 2012.

What you will be asked to do

- Following familiarisation with all experimental measures and procedures You will be asked to complete three trials over three consecutive weeks;
  1. 23rd - 25th March - Trial D - simulated 5 h domestic flight, similar to a flight from Sydney to Perth.
  2. 29th March - 1st April - Trial I - simulated 24 h international flight (a 22 h flight, including a 9 h and 13 h flight separated by a 2 h stopover) similar to a flight from Sydney to London.
  3. 5th - 8th April - Trial C - control trial without simulated flying.
- During the simulated flights in Trial D and I, you will be in the altitude house at the AIS, where we are aiming to simulate commercial air travel as closely as possible. This will include;
  a. The altitude and environment (temperature and humidity)
  b. Seating arrangement (economy class)
  c. Food and fluid intake
  d. Lighting
  e. Activity levels - will be kept to a minimum in order to simulate the activity levels of airplane travellers
  f. In Trial I, several strategies will be used to simulate the disruption to normal sleep patterns that occur during international commercial airline travel
- During Trial C, measurements will be taken at similar time points to Trial D and I, however, you won’t be exposed to the same conditions as listed above. Instead, you will be permitted to move around freely, similar to a normal sedentary day.
- A range of physiological, perceptual, performance and recovery measures will be taken throughout all trials (please refer to schematic diagrams of the study design for further details).

Risks and Discomforts

- The Yo-Yo Intermittent Recovery test requires you to keep running until volitional exhaustion. Exercising at this very high intensity will place a substantial level of stress on the body, which will be an uncomfortable experience, but will only last for the final few minutes of the test.
- To simulate the disruption to normal sleep patterns that occur during international commercial airline travel, you will experience sleep deprivation during Trial I, which, again you may find uncomfortable. As you will finish trial I at 09:00 in a sleep deprived state, to ensure your safety,
you will be driven home and monitored for 24 h post trial. You will be advised not to drive or consume alcohol for 24 h post trial.

The risks of complications related to any testing protocol are always present, however with correct instruction and supervision all dangers will be kept to a minimum. Investigation will occur at the Australian Institute of Sport (Canberra, ACT) where medical assistance, first aid kits and telephones are readily available.

**What will be done with my results?**

- Your privacy will be guaranteed and all data acquired will be kept strictly confidential.
- Only the Chief Investigator will have access to your identity and the only other people to have access to the raw data will be the members of the research team for this project.
- All raw data will be held in a password protected, secure location with access restricted to members of the research team.
- Reports, oral presentations and any published data resulting from this project will exclude the names of participants in order to protect your identity.
- It is expected that the data gained from this investigation will be included in a scholarly research article published in an esteemed international sports science journal.
- Furthermore, as this study is being conducted as part of a collaborative research partnership with the AIS, the results of the study will be shared with coaches and scientists at the AIS. However, no individual names or individual data will be revealed.

**Coercion and Withdrawal**

You have the right to participate in this investigation without the intervention of any element of force, fraud, deceit, duress, coercion, or undue influence on your decision. In the event that you agree to participate you have the right to withdraw your consent and cease involvement in the investigation at any time.

**Institutional Review Board**

<table>
<thead>
<tr>
<th>Charles Sturt University’s Human Research Ethics Committee has approved this project. I understand that if I have any complaints or concerns about this research I can contact:</th>
</tr>
</thead>
</table>
| Executive Officer  
Human Research Ethics Committee  
Office of Academic Governance  
Charles Sturt University  
Panorama Avenue  
Bathurst NSW 2795  
Tel: (02) 6338 4628  
Fax: (02) 6338 4194 |

Any issues you raise will be treated in confidence and investigated fully and you will be informed of the outcome.

Thank you for expressing interest in this research. If you agree to participate in this study, please sign the attached consent form.
INFORMED CONSENT

Effects of simulated domestic and international air travel on physiological, perceptual, performance and recovery responses.

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I, ______________________________________ (print name) consent to participating in the research project titled *Effects of simulated domestic and international air travel on physiological, perceptual, performance and recovery responses*. 

My consent to participate in this research is based on the following terms:

1. The purpose of the research has been explained to me, including the potential risks and discomforts involved.

2. I confirm that I am capable of completing the physical requirements of this research.

3. I have read and understood the information sheet provided to me, and have retained a copy of the information sheet provided to me.

4. I have been given the opportunity to ask questions about the research and received satisfactory responses to all questions I have asked.

5. I am content that I understand what I will be required to do as research participant.

6. I understand that any information or personal details gathered in the course of this research about me are confidential and that neither my name nor any other identifying information will be used or published without my written permission.

7. I understand that I can withdraw my consent at any time before, during, or after testing, without any penalty.

8. I nominate the person below as someone that can be contacted on my behalf in the unlikely event of an emergency:

   Name: ____________________________________________

   Address: ____________________________________________

   Phone: ____________________________________________

9. I am aware Charles Sturt University’s Human Research Ethics Committee has approved this project. I understand that if I have any complaints or concerns about this research I can contact:

   Executive Officer
   Human Research Ethics Committee
   Office of Academic Governance
   Charles Sturt University
   Panorama Avenue
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   Tel: (02) 6338 4628
   Fax: (02) 6338 4194

Participant signature: _________________________________

Date: _________________________________
INFORMATION SHEET

Effects of domestic air travel on physiological, perceptual, performance and recovery responses in professional Australian football players.

