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The Effects of Travel Demands on Athlete Preparation, Performance and Recovery in National Football Teams

by Ewan Clements

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Certificate of Authorship and Originality of Thesis

I, Ewan Clements, declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Health at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Abbreviations, Symbols and Subunits

Abbreviation/Symbol/Unit	Word/Phrase
ACC	Accelerations
AEDT	Australian Eastern Daylight Time
AFL	Australian Football League
AIC	Aikake Information Criterion
A-League	Australian League
D	Day
DEC	Decelerations
FIFA	Federation Internationale de Football Association
GPS	Global Positioning System
GMT	Greenwich Mean Time
HDOP	Horizontal Dilution of Precision
HSD	High-Speed Distance
LJMQ	Liverpool John Moore University Jet Lag Questionnaire
MD	Match Day
NFL	National Football League
NT	National Team
P	Probability Value
SMC	Simple Matching Coefficient
TD	Total Distance
VHSD	Very High-Speed Distance
AU	Arbitrary Units
β	Coefficient Value
h	Hours
km	Kilometres
%	Percentage

Publications Resulting from Thesis

Clements, E., Ehrmann, F., Clark, A., Jones, M., McCall, A. & Duffield, R. 2023, 'Travel Across More Time Zones Results in Worse Perceived Fatigue and Sleep in National-Team Footballers', *International Journal of Sports Physiology & Performance*, vol. 18, no. 3, pp. 268-75.

Clements, E., Ehrmann, F., Clark, A., Jones, M., McCall, A. & Duffield, R. 2023, 'Flight Path and Scheduling Effects on Perceived Jet Lag, Fatigue, and Sleep in Footballers Traveling to and From National Teams', *International Journal of Sports Physiology & Performance*, vol. 18, no. 10, pp. 1132-40.

Clements, E., Ehrmann, F., Clark, A., Jones, M., McCall, A. & Duffield, R. 2024, ' Effects of pre-match travel and training on physical and technical performance in international football matches.', *International Journal of Sports Physiology & Performance*, vol. 20, no. 1, pp.73-79.

Clements, E., Ehrmann, F., Clark, A., Jones, M., McCall, A. & Duffield, R. ' Influence of travel demands and match load on recovery following post-match travel in national team footballers.' *International Journal of Sports Physiology & Performance*. In press.

In Review

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Statement of Authorship

Role	Name	Signature	Date
Graduate Research Student	Ewan Clements	Production Note: Signature removed prior to publication.	21/10/2024
Principal	Prof Rob Duffield	Production Note: Signature removed prior to publication.	21/10/2024
Co-supervisor	Dr Alan McCall	Production Note: Signature removed prior to publication.	21/10/2024
External Supervisor	Fabian Ehrmann	Production Note: Signature removed prior to publication.	21/10/2024
External Supervisor	Andrew Clark	Production Note: Signature removed prior to publication.	21/10/2024
External Supervisor	Dr Mark Jones	Production Note: Signature removed prior to publication.	21/10/2024

Abstract

This thesis examined the effect of variations in travel demands on the preparation, performance, and recovery of professional footballers competing in national football teams. Data was obtained from over 1000 individual trips with varying durations, time zone changes, directions, and schedules. The first four studies of this thesis aimed to determine how variations in the travel demands experienced by athletes influenced measures of perceptual wellbeing, match performance and recovery. Study 5 then reviewed currently available mobile applications focusing on managing jet lag to identify the content provided and their usefulness for travelling athletes.

Study 1 assessed how variations in travel duration, time zone change, and direction influenced perceptual fatigue, sleep quality, muscle soreness and stress for the first 2 days after arrival. Linear mixed models were built to identify relationships between travel variables and perceptual outcome measures. Increases in time zones crossed negatively affected perceptual fatigue ($p<0.001$) and sleep quality ($p<0.001$), while travelling eastward resulted in poorer sleep quality than travelling westward ($p<0.001$).

Study 2 determined how the travel route, arrival/departure time and travel context (into national team, between national team, or out of national team) influenced the perceptual fatigue, sleep, soreness, stress and jet lag responses after arrival. Linear mixed models were fitted for each perceptual outcome. Perceptual jet lag ratings were more responsive ($R^2 = 0.48$) to travel demands than other perceptual scales ($R^2 = 0.15$-0.26). Poorer jet lag ($p<0.001$), fatigue ($p<0.05$), and sleep scores ($p<0.001$) were observed after travel from Europe to Australia, while travelling out of the national team resulted in worse fatigue, sleep, and soreness ($p<0.05$). Arriving in the morning (05:00-11:00) or night (23:00-05:00) also resulted in worse fatigue

(p=0.06-0.013), while sleep ratings were worse (p=0.002-0.050) following morning (05:00-11:00) or evening (17:00-23:00) arrivals.

For Study 3, travel data was paired with physical and technical match performance data for the first match after each trip. Match-running performance was assessed via global positioning units (GPS), and technical match statistics were obtained from a match statistics partner. Linear mixed models determined the relationship between travel variables and match performance outcomes. Travel variables had minimal influence on physical or technical match performance. Eastward travel was associated with reduced pass accuracy (p=0.012), and increased total (p=0.042) and very high-speed distance, although this was likely influenced by opposition quality. Greater high-speed distance in training across the 3 days prior to matches was positively associated with match high-speed distance (p=0.004) and decelerations (p<0.001).

Study 4 used the perceptual recovery status scale and perceptual wellbeing ratings to assess recovery responses to different match loads and post-match travel demands. Recovery outcomes were measured for the first 3 days after post-match travel and at a standardised post-match time point of match day +3. Separate linear mixed models were built for each recovery outcome. For the 3 days after arrival from travel, perceived recovery status, fatigue, sleep, and soreness were all negatively affected by greater high-speed match load prior to travel (p=0.001-0.032), and sleep scores were worse after eastward travel (p=0.004). Longer post-match travel demands negatively affected perceived recovery status on match day +3 (p=0.004), with scores also worse when post-match travel was in an eastward direction (p<0.001). Lastly, longer periods of time between matches and travel departure were associated with reduced sleep quality on match day +3 (p=0.003).

Study 5 aimed to identify whether mobile applications targeted at managing jet lag may be useful for travelling athletes by reviewing the content and recommendations provided and by comparing the intervention schedules between apps for a single simulated flight. Importantly, none of the available applications were supported by peer-reviewed research. The most common recommendations provided by apps were adjustment to sleep schedules (42% of apps), timed light avoidance/attainment (33% of apps), acupressure treatments (33% of apps), and timed melatonin consumption (25% of apps). Large variations existed between the intervention schedules provided by apps. The mean similarity between apps for pre/during travel schedules was only 58% (±18) for light schedules and 78% (±9) for sleep schedules. Similarly, post-travel schedules had mean similarities between apps of 57% (±14) for light schedules and 93% (±3) for sleep schedules.

In summary, this thesis has identified that athlete responses to travel will differ significantly between different travel demands. Longer duration travel or travel across a greater number of time zones appears to result in poorer perceptual fatigue, sleep and jet lag ratings, while travel in an eastward direction will exacerbate this effect. Further, factors such as the travel route, the travel schedule, and the context of travel may also influence athlete responses to the journey. While perceptual measures may be affected by travel demands, match performance did not appear to be affected by the travel demands of the national team studied in this thesis; however, athletes usually arrived at least 2 days in advance of matches. Travel did affect the recovery of athletes after matches, with poorer recovery responses observed when athletes had longer post-match travel demands, particularly in an eastward direction. This thesis has highlighted that individualised planning is essential for travelling national teams, and practitioners should use the findings of this thesis to prioritise athletes based on their specific travel demands.

Chapter 1: Introduction

1.1 Introduction

International football (soccer) windows typically consist of ≈9-11 days and occur frequently throughout the football calendar for camps, qualification matches and tournaments in various locations around the world. National football federations are therefore challenged with transporting players into and out of these match locations, often during the congested scheduling of club domestic seasons (Carling et al. 2015). Hence, national team players must travel from club teams into national teams, compete in 1-2 national team matches (often with further travel between matches), and then travel back to clubs all within a 9-11 day period. Such schedules can result in demanding travel, alongside restricted time between travel and matches, posing concerns for athletes' preparation, performance and recovery (Gouttebarge, Brink & Kerkhoffs 2019).

Given that athletes can be based at a wide range of clubs across the world, travel requirements can vary considerably between players within a national team (Clements et al. 2023) and the prevailing view is that air travel, particularly of a long-haul nature, can negatively influence athlete preparation, performance and recovery (Rossiter, Warrington & Comyns 2022). Symptoms of jet lag, travel fatigue and sleep disruption may be expected during and after travel; however, the extent and nature of symptoms are likely to vary based on the specific travel demands experienced by each athlete (Janse Van Rensburg et al. 2021). Despite this, most research assessing the effect of travel on athlete wellbeing, performance and recovery is based on data from individual flights that provide limited transferability to other travel demands. In turn, it is difficult to understand athlete responses to the wide variations in travel duration, direction, time zone difference, arrival/departure times and flight paths (Rossiter, Warrington & Comyns 2022). Such a restricted view of the effects of travel makes managing national team travel difficult, and insufficient evidence exists to inform expected responses to the wide range of travel undertaken by footballers (Clements et al. 2023).

Travel requirements for a national football team are diverse and can vary considerably for a single match or window within a national team. Previously, athletes within a single national team (soccer) were observed to undertake travel durations ranging from <1h up to 31h duration, with 51% of total trips requiring greater than 10h of travel, during which time zone changes could be as large as 10h in both eastward and westward directions (Clements et al. 2023). As such, understanding how factors, including the duration of travel, the number of time zones crossed, the direction of travel, or the departure and arrival time of flights, is vital in identifying athletes at the most risk of the negative impacts of travel. Furthermore, understanding the specific influence of these variables on athlete fatigue, sleep, and recovery may assist practitioners in individualising interventions or schedules to support the athlete – which in itself is a difficult task in national teams. Further complicating the problem of travel for national football teams is that players are often based at clubs outside of their representative nation, meaning access to players is limited outside of the national team windows (Buchheit & Dupont 2018). As such, commonly reported pre- and post-travel physical or cognitive performance measures are logistically impractical for national football teams due to lack of access to players. Instead, a large proportion of player monitoring for national teams is completed via remote self-reporting of perceptual scales (McCall et al. 2015). Therefore, a detailed understanding of how perceptual ratings of fatigue, sleep quality, soreness, jet lag or recovery respond to different travel demands may assist inform national football teams' monitoring and travel practices.

Travel for athletes, and specifically footballers, is commonly reported as having negative effects on wellbeing, performance and recovery (Gouttebarge, Brink & Kerkhoffs 2019), with these effects likely stemming from the physiological and psychological symptoms of jet lag, travel fatigue, and sleep disruption (Janse Van Rensburg et al. 2021). Symptoms of jet lag are expected when travel occurs across ≥3 time zones and can include daytime fatigue, concentration loss, difficulties attaining or maintaining sleep, and gastrointestinal distress (Reilly, Waterhouse & Edwards 2009). The extent and duration of such symptoms are expected to differ based on the number of time zones crossed during travel and the direction of travel, with eastward travel expected to produce greater and longer-lasting symptoms (Janse Van Rensburg et al. 2021). Separate from jet lag, travel fatigue describes feelings of tiredness or malaise resulting from the stresses of undergoing long-haul or repeated journeys (Reilly, Waterhouse & Edwards 2009). Factors influencing travel fatigue include exposure to aircraft cabin environments (mild hypoxia, dry air, loud noise), cramped seating conditions, disruption to sleep schedules, and the general stresses of preparing for flights (Janse Van Rensburg et al. 2021). Based on this, the duration of travel is expected to influence the extent of travel fatigue symptoms in footballers travelling in and out of national teams. Additionally, arrival and departure times may influence the extent of sleep disruption before, during, and after travel. Despite the complexity of travel-related stresses, limited research has investigated responses to the multitude of travel factors across a wide range of journeys in football. Hence, further understanding of how these variables influence the wellbeing, performance and recovery of athletes travelling to and from national football teams is essential in managing each individual athlete's travel responses.

National team footballers undergoing extensive travel demands are likely to experience poorer sleep and elevated fatigue following travel; however, it is unclear when such problems are likely to appear and how variations in travel variables influence these symptoms. For example, longer travel demands are expected to produce poorer sleep and fatigue responses, as has been shown in comparisons between travel of 5h vs 24h (Fowler, Duffield & Vaile 2015); 4-7h vs 10-31h (Thornton et al. 2018); and <5h vs >5h (Mitchell, Pumpa & Pyne 2017). However, these studies provide only general comparisons and do not assist practitioners in identifying when travel becomes problematic, nor do they differentiate the symptoms across a broader range of flight demands. The direction of travel is also expected to influence the fatigue and sleep of athletes after travel (Janse Van Rensburg et al. 2021). Eastward travel across 8 time zones was previously observed to produce lower sleep duration and worse function ratings in physically trained individuals compared to westward travel of the same extent (Fowler et al. 2017a). However, this highlights the difference between only one flight path and a single non-elite population; it is currently unknown how these differences manifest following different flight scenarios. Based on the limited comparisons between different flights, analysing a larger flight database will provide more nuanced outcomes that can help national team practitioners better prepare for athlete travel.

Variations in the travel-related factors of national team footballers also exist for the flight path, the arrival and departure time, or the context of the journey (as either travel into or out of national teams); however, very little research exists to identify the influence of these factors on athlete fatigue, sleep and jet lag symptoms. Due to national team travel schedules often being finalised at the last minute, understanding the different responses to general flight paths that are commonly used will assist practitioners in developing general travel management strategies. Although athlete fatigue and sleep responses to specific flight paths exist, including Australia, Asia, Europe, South America and North America, these have been assessed individually in different populations (Bullock et al. 2007; Fowler et al. 2015a; Fowler et al. 2017b; Fowler et al. 2016; Fullagar et al. 2016; Kölling et al. 2017; Lastella, Roach & Sargent 2019; Stevens et al. 2018), and no comparisons have been made between these different common flight paths. Likewise, flight arrival and departure times represent another potential source of variation in travel responses that have been poorly explored. The only study to compare different arrival times found late afternoon arrivals, compared to early morning, to be associated with reduced jet lag and fatigue ratings in Olympic-level athletes (Waterhouse et al. 2002). While this suggests that arrival and departure times may influence the sleep and activity of athletes before and after flights, further comparisons are needed to support this and explore a broader range of arrival and departure times. Overall, comparisons between a broad range of flight paths and schedules will better inform the expected fatigue and sleep responses of athletes travelling for national football teams and assist in selecting and planning flight schedules.

Another concern with travel relates to the nature of the qualifying stages of international tournaments, whereby athletes in national football teams are regularly required to travel from club teams to national teams, often arriving within 3 days of matches. Pre-match travel demands may pose concerns for the match performance of players, and evidence exists supporting the reduction of several physical performance measures after extensive travel demands (Rossiter, Warrington & Comyns 2022). Specifically, reduced intermittent sprint performance has been observed after travel of 21h (Fowler et al. 2017a) and 24h (Fowler, Duffield & Vaile 2015) duration, while reduced maximal sprint performance and jump performance has been observed after travel of 6h (Kraemer et al. 2016), 21h (Fowler et al. 2017a) and 24h (Fowler, Duffield & Vaile 2015). Based on this, travel is often suggested to impair match performance; however, specific evidence for such an effect is lacking. Further, if negative effects of travel exist on match outcomes, it is unclear how variations in travel influence these match performances. For example, reduced running distance in matches has been previously observed after eastward travel (max 2 time zones) during the 2018 FIFA World Cup in Russia (Zacharko et al. 2022), while no effect of travel distance (mean: 1573km) was observed on total distance, high speed distance or sprints during matches at the 2014 FIFA World Cup in Brazil (Watanabe, Wicker & Yan 2017). However, pre-match travel demands in these studies are short as athletes arrived weeks in advance for the final stages and tended to be based near match locations. Separately, negative effects of longer travel (>5h) on total distance and distance >5m/s have been previously observed during international Rugby 7s matches (Mitchell, Pumpa & Pyne 2017); however, it is unclear how early athletes arrived for matches. Further, conflicting findings exist, with another study reporting no effect of travel duration or time zone difference on match running performance in Rugby 7's (Ullersperger et al. 2022). As such, further investigation into the effects of different travel demands on performance in international football matches is required to determine the influence of specific travel variables.