Thank you for expressing interest in this research. Please read and retain this information sheet. Should you have any questions regarding this study please do not hesitate to contact:

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Information about the Research

With the development and growth of Australian football (soccer) into Northern Australia, Oceania and Asia, a topic of heightened media, coach and player interest relates to the volume and regularity of travel facing playing squads. With the growth of the domestic competition, and integration into the Asian Football Confederation (AFC) Champions League, Australian football players face an increased regularity, duration and distance of airline travel.

Despite the amount of research literature published on airline travel, the effects on performance and recovery remain equivocal. Most research studies on airline travel involve uni-dimensional approaches, investigating singular physiological or perceptual responses to travel, with little or no relation to performance measures, especially competition performance. Furthermore, to date, almost all studies have investigated the effects of flights before competition, with no study investigating the effects of post-match flights on recovery. This is of particular interest considering the turnaround for subsequent competitive matches in the A-League is ‘typically’ 4 - 6 days.

Consequently, the purpose of this study is to investigate the effect of domestic commercial airline travel on the physiological, perceptual, performance (game and non-game based) and recovery responses before, during and following competitive matches in professional (Hyundai A-League) Australian football players.

What you will be asked to do

During the pre-season training period familiarisation sessions will be conducted to ensure you understand the experimental measures and procedures, particularly the unstimulated salivary sampling method, actimeter’s, ‘Sleep and Training Diary’ and counter movement jump (CMJ) protocol. Additionally, baseline sleep pattern data and baseline data for all other measures will be collected from you for 7 and 4 consecutive days, respectively during late pre-season, neither immediately preceding nor following a game.

Throughout the 2010/11 A-League season physiological, perceptual, functional and performance (game and non-game based) measures will be obtained around 8 games, or 4 ‘pairs’ of ‘home’ and ‘away’ games involving North Queensland Fury Football Club (NQF FC) against other A-League teams (Perth Glory, Melbourne Victory, Melbourne Heart and Wellington Phoenix). Completion of a minimum of 70 min in a pair of games (‘home’ and ‘away’) will be the criterion for inclusion of the data in the study.

Physiological, perceptual, functional and performance (non-game based) measures will be obtained before, during and following domestic travel, both prior to and following competitive A-League games. In conjunction, game and physical performance measures will be recorded during all ‘home’ and ‘away’ A-League games. Specifically, measures will be obtained in the 2 days prior to each game, before and during each game, and for 2 days after (refer to attached schematic diagrams of the study design). You will be asked to complete food and fluid diaries throughout the study period for both ‘home’ and ‘away’ games.

Physiological Measures

Heart rate (HR)/HR variability will be recorded using a HR monitor between 07:00 and 09:00 hrs local time 2 days before each game, on game day and 2 days following each game for both ‘home’ and ‘away’ games. In addition, for ‘away’ games, measures will be recorded during (1 hr after takeoff and 1 hr before landing) and following ‘outbound’ and ‘return’ travel. For the collection of HR variability data you will be required to wear a HR monitor belt around your chest (just below the sternum) for 10min in supine rest (lying down with your face up).

For ‘away’ games, oxygen saturation will be measured using a pulse oximeter, which will be attached to your index finger. Measures will be recorded following stabilisation or after 30 sec before, during (1 hr after takeoff and 1 hr before landing) and after ‘outbound’ and ‘return’ travel.

Unstimulated saliva samples will be collected between 07:00 and 09:00 hrs local time for 2 days before, on game day and 2 days following each game for both ‘home’ and ‘away’ games. For all collections you will be seated and instructed not to drink any fluid 10 min before. You will first swallow to empty your mouth and then with your head tilted slightly forward and making minimal orofacial movement, you will
dribble saliva into a sterile vial until 1 ml has been collected. Your saliva will subsequently be analysed for
the concentration of the stress marker cortisol.

To assess hydration status, you will be asked to produce a midstream urine sample on awakening on
each day listed previously for both ‘home’ and ‘away’ games, and 1hr after ‘outbound’ and ‘return’ travel
for ‘away’ games.
Duplicate mid-thigh and mid-calf circumference measurements will be recorded with a measuring tape to
assess muscle swelling between 07:00 and 09:00 hrs local time on the days outlined previously for both
‘home’ and ‘away’ games and 1 hr after ‘outbound’ and ‘return’ travel for ‘away’ games.

Sleep patterns and daytime activity levels will be assessed using actimetry (Activitaches) measures.
Measurements will be obtained from an actimeter (similar to a watch) worn on your non-dominant wrist
from bedtime on day -3 until awakening on day +3.

Functional Measures

Functional movement measures will be performed by the teams physiotherapist between 07:00 and 09:00
hrs for 2 days before, on game day and 2 days following the game for both ‘home’ and ‘away’ games, and
1 hr after ‘outbound’ and ‘return’ travel for ‘away’ games. The functional range of motion (ROM) measures
will include; the slump test and Thomas test (hip-flexors), and back ROM and site-specific pain tests. The
slump test will require you to sit on the edge of the physiotherapist's plinth and with your hands behind
your back ‘slump’ forwards (move your head towards your knees). The physiotherapist will help you to
maintain that position whilst simultaneously raising one of your legs and ensuring that your foot remains
in a plantar flexed (pointing downwards) position. Your knee angle will then be measured and recorded
and this same procedure will be repeated for the other leg. For the Thomas test, you will lay on the
physiotherapist’s plinth with your gluteal muscles right on the edge. The physiotherapist will move the
knee of one of your legs into your chest and simultaneously place downward pressure on the other leg,
which will be fully extended. Your hip angle will then be measured and recorded and this same procedure
will be repeated for the other leg. For the back ROM test a specially designed goniometer will be
positioned on your lower back to measure ROM. Finally, the site-specific pain tests will require you to rate
on a scale of 1 (‘no pain at all’) to 10 (‘extremely painful’) the pain/soreness of specific muscle groups.

Perceptual Measures

You will be asked to complete a ‘Sleep and Training Diary’ for 2 days before, on game day and 2 days
following each game for both ‘home’ and ‘away’ games. The diary will include an assessment of your
‘recovery-stress state’ and ratings of sleepiness, sleep quality, fatigue and muscle soreness. Your
‘recovery-stress state’ will be assessed using the Recovery-Stress Questionnaire for Athletes (RESTQ-19
Sport) (Kellmann & Kallus, 2001), which consists of a series of statements possibly describing your
mental, emotional, or physical well-being or activities during the past few days and nights. You will be
asked to indicate how often each statement was right in your case in the past few days on a scale of 0
(‘never’) to 6 (‘always’). Sleepiness will be assessed using the Epworth Sleepiness Scale (Johns, 1991)
and quality of sleep, and level of fatigue, stress and muscle soreness will be assessed on a scale
(Hooper et al., 1995) of 1 (‘very, very good/low’) to 7 (‘very very bad/high’). Finally, 30 min after each
game, you will be asked to give a rating of perceived exertion (RPE) during the game on a scale of 0
(‘nothing at all’) to 10 (‘maximal’) (Foster et al., 1996) and a rating of your feeling during the game on a scale
of -5 (‘very bad’) to 5 (‘very good’) (Rejeski et al., 1987).

Performance Measures

Non-Game Based

Physical (neuromuscular) performance will be assessed between 07:00 and 09:00 hrs local time 1 day
beforehand, on game day, and for 2 days following each game for both ‘home’ and ‘away’ games using a
counter movement jump (CMJ) protocol. Prior to each jump testing session you will perform a 10 min
dynamic warm-up consisting of general whole body movements emphasising an increase in range of
movement, a variety of running patterns and 4 sets of 3 practice jumps. You will be required to progressively increase the intensity of the exercises until the end of the warm-up period until you feel you
are capable of maximal performance. Jump assessments will consist of you performing a CMJ with a
lightweight bar (350~400 g) firmly stabilised on your shoulders. You will be asked to stand erect with the
bar positioned across your shoulders and will be instructed to jump for maximal height whilst keeping
constant downward pressure on the bar to prevent the bar moving independently of the body. You will
perform three repetitions, pausing for ~3-5 s between each jump, after which you will rest for 2-3 minutes before repeating a second set of three jumps.

Game Based

Game-based physical performance will be assessed via the use of individual GPS devices worn during each match (SPI elite, GPSports). Individual technical performance will be subjectively assessed by coaching staff, using a rating scale from 1 (very poor) to 10 (excellent). In addition, team technical performance will be assessed using available technical statistics from Champions Data analyses of all games.

Risks and Discomforts

All of the testing procedures involved in this study are of minimal invasiveness and you will already be familiar with many of the procedures due to the regular fitness and sport science testing you undergo and your involvement in a research project last season. In addition, the physical stress placed upon you throughout the research is part of your normal routine during the A-League season. For example, the physical demands of a competitive football match and the fatigue associated with long distance travel. We are purposely using measures that aim to cause minimal disruption to your normal preparation for an A-League match and pilot testing will be conducted prior to the beginning of the season to ensure that you are used to/comfortable with measures being taken in the ‘build-up’ to a game. However, you need to be aware that there will be some time commitments to the research project (approximately 1 hr each day), that you are not used to, in the 2 days before, on game day, and for 2 days following 8 competitive A-League matches throughout the 2010/11 season.

Time commitments

In the 2 days before, on game day, and for 2 days following 8 competitive A-League matches throughout the 2010/11 season, approximately 1 hr of your time each day will be required to complete all experimental measures and procedures. This is a total of approximately 40 hrs over the 2010/11 A-League season.

Benefits

The benefits of this study is that it will improve the NQF FC’s Sport Science and Medical Teams understanding of the effects of domestic airline travel on the physiological, perceptual, performance (game and non-game based) and recovery responses before, during and following competitive matches in professional (Hyundai A-League) Australian football players. This will subsequently allow us to investigate the use of practical, field-based interventions to be used by NQF FC players to reduce these effects and improve competition performance following domestic travel. In addition, you will be provided with individual information on the effects of domestic travel on your physiological, perceptual, performance (game and non-game based) and recovery responses and your physical and technical performance during competitive A-League matches throughout the 2010/11 season.

What will be done with my results?

Your privacy will be guaranteed and all data acquired will be kept strictly confidential. Only the Chief Investigator will have access to your identity and the only other people to have access to the raw data will be the members of the research team for this project. All raw data will be held in a password protected, secure location with access restricted to members of the research team. Reports, oral presentations and any published data resulting from this project will exclude the names of participants in order to protect your identity. It is expected that the data gained from this investigation will be included in a scholarly research article published in an esteemed international sports science journal. Furthermore, as this study is being conducted as part of a collaborative research partnership with NQF FC and the FFA and the FFA are funding the project, the results of the study will be shared with coaches and scientists at NQF FC and the FFA. However, no individual names or individual data will be revealed.