Due to potential cognitive impairments associated with jet lag, travel fatigue and sleep loss (Rossiter, Warrington & Comyns 2022), extensive travel into national team matches has the potential to impair skill execution and technical performance. However, limited research exists exploring the effects of various travel demands on technical performance in football matches. In Australian domestic football matches, a greater number of goals conceded, fewer shots on goal, and more opposition shots on goal have been observed in away matches compared to home matches (Fowler, Duffield & Vaile 2014); however, travel demands for away matches were short (5.3 ± 2.2 h), and the effects observed may be a result of away-match disadvantage. Outside of football, research in international Rugby 7s has identified a reduction in several technical match performance markers to be associated with both eastward and westward travel of 24h duration across 12 time zones, with this study also accounting for the effects of away match disadvantage (Lo et al. 2019a). Based on this, further investigations are warranted to identify whether such effects of travel exist within international football. Further, it is unclear how variations in travel demands experienced by athletes influence the potential effects on technical match performance.

Finally, athletes within a national football team are often required to return to their clubs as soon as possible after the completion of national team matches, which likely results in suboptimal conditions for post-match recovery. Specifically, reductions in sleep have been commonly reported in athletes undertaking long-haul travel (Doherty et al. 2023; Fowler et al.

2017b; Stevens et al. 2018), while air-craft cabins represent hypoxic environments, and the cramped conditions limit movement opportunities (Janse Van Rensburg et al. 2021). Furthermore, the time loss associated with travel is likely to reduce the time available for athletes to implement other recovery or medical strategies. Despite this, the influence of post-match travel demands on recovery has not been explored. Home and away comparisons in Australian domestic football competition have identified post-match recovery (Fowler, Duffield & Vaile 2014) and perceptual wellness (Fowler et al. 2015c) to be similar after away matches compared to home matches; however, these only consider short-haul domestic travel schedules. In contrast, increased blood markers of muscle damage were observed in physically trained individuals following a simulated team sport match and a 5h post-match travel bout (Kraemer et al. 2016); although all participants undertook the same travel demands, making it impossible to isolate the effects of travel on these recovery measures. Comparisons in recovery measures from international football matches with different post-match travel demands are needed to assist national teams in identifying the recovery needs of individual athletes and inform decisions about when to travel following matches. By providing such comparisons, national football teams can make better informed decisions around recovery strategies and player availability, and better collaborate with club teams to ensure athletes achieve adequate recovery from international matches.

1.2 Thesis Aims

The aim of this thesis was to identify the influence of variations in travel demands on measures of preparation, performance and recovery in national team footballers travelling for international competition. To achieve this, the following specific objectives were established:

1. Investigate the association between i) time zone difference and ii) travel direction (east vs west) on the post-travel changes in perceptual fatigue, sleep, soreness and stress in national team footballers (Study 1).
2. Compare post-travel perceptual jet lag, fatigue, sleep, soreness, and stress ratings between different flight paths, travel schedules, and trip contexts (Study 2).
3. Identify the effects of travel duration, direction, time zone change, the time between arrival and matches, and training loads upon arrival on physical and technical performance in national team matches (Study 3).
4. Describe the relationship of match load, travel duration, time zone change, direction, and time between match and travel departure on the perceptual fatigue, sleep, soreness, and recovery status of national team footballers upon arrival from post-match travel and 3 days after a match (Study 4).
5. Review current apps available to manage jet lag, identify their recommendations, and compare the interventions of apps for a simulated travel bout (Study 5).

1.3 Significance of Thesis

Air-travel places travelling athletes under a number of different physiological and psychological stresses and can cause poor sleep, elevated fatigue, decreased physical performance, and poorer recovery (Rossiter, Warrington & Comyns 2022). However, current research on the effects of travel is limited in the diversity of travel demands assessed. Thus, knowledge of athlete responses is restricted to a series of specific individual trips (Rossiter, Warrington & Comyns 2022). For national football teams, travel demands can vary from <1h through to >31h duration and can occur across 10 or more time zones (Clements et al. 2023). As such, the majority of possible travel demands that can be experienced by athletes travelling for national football teams have not yet been explored, making it difficult to support athletes based on their own travel requirements. Furthermore, other factors associated with travel, such as the arrival/departure time and flight path, have rarely been considered in research and may further influence how an athlete responds to a specific travel bout. Therefore, the large flight database available for use in this thesis represents an opportunity to provide comparisons across a much broader range of flights than what currently exists in travel research and allows the specific effects of individual travel variables to be identified.

While travel demands have been frequently suggested to be detrimental to match performance in professional football, evidence supporting such claims is limited. The current evidence in football comes from domestic competitions (Augusto et al. 2021; Fowler et al. 2015c) or matches within the final stages of international tournaments where travel demands are short (Watanabe, Wicker & Yan 2017; Zacharko et al. 2022). This evidence does not mimic the travel demands of international footballers during most national team windows, where travel demands can be extensive and arrival often only occurs a couple of days before matches (Clements et al. 2023). Further, athletes in these previous studies travel together, and thus, travel demands do not differ between individuals, making it difficult to determine the influence of away match disadvantage on research findings. While evidence exists suggesting long-haul travel (24h duration), regardless of away match disadvantage, can negatively affect performance in international Rugby matches (Lo et al. 2019a), it is currently unclear whether this translates to football or how variations in travel demands and how early athletes arrive for matches influence this effect.

Optimal recovery from international football matches is essential for both performance in subsequent matches and availability upon return to club teams. However, post-match travel demands impose conditions that may not support athlete recovery and instead increase fatigue, soreness or slow perceptual recovery after matches. Despite this, there is a lack of research exploring recovery measures after varying post-match travel demands. While a reduction in recovery status has been observed following a simulated team sport match and a 5h post-match journey (Kraemer et al. 2016), without variation in the travel demands experienced, it is impossible to determine whether travel itself affected post-match recovery. Therefore, by comparing the perceptual recovery responses of athletes with different travel demands, this thesis will identify whether different post-match travel requirements affect recovery from international football matches. This understanding can support the implementation of travel advice procedures (i.e. jet lag apps) and recovery strategies after matches, guide decisions on when to travel after matches, and better inform player readiness and availability upon return to clubs.

Overall, the investigations of this thesis will enable practitioners working with national football teams or other international sports to understand better the effects specific flights will have on their athletes' fatigue, sleep, performance, and recovery. This, in turn, can lead to more informed decisions around flight selection and the implementation of strategies and interventions specific to the travel experienced by each athlete.

1.4 Limitations

To set the context for this thesis, several limitations exist within this body of research that should be considered; these include:

- The population used was limited to only a single male national federation, and thus, variations in responses may be expected within different population groups (i.e. younger or female).
- Due to the design of these studies, the use of interventions and tools to manage travel for the included athletes was not controlled, and the authors had no influence over their use.
- Outside of national team windows, athletes within the national team are based at a range of clubs around the world. Thus, objective sleep data or pre- and post-travel measures of physical performance are unobtainable to national teams. As such, national teams and this thesis rely on perceptual scales and match performance data; however, these measures are likely to be influenced by other external factors.
- The class of travel was not controlled within each of these studies (and not always documented), and it is unclear how variations in flight class or seating arrangement may influence outcomes.

1.5 Delimitations

To set the context for this thesis, several delimitations are present in this sequence of studies, including:

- The population used represents a senior, elite, professional men's football team and thus, monitoring practices and travel behaviours likely reflect the current best practices of national football teams.

- The flight database used within each of the studies is larger than any pre-existing works and comprises a broader range of flight scenarios than what has previously been compared. Thus, the findings of this thesis apply to a variety of different teams and their own travel demands.

- Repeated measures data was included for most athletes, with data existing for individual athletes across multiple different travel demands.

- Actual flight details were obtained from booked travel schedules and verified via an online flight database; as such, travel demands are specific to the actual demands experienced by the athlete. This provides a more valid measure of travel demands than comparing distance between competition locations.

Chapter 2: Literature Review

2.1 Overview

This thesis aims to support the planning and management of travel for national football teams by exploring the effects that variations in travel may have on performance, preparation and recovery measures in national team footballers. This literature review will first describe the context and challenges of travel for national football teams and outline the potential demands experienced by athletes competing in such contexts. An athlete's response to travel will likely vary based on the extent of jet lag, travel fatigue and sleep loss they experience. Therefore, to understand how variations in travel may influence athlete responses, an overview of the psycho-physiological stresses that exist during and after travel will be provided, with reference to the travel variables that may influence the extent to which these stresses exist. Following this, existing literature on the effects of travel on measures of physical performance, match performance, physiological response, and perceptual wellbeing will be reviewed in the context of athletic populations and, more specifically, as related to football.

2.2 Methodology

All research relevant to the contents of this review was located via online searches of scholarly databases, including Google Scholar and PubMed. The key search terms "Travel" and "Athlete" were included in database searches, with combinations of other search terms including "Performance", "Sleep", "Match", "Competition", "Physical", "Cognitive", and "Perceptual". Articles were screened and excluded if they did not include any measures of performance, sleep or perceptual wellbeing/readiness. Lab-based studies that did not include participants undertaking travel (or simulated travel) were also excluded. Additionally, only studies on human populations were included. To identify additional research studies, reference lists of included papers were screened, and any additional papers that met inclusion criteria were added. Accordingly, 83 articles were included in this review.

2.3 Travel for National Football Teams

International football calendars require national team athletes to come together regularly for tournaments, qualification matches and training camps throughout the calendar year. Many of these matches and camps occur during scheduled international windows, which usually involve a 9-11 day period during domestic football seasons and require participating athletes to travel from their club to and from various national team locations. During these international windows, athletes are regularly required to travel immediately after club matches, compete in 1-2 national team matches (often with further travel in between), travel back to their clubs and then prepare for their next club match, which can occur within 2-3 days after arrival. Such demands add to an already highly congested schedule for many elite-level footballers and pose concerns over the potential effects of these travel demands on match performance and well-being (Gouttebarge, Brink & Kerkhoffs 2019).

To further complicate the above issue, for many national teams, players can be based at a wide range of clubs across the world, and thus, the travel demands for a single national team match can vary considerably between players within the same team. As shown in Figure 2.1, the travel duration for athletes within a single national team was observed to range from <1h to 31h, with travel occurring across up to 10 time zones in both eastward and westward directions (Clements et al. 2023). Such variations in travel demands are likely to greatly influence performance, well-being, and recovery (Janse Van Rensburg et al. 2021). As such, planning travel schedules and managing arriving athletes requires a highly individualised approach for national football teams. Research guiding the expected response to different travel demands is therefore crucial in optimising national team performance and returning athletes to clubs in an optimal state.

Prior research in national football team environments shows the extensive travel demands that players can experience. Travel duration of 19h across 11 time zones westward has been previously reported in the Australian national team travelling from Australia to South America for the FIFA World Cup (Fowler et al. 2017b), while the Northern Irish national team experienced 15h of travel across 4 time zones westward when travelling to South America (Fullagar et al. 2016). While these studies demonstrate that travel for national football teams can be extensive, they only report on situations where teams travelled together from one destination to another. During the qualification stages of many international tournaments, players are required to travel directly from clubs to the national team. Thus, a much larger variation and extent of travel is often required, which in turn needs more planning and player support. Additionally, international travel demands are not exclusive to national teams in football, with long-haul international travel also a requirement for many continental club competitions. Australian club teams competing in the Asian Champions League have reported travel demands of 10h across 1 time zone (Fowler et al. 2015a) and 24.5h across 1.5 time zones (Lastella, Roach & Sargent 2019). Although these trips do not require large time zone changes, players may still be prone to fatigue from travel and disruption to normal routine. Overall, while studies in national football teams are limited, extensive travel is a fundamental part of competition requirements. Thus, preparing athletes both before and after arrival into national football teams is vital for the national team and the players involved.

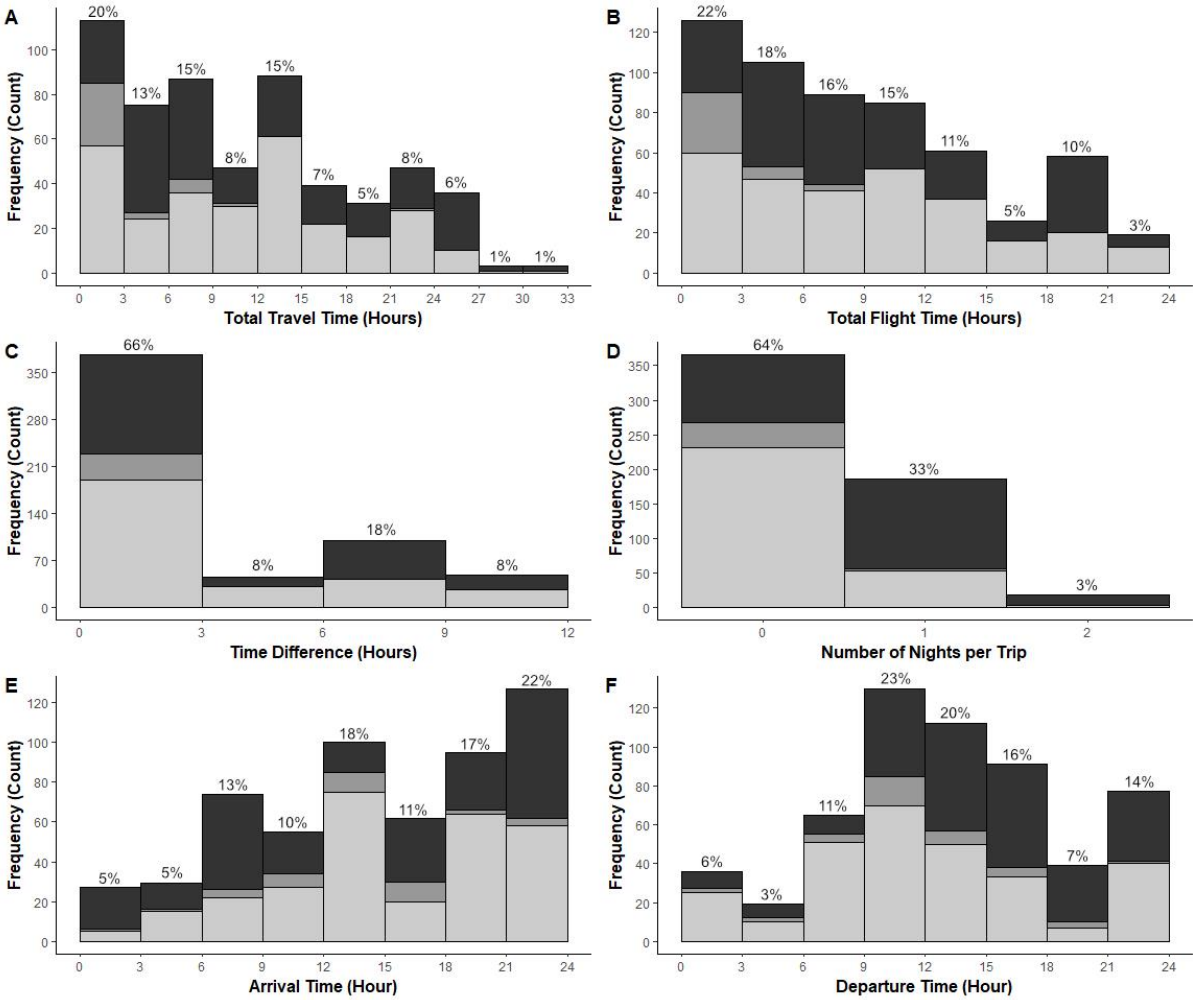


Figure 2.1. Distribution of travel demands experienced by a national football team (Clements et al. 2023)

Monitoring athlete responses to travel is essential to assist athlete recovery from travel-related stresses, prepare for upcoming matches, and optimise recovery after matches during periods of travel. However, monitoring travel in national team footballers is difficult as the availability and contact with athletes outside of national team windows is limited when players are at their club. As players within national teams are likely to be based at a vast range of clubs, the regular monitoring practices of players are likely to vary and are rarely consistent with the tools and measures used by the national team (Buchheit & Dupont 2018). As a result, pre- and post-travel measures of physical performance or physiological response are rarely available, making them impractical to monitor post-travel responses. Due to these issues, national teams frequently rely on simple perceptual scales relating to fatigue, soreness, sleep and stress to monitor an athlete's status and inform decisions around readiness to train (McCall et al. 2015). While the validity of these scales as a monitoring tool has been questioned (Jeffries et al. 2020), prior evidence has shown them to be responsive to variations in training and match load (Noor et al. 2021; Thorpe et al. 2015). However, while responses of perceptual wellness scales have been observed following travel bouts, no prior research exists across a broad range of flights; thus, it is difficult for staff of national football teams to determine how these tools can be used to monitor responses to travel.