Coercion and Withdrawal

You have the right to participate in this investigation without the intervention of any element of force, fraud, deceit, duress, coercion, or undue influence on your decision. In the event that you agree to
participate you have the right to withdraw your consent and cease involvement in the investigation at any time.

**Role of Mr A McCall**
Mr A McCall, the Head of Sports Science and Conditioning at NQF will be involved in the research. He has been involved in the planning and organisation of the research project, he will be involved in data collection and will facilitate communication between the coaching staff, players and support staff for the required aspects of the study.

**Institutional Review Board**

Charles Sturt University's Human Research Ethics Committee has approved this project. I understand that if I have any complaints or concerns about this research I can contact:

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<tr>
<th>Executive Officer</th>
<th>Human Research Ethics Committee</th>
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<td>Office of Academic Governance</td>
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<td>Bathurst NSW 2795</td>
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<td>Tel:</td>
<td>(02) 6338 4628</td>
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<td>Fax:</td>
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Any issues you raise will be treated in confidence and investigated fully and you will be informed of the outcome.

Thank you for expressing interest in this research. If you agree to participate in this study, please sign the attached consent form.
INFORMED CONSENT

Effects of domestic air travel on physiological, perceptual, performance and recovery responses in professional Australian football players.

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I, ______________________________________ (print name) consent to participating in the research project titled *Effects of domestic air travel on physiological, perceptual, performance and recovery responses in professional Australian football players*.

My consent to participate in this research is based on the following terms:

1. The purpose of the research has been explained to me, including the potential risks and discomforts involved.

2. I confirm that I am capable of completing the physical requirements of this research.

3. I have read and understood the information sheet provided to me, and have retained a copy of the information sheet provided to me.

4. I have been given the opportunity to ask questions about the research and received satisfactory responses to all questions I have asked.

5. I am content that I understand what I will be required to do as research participant.

6. I understand that any information or personal details gathered in the course of this research about me are confidential and that neither my name nor any other identifying information will be used or published without my written permission.

7. I understand that I can withdraw my consent at any time before, during, or after testing, without any penalty.

8. I nominate the person below as someone that can be contacted on my behalf in the unlikely event of an emergency:

   Name: _______________________________________________

   Address: ____________________________________________

   Phone: _____________________________________________

9. I am aware Charles Sturt University’s Human Research Ethics Committee has approved this project. I understand that if I have any complaints or concerns about this research I can contact:

   Executive Officer
   Human Research Ethics Committee
   Office of Academic Governance
   Charles Sturt University
   Panorama Avenue
   Bathurst NSW 2795
   Tel: (02) 6338 4628
   Fax: (02) 6338 4194

Participant signature: _____________________________________

Date: ________________________________________
INFORMATION SHEET

Acute and longitudinal effects of international and domestic travel throughout a season on recovery and training in professional Australian soccer players.

Please read and retain this information sheet. Should you have any questions regarding this study please do not hesitate to contact;

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Why are we doing the research?

- Due to the geographical size of Australia and the development and growth of Australian football into Asia, Australian football players face an increased frequency and duration of airline travel.

- Despite these travel demands, few research studies have investigated acute travel effects on player readiness to perform.

- Whilst long distance air travel with a minimal change in time-zones may temporarily increase perceptual fatigue, it appears to have negligible effects on physiological and performance responses.

- Therefore, it has been proposed that frequent travel throughout a season may result in the summation of these acute intangible effects. However, as yet there is no evidence to support this hypothesis.

- Since travel is often a requirement for teams the day after an away match, ensuing training loads (TL) and recovery may be disrupted, which in turn can reduce player preparedness and thus, increase the risk of injury.

- Considering the suggested accumulation of travel fatigue, it could be anticipated that reduced player preparedness and greater risk of injury may be present following away matches in the latter half of the season. However, to date no studies have investigated the longitudinal effects of frequent travel on TL, recovery and injury in football.

- A better understanding of travel effects on player readiness to perform, would allow practitioners to provide improved and more specific guidelines to players, in order to help them cope with the additional demands of travel around training and competition.

Aims

1. Examine the interactive effects of match location (home v away) and competition phase (early v late) on training loads (TL), player wellness and injury prior to and following competitive football matches.

2. Determine the effects of international air travel on TL, player wellness, injury, sleep and jet-lag prior to and following competitive football matches.

What you will be asked to do

- During the pre-season training period we will familiarise you with all measures and procedures to ensure that you are familiar with them and know what they involve.

- Data will be obtained from 27 matches during the 2014/2015 A-League season, which will include 14 home and 13 away matches against the same nine opposition.

- Furthermore, data will be collected for six matches during the group stage of the 2015 Asian Football Confederation Champions League, which will include three home and away matches against the same three opposition.

What are the measures?

All measures will be collected as part of the clubs normal training monitoring procedures, though you have the right to withdraw your consent and cease providing this information at any time.

1. Training load

Will be calculated by multiplying your total session or match duration by your session rating of perceived exertion, provided approximately 30 min following each training session or match on a 0 - 10 scale.
2. Wellness

Approximately 60 min prior to all training sessions and matches, you will be required to complete a questionnaire assessing your fatigue, sleep quality, general muscle soreness, stress levels and mood on a 5 point scale. Your overall wellness will then be determined by summing the five scores.

3. Injury

All injuries will be diagnosed by the team physiotherapist. The time lost as a result of an injury will be calculated by the number of training sessions and matches missed. Injuries will also be classified according to their type (non-contact or contact) and the activity at the time of injury (training or match).

4. Sleep quantity and quality

Your sleep will be monitored using an activity monitor, which is worn on your non-dominant wrist like a watch. Data from the activity monitor will be used to determine your: sleep duration (h): the amount of time spent in bed asleep; and sleep efficiency (%): sleep duration expressed as a percentage of time in bed.

5. Subjective jet-lag

You will be required to complete the Liverpool John Moores University jet-lag questionnaire at a standardized time each day (09:00), which will assess your subjective ratings of jet-lag, together with your sleep, function, diet and bowel movement ratings.

When will the measures be collected and who will they be collected from?

- Measures 1-3 will be collected on a daily basis as part of the club’s normal training monitoring procedures.
- Measures 4 and 5 will be obtained one day prior to and for five days following international air travel.
- Measures will be obtained from all players.

What will you and the club get out of the study?

1. Individual sleep monitoring reports. These will include general information regarding the importance of sleep for recovery and performance, individual sleep quantity and quality results, how they compare to the general population and the rest of the team, and if necessary, tips on how to improve your sleep.

2. An improved understanding of travel effects on player readiness to perform, which will allow coaching and medical staff to make informed decisions on travel arrangements and/or interventions to implement around travel.

3. Which specific players are most affected by the club’s travel demands and therefore, who requires more assistance with and advice on overcoming travel effects.

Will there be any risks of harm or discomfort?

- The research will not result in any additional risks of harm or discomfort to you.

- All of the testing procedures involved in this study are non-invasive and you will already be familiar with many of the procedures due to regular sports science training load monitoring.

- In addition, the physical stress placed upon you throughout the research is part of your normal routine during the season. For example, the physical demands of a competitive football match and the fatigue associated with long distance travel.
Finally, we are purposely using measures that will cause minimal disruption to your normal preparation for matches.

**What will be done with the results?**

- Your privacy will be guaranteed and all data acquired will be kept strictly confidential.
- All raw data will be held in a password protected, secure location with access restricted to members of the research team.
- Reports, oral presentations and any published data resulting from this project will exclude the names of participants in order to protect your identity. It is expected that the data gained from this investigation will be included in a scholarly research article published in an esteemed international sports science journal.
- The study is being conducted as part of a collaborative research partnership with Western Sydney Wanderers Football Club. Therefore, some individual results will be shared with coaches and medical staff to assist them with providing individualised support around travel.

**Coercion and Withdrawal**

- You have the right to participate in this investigation without the intervention of any element of force, fraud, deceit, duress, coercion, or undue influence on your decision.
- In the event that you agree to participate you have the right to withdraw your consent and cease involvement in the investigation at any time.

**Institutional Review Board**

Charles Sturt University’s Human Research Ethics Committee has approved this project. I understand that if I have any complaints or concerns about this research I can contact:

Executive Officer  
Human Research Ethics Committee  
Office of Academic Governance  
Charles Sturt University  
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Thank you for expressing interest in this research. If you agree to participate in this study, please sign the attached consent form.
INFORMED CONSENT

Acute and longitudinal effects of international and domestic travel throughout a season on recovery and training in professional Australian soccer players.

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Tel: +61 295 145 294
Email: rob.duffield@uts.edu.au
I, ____________________________ (print name) consent to participating in the research project titled Acute and longitudinal effects of International and domestic travel throughout a season on recovery and training in professional Australian soccer players.

My consent to participate in this research is based on the following terms;

1. The purpose of the research has been explained to me, including the potential risks and discomforts involved.

2. I confirm that I am capable of completing the physical requirements of this research.

3. I have read and understood the information sheet provided to me, and have retained a copy of the information sheet provided to me.

4. I have been given the opportunity to ask questions about the research and received satisfactory responses to all questions I have asked.

5. I am content that I understand what I will be required to do as research participant.

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7. I understand that I can withdraw my consent at any time before, during, or after testing, without any penalty.

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   Charles Sturt University
   Panorama Avenue
   Bathurst NSW 2795
   Tel: (02) 6338 4628
   Fax: (02) 6338 4194

Participant signature: __________________________________________

Date: __________________________________________

I, the undersigned, was present when the study was explained to the subject/s in detail and to the best of my knowledge and belief it was understood.

Signature of Researcher: ____________________________ Date: ___/___/___
INFORMATION SHEET

Practical methods to enhance recovery and athletic performance following simulated international air travel.

Thank you for expressing interest in this research. Please read and retain this information sheet. Should you have any questions regarding this study please do not hesitate to contact:

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PHYSICALLY TRAINED MALES REQUIRED FOR RESEARCH STUDY

Information about the Research

- Purpose is to investigate the effectiveness of interventions aimed at minimising the loss of sleep during travel on the recovery of team sport physical performance following simulated international air travel.
- As international air travel is an additional stress frequently imposed on team sport athlete’s busy schedules, the development of interventions that can enhance the recovery of physical performance following travel will assist with their preparation for competition.