2.4 The Physiological Stresses of Travel

The manner in which travel may affect an athlete's physical performance, perceptual wellbeing, and recovery is complicated and involves the interaction between multiple neuro-physiological mechanisms (Figure 2.2). Based on the travel experienced by the athlete, symptoms of jet lag, travel fatigue and sleep loss may be prevalent; however, the extent of symptoms is likely to vary based on the travel experienced. Understanding the mechanism behind these conditions and the travel variables that influence them may help inform how an athlete may be affected by their travel.

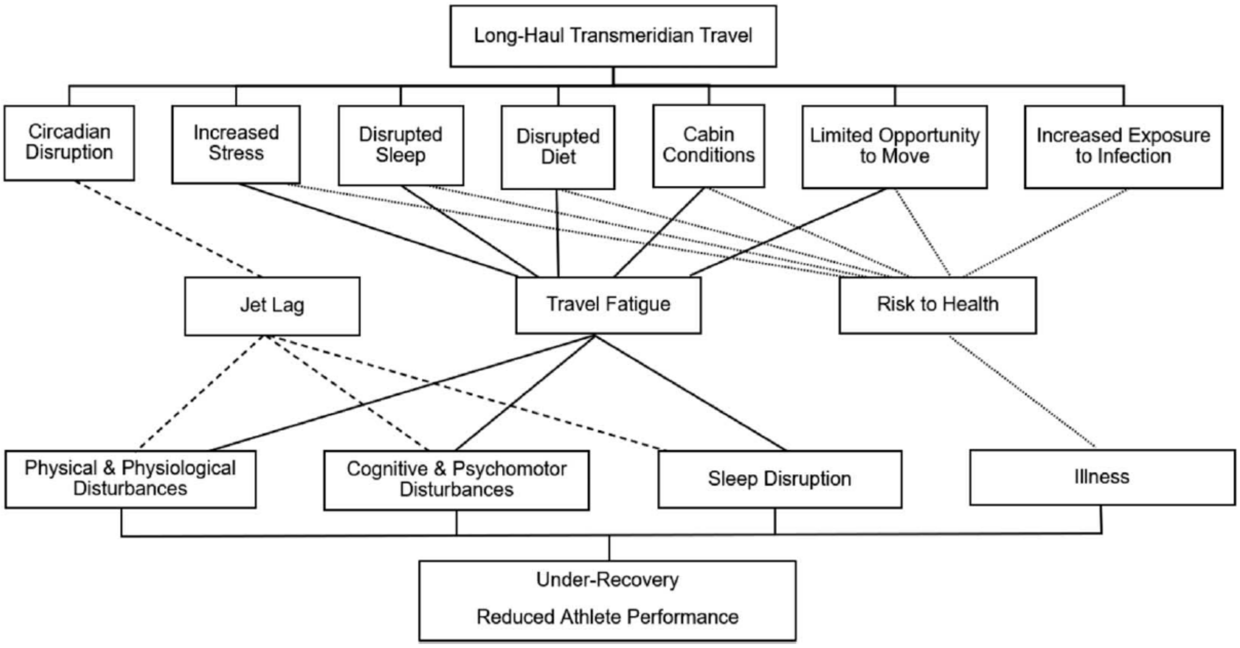


Figure 2.2. Conceptual overview of the physiological mechanisms in which long-haul transmeridian travel may impact athlete performance. Dashed lines represent factors causing and issues arising from jet lag. Solid lines represent factors causing and issues arising from travel fatigue. Dotted lines represent factors causing and issues arising from risk to health (Rossiter, Warrington & Comyns 2022)

2.4.1 Jet Lag and Circadian Misalignment

National team travel frequently requires athletes to travel around the world, crossing multiple time zones in a short period of time (Clements et al. 2023) and placing athletes at risk of negative symptoms of circadian misalignment and jet lag. Humans experience natural daily variations in physiological functions, including heart rate, body temperature, sleep/wake cycles, mood and stress (Pradhan et al. 2024). These circadian rhythms, often referred to as the 'body clock', exist to ensure the appropriate timing of many physiological processes relative to the timing cues of the external environment (Reilly, Waterhouse & Edwards 2009). While circadian rhythms exist internally to the body and persist without external cues, the rhythms are reset daily and synchronised to the ≈24h external light/dark cycle (Forbes-Robertson et al. 2012). The primary regulator of circadian rhythms, the suprachiasmatic nuclei, is located in the base of the hypothalamus and functions to receive signals from the external environment and use them to synchronise with the external time cues (Forbes-Robertson et al. 2012). External factors synchronizing the body clock are known as zeitgebers, with the most prominent being the light-dark cycle. Other contributors to the resynchronisation of circadian rhythms include food, exercise, and sleep (Forbes-Robertson et al. 2012). However, as the synchronisation of the body clock is not an instantaneous process, a large time zone change, such as those encountered from long-haul travel, will cause a loss of synchrony between the body clock and the external environment (Janse Van Rensburg et al. 2021).

Significant evidence exists to demonstrate that measures of physical and cognitive performance also show circadian rhythmicity and vary throughout the 24h cycle (Pradhan et al. 2024). Circadian variation in physical performance has been observed in several measures, including time trials, sport-specific skills, strength and power assessments, and endurance capacities (Ayala et al. 2021). Based on this, physical performance capabilities are expected to peak in the afternoon and early evening (approx. 16:30-18:30) and be reduced during the morning and biological night (Ayala et al. 2021; Thun et al. 2015). Similarly, cognitive performance shows circadian variation, with attention and working memory peaking in the afternoon and worst during the morning, while inhibition and creativity may be best in the morning (Xu, Akioma & Yuan 2021). Large time zone shifts will, therefore, alter the external clock time in which peaks and troughs in performance occur. This may pose a concern for competition or training performance if the time zone adjustment requires performance at a circadian low point such as the biological night or early morning (Reilly, Waterhouse & Edwards 2009). An example could be after an 8h westward time zone transition for a 17:00h local time competition. While this competition time would fall within the peak of performance for an adjusted rhythm, the biological timing of this competition would occur at 01:00h and, thus, in a low performance point. As such, performance during national team football matches may be impaired by time zone changes; however, this effect will vary based on the extent and direction of the time zone change.

Jet lag occurs following travel across multiple time zones as the internal body clock is out of synchronisation with the timing cues of the external environment, resulting in the timing of many biological processes occurring at inappropriate times in the new environment (Sack 2010). As a result, individuals can experience symptoms including difficulties attaining or maintaining sleep, daytime fatigue, loss of alertness and concentration, and gastrointestinal distress (Waterhouse et al. 2002; Waterhouse et al. 2005). For symptoms of jet lag to be alleviated, the body clock must adapt to the new time zone; however, adaptation takes time, and thus, symptoms can last for multiple days after travel (Forbes-Robertson et al. 2012). Current guidelines on the rate of readaptation suggest adaptation will take 0.5 days per westward time zone crossed and 1 day per eastward time zone crossed; however, these guidelines come from an early travel research paper where the average rates of adaptation were 92 min/day for westward trips and 57min/day for eastward trips (Aschoff et al. 1975). The discrepancy between adaptation rates for eastward and westward travel is explained by the length of the circadian clock, whereby an average cycle is slightly longer than 24h; thus, there is a natural tendency to drift later each day (Burgess & Eastman 2008). Consequently, delaying the body clock, as required after a westward trip, is easier than advancing it. While a 'central clock' component exists to synchronise the body's internal rhythms, individual clock cells exist within different organs across the body, each maintaining their own cycles (Arendt 2009). As such, different symptoms of jet lag are expected to alleviate at different rates due to the different rates of resynchronisation that occur between peripheral clocks (Forbes-Robertson et al. 2012). Based on these chronobiological underpinnings, the extent to which an individual experiences jet lag is likely to vary significantly between travel demands and individuals (Janse Van Rensburg et al. 2021). Thus, in national football team environments, where travel across time zones is frequent, understanding the differential responses of athletes based on the wide range of specific travel demands is essential for managing athlete arrival.

The extent of jet lag symptoms experienced is also likely to differ significantly between individuals. Age is expected to influence jet lag responses, although whether the effect is positive or negative is unclear. One study found older individuals to experience less jet lag and fatigue after travel from the United Kingdom to Australia, suggesting that these individuals were better able to 'pace themselves' than the younger individuals (Waterhouse et al. 2002). In contrast, Fowler et al. (2017b) and Moline et al. (1992) reported that older individuals experienced poorer sleep and fatigue symptoms after 11h and 6h time zone changes, respectively. Further, age has also been observed to have no influence on individuals travelling across a varied number of time zones (mean 6.55 ± 1.32 h) (Becker, Penzel & Fietze 2015) or 1 time zone (Fowler et al. 2015a). While the effects of age are unclear, prior travel experience appears to have a positive effect on jet lag responses. Lower jet lag scores were reported in national team footballers with a greater number of international appearances after an 11h time zone change (Fowler et al. 2017b), while professional first-team appearances were also higher in those reported lower jet lag scores in professional footballers travelling for 10h across 1 time zone (Fowler et al. 2015a). Accordingly, while individual characteristics are likely to influence athlete responses to travel, further comparisons within national teams are needed to support the individualised planning for travelling athletes.

Concerns around jet lag in national football teams exist as the symptoms of jet lag may disrupt an athlete's preparation for international football matches and place the athlete in a suboptimal condition to perform. Disruption to sleep is one of the most common symptoms of jet lag following significant time zone transitions. More specifically, due to the misalignment of individual sleep-wake cycles and the light-dark cycle of the new time zone, difficulty getting to sleep is expected following an eastward time zone transition, while early waking and difficulty maintaining sleep is expected following a westward time zone transition (Janse Van Rensburg et al. 2021). Consequently, in the days following long-haul travel, sleep quality and quantity reductions are common and may reduce an athlete's readiness to train/compete and impair recovery (Walsh et al. 2021). Other commonly reported symptoms of jet lag include daytime fatigue, loss of alertness and concentration, and gastrointestinal distress (Waterhouse et al. 2002; Waterhouse et al. 2005). These symptoms are likely to negatively affect readiness, mental well-being, and motivation and, therefore, may indirectly affect physical and cognitive performance (Rossiter, Warrington & Comyns 2022). Thus, management of the symptoms of jet lag may be as important as circadian adaptation when preparing athletes following arrival into and out of national football teams. However, to appropriately manage jet lag symptoms, understanding the extent and nature of symptoms based on the specific travel experienced by the athlete is essential.

2.4.2 Travel Fatigue

Regardless of the number of time zones crossed, long-haul air travel will likely induce symptoms of travel fatigue in athletes travelling for national teams. Travel fatigue is defined as feelings of exhaustion and tiredness that occur as a result of the accumulation of physical, physiological and psychological stresses that occur during long journeys (Janse Van Rensburg et al. 2021). Travel fatigue can occur both acutely following individual trips and cumulatively with repetitive travel demands (Samuels 2012). Symptoms of travel fatigue are associated with the disruption to routine caused by travel, the plane cabin conditions, and other stresses associated with completing the journey (Janse Van Rensburg et al. 2021). Table 2.1 describes a list of possible contributors to travel fatigue. Common symptoms of travel fatigue can include daytime fatigue, decreased concentration and motivation, increased irritability and general weariness (Reilly, Waterhouse & Edwards 2009). Acute travel fatigue symptoms are expected to be alleviated following a night of good sleep (Janse Van Rensburg et al. 2021); however, if frequent travel is required, symptoms may also be expected to accumulate over multiple trips (Samuels 2012). One of the most significant causes of travel fatigue is the disruption to sleep routine associated with travel timings and the difficulties attaining sleep during air travel (Weingarten & Collop 2013). Sleep is often reduced during travel due to uncomfortable seating conditions, loud aircraft noise, and bright environments (Janse Van Rensburg et al. 2021). Further symptoms of travel fatigue may also arise from the lack of mobility during travel and prolonged time spent sitting, the mental monotony of the journey, and the psychological stresses associated with check-ins, arrivals and managing the journey (Janse Van Rensburg et al. 2021). As such, travel fatigue may be expected to worsen based on the duration and timing of travel, particularly if it increases the disruption to normal sleep windows and requires athletes to be awake during these times.

While symptoms of travel fatigue may occur after any form of long-duration transport, prolonged time spent in aircraft cabin environments also places the travelling athlete under several unique physiological stresses that are likely to contribute to travel fatigue (Janse Van Rensburg et al. 2021). Pressurised cabin air conditions during flights are equivalent to those at approximately 8000m altitude and thus represent mild hypoxia and low hypobaric pressure (Coste et al. 2007). Such conditions may negatively impact the sleep of travellers (Coste, Van Beers & Touitou 2009) and cause fatigue and discomfort (Muhm et al. 2007). Further, the dry cabin air is also likely to impact fluid balance and potentially cause dehydration (Zubac, Buoite Stella & Morrison 2020), while the proximity to other passengers and recirculated air may also increase the risk of infection (Mangili, Vindenes & Gendreau 2016). Together, these physiological stressors may further contribute to poor well-being and sleep during and after travel, potentially impacting an athlete's preparation for national team competition. However, these conditions' influence will largely depend on the travel duration and time spent in air-craft conditions.

Table 2.1. – Possible physical, physiological, and psychological contributors to travel fatigue (Janse Van Rensburg et al. 2021)

Physical

Internal factors

- General Health

External factors

- Confined and uncomfortable space for a prolonged period of time
- Restricted movement and muscle inactivity
- Vibration effects from the mode of transport

Physiological (external factors causing internal physiological changes)

- Exposure to dry cabin air and low hypobaric pressure (causing dehydration)
- Prolonged exposure to low air quality (impairing immunity)
- Prolonged exposure to mild hypoxia (reducing oxygen saturation)
- Experiencing sleep disturbances, due to the cabin environment (i.e. cramped conditions, light and noise) and travel schedule
- Impaired nutritional intake (including timing and quality)

Psychological

- Mental monotony of a journey
- Concerns regarding the journey, logistics, competition and/or the destination
- Disruptions to daily routines
- Noise stress from the mode of transport and fellow passengers
- Home and societal influences
- Fulfilment/enjoyment of the craft/trade

2.4.3 Sleep Loss

Sleep is an essential component of athletic preparation, and reduced sleep volume or poor quality can negatively affect physical and cognitive function (Walsh et al. 2021). The conditions of air travel are unfavourable for the attainment of sleep, and thus, sleep quality and quantity are likely to be impaired during long-haul travel, particularly if travel occurs across normal sleep periods (Janse Van Rensburg et al. 2021; Rossiter, Warrington & Comyns 2022). Upright and cramped seating conditions, loud noise levels, and exposure to mild hypoxia can all negatively impact an athlete's sleep during travel (Coste, Van Beers & Touitou 2009; Janse Van Rensburg et al. 2021). Furthermore, the need to be awake during boarding, layovers, and arrival may further impact sleep on the days surrounding travel, particularly when early or late departures and arrivals occur. As such, reductions in sleep quantity and quality are commonly observed by athletes during travel (Rossiter, Warrington & Comyns 2022). However, the extent to which sleep is affected during travel will largely depend on the timing and duration of travel, with daytime travel unlikely to have major effects on sleep. An increase in sleep, likely driven by the body's homeostatic drive for sleep, on the night after arrival from travel has been frequently reported in travelling athletes and likely represents a compensatory strategy to manage sleep loss during travel (Fowler et al. 2019; Fullagar et al. 2016; Kölling et al. 2017; Lastella, Roach & Sargent 2019; Stevens et al. 2018). However, the commitments of an athlete on arrival may not always permit extended sleep, and jet lag may also interfere with sleep after arrival, potentially limiting the ability of athletes to make up for sleep debts accrued during travel. Given that reductions in sleep can negatively impact athlete performance and recovery (Fullagar et al. 2015), understanding the extent to which sleep is affected by different travel demands is essential for preparing for national team travel.

Large time zone transitions are likely to impact athletes' sleep for multiple days after travel due to the loss of synchrony between the individual's normal sleep-wake schedule and the external clock time of the new environment (Janse Van Rensburg et al. 2021). Human sleep cycles are driven by both a homeostatic and a circadian process, with the circadian drive for sleep instigated by daily fluctuations in core body temperature and melatonin secretion (Baranwal, Phoebe & Siegel 2023). To initiate sleep, the body naturally displays an increase in melatonin release from the pineal gland around two hours before sleep onset (Zisapel 2018), accompanied by a reduction in core body temperature (Reilly, Waterhouse & Edwards 2009). Following time zone transition, therefore, the rhythms of both melatonin release and core body temperature are misaligned with the external environment, resulting in the circadian drive for sleep to occur at inappropriate times (Forbes-Robertson et al. 2012). The manner in which a time zone transition impacts sleep will differ based on the direction of the time zone change. Following an eastward transition, individuals may experience difficulty attaining sleep due to a reduced circadian drive for sleep at night time in the new time zone (Steele et al. 2021). Conversely, individuals travelling westward may experience early waking and difficulty maintaining sleep in the morning due to the increased circadian drive for wakefulness (Steele et al. 2021). Following travel across multiple time zones, sleep quality and quantity reductions may be expected until the athlete's body clock adjusts to the new time zone. However, the duration and nature of sleep disruption will vary based on the number of time zones crossed and the direction of travel. Understanding the specific response to variations in these travel variables is therefore important in managing the sleep of athletes arriving and departing national football teams.

The detrimental effects of travel on sleep should be a concern for national football teams due to the potential adverse effects sleep loss may have on performance and recovery. Sleep deprivation and restriction have been suggested to impact exercise performance via a reduction in energy resynthesis, impairment of cognitive functioning, and elevated inflammatory responses (Gong et al. 2024). Sufficient evidence supports a detrimental effect of total sleep deprivation on exercise performance, with reductions in high-intensity intermittent capacity, sport-specific skill execution, speed and endurance all observed (Fullagar et al. 2015; Gong et al. 2024). However, complete sleep deprivation is unlikely during travel, and studies in athletes travelling for 18-24h duration have reported sleep durations ranging from 2.2h to 5.5h (Doherty et al. 2023; Fowler et al. 2015b; Fowler, Duffield & Vaile 2015; Fowler et al. 2017b; Fullagar et al. 2016; Lastella, Roach & Sargent 2019; Stevens et al. 2018). As such, research on partial sleep restriction may better represent the sleep behaviours of travelling athletes. While less conclusive than findings on sleep deprivation, research on sleep restriction has observed reductions in exercise performance in some studies (Fullagar et al. 2015; Walsh et al. 2021). A recent systematic review with meta-analysis identified sleep restriction to be detrimental to explosive power, speed, high-intensity intermittent exercise, aerobic endurance, and skill control (Gong et al. 2024); however, inconsistent results exist, and differences in sleep protocols and time of testing are likely also to influence results (Walsh et al. 2021). Limiting sleep losses during and after travel may be important to optimise the performance capacities of athletes travelling to and from national football teams. Further, reductions in sleep may cause alterations in growth hormone and cortisol secretion and an increase in the inflammatory response, which may have implications for an athlete's recovery (Charest & Grandner 2022). Given that travel shortly after matches is frequently required for national team footballers, understanding the extent to which travel demands may affect sleep is essential for promoting recovery.

2.5 Effects of Travel on Athletic Performance

Based on the effects of jet lag, travel fatigue, and sleep loss, travel into competition is often perceived to negatively affect athletes' performance (Gouttebarge, Brink & Kerkhoffs 2019). To determine the influence of travel on athletic performance, various measures of competition performance have been explored in response to both domestic and international travel, i.e. match outcomes or running demands. Further, as competition performance is likely to be influenced by a myriad of other factors outside of travel, pre- and post-travel physical and cognitive performance tests may further inform the effect of travel on performance. As such, this section will first discuss evidence for travel-related changes in physical and technical match performance in team sports before exploring the evidence for decrements in physical and cognitive performance testing following travel.

2.5.1 Match Performance

Due to the physiological and psychological stresses of travelling for competition, pre-match travel demands have often been suggested to be detrimental to match performance (Gouttebarge, Brink & Kerkhoffs 2019). The effects of travel on physical match-running demands are unclear, with mixed findings across current literature. For example, Table 2.2 summarises current research on the effects of travel on match-running performance measures. Existing research assessing the effects of travel on football (soccer) performance is limited, and no studies have explored performance in international football matches with long-haul travel demands. Pre-match travel distances ranging from 0km to 7296km (approx. 9h duration) had no relationship to the total distance, sprint distance or high-speed distance covered in the matches during the 2014 FIFA World Cup in Brazil (Watanabe, Wicker & Yan 2017). However, while these are the longest travel demands currently observed in football match performance research, the duration of travel <10h and a maximum of 3 time zones is still significantly less than what may occur throughout the qualifying stages of such tournaments (Clements et al. 2023).

Alterations in running performance have been previously observed following shorter travel demands; however, other factors, such as away-match disadvantage, likely influence this effect. Fowler, Duffield and Vaile (2014) observed professional footballers in the Australian domestic league (A-League) to cover more total and low-intensity distance in away matches (travel duration 3.1-7.5h) compared to home matches; however, as no differences in perceptual sleep quality, fatigue and soreness were observed, it is unlikely that such an effect was a result of pre-match travel demands. Further supporting this, another study in the Australian domestic league observed similar match-running performances in home matches compared to matches requiring short (<2h) and long (2-5h) duration air travel (Hands et al. 2023). Therefore, current findings suggest that short-haul travel is unlikely to influence football match-running performance, although conflicting findings exist. Augusto et al. (2021) reported that high-intensity distance and sprint distance were reduced in matches requiring travel of >520km compared to matches with no travel in the Brazilian professional football league. Aside from a median travel distance of 520km, the range of travel experienced by athletes was not reported in this study, and thus, it is unknown what the maximal travel demands of players were. Similarly, Zacharko et al. (2022) observed reduced total distance covered in matches when teams were required to travel eastward across 0-2 time zones for matches compared to matches requiring westward travel or no time zones crossed. Therefore, while several studies support the notion that short-haul travel will not influence match running performance in football, conflicting findings highlight the need for further research to support this. Additionally, long-haul international travel studies are lacking in professional football, and thus, the influence of longer travel demands on football match running is currently unknown.

Table 2.2. Match-running performances following travel demands

Article	Population	Travel	Match-Running Performance
Augusto et al. (2021)	Professional Football Athletes (n=22)	No Travel Short Travel (<520km) Long Travel (>520km)	↓ High-intensity distance, Sprint Distance after Long Travel compared to No Travel
Esmaeili, Clifton and Aughey (2020)	AFL Athletes (n=657)	Australian Domestic	No effect of travel distance on match activity
Fowler, Duffield and Vaile (2014)	Professional Football Athletes (n=6)	Home vs Away Matches (5.3 ± 2.2 h)	↑Total Distance and low-intensity activity during away matches ↔ High Intensity Running & Very High Intensity Running
Hands et al. (2023)	Professional Football Athletes (n=29)	Home Match Road Travel (1-2h) Short Flight (<2h) Long Flight (2-5h)	↑ Low-speed distance after Road Travel compared to Home and Long-Flight ↓ High-speed distance after Road Travel compared to Home and Long-Flight
Mitchell, Pumpa and Pyne (2017)	International Rugby 7s Athletes (n=22)	Short Travel (<5h) Long Travel (>5h)	↑ Distance per Tournament & Metres >5m.s in Long Travel compared to Short Travel ↔ Metres per Minute & High Speed Distance
Ullersperger et al. (2022)	International Rugby 7s Athletes (n=18)	0 – 23.6h	↓ Worst Case Scenario High-Speed Running & Average Speed after Eastward Trips No effect of travel duration or No. Time Zones crossed
Watanabe, Wicker and Yan (2017)	Professional Football Athletes (n=1644 player-match observations)	0-7296km	Travel Distance did not affect any running measures
Zacharko et al. (2022)	Professional Football Athletes (n=340)	Eastward Travel (0-2 Time Zones) Westward Travel (0-2 Time Zones) No Time Zones	↓ Total Distance after Eastward Travel compared to No Time Zones Crossed or Westward Travel

While match performance research in football is limited, evidence for reduced running performance following long-haul travel has been observed in other team sports. Ullersperger et al. (2022) observed reductions in worst-case scenario average speed and high-speed running (>5m.s) distance in international Rugby 7s matches requiring eastward travel (2.8 - 23.6h duration) compared to matches where no travel was required, although, variations in the duration of travel did not influence outcomes. Only trivial changes occurred in whole-match average speed measures, with the authors suggesting the lack of effect on whole-match measures may be due to alterations in the running mechanics of fatigued athletes (Ullersperger et al. 2022). Similarly, Mitchell, Pumpa and Pyne (2017) suggested altered running mechanics due to neuromuscular fatigue to result in increases in total distance and low-end high-speed distance (>5m.s) during Rugby 7s tournaments with >5h of travel compared to <5h travel, while no changes were observed in higher speed zones. These studies may suggest that while total match values may still be maintained after long-haul travel, the high-speed load capabilities of athletes in Rugby 7s matches may be reduced. In relation to short-haul domestic travel, Esmaeili, Clifton and Aughey (2020) found the distance travelled to the current match or in the previous round did not have any relationship with match-running outcomes in the Australian Rules Football League (AFL). As such, these findings suggest that domestic short-haul travel does not appear to have major effects on match-running performance in team sports. Overall, evidence from outside football suggests long-haul travel may be disruptive to running performance in team sport matches; however, as no research exists in football contexts, further evidence is needed to support this.

The fatiguing effects of travel and possible impairments to physical and cognitive functioning may result in reduced skill execution and tactical performance in football (Rossiter, Warrington & Comyns 2022). However, research assessing post-travel technical and tactical performance in football has only considered short-duration trips (<8h), and contrasting findings are observed. Current research on the effects of different travel demands on technical and tactical performance is summarised in Table 2.3. In the Australian Domestic Football League (A-league), comparisons between home and away matches (travel duration: 5.3 ± 2.2h) revealed more goals conceded, more opposition corners, and fewer points obtained in away matches compared to home matches (Fowler, Duffield & Vaile 2014). However, as noted by the authors, such effects are more likely to result from away-match disadvantage and variations in tactics, as no alterations in perceptual fatigue or sleep ratings were observed. In contrast, Zacharko et al. (2022) reported that during matches at the 2018 FIFA World Cup in Russia, teams travelling Eastward across 1-2 time zones attempted fewer passes compared to those travelling Westward across 1-2 time zones. However, passes were similar for eastward travel compared to matches with no time zone changes required, making it unclear whether this outcome is purely a travel-related effect. Based on the limited evidence available, the effects of travel, particularly long-haul, on technical match performance in football is unclear, and further research is warranted to support travelling national teams.

Table 2.3. Technical/Tactical match performance following travel demands

Article	Population	Travel	Technical/Tactical Performance
Fowler, Duffield and Vaile (2014)	Professional Football Athletes (n=6)	Home vs Away Matches (5.3 ± 2.2 h)	↑ Goals Conceded & Opposition Corners in Away Matches compared to Home
Lo et al. (2019a)	Professional Rugby Athletes (n=2474 observations)	24h +12 Time Zones	↓ Carries, clean breaks, metres, passes & tackles after Eastward Travel
McGuckin et al. (2014)	Professional Rugby Athletes (n=12)	Home vs Away Matches (3.1 ± 1.2 h)	↓ Metres gained in away games ↑ Tackles in away games
Morvant, Heintz and Foreman (2021)	NFL Quarterbacks (n=527 observations)	0 - 2586km	↓ Quarterback Rating with longer travel distances
Richmond et al. (2007)	Professional AFL Athletes (n=19)	Home vs Away Matches 1.5 – 2 Time Zones	No difference in any technical performance markers between home and away matches
Zacharko et al. (2022)	Professional Football Athletes (n=945 observations)	Eastward Travel (0-2 Time Zones) Westward Travel (0-2 Time Zones) No Time Zones Crossed	↓ Passes after eastward travel compared to westward and no time zones crossed

Currently, assessments of technical performance measures in response to long-haul travel have only been made in international Rugby, where 24h of eastward travel across 12 time zones was associated with a significant reduction in carries, clean breaks, metres gained, passes and tackles (Lo et al. 2019a). Interestingly, as the authors note, the performance indicators affected by travel predominantly require repeated high-intensity efforts, potentially suggesting fatigue from travel may have impaired these technical performance outcomes. The authors also suggested that the time between arrival and matches influenced findings, with the negative effects of eastward travel being greater in more recent seasons where the time between arrival and matches was shorter; however, further research is needed to support this view. While these findings suggest that long-haul travel may have detrimental effects on technical team sport performance, no other studies exist in any sports regarding long-haul travel and technical performance, and thus, further research is required.

Alterations in technical performance in Rugby League have also been observed following short-haul travel. McGuckin et al. (2014) reported fewer metres gained and more tackles in away matches than in home matches in the Australian professional Rugby league. However, as differences in travel demands for away matches were not assessed, and all athletes experience the same travel demands, it is unclear how away-match disadvantage influences this outcome. Mixed results exist in other sports regarding the effect of short-haul travel on technical performance. In American Football, greater distance travelled to matches (Range: 0km to 2586km) was associated reductions in quarterback rating in National Football League (NFL) matches (Morvant, Heintz & Foreman 2021). However, in AFL athletes, no differences were observed between home and away matches for any technical performance markers, with travel to away matches requiring eastward travel across 1-2 time zones (Richmond et al. 2007). As such, while some evidence exists to suggest team sport performance may be impaired by short-haul travel, research in this area is limited and broader comparisons are needed to explore how variations in travel may affect this response.

2.5.2 Physical Performance

While evidence suggests that pre-competition travel demands can impair competition performance in football and other sports, many confounding factors, such as away-match disadvantage, are likely to influence results. To better understand travel's influence on competition performance, several studies have sought to identify the responses of various physical performance capacities to travel bouts. As such, this next section will discuss the current evidence for travel-related alterations to performance across speed, power, and endurance.