What you will be asked to do

- You will be asked to complete two trials;
  1. 5th - 7th March
  2. 19th - 21st March
- For each trial you will be required to complete 24 h of simulated international travel, consisting of a 9 h and 13 h flight separated by a 2 h stopover, replicating the demands of travel from Sydney to Europe.
- You will be required to complete one trial with and one trial without the use of behavioural interventions aimed at minimising the loss of sleep during travel.
- The simulated travel will be conducted in the altitude house at the AIS, where the conditions typically encountered during actual air travel will be simulated as closely as possible.
- This will include exposure to a mild level of altitude (2100 m), seating arrangement (economy class), food and fluid intake, and activity and sleep restrictions.
- A range of physiological, perceptual and performance measures will be taken before, during and after the simulated travel (see below for the specific times you will be required to be available).

Risks and Discomforts

- The Yo-Yo Intermittent Recovery test requires you to keep running until volitional exhaustion. Exercising at this very high intensity will place a substantial level of stress on the body, which will be an uncomfortable experience, but will only last for the final few minutes of the test.
- To simulate the disruption to normal sleep patterns that occur during international commercial airline travel, you will experience sleep deprivation following each trial, which again you may find uncomfortable. As you will finish each trial in a sleep deprived state, to ensure your safety, you will be driven home and monitored for 24 h post trial. You will be advised not to drive or consume alcohol for 24 h post trial.

The risks of complications related to any testing protocol are always present, however with correct instruction and supervision all dangers will be kept to a minimum. Investigation will occur at the Australian Institute of Sport (Canberra, ACT) where medical assistance, first aid kits and telephones are readily available.

Benefits

- Help Australian athletes gain a competitive advantage. The results of the study will be directly applied to help Australian athletes improve their preparation for competition after international travel.
- A unique opportunity to go behind the scenes and use the world-class facilities at the AIS.
- Provided with free information on your fitness levels and sleep patterns (are you sleeping enough?)

What will be done with my results?

- Your privacy will be guaranteed and all data acquired will be kept strictly confidential.
- Only the Chief Investigator will have access to your identity and the only other people to have access to the raw data will be the members of the research team for this project.
- All raw data will be held in a password protected, secure location with access restricted to members of the research team.
- Reports, oral presentations and any published data resulting from this project will exclude the names of participants in order to protect your identity.
- It is expected that the data gained from this investigation will be included in a scholarly research article published in an esteemed international sports science journal.
Furthermore, as this study is being conducted as part of a collaborative research partnership with the AIS, the results of the study will be shared with coaches and scientists at the AIS. However, no individual names or individual data will be revealed.

**Coercion and Withdrawal**

You have the right to participate in this investigation without the intervention of any element of force, fraud, deceit, duress, coercion, or undue influence on your decision. In the event that you agree to participate you have the right to withdraw your consent and cease involvement in the investigation at any time.

**Institutional Review Board**

<table>
<thead>
<tr>
<th>Charles Sturt University’s Human Research Ethics Committee has approved this project. I understand that if I have any complaints or concerns about this research I can contact:</th>
</tr>
</thead>
</table>
| Executive Officer  
Human Research Ethics Committee  
Office of Academic Governance  
Charles Sturt University  
Panorama Avenue  
Bathurst NSW 2795  
Tel: (02) 6338 4628  
Fax: (02) 6338 4194 |
| Any issues you raise will be treated in confidence and investigated fully and you will be informed of the outcome. |

Thank you for expressing interest in this research. If you agree to participate in this study, please sign the attached consent form.
INFORMED CONSENT

Practical methods to enhance recovery and athletic performance following simulated international air travel.

Peter Fowler (Principal Investigator)
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Prof Frank Marino (Co-Supervisor)
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Bathurst, NSW
2795
Tel: (02) 6338 4268
Fax: (02) 6338 4065
Email: fmarino@csu.edu.au
I, ________________ (print name) consent to participating in the research project titled *Practical methods to enhance recovery and athletic performance following simulated international air travel.*

My consent to participate in this research is based on the following terms:

1. The purpose of the research has been explained to me, including the potential risks and discomforts involved.

2. I confirm that I am capable of completing the physical requirements of this research.

3. I have read and understood the information sheet provided to me, and have retained a copy of the information sheet provided to me.

4. I have been given the opportunity to ask questions about the research and received satisfactory responses to all questions I have asked.

5. I am content that I understand what I will be required to do as research participant.

6. I understand that any information or personal details gathered in the course of this research about me are confidential and that neither my name nor any other identifying information will be used or published without my written permission.

7. I understand that I can withdraw my consent at any time before, during, or after testing, without any penalty.

8. I nominate the person below as someone that can be contacted on my behalf in the unlikely event of an emergency:

   Name: ________________________________________________________________

   Address: ______________________________________________________________

   Phone: _________________________________________________________________

9. I am aware Charles Sturt University’s Human Research Ethics Committee has approved this project. I understand that if I have any complaints or concerns about this research I can contact:

   Executive Officer
   Human Research Ethics Committee
   Office of Academic Governance
   Charles Sturt University
   Panorama Avenue
   Bathurst NSW 2795
   Tel: (02) 6338 4628
   Fax: (02) 6338 4194

   Participant signature: ____________________________________________________

   Date: ____________________________________________________________________
Appendix B
Perceptual Scales
Session Rating of Perceived Exertion (sRPE) (Foster et al., 1996)

<table>
<thead>
<tr>
<th>Rating</th>
<th>Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>NOTHING AT ALL</td>
</tr>
<tr>
<td>1</td>
<td>VERY, VERY EASY</td>
</tr>
<tr>
<td>2</td>
<td>EASY</td>
</tr>
<tr>
<td>3</td>
<td>MODERATE</td>
</tr>
<tr>
<td>4</td>
<td>SOMEWHAT HARD</td>
</tr>
<tr>
<td>5</td>
<td>HARD</td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>VERY HARD</td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>MAXIMAL</td>
</tr>
</tbody>
</table>
Hooper Scale (Hooper et al., 1995)