Speed & Power

Existing literature on athletic populations suggests that long-haul, but not short-haul travel, may have detrimental effects on speed and power performance. Lower body power was reduced following travel of >5h into international Rugby 7s tournaments, whereas travel of <5h had no effect (Mitchell, Pumpa & Pyne 2017). In contrast, Fowler, Duffield and Vaile (2015) found the countermovement jump of physically trained individuals not to be significantly different between trials of 5h and 24h of simulated travel. However, the authors suggest that interindividual variability and relatively large typical error of the countermovement jump test may explain the lack of observed effect. Studies assessing the speed and power responses to individual long-haul travel bouts further support a detrimental effect. In physically trained individuals, reduced maximal sprint and countermovement jump performance has been observed following eastward and westward travel of 21h across 8 time zones (Fowler et al. 2017a) and westward travel of 24h duration across 10 time zones (Fowler, Duffield & Vaile 2015). Further, in national skeleton athletes, reduced countermovement jump performance was observed after 24h eastward travel across 8 time zones (Chapman et al. 2012). An increase in countermovement jump has also been observed in international rowers following westward travel of 30h across 9 time zones; however, the authors attribute these conflicting findings to a relatively high training load prior to travel, with the travel bout therefore representing a period of forced rest for the athletes (Everett et al. 2020). Similarly, Fowler et al. (2015b) found countermovement jump to be unchanged, but 5m and 20m sprint time to be reduced following a 24h simulated travel bout and 10h time zone change. Such findings suggest that while speed and power may be affected by long-haul travel, the specific tests and sensitivity of measures may also influence this effect. Overall, evidence suggests that long-haul travel may impair the speed and power performance of athletes travelling for international competitions in the days after travel.

While long-haul travel may reduce speed and power capabilities, shorter duration does not appear to have significant effects. In comparisons between travel durations, both Mitchell, Pumpa and Pyne (2017) and Fowler, Duffield and Vaile (2015) identified measures of lower body power to be unaffected by travel of <5h and 5h, respectively. Further supporting this, squat jump performance was similar immediately following away-match travel (3.1h ± 1.2) in professional Rugby players compared to a similar time before home matches (McGuckin et al. 2014). Unchanged countermovement jump height has also been observed in elite volleyballers following slightly longer travel demands of 9.5h across 2 time zones (Broatch et al. 2019). Based on these studies, short-haul domestic travel appears unlikely to have major implications for speed and power performance. However, the extent of travel in which detrimental effects on speed and power performance may exist is unclear. Further comparisons are therefore needed to better understand the specific influence of the number of time zones crossed and travel duration on speed and power performance measures.

In addition to the duration and time zone difference of travel, speed and power responses to travel also appear to be influenced by the direction of the journey. Currently, the only study comparing speed and power responses to eastward and westward travel reported that eastward travel results in greater reductions in countermovement jump performance and 20m sprint speed compared to westward travel (Fowler et al. 2017a). These findings did not align with a possible circadian influence, and thus, the authors suggest differences between travel directions may instead have been related to poorer sleep, fatigue and motivation after the eastward trip (Fowler et al. 2017a). As such, the poorer jet lag symptoms that may be expected after eastward travel (Janse Van Rensburg et al. 2021) may indirectly have a negative impact on speed and power in travelling athletes. However, the influence of travel direction is likely to differ based on the number of time zones crossed, and, given that no other comparisons currently exist between travel directions, it is difficult to determine how this effect may manifest across a broader range of trips.

Intermittent Sprint and Endurance Performance

Intermittent sprint and endurance capabilities are essential in football performance; thus, alterations in these capacities due to travel are important for national football team performance (Bangsbo, Mohr & Krustrup 2006). Mixed results exist for the effects of long-haul travel on intermittent sprint performance. Reduced Yo-Yo test performance has been observed for up to 2 days following 21h of travel across 8 time zones eastward, but the equivalent westward trip resulted in unchanged performance (Fowler et al. 2017a). As the timing of the tests relative to the body clock occurred at a more unfavourable time following the westward trip, it is unlikely that this effect is a direct influence of circadian misalignment. Instead, the authors suggest that reduced sleep duration in the first three nights after arrival from the eastward trip, which reduced subjective fatigue and motivation, may have influenced these findings (Fowler et al. 2017a). Similar findings were reported in a prior study, whereby Yo-Yo test performance was reduced on the day after 24h of simulated travel (Fowler, Duffield & Vaile 2015), while another study reported unchanged Level 1 Yo-Yo performance following the same travel demands (Fowler et al. 2015b). The author of these studies suggests that differences in the quantity of sleep between testing sessions may explain these discrepancies, with reduced sleep quantity occurring in the participants whose Yo-Yo test performance was affected. In addition, short-haul travel appears unlikely to influence intermittent sprint performance, as no effect on Yo-Yo performance was observed following a 5h simulated travel bout (Fowler, Duffield & Vaile 2015). As such, while long-haul travel has the potential to influence intermittent sprint capabilities, this effect will depend on the travel conditions and the extent to which sleep is disrupted.

2.5.3 Cognitive Performance

Football matches require players to process information from different stimuli, make decisions and react appropriately in various tactical situations (Williams 2000). As such, alterations in cognitive processing due to travel demands may have detrimental effects on match performance in international footballers. However, limited research exists assessing measures of cognitive performance in response to travel demands. Currently, pre- and post-travel assessments of cognitive performance are limited to simple reaction time tests (Fowler et al. 2015b; Reilly, Atkinson & Budgett 2001). Simple reaction test measures appear unaffected by travel demands, with Fowler et al. (2015b) reporting two- and four-choice reaction times of physically trained individuals to be similar to baseline on the day after 24h of simulated travel. Likewise, one-, two- and four-choice reaction times were similar throughout 7 days after 9h of travel across 5 time zones in Olympic gymnasts (Reilly, Atkinson & Budgett 2001). However, 8-choice reaction time was slower on day 1 after travel compared to other time points, suggesting that more complex reaction time tests with greater decision-making components may be affected by long-haul travel demands; however, pre-travel measures were not obtained by the study

(Reilly, Atkinson & Budgett 2001). While current findings suggest that long-haul travel demands affect performance in cognitive reaction time tests, these measures do not accurately reflect decision-making in real football contexts. As such, it is still unclear whether football performance is affected. Further research is therefore needed on more sport-specific cognitive performance tests, particularly across a greater range of travel scenarios.

2.6 Effects of Travel on Sleep

During Travel

Travel has the potential to disrupt sleep behaviours due to the uncomfortable conditions of air travel and the need for wakefulness during boarding, layovers and arrivals. However, the extent to which sleep is affected during travel largely depends on whether it occurs during normal sleep periods. As such, the duration and timing of travel are likely to greatly influence sleep responses. Reductions in sleep quantity and quality have been reported during long-haul trips ranging from 18-24h duration in populations including professional footballers (Fowler et al. 2017b; Fullagar et al. 2016; Lastella, Roach & Sargent 2019), endurance athletes (Doherty et al. 2023; Stevens et al. 2018), and physically trained individuals (Fowler et al. 2015b; Fowler, Duffield & Vaile 2015). Long-duration travel will likely interrupt normal sleep windows, and sleeping difficulties during travel may reduce the total sleep an athlete receives on travel nights. Average sleep durations reported during travel in the above studies ranged from 2.2h to 5.5h for 18 – 24 h flights. These sleep durations are much lower than the recommended ~8h of sleep for athletes (Sargent et al. 2021), and as such, ensuring athletes can make up for sleep deficits may be important. The seating class of travel may also influence sleep responses as Lalor et al. (2021) reported higher sleep duration (14.6h) and sleep efficiency (86.66%) in professional cricket athletes travelling in business class for 19h than what has been observed in other studies (Lalor et al. 2021). However, as no comparisons were made within the same athlete population, further research is needed to support this outcome. To compensate for reduced sleep during travel, increased sleep is often observed on the first night of arrival (Fullagar et al. 2016; Kölling et al. 2017; Lastella, Roach & Sargent 2019; Rossiter et al. 2022a). However, this strategy may not always be possible if athletes arrive in the morning or have morning commitments, potentially limiting their ability to make up for sleep debts.

Short-haul travel is unlikely to significantly affect athletes' sleep; however, this may depend on the timing of travel, as travel near sleep periods may restrict the time available to sleep. Several studies have observed sleep responses to be unaffected by short-haul daytime travel (Fowler, Duffield & Vaile 2014, 2015; Richmond et al. 2004; Richmond et al. 2007). Simulated travel of 5h duration had resulted in no differences from baseline for any sleep measure in physically trained individuals (Fowler, Duffield & Vaile 2015). Similar findings have been observed in comparisons in sleep quality and quantity between home and away matches in Australian football (A-League) (Fowler, Duffield & Vaile 2014) and AFL (Richmond et al. 2004; Richmond et al. 2007). Fowler, Duffield and Vaile (2014) observed that professional footballers travelling for away matches (5.3 ± 2.2h sleep duration) went to bed earlier on the day before and after matches and achieved greater sleep on the day after matches, compared to home matches. Similarly, Australian Rules Football League athletes had similar sleep patterns the day before and the day after both home and away matches, with travel requiring an eastward time zone change of 1.5-2h (Richmond et al. 2004; Richmond et al. 2007). However, reduced sleep duration was also observed on the night of away matches compared to home matches, with the authors noting that athletes tended to travel immediately after away matches. Thus, the interstate post-match travel requirements may have caused athletes to arrive home late and reduce their total sleep time (Richmond et al. 2004). As such, the sleep response to travel will also likely be affected by the timing of the trip. Supporting this, Fowler et al. (2015a) observed an 8 am departure for a 10h flight to reduce the sleep duration of professional footballers the night before travel, while the 5 pm arrival did not impact sleep after arrival. As such, departures near sleep windows may have a negative effect on sleep prior to travel. Based on this, it may also be expected that evening arrivals for short-haul trips may also potentially reduce sleep on the night of arrival; however, further research assessing the sleep responses to different arrival and departure times is needed.

After Travel

Symptoms of jet lag, most notably the misalignment of sleep/wake rhythms with external time cues, are likely to result in sleep difficulties in the days following travel across multiple time zones. Several studies have reported prolonged impacts of large time zone changes on sleep after travel. University footballers experienced reduced sleep duration and quality due to an earlier wake time across 5 days after 21h of eastward travel across 7 time zones (Biggins et al. 2022). Similarly, professional footballers experienced reduced sleep efficiency due to earlier wake times for up to 5 days following 19h of eastward travel across 11 time zones (Fowler et al. 2017b). Further, reduced sleep duration and later onset were reported for up to 3 days in physically trained individuals travelling 21h eastward across 8 time zones (Fowler et al. 2017a). These studies demonstrate that travel with large time zone changes, particularly in eastward directions, may alter an athlete's sleep behaviour and reduce total sleep duration for several days after arrival. Reduced total sleep time and poorer perceived sleep up to 6 days post travel has also been reported in Olympic support staff following eastward travel across 8 time zones (Rossiter et al. 2022b); however, as sleep onset latency was reduced and bedtime was earlier after travel, other factors such as social or work activities are likely to have influenced sleep behaviour. Rossiter et al. (2022a) also observed earlier bedtimes and wake-up times in international swimmers during a 6-day camp following eastward travel across 8 time zones, although total sleep duration was unchanged. However, training commitments and resulting fatigue likely increased the drive for sleep and, therefore, counteracted the expected difficulties of attaining sleep following eastward travel. Shorter lasting effects on sleep have also been observed, with total sleep time, sleep onset latency, and sleep efficiency returning to baseline 2 days after travel in track cyclists following a 7h eastward time zone change (Doherty et al. 2023). As such, while it is likely that sleep may be impacted after travel, comparisons between different time zone changes are lacking, making it difficult to identify how variations in travel will affect sleep differently.

The number of time zones crossed during travel appears to be largely influential on post-travel sleep patterns, as several studies assessing long-duration travel with smaller (<6) time zone changes have reported no differences in post-travel sleep (Fullagar et al. 2016; Kölling et al. 2017; Stevens et al. 2018). Stevens et al. (2018) found the sleep of Masters triathletes for 4 days after a 22.6h eastward flight across 4 time zones to be unaffected, aside from an initial increase in sleep on the first night after arrival. Similarly, Fullagar et al. (2016) observed sleep measures in national team footballers to be unchanged after an 18h eastward flight across 4 time zones, while Kölling et al. (2017) reported the sleep of junior professional rowers to be improved after travelling into camp following a 11h westward flight across 5 time zones. As such, travel across a small number of time zones appears less likely to have implications for sleep in the nights after arrival; however, a lack of comparisons exists to identify the number of time zones that can be crossed without major effects on sleep.

The direction of time zone changes are also likely to influence the sleep responses of athletes after travel, with adaptation to an eastward time zone change expected to take longer than an equivalent westward change (Eastman & Burgess 2009). Supporting this, reduced sleep quantity due to later sleep onset was reported for 3 days in a physically trained population after an 8h eastward time zone shift; however, unchanged sleep patterns were observed following the equivalent westward time zone shift (Fowler et al. 2017a). Similarly, academics travelling eastward across 8-11 time zones to conferences experienced reductions in sleep duration and sleep quality for 2 days after travel, while the sleep of those who travelled westward across 7-8 time zones did not change (Takahashi, Nakata & Arito 2002). As such, it appears as though sleep may be affected to a greater extent following large eastward time zone transitions; however, as currently only two studies have conducted such comparisons, further research is needed to support this and explore this effect at varying time zone differences.

2.7 Effects of Travel on Jet Lag and Perceptual Measures

Jet Lag

Athletes travelling across multiple (≥3) time zones are likely to experience symptoms of jet lag until their body clock has successfully adjusted to the new time zones (Janse Van Rensburg et al. 2021). While circadian misalignment can directly affect performance, other symptoms of jet lag, including fatigue, sleep difficulties, difficulty concentrating, and gastrointestinal distress, may also be disruptive to training and competition and affect athlete well-being (Leatherwood & Dragoo 2013). As such, perceptual scales of jet lag and its individual symptoms are often used to monitor the extent of these symptoms and assist in managing jet lag. These perceptual scales represent practical and cost-effective tools, making them highly relevant in athletic environments due to their ease of use. The most commonly used scale, Liverpool's John Moore University Jet Lag Questionnaire (LJMQ) (Waterhouse et al. 2000), is a 15-item visual analogue scale that attempts to measure both overall jet lag and the extent of its symptoms, including sleep, fatigue, appetite, mental performance and bowel function. While it should be acknowledged that physiological markers of the circadian phase are required to accurately measure jet lag and the extent of circadian misalignment (Janse Van Rensburg et al. 2021), many symptoms of jet lag are perceptual in nature and thus perceptual measurement scales provide useful tools to monitor the extent of symptoms individuals experience. As such, the perceptual scales of jet lag and its symptoms are a practical tool for monitoring travelling national team.

Perceptual jet lag symptoms have been well-researched in individual flight studies, and elevated symptoms following travel across multiple time zones have been commonly reported; however, the extent and duration of symptoms differ. A 4h westward time zone change was enough to elicit elevations in perceived jet lag ratings 2 days after travel in international footballers, with scores normalising at the next measure on day 4 (Fullagar et al. 2016). While comparisons between studies are difficult due to differences in populations and methodologies, a trend across studies supports the idea that larger time zone changes will produce longer-lasting jet lag symptoms. A 5h westward time zone change was enough to elicit elevated perceptual jet lag for 6 days in junior professional rowers (Kölling et al. 2017), while an eastward time zone change of 8h resulted in perceptual jet lag for 6 days in Olympic support staff (Rossiter et al. 2022b) and international swimmers (Rossiter et al. 2022a), and 7 days in national skeleton athletes (Bullock et al. 2007). Similarly, an 8h time zone change in both eastward and westward directions resulted in elevated jet lag ratings up to the end of data collection 4 days after travel in a physically trained population (Fowler et al. 2017a). Further, larger time zone changes appear to produce longer-lasting jet lag symptoms. Biggins et al. (2022) observed jet lag to remain elevated for up to 13 days in elite university footballers travelling across 7 time zones eastward, while elevated jet lag for up to 8 days was observed in professional Rugby players after an 11h westward time zone change (Fowler et al. 2016). Fowler et al. (2017b) also observed increased jet lag for up to 4 days in national team footballers after an 11h eastward time zone change; however, further data was not collected, and it is unclear how long symptoms lasted. Overall, significant evidence supports the existence of perceived jet lag following travel across time zones; however, individual flight studies provide insight into a specific trip and do not inform how symptoms may vary for different travel demands.

While individual flight studies provide some insight into jet lag responses to specific travel bouts, studies comparing different trips within the same athlete group and methodology may better inform the expected variation in jet lag symptoms from different travel demands. While greater jet lag symptoms are expected with larger time zone changes, only one study has compared perceptual jet lag responses between time zone differences. Thornton et al. (2018) found subjective jet lag to be greater and perceived vigour lower in wheelchair basketball athletes travelling across 6-11 time zones compared to those travelling across a single time zone. While this affirms the expectation that jet lag will be worse with larger time zone changes, it only compares extremes of long and short-haul travel and thus does not inform smaller differences in time zones. Perceptual jet lag is also expected to be worse following eastward travel than westward due to the difficulties in advancing the body clock (Sack 2010). Supporting this, Fowler et al. (2017a) reported perceived jet lag to be greater on the first 3 days after an 8h eastward time zone change than an equivalent westward change. These findings echo the earlier works of Lemmer et al. (2002), who also found that higher jet lag ratings were reported in Olympic gymnasts after an eastward trip across 8 time zones compared to those who travelled westward across 6 time zones, although no statistical comparisons were made between groups. As such, while the number of time zones crossed and direction of travel both appear to influence the extent of perceptual jet lag symptoms, current comparisons are limited, and broader comparisons are needed to provide more nuanced information.

Perceptual Monitoring

In addition to ratings of jet lag and its symptoms, several studies have also sought to assess the athlete response to travel using different perceptual monitoring tools, including both validated tools (REST-Q, DALDA, POMS) and single item perceptual scales (“Wellness”), commonly used throughout professional sport. While the specific scales implemented differ between studies, these scales aim to assist in the monitoring of travel responses by measuring athlete perceptions of fatigue, sleep quality, muscular soreness, stress, and recovery with the overall aim to measure responses to training and competition loads (Sansone et al. 2023). Given that jet lag, travel fatigue, and sleep loss are all likely to produce symptoms that may influence these perceptual measures, these tools may provide useful insight into the athlete's response to travel and readiness to compete. The use of validated perceptual scales to monitor training responses is well-supported, with evidence suggesting such scales may provide better insight than blood and saliva indices concerning acute and chronic training load monitoring (Saw, Main & Gastin 2016); however, many of the validated scales are extensive and unlikely to warrant high compliance. As such, shorter single-item scales are frequently used to monitor training responses in sports (Jeffries et al. 2020; Neupert et al. 2022), with the majority of these custom scales focusing on measures of fatigue, sleep quality, muscular soreness and stress (Jeffries et al. 2020; Neupert et al. 2022).

The use of single-item perceptual monitoring scales has been questioned as the majority of these scales do not have any validation studies to support their use and lack conceptual frameworks regarding what they measure (Jeffries et al. 2020), while their relation to training load is also inconsistent between studies (Duignan et al. 2020; Noor et al. 2021; Thorpe et al. 2015). However, these scales have been observed to share significant associations with match performance in various sports, and thus may be useful for informing readiness for competition (Sansone et al. 2023). Further, a recent systematic review also identified some of these individual scales to be responsive to travel in professional athletes (Rossiter, Warrington & Comyns 2022). Given that more sophisticated (i.e. longer) questionnaires are unlikely to attain sufficient compliance in national football teams, single-item scales are often all that is available

(McCall et al. 2015; McCall et al. 2022). As such, understanding how these scales respond to travel demands, in the absence of any other available data, is important for improving the monitoring of athletes when travelling into and out of national teams.

Several studies have reported detrimental effects of international travel on perceptual wellbeing states, particularly perceptual fatigue ratings. Rossiter et al. (2022a) reported increased perceptual fatigue up to 5 days after a 20h eastward trip across 8 time zones. Similarly, increased perceptual fatigue was observed up to day 6 in Olympic support staff after 23-27h of travel across 8 time zones eastward (Rossiter et al. 2022b). As such, travel and related large time zone changes may increase fatigue for prolonged periods after travel; however, it should be noted that both of these studies occurred during swimming world championships and the Olympic games, respectively, and thus training and work commitments may have added to fatigue from travel. Other shorter-lasting increases in fatigue following travel have also been reported, including in physically trained individuals for 1 (Fowler, Duffield & Vaile 2015) and 2 (Fowler et al. 2015b) days after 24h of simulated westward travel across 10 time zones; in Masters triathletes for 1 day after 22.6h of travel across 4 eastward time zones (Stevens et al. 2018); and professional footballers after 19h of eastward travel across 11 time zones (Fowler et al. 2017b). As such, a short-term increase in fatigue may likely follow long-haul travel, possibly due to the combined influence of sleep loss from the journey and increased initial jet lag after the time zone transition.

Contrasting with the above findings, Kölling et al. (2017) reported general stress, fatigue, lack of energy, physical complaints and emotional exhaustion scores to be improved in junior professional rowers after 11h of travel across 5 time zones. However, the authors suggest these findings may be related to reductions in training load after travel. Additionally, Fullagar et al. (2016) observed stress-recovery and other perceptual measures to be unchanged in professional footballers after an 18h eastward flight across 4 time zones, which may be explained by the relatively small time zone change and the fact athletes had obtained a full night's sleep prior to perceptual measures being taken. In contrast to the negative effects of travel on perceptual fatigue, unchanged perceptual recovery was observed after 11h of travel across 5 time zones (Kölling et al. 2017) and 2.6h of travel across 4 eastward time zones (Stevens et al. 2018), while muscular soreness was unchanged after 24h of simulated travel (Fowler, Duffield & Vaile 2015). Therefore, while these findings suggest that travel will not affect these perceptual scales, further research is needed to support this across a broader range of travel demands.

Research on perceptual responses to short-haul domestic travel appears to suggest that detrimental effects are unlikely. An increase in perceived fatigue and sleepiness was observed on travel days in professional footballers competing in the Australian domestic league (Mean travel duration: 5.3h ± 2.2); however, scores returned to baseline in time for matches on the next day (Fowler, Duffield & Vaile 2014). Likewise, in the same competition, although with slightly shorter travel demands (Mean travel duration: 2.3 ± 1.0), no differences were observed in perceptual wellness measures between the same time points at home and away matches (Fowler et al. 2015c). As such, while domestic travel may temporarily increase fatigue on the day of travel, athletes appear to recover after arriving at the destination; however, this will likely depend on the extent of travel required.

Comparison studies further support poorer perceptual fatigue responses to greater travel demands; however, only extreme long vs short haul comparisons have been made. Greater whole-body fatigue was reported the day after 24h of simulated travel compared to 5h in physically trained individuals. However, as data collection stopped after one day, the length of time fatigue would last after the longer journey is unknown. Similar findings were reported by Thornton et al. (2018), with wheelchair basketball athletes who travelled long-haul (10.7 - 31.0 h) reporting greater mean perceptual fatigue across 5 days compared to those who travelled short-haul (4.5 – 6.5 h); however, day to day values were only different the first day after arrival. Expectedly, these studies show that longer travel demands are likely to induce greater fatigue in athletes the day after travel; however, comparisons are needed across a greater extent of travel demands. Differences in perceptual responses have also been observed between eastward and westward travel. Fowler et al. (2017a) observed reduced perceptual function ratings (representing fatigue, mental performance, and mood ratings) up to 2 days after eastward travel compared to westward in physically trained individuals. Given that the travel durations and time zones crossed were the same between the two directions, such differences may result from jet lag or variations in sleep after arrival. However, this considers the difference in direction for a time zone difference of 8h, and it is unclear how direction will influence perceptual responses at different time zone changes.

Mood and Motivation

In addition to fatigue and perceptual well-being measures, mood states have also been observed to be affected by travel demands. After 23-28h of eastward travel across 8 time zones, Olympic support staff reported increased confusion on days 2 and 3 after travel and increased depression on days 3 and 7 (Rossiter et al. 2022b). Increased confusion in physically trained individuals on the day after travel has also been reported in two separate 24h simulated travel studies (Fowler et al. 2015b; Fowler, Duffield & Vaile 2015), with one of the two studies also observing increased depression scores (Fowler, Duffield & Vaile 2015), and the other observing increased anger scores (Fowler et al. 2015b). Reduced motivation was reported in physically trained individuals for up to 3 days after 21h of eastward travel across 8 time zones, with the return to baseline for motivation also aligning with normalisation of countermovement jump scores (Fowler et al. 2017a). However, studies assessing elite athlete populations have observed motivation to remain unchanged after travel of 9.5h across 2 time zones west (Broatch et al. 2019) and 24h across 8 time zones east (Bullock et al. 2007), while perceived readiness to train was unchanged in elite university footballers after 21h of travel across 7 time zones east

(Biggins et al. 2022). As such, while the negative effects of travel may reduce motivation, such an effect may be less likely in highly motivated elite populations. Overall, the impacts of jet lag, travel fatigue, and sleep loss may negatively affect the mood states of athletes travelling for international competition; however, more research is needed to assess mood responses to travel, particularly across a greater range of travel demands.

2.8 Summary of Literature

Air travel represents a significant challenge for athletes competing in national football teams due to a diverse range of travel demands that are all likely to impact the athlete differently. Large variation exists within the travel demands of players within a national football team (Clements et al. 2023); thus, managing the travel demands of players individually is warranted. The combined effects of jet lag, travel fatigue, and sleep loss due to travel demands are likely to negatively impact the performance, well-being, and recovery of national team athletes. However, the prevalence of each of these conditions will vary based on the specific demands of travel experienced (Janse Van Rensburg et al. 2021). Greater time zone differences and eastward travel directions will likely induce greater and longer-lasting symptoms of jet lag, potentially having further implications for sleep after arrival (Reilly, Waterhouse & Edwards 2009). Longer travel durations and flight schedules that interrupt regular sleep periods are likely to increase the travel fatigue athletes experience and reduce the sleep obtained on travel days (Janse Van Rensburg et al. 2021). As such, understanding the specific effects of different travel variables on measures of performance, wellbeing and recovery, is essential in managing athletes travelling for national teams.

While evidence in the form of match performance outcomes, physical performance measures, sleep quality and quantity, perceptual well-being, and mood pre- and post-travel do suggest that travel may negatively affect athletic performance, the lack of diversity in travel demands assessed within studies makes it difficult to identify travel demands in which performance may be impacted. Currently, existing comparisons support the view that long-haul travel demands are likely to result in greater negative effects on athletes than short-haul; however, such comparisons are generic and do not consider nuanced travel demands. Likewise, comparisons across travel directions have been made, but again, only consider a couple of flight scenarios (Fowler, Duffield & Vaile 2015; Fowler et al. 2017a; Mitchell, Pumpa & Pyne 2017; Thornton et al. 2018). Furthermore, comparisons across other factors, such as the timing of arrival and departure, the amount of time between arrival and matches, or the amount of time between matches and departure, have not been considered within the current body of literature. Overall, there is a lack of detail in the current evidence, making it difficult to inform decisions in national football teams due to the diverse travel schedules that exist.

Chapter 3: Study 1

Travel Across More Time Zones Results in Worse Perceived Fatigue and Sleep in National-Team Footballers

Clements, E., Ehrmann, F., Clark, A., Jones, M., McCall, A. & Duffield, R. 2023, 'Travel Across More Time Zones Results in Worse Perceived Fatigue and Sleep in National-Team Footballers', *International Journal of Sports Physiology & Performance*, vol. 18, no. 3, pp. 268-75.

3.1 Abstract

Purpose: This study investigated the association between (1) time zone difference and (2) travel direction (east vs west) with post-travel changes in perceptual responses of national-team footballers.

Methods: Travel schedules from 355 national-team trips (50 elite soccer players) were verified using an online flight database. All players provided perceptual ratings of fatigue, sleep quality, soreness, and stress to calculate changes in scores up to 2 days after travel. Trips were categorized as <3, 3 to 6, 6 to 9, or 9+ time zone changes, along with travel direction (eastward or westward). The pretravel to post-travel changes in perceptual ratings at days 1 and 2 post-arrival were compared between time zone change and travel direction with linear mixed models.

Results: For every time zone crossed, poorer ratings of perceptual fatigue ($\beta = 0.068$, $P < .001$), sleep ($\beta = 0.095$, $p < .001$), soreness ($\beta = 0.0049$, $p < .001$), and total wellness ($\beta = 0.214$, $p < .001$) were observed. However, the models explained only small proportions of the variation in postflight perceptual responses (7%–18%). Regardless, travel across 9+ time zones resulted in significantly worse perceived fatigue, sleep, and total wellness for days 1 and 2 post-arrival compared with travel with <6 time zones ($p < .05$). Additionally, fatigue, sleep, and total scores were worse on day 2 following trips of 9+ time zones. Eastward travel resulted in poorer sleep ratings ($\beta = 0.52$, $p < .001$) than westward travel within time zone groupings.

Conclusions: Perceptual ratings of fatigue and sleep become progressively worse as travel increases in national-team soccer players, especially after travel across 9+ time zones and eastward travel.

3.2 Introduction

Travel remains a concern for national team footballers (soccer) due to the effects of jet lag and travel fatigue on camp and tournament preparation (McCall et al. 2015). The physiological and psychological stresses associated with prolonged air travel and rapid time zone change can negatively influence fatigue and sleep (Fowler, Duffield & Vaile 2015; Fowler et al. 2017b), potentially resulting in poorer physical and mental performance (Chapman et al. 2012; Fowler et al. 2015b; Fowler et al. 2017a). For a national football team, athletes are located at different clubs around the world, and thus, significant variations in travel requirements exist for any single camp or tournament. As such, when planning for the potential effects of jet lag and travel fatigue, various flight-related factors need to be considered, including the travel distance, duration, time zone change and direction, as these are likely to influence the extent of symptoms (Janse Van Rensburg et al. 2021). However, limited data exists for any measure comparing athletes across a large number of trips with varying distances, directions and time zone changes, let alone in elite football contexts. Hence, it is difficult to determine the specific variation in athlete responses based on the diversity of travel demands and factors (Rossiter, Warrington & Comyns 2022). Physical performance measures or detailed jet lag scales are difficult to obtain when athletes travel for camp or competition, and often only simple perceptual measures (i.e. fatigue, sleep, soreness, stress) exist. Regardless, comparisons between travel durations, directions and time zone changes on athlete perceptual responses are yet to be reported, especially in national team footballers.

The effects of specific travel durations on athlete responses remain ambiguous, though common responses to long-haul include altered sleep and fatigue responses (Rossiter, Warrington & Comyns 2022). Travel durations of >5h caused greater reductions in lower-body power of professional Rugby 7s players compared to travel <5h (Mitchell, Pumpa & Pyne 2017), though the trips >5h actually ranged from 9.5 to >24 hr. Similarly, greater reductions in intermittent sprint performance, sleep duration, mood and perceptual fatigue were observed following 24h of simulated travel compared to 5h in physically-trained individuals (Fowler, Duffield & Vaile 2015). Further, Thornton et al. (2018) observed poorer ratings of jet lag, fatigue and vigour following a 6h time zone change compared to a 1h time zone change in wheelchair basketballers. These studies highlight that longer travel demands are likely to induce more detrimental symptoms of jet lag and/or travel fatigue. However, monitoring athlete responses to national team travel is difficult as often only limited perceptual ratings are available; thus, understanding responses of these measures to different travel demands is important. Furthermore, these studies represent only extreme comparisons of short vs long-haul flights from singular travel bouts and do not provide sufficient detail to differentiate between the full range of travel demands encountered by national football teams. Therefore, further exploration using larger data sets from elite athletes across broader ranges of travel duration, time zone change, and direction are required.

National football teams require travel from clubs located in a range of geographical locations, involving many trips with differing directions and durations. Chronobiological principles suggest that eastward travel will be more disruptive to performance than westward travel (Reilly, Waterhouse & Edwards 2009). In support, worse sleep duration, perceived fatigue, motivation and jet lag existed following eastward travel in sub-elite populations following a 21h flight across 8 time zones compared to an equivalent westward flight (Fowler et al. 2017a). Further, poorer subjective jet lag ratings were reported in Olympic gymnasts following eastward compared to westward travel (Lemmer et al. 2002). However, the number of time zones crossed and the population used differed between these acute travel bouts. While detrimental effects of travel on sleep and recovery have previously been observed in both professional football (Fullagar et al. 2016) and Rugby athletes (Smithies et al. 2021), no comparisons exist between travel directions and comparisons between time zone differences/durations are limited to only a small number of flights. As such, a better understanding of the effects of travel direction, duration, and time zone change on perceptual responses of fatigue, sleep, soreness and stress can assist planning for national team travel schedules.

Given that different players within a national team are often located across a variety of clubs around the world, it is important for national federations to have further insight into the effects of travel demands to inform player recovery and preparation strategies. Therefore, this study investigated the association between i) time zone difference and ii) travel direction (east vs west) on the post-travel changes in perceptual responses of national team footballers.

3.3 Methods:

Subjects

Participants included 62 elite senior male national footballers (soccer) (age 25.6 ± 4.1y) from a national football team inside FIFA's top 50 ranked teams. Players were based across various clubs around the world, including those in Europe, Asia, and Australia. Through individual contracts with the national football federation, participants consented to the use of their anonymous data for research. Consent was obtained from the national football federation for the use of data, whilst Human Ethics approval was provided by the institutional Human Ethics Committee (ETH20-5080).

Design

Data was collated for all trips between March 2018 and November 2021 (n=679 flights). Travel details and perceptual measures were collated and anonymised using numeric codes. Baseline perceptual measures as part of normal team monitoring were obtained the day prior to departure (or 2 days before if unavailable). Post-flight perceptual data was obtained in the morning on days 1 (D1) and 2 (D2) following arrival to calculate the change from pre-flight outcomes each day. In total, 355 trips with relevant pre- and post-flight data were included in the study. Of these 355 trips, 50 players were included with 7.1 (±5.1) trips per player.

Methodology

Using flight bookings obtained from the Federation, details of each trip were verified using an online flight database (Flightera.net). The following details were obtained: arrival and departure locations, arrival time, departure time and flight duration. Based on these details, the total travel duration of the trip was calculated as the total time between aircraft departure and aircraft arrival at the final destination's airport, including the duration of stopovers. Time zone difference was defined as the difference in time zone between departure and arrival locations. Travel direction was labelled as westward or eastward based on the initial departure location and final arrival destination. To allow further comparisons between travel bouts, trips were grouped by travel duration and time zone difference. Prior studies have compared travel bouts of 5h and 24h (Fowler, Duffield & Vaile 2015), <5h and >5h (Mitchell, Pumpa & Pyne 2017), and 1 time zone compared to >6 time zones (Thornton et al. 2018). As such, smaller travel duration and time zone difference groupings were used in this study. Categories of travel duration included <5 h, 5-10 h, 10-15 h, 15-20 h and 20^{+} h. Categories of time zone difference included <3 h, 3-6 h, 6-9 h and 9^{+} h.

Players completed an online perceptual "wellness" questionnaire every morning (09:00 – 10:00) as part of national team commitments. This questionnaire comprised of 4 items requiring players to rate their current perceived fatigue, soreness, stress, and sleep quality. Players answered each question on a seven-point Likert scale with values between 1 and 7 in increments of 1. Each scale included descriptive anchors at scores of 1 and 7, with a midpoint anchor at 4. For the fatigue, soreness, and stress scales, these anchors included "No Fatigue/Soreness/Stress", "Moderate Fatigue/Soreness/Stress", or "Maximal

Fatigue/Soreness/Stress". The sleep scale required players to rate their perceived sleep quality from the previous night with scores of 1 described as "Outstanding Sleep", scores of 4 described as "Average Sleep", and scores of 7 described as "Horrible Sleep". A total score was calculated from the sum of the 4 items. Each score was assigned as day 1 (D1) or day 2 (D2) in relation to their arrival from travel. Players completed the questionnaire through their smartphones via the athlete monitoring system (SMARTABASE, Fusion Sport, Brisbane, Australia). All participants had previously used the questionnaire for regular monitoring and all participants had high familiarity. Whilst it is recognised that a specific jet lag scale may have provided more valid measurements of travel stress, such data collection was unavailable.

The use of single-item perceptual "wellness" measures has been debated recently due to a lack of an underpinning conceptual framework and the absence of validation studies (Jeffries et al. 2020). However, these measures represent a practical tool likely to achieve high compliance due to the low burden on elite athletes. These measures have also been observed to be responsive to acute training load in professional footballers both at the club (Thorpe et al. 2015) and national team level (Noor et al. 2021). However, questions remain in their ability to differentiate between levels of training load (Noor et al. 2021). Further, several studies have observed changes in perceptual sleep and fatigue following travel bouts (Fowler, Duffield & Vaile 2015; Stevens et al. 2018), highlighting the potential for these measures to infer the impact of travel-related stress.

Statistical Analysis

Travel details were collated into a single Excel spreadsheet, and perceptual response scores before and after travel were aligned. All perceptual rating scales were converted into a change score by subtracting the pre-travel score from scores at D1 and D2. For all statistical tests, alpha was set at 0.05 for statistical significance.

To analyse the effects of travel variables on perceptual responses, linear mixed models were built using the 'lme4' package (Bates et al. 2015) in the R statistical software (R Core Team 2021). The presence of multi-collinearity was checked prior to modelling using Pearson's r correlation coefficient. Travel duration was excluded from the model due to a strong correlation with time zone difference ($r=0.84$, $p<0.001$). To account for non-independence between observations, the anonymous player code was included as a random effect. Models were built using a stepwise approach, with each new variable assessed by examining the model's Aikake information criterion (AIC), R^2 values and the significance of the fixed effects. The significance of fixed effects were calculated using an F-test with Satterthwaite degrees of freedom approximation (Kuznetsova, Brockhoff & Christensen 2017). Assumptions of normality and homogeneity of variance were assessed using final model residual QQ-plots and residual plots, respectively. Cooks Distance was calculated to identify influential points, though no points were deemed to have a major effect on the model.

Linear mixed models were also created using time zone difference as a factored variable consisting of groups of <3h, 3-6h, 6-9h and 9^{+}h. While measurement day (D1, D2) was also included as a fixed effect. To control for non-independence of observations, the anonymous player code was included as a random effect. For the total wellness variable, the direction of travel (East or West) was also entered as a fixed effect to assess the influence of travel direction on subjective wellness. Pairwise comparisons were made within each variable (i.e. holding other variables constant) using estimated marginal means calculated by the "emmeans" package in R (Lenth 2021). Normality and homogeneity of variance were again assessed using model residual QQ-plots and residual plots, respectively.

3.4 Results:

Relationships between travel variables and perceptual responses

The stepwise approach used for the linear mixed models and the regression coefficients are shown in Table 3.1. Time zone difference had a significant effect on total wellness ($p<0.001$), fatigue ($p<0.001$), sleep ($p=<0.001$), and soreness ($p<0.001$). The direction of travel had a significant effect on sleep ($p<0.001$) and stress ($p<0.001$). Lastly, the days since arrival had a significant effect on total wellness ($p<0.001$), fatigue ($p<0.001$), sleep ($p<0.001$), and soreness ($p=0.027$).

Total Wellness Grouped Time Zone Difference and Direction

The mean change in total wellness for each time zone group and direction is shown in Figure 3.1. On D1 and D2, the change in total wellness was significantly worse (i.e. increased) after a 9^+ h time zone change compared to both <3h (D1: $p<0.001$; D2: $p<0.001$) and 3-6h (D1: $p=0.005$; D2: $p=0.013$). Total wellness was also significantly worse after a 9^+h time zone change difference compared to 6-9h on D1 only ($p=0.012$). Similarly, a significant increase (worse value) was observed after a 6-9h time zone change compared to <3h on D2 only ($p=0.035$). Total wellness significantly improved between D1 and D2 for time zone changes of <3h ($p=0.001$) and 3-6h ($p=0.042$).

Directional analyses revealed a significantly worse change in total wellness following eastward travel compared to westward on D1 after <3h time zone change ($p=0.006$) and on D2 following a 3-6h time zone change ($p=0.016$). In contrast, total wellness was significantly better on D2 after eastward travel of 6-9h time difference compared to westward travel ($p=0.003$). Significant improvements in total wellness were observed on D2 compared to D1 for westward time zone changes of 3-6h ($p=0.010$) and eastward time zone changes of <3h ($p<0.001$).

Perceptual response Subscales across Grouped Time Zones

The mean change in each perceptual subscale across time zone groups is shown in Figure 3.2. Fatigue scores were significantly worse following 9^+ h time difference on both days when compared to <3 h (D1: p=0.015; D2: p=0.004) and 3-6 h (D1: p=0.022; D2: p=0.004). Fatigue ratings improved from D1 to D2 for time zone changes of <3h (p=0.008), 3-6h (p=0.012), and 6-9h (p=0.007). Sleep ratings were significantly worse after 9^+ h time difference on both D1 and D2 compared to <3h (D1: p<0.001; D2: p<0.001), 3-6 h (D1: p<0.001; D2: p<0.001) and 6-9h (D1: p<0.001; D2 p=0.002). Sleep ratings significantly improved between D1 and D2 for trips of <3h (p=0.001) and 9^+h (p=0.012) time difference. Soreness ratings were significantly worse on both days after 6-9 h time difference compared to <3 h (D1: p=0.038; D2: p=0.007). Stress rating changes were significantly better after 9^+h time difference on D2 compared to 3-6h time difference (p=0.034).

Table 3.1. Model fit for each perceptual wellness scale

Model	AIC	R^2	R^2 Fixed
Total Wellness			
Total ~ (1|Player Code)	3411.6	0.08	
Total ~ Time Difference + (1|Player Code)	3381.9	0.11	0.05
Final Model: Total ~ Time Difference + Day + (1|Player Code)	**3364.2**	**0.13**	**0.07**
Time Difference β = 0.214 p<0.001			
DayD2 β = -1.000 p<0.001			
Total ~ Time Difference + Day + Direction + (1|Player Code)	3364.4	0.14	0.07
Fatigue			
Fatigue ~ (1|player_code)	2112.6	0.07	
Fatigue ~ Time Difference + (1|player_code)	2092.0	0.09	0.03
Final Model: Fatigue ~ Time Difference + Day + (1| Player Code)	**2073.0**	**0.12**	**0.06**
Time Difference β = 0.068 p < 0.001			
DayD2 β = -0.394 p<0.001			
Fatigue ~ Time Difference + Day + Direction + (1| Player Code)	2073.5	0.12	0.06
Sleep			
Sleep ~ (1|player_code)	2422.3	0.09	
Sleep ~ Time Difference + (1|Player Code)	2392.4	0.13	0.05
Sleep ~ Time Difference + Direction + (1|Player Code)	2372.2	0.15	0.07
Final Model: Sleep ~ Time Difference + Direction + Day + (1|Player Code)	**2357.8**	**0.18**	**0.09**
Time Difference β = 0.095 p<0.001			
DirectionEast β = 0.522 p<0.001			
DayD2 β = -0.426 p<0.001			
Soreness			
Soreness ~ (1|Player Code)	1978.1	0.05	
Soreness ~ Time Difference + (1|Player Code)	1966.2	0.07	0.02
Final Model: Soreness ~ Time Difference + Day + (1|Player Code)	**1963.2**	**0.07**	**0.03**
Time Difference β = 0.049 p<0.001			
DayD2 β = -0.176 p=0.027			
Soreness ~ Time Difference + Day + Direction + (1|Player Code)	1963.8	0.08	0.03
Stress			
Stress ~ (1|Player Code)	1190.1	0.06	0
Final Model: Stress ~ Direction + (1|Player Code)	**1166.9**	**0.11**	**0.04**
DirectionEast β = -0.23 p<0.001			
Stress ~ Direction + Day + (1|Player Code)	1168.8	0.11	0.04
Stress ~ Direction + Time Difference + (1|Player Code)	1168.8	0.11	0.04

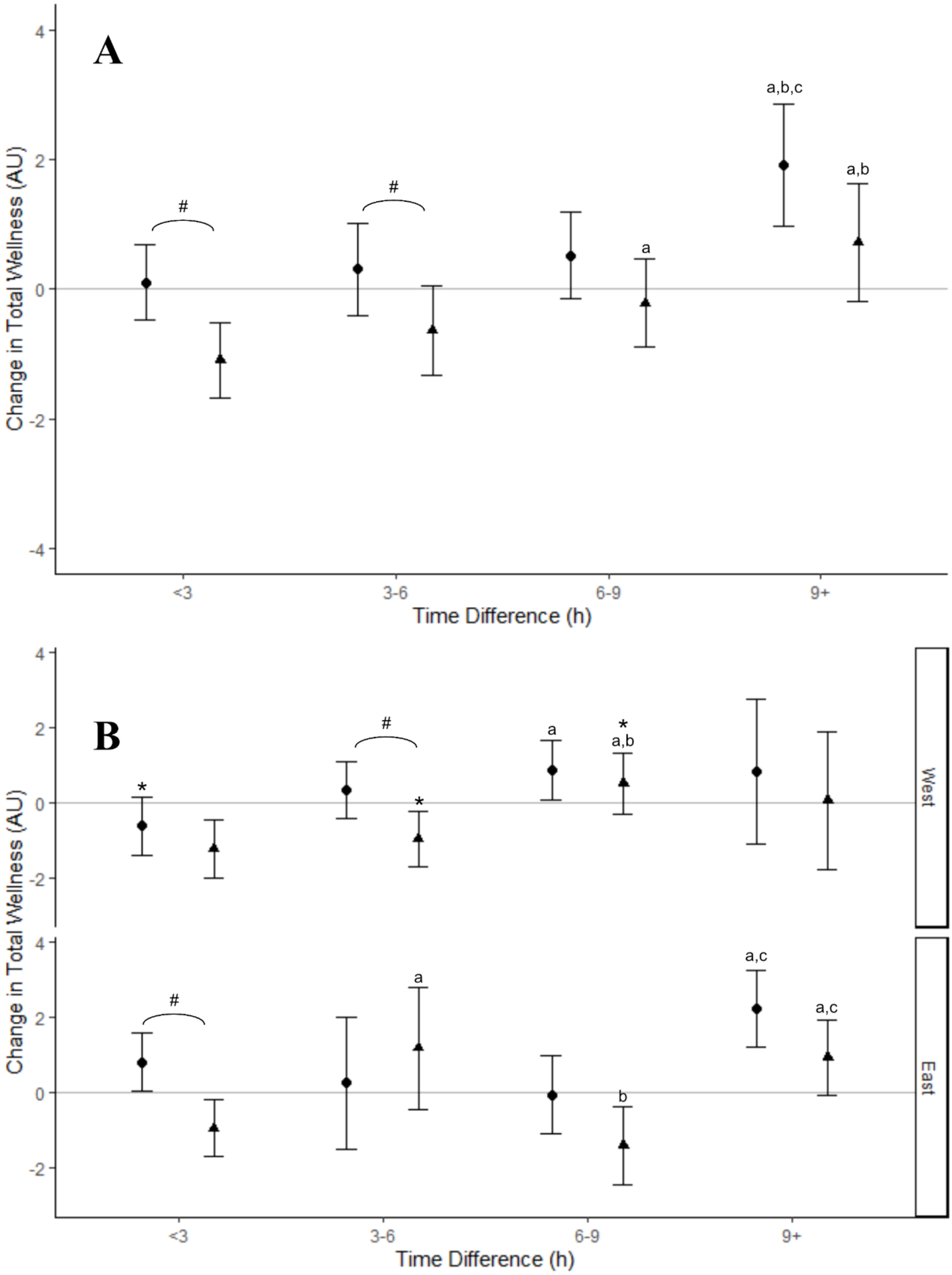


Figure 3.1. Mean ± SD change in total wellness at D1 (circles) and D2 (triangles) post-travel across A) time zone change and B) time zone change and direction. Lower values indicate an improvement in wellness score.