<table>
<thead>
<tr>
<th>SLEEP</th>
<th>STRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- VERY, VERY GOOD</td>
<td>1- VERY, VERY LOW</td>
</tr>
<tr>
<td>2- VERY GOOD</td>
<td>2- VERY LOW</td>
</tr>
<tr>
<td>3- GOOD</td>
<td>3- LOW</td>
</tr>
<tr>
<td>4- AVERAGE</td>
<td>4- AVERAGE</td>
</tr>
<tr>
<td>5- BAD</td>
<td>5- HIGH</td>
</tr>
<tr>
<td>6- VERY BAD</td>
<td>6- VERY HIGH</td>
</tr>
<tr>
<td>7- VERY, VERY BAD</td>
<td>7- VERY, VERY HIGH</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FATIGUE</th>
<th>MUSCLE SORENESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- VERY, VERY LOW</td>
<td>1- VERY, VERY LOW</td>
</tr>
<tr>
<td>2- VERY LOW</td>
<td>2- VERY LOW</td>
</tr>
<tr>
<td>3- LOW</td>
<td>3- LOW</td>
</tr>
<tr>
<td>4- AVERAGE</td>
<td>4- AVERAGE</td>
</tr>
<tr>
<td>5- HIGH</td>
<td>5- HIGH</td>
</tr>
<tr>
<td>6- VERY HIGH</td>
<td>6- VERY HIGH</td>
</tr>
<tr>
<td>7- VERY, VERY HIGH</td>
<td>7- VERY, VERY HIGH</td>
</tr>
</tbody>
</table>

SCALE FROM 1 TO 7 (HOOPER et al., 1995)
**Brunel Mood Scale (Galambos et al., 2005)**

Below is a list of words that describe feelings. Please read each one carefully. Then cross the box that best describes *HOW YOU FEEL RIGHT NOW*. Make sure you answer every question.

<table>
<thead>
<tr>
<th>Mood Scale</th>
<th>Not at all</th>
<th>A little</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Panicky</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Lively</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Confused</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Worn out</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Depressed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Downhearted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Annoyed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Exhausted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Mixed-up</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Sleepy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Bitter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Unhappy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Anxious</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. Worried</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Energetic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. Miserable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. Muddled</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. Nervous</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19. Angry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20. Active</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21. Tired</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22. Bad tempered</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23. Alert</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24. Uncertain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Recovery-Stress Questionnaire for Athletes (Kellmann et al., 2001)

RESTQ - 19 Sport

This questionnaire consists of a series of statements. These statements possibly describe your mental, emotional, or physical well-being or your activities during the past few days and nights. Please select the answer that most accurately reflects your thoughts and activities. Indicate how often each statement was right in your case in the past few days.

The statements related to performance should refer to performance during competition as well as during practice.

For statement there are seven possible answers.

Please make your selection by making the number corresponding to the appropriate answer.

Example:

In the past (3) days/night
… I read a newspaper

<table>
<thead>
<tr>
<th>0</th>
<th>never</th>
<th>1</th>
<th>seldom</th>
<th>2</th>
<th>sometimes</th>
<th>3</th>
<th>often</th>
<th>4</th>
<th>more often</th>
<th>5</th>
<th>very often</th>
<th>6</th>
<th>always</th>
</tr>
</thead>
</table>

In this example, the number 5 is marked. This means that you read a newspaper very often in the past three days.

Please do not leave any statements blank.

If you are unsure which answer to choose, select the one that most closely applies to you.

Please turn the page and respond to the statements in order without interruption.


In the past (3) days/night

1) … I felt down

<table>
<thead>
<tr>
<th>0</th>
<th>never</th>
<th>1</th>
<th>seldom</th>
<th>2</th>
<th>sometimes</th>
<th>3</th>
<th>often</th>
<th>4</th>
<th>more often</th>
<th>5</th>
<th>very often</th>
<th>6</th>
<th>always</th>
</tr>
</thead>
</table>

2) … I was in a bad mood

<table>
<thead>
<tr>
<th>0</th>
<th>never</th>
<th>1</th>
<th>seldom</th>
<th>2</th>
<th>sometimes</th>
<th>3</th>
<th>often</th>
<th>4</th>
<th>more often</th>
<th>5</th>
<th>very often</th>
<th>6</th>
<th>always</th>
</tr>
</thead>
</table>

3) … I was annoyed by others

<table>
<thead>
<tr>
<th>0</th>
<th>never</th>
<th>1</th>
<th>seldom</th>
<th>2</th>
<th>sometimes</th>
<th>3</th>
<th>often</th>
<th>4</th>
<th>more often</th>
<th>5</th>
<th>very often</th>
<th>6</th>
<th>always</th>
</tr>
</thead>
</table>

4) … I couldn’t switch off my mind

<table>
<thead>
<tr>
<th>0</th>
<th>never</th>
<th>1</th>
<th>seldom</th>
<th>2</th>
<th>sometimes</th>
<th>3</th>
<th>often</th>
<th>4</th>
<th>more often</th>
<th>5</th>
<th>very often</th>
<th>6</th>
<th>always</th>
</tr>
</thead>
</table>