a significantly different to <3 h within the same time point and direction
b significantly different to 3-6h within the same time point and direction
** significantly different to West for the same time difference and time point*
 # significantly different between D1 and D2 time points within time zone

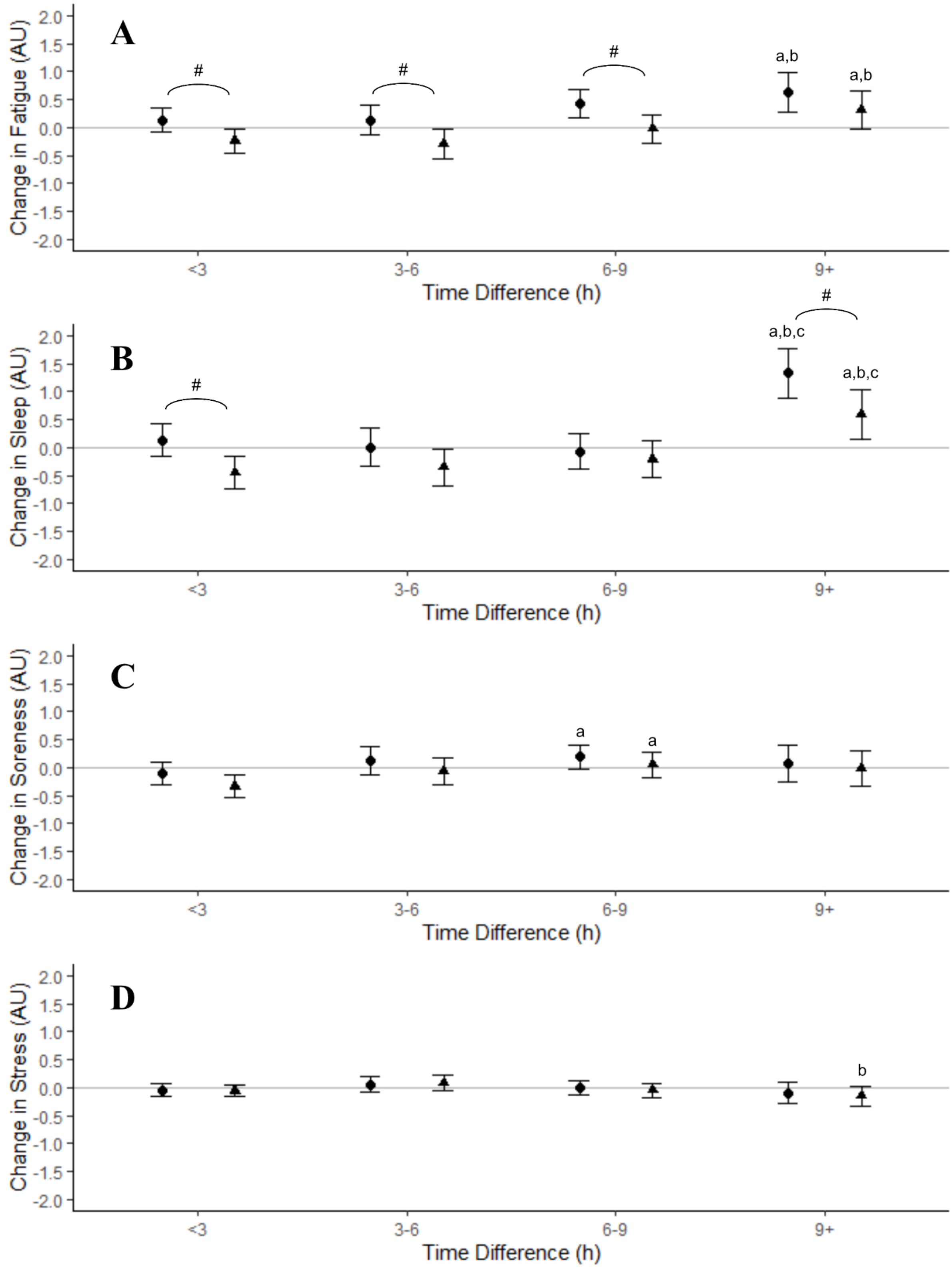


Figure 3.2 Mean ± SD change on D1 (circles) and D2 (triangles) post-travel A) Fatigue, B) Sleep, C) Soreness and D) Stress by time zone change. Lower values indicate an improvement in wellness score.
a significantly different to <3 h within the same time point
b significantly different to 3-6h within the same time point
c significantly different to 6-9h within the same time point
 # significantly different between D1 and D2 within time zone

3.5 Discussion

This study examined the influence of travel direction and time zone change on subjective ratings of fatigue, sleep, soreness and stress in national team footballers. Larger time zone changes resulted in worse perceptual fatigue, sleep, soreness and total wellness scores. Additionally, eastward travel resulted in poorer sleep and improved ratings of stress. Further, fatigue, sleep, and total scores improved on D2 compared to D1, and whilst total scores returned to baseline by D2 on trips of <9h time zones, they remained elevated for trips >9^+ time zones. Importantly, the models explained only a small portion of the variation in post-flight perceptual responses (7 – 18%), indicating that these perceptual scales may not provide a sensitive measure of travel stress in footballers until the time zone change is large. Regardless, if such scales are used by practitioners for travel, poorer fatigue and sleep ratings may be expected for travel bouts across 9^+ time zones, while trips <6 time zones may warrant less concern.

This study reports a change in total (wellness) score of 0.21AU for each time zone crossed in national team players, while trips >9 time zones produced significantly poorer scores than trips across <9 time zones. Our work supports previous observations on poorer wellness scores in professional footballers following a singular trip across 11 time zones (Fowler et al. 2017b), while negligible effects were observed following shorter domestic trips across <2 time zones (Fowler, Duffield & Vaile 2015; Fowler et al. 2015c). It is likely that the impact of the larger time zone change results in increased jet lag and travel fatigue symptoms (Reilly, Waterhouse & Edwards 2009) that manifest in the wellness scales. Further, for trips of 9^+ time zones, total wellness scores remained above baseline on D2, with a longer time required to adjust to the greater time zone change (Reilly, Waterhouse & Edwards 2009). However, minimal (or improved) changes following trips <6 and especially <3 time zones suggest such travel demands may not have substantial implications for the athlete's perceived wellness, perhaps even acting as periods of reduced load (Everett et al. 2020). Travel across 9^+ time zones may require additional support, including scheduled naps, sleep hygiene or circadian realignment interventions (Fowler et al. 2020; Janse Van Rensburg et al. 2020; Petit et al. 2018). Importantly, despite the association between time zone difference and total wellness, only a small amount of wellness variance ($R^2 = 0.07$) was explained by the fixed travel effects. Hence, other influences such as training or match loads (Noor et al. 2021), team selection and match outcomes (Fessi & Moalla 2018) may be co-founders and mask the effects of travel. This highlights the limitations of using subjective wellness scales to infer travel related stress and future use of more specific jet lag and travel fatigue scales are required.

Respective subscales of fatigue and sleep showed the strongest association with worse outcomes for greater time zone changes in national team footballers. However, the regression models for perceived fatigue and sleep still showed low associations ($R^2 = 0.12$ and 0.18). Simulated long-haul travel bouts (>24h) have reported higher fatigue ratings in physically-trained subjects (Fowler, Duffield & Vaile 2015), as well as in wheelchair basketball athletes travelling across 6-11 time zones compared to 1 time zone. In the current study, athletes reported significantly worse changes in fatigue and sleep quality after travel across >9 time zones compared to <9 time zones. Similar to total wellness, fatigue and sleep also remained above baseline on D2 for trips of 9^{+}h time difference, with prolonged sleep loss and fatigue likely symptoms of jet lag (Waterhouse et al. 2000). For time zone changes <9h, fatigue and sleep were largely unchanged, suggesting such trips are unlikely to cause major impairment to player wellness. Negligible effects of time zone difference existed on stress and soreness, which may not be sensitive to travel-related influences. In support, unchanged muscular soreness was observed in physically trained individuals after 24h of simulated travel (Fowler, Duffield & Vaile 2015) and professional Rugby players travelling for 25h across 11 time zones (Fowler et al. 2016). Therefore, practitioners should be aware of current recommendations regarding jet lag/travel fatigue interventions (Janse Van Rensburg et al. 2020) and should consider interventions targeted at improving sleep and reducing fatigue in the first 48h after travel, particularly when athletes are required to travel more than 9 time zones.

Regression models used in this study found the direction of travel to be significantly related to sleep and stress responses. Eastward travel is expected to invoke more detrimental jet lag effects than westward due to the body's circadian rhythms taking longer to advance than delay (Reilly, Waterhouse & Edwards 2009). While no effect of travel direction was found on overall wellness or fatigue scores, travelling eastward resulted in a 0.522 AU increase in worse perceived sleep quality. Eastward travel is expected to delay getting to sleep as arousal is likely high at night-time in the new environment based on the circadian phase (Forbes-Robertson et al. 2012). Similar findings have been observed in a physically trained population, with later sleep onset and reduced mean time in bed and sleep duration observed following eastward travel compared to westward (Fowler et al. 2017a). The lack of direction effect on fatigue and total wellness measures may be due to the lack of specificity of these measures to travel-related stress. It is possible that any effect of direction was masked by other factors, such as training load (Noor et al. 2021), and thus jet-lag-specific scales may be more appropriate. For athletes travelling eastward, sleep-promoting interventions in the first 48h after travel are recommended. Future research should seek to expand on these findings by analysing more objective sleep measurements before and after travel bouts.

Whilst recognising the novelty of the current findings, certain limitations are also acknowledged when interpreting the results. Although data was collected in a systematic manner by national team staff, there was no control over what athletes did before, during or after travel, i.e. training, matches or travel interventions. Further, perceptual wellness measures are likely influenced by other external factors and may not represent a true measure of travel stress; hence, a specific jet lag or travel fatigue scale may provide a more valid measurement. While perceptual measures may provide some insight into an athlete's response the stress associated with air travel, the lack of physical performance measures means no inferences can be made relating to athlete performance. Additionally, using only a single value as the baseline measure should also be recognised as a potential limitation as external factors were not controlled and thus may have influence on the baseline score. Lastly, perceptual wellness measures were only obtained at a single time point each day, and hence, alterations in scores may have been reported if taken at other times throughout the day (Waterhouse et al. 2000).

3.6 Practical Applications

- In professional footballers, ratings of perceptual fatigue and sleep appear more responsive to travel stress than other perceptual wellness ratings.
- Interventions to promote sleep and reduce fatigue may be especially important for footballers travelling across 9 or more time zones.
- Footballers travelling eastward are likely to experience poorer perceived sleep, and thus, additional focus on sleep-promoting interventions is required.

3.7 Conclusion

Perceptual ratings of fatigue, sleep and soreness from national team footballers in the first 48h after travel are worse when required to travel across a greater number of time zones. Particularly, travel across 9 or more time zones is likely to have greater and longer-lasting effects on an athlete's sleep and fatigue ratings than travel across <6 time zones. Poorer perceived sleep was also observed when players were required to travel eastward. Therefore, focusing on interventions to maintain sleep and potentially hasten the adaptation to the new time zones is especially important. This study highlights the greatest concern for national team footballers should be with athletes travelling across 9 or more time zones in an eastward direction.

Chapter 4: Study 2

Flight Path and Scheduling Effects on Perceived Jet Lag, Fatigue, and Sleep in Footballers Traveling to and From National Teams

Clements, E., Ehrmann, F., Clark, A., Jones, M., McCall, A. & Duffield, R. 2023, 'Flight Path and Scheduling Effects on Perceived Jet Lag, Fatigue, and Sleep in Footballers Traveling to and From National Teams', *International Journal of Sports Physiology & Performance*, vol. 18, no. 10, pp. 1132-40.

4.1 Abstract:

Purpose: This study examined post-travel perceptual responses of national team footballers (soccer) following different travel routes, arrival/departure times and trip contexts.

Methods: Details of 396 flights from national team players (n=68) were obtained and verified via an online flight database. Each player provided ratings of perceptual fatigue, sleep, soreness, stress, and jet lag for two days before and after each trip. The travel route (continents of departure and arrival), travel context (into vs out of national team), and arrival and departure time were obtained for each trip. Linear mixed models compared the pre- to post-travel change in perceptual responses based on travel route, context and schedule.

Results: Perceived jet lag ratings were more responsive to travel variables ($R^2=0.48$) than other perceptual ratings ($R^2<0.26$). Travel from Asia to Europe ($p<0.05$) and Europe to Australia ($p<0.001$) had significantly higher jet lag ratings than all other routes. Fatigue scores were worst following Asia to Europe ($p<0.05$) and Europe to Australia ($p<0.05$) travel, while sleep scores were worst following Europe to Australia ($p<0.01$). Perceptual responses were poorer following travel from national team to club compared to all other travel contexts ($p<0.05$). Arrival around lunch (11:00-17:00) resulted in better perceptual responses than early morning or late-night arrivals ($p<0.05$).

Conclusions: Perceived jet lag ratings are more responsive to travel demands than perceptual wellness scales in national football athletes. Poorer perceptual responses may be expected when travel is longer in nature, arrives later in the day or involves travel out of the national team back to club.

4.2 Introduction:

National football (soccer) teams often require athletes to undertake extensive travel from different club locations into a single competition or camp location. The diversity of travel for athletes spread around the world results in a range of travel-induced states on arrival into each camp (Janse Van Rensburg et al. 2021). Factors that influence this post-travel state, such as jet lag, travel fatigue or sleep disruption, are dependent on the travel duration, time zone change and direction, which vary based on individual travel schedules (Clements et al. 2023; Janse Van Rensburg et al. 2021). Hence, practitioners need to consider the effects of these schedules on athlete arrival into the national team and return to club. Further, the travel route, arrival and departure time, and whether the trip was into or from the national team are all likely to influence the athlete's response to the journey (Janse Van Rensburg et al. 2021). Whilst travel research uses extensive jet lag questionnaires and physiological or performance measures (Rossiter, Warrington & Comyns 2022), these are logistically impossible in national team contexts, where player monitoring is commonly limited to perceptual questionnaires relating to fatigue, sleep, soreness and stress (McCall et al. 2015). Despite concerns about the validity of these "wellness" scales (Jeffries et al. 2020), they capture elements of symptoms reported in jet lag and travel fatigue (Janse Van Rensburg et al. 2021), though few studies assess their responsiveness to different travel demands. Given the pervasive use of these scales in football teams, understanding their responses to travel across different routes, schedules, and contexts can inform athlete monitoring of travel for national football teams.

For many non-European national teams, travel often follows particular patterns, whereby players located in a range of countries will travel routes based on club and competition locations (Clements et al. 2023). Prior research has identified a detrimental effect of time zone change and direction of travel on jet lag/travel fatigue symptoms following arrival in the club or national team (Fowler, Duffield & Vaile 2015; Fowler et al. 2017a). However, travel schedules for national teams are often determined at the last minute, and as such, practitioners are often left with only knowledge of the continent an athlete is travelling to and from. While current travel studies have explored fatigue, jet lag and sleep responses in footballers following trips between Australia, Asia, Europe, South America and North America (Bullock et al. 2007; Fowler et al. 2015a; Fowler et al. 2017b; Fowler et al. 2016; Fullagar et al. 2016; Kölling et al. 2017; Lastella, Roach & Sargent 2019; Stevens et al. 2018), such studies only explore singular trips and deeper understanding of responses to common travel routes is missing. Given the variation in populations and methodologies between studies, drawing