5) … I did not get enough sleep

<table>
<thead>
<tr>
<th>0</th>
<th>never</th>
<th>1</th>
<th>seldom</th>
<th>2</th>
<th>sometimes</th>
<th>3</th>
<th>often</th>
<th>4</th>
<th>more often</th>
<th>5</th>
<th>very often</th>
<th>6</th>
<th>always</th>
</tr>
</thead>
</table>

6) … I felt lethargic

<table>
<thead>
<tr>
<th>0</th>
<th>never</th>
<th>1</th>
<th>seldom</th>
<th>2</th>
<th>sometimes</th>
<th>3</th>
<th>often</th>
<th>4</th>
<th>more often</th>
<th>5</th>
<th>very often</th>
<th>6</th>
<th>always</th>
</tr>
</thead>
</table>

7) … I felt physically bad

| 0 | never | 1 | seldom | 2 | sometimes | 3 | often | 4 | more often | 5 | very often | 6 | always |
Appendix B

8) … I was successful in what I did

never  seldom  sometimes  often  more often  very often  always

9) … I had some good time with friends

never  seldom  sometimes  often  more often  very often  always

10) … I felt physically relaxed

never  seldom  sometimes  often  more often  very often  always

In the past (3) days/nights

11) … I was in good spirits

never  seldom  sometimes  often  more often  very often  always

12) … I fell asleep satisfied and relaxed

never  seldom  sometimes  often  more often  very often  always

13) … I had the impression there were too few breaks

never  seldom  sometimes  often  more often  very often  always

14) … I felt emotionally drained from my sport

never  seldom  sometimes  often  more often  very often  always

15) … parts of my body were aching

never  seldom  sometimes  often  more often  very often  always

16) … I recovered well physically

never  seldom  sometimes  often  more often  very often  always

17) … I dealt with emotional problems in my sport very calmly

never  seldom  sometimes  often  more often  very often  always

18) … I was convinced I could achieve my set goals during performance

never  seldom  sometimes  often  more often  very often  always

19) … I prepared myself mentally for training and performance

never  seldom  sometimes  often  more often  very often  always

Thank you very much!
Liverpool John Moores University jet-lag questionnaire (Waterhouse et al., 2000)

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Jet lag:</td>
<td>How much jet lag do you have?</td>
</tr>
<tr>
<td></td>
<td>0 = insignificant jet lag (very bad jet lag)</td>
</tr>
<tr>
<td>2. Last night's sleep. When compared with normal:</td>
<td></td>
</tr>
<tr>
<td>a. How easily did you get to sleep?</td>
<td>-5 = (less) 0 = normal 5 = (more)</td>
</tr>
<tr>
<td>b. What time did you get to sleep?</td>
<td>-5 = (earlier) 0 = normal 5 = (later)</td>
</tr>
<tr>
<td>c. How well did you sleep?</td>
<td>-5 = (more waking episodes) 0 = normal 5 = (fewer waking episodes)</td>
</tr>
<tr>
<td>d. What was your waking time?</td>
<td>-5 = (earlier) 0 = normal 5 = (later)</td>
</tr>
<tr>
<td>e. How alert did you feel 30 min after rising?</td>
<td>-5 = (less) 0 = normal 5 = (more)</td>
</tr>
<tr>
<td>3. Fatigue:</td>
<td>In general, compared to normal, how tired do you feel at the moment?</td>
</tr>
<tr>
<td></td>
<td>-5 = (more) 0 = normal 5 = (less)</td>
</tr>
<tr>
<td>4. Meals. Compared with normal:</td>
<td>How hungry did you feel before your meal?</td>
</tr>
<tr>
<td>a. How hungry did you feel before your meal?</td>
<td>-5 = (less) 0 = normal 5 = (more)</td>
</tr>
<tr>
<td>b. How palatable (appetising) was the meal?</td>
<td>-5 = (less) 0 = normal 5 = (more)</td>
</tr>
<tr>
<td>c. After your meal, how do you now feel?</td>
<td>-5 = (still hungry) 0 = (satisfied) 5 = (bloating)</td>
</tr>
<tr>
<td>5. Mental performance and mood. Compared with normal:</td>
<td>How well have you been able to concentrate?</td>
</tr>
<tr>
<td>a. How well have you been able to concentrate?</td>
<td>-5 = (worse) 0 = normal 5 = (better)</td>
</tr>
<tr>
<td>b. How motivated do you feel?</td>
<td>-5 = (less) 0 = normal 5 = (more)</td>
</tr>
<tr>
<td>c. How irritable do you feel?</td>
<td>-5 = (less) 0 = normal 5 = (more)</td>
</tr>
<tr>
<td>6. Bowel activity today. Compared with normal:</td>
<td>How frequent have your bowel motions been?</td>
</tr>
<tr>
<td>a. How frequent have your bowel motions been?</td>
<td>-5 = (less) 0 = normal 5 = (more)</td>
</tr>
<tr>
<td>b. How has the consistency been?</td>
<td>-5 = (harder) 0 = normal 5 = (looser)</td>
</tr>
</tbody>
</table>
Appendix C
Photographs
Simulated air travel study one (chapter three), including: **A** the plane cabin; **B** meal composition; **C** indoor testing environment to minimise participants’ exposure to natural light.
Simulated air travel study two (chapter six), including: A the plane cabin; B artificial bright light intervention; C indoor testing environment with natural light blocked out; D participants awake overnight (AEST) in the altitude house; E meal composition; F loaded (40 kg) CMJ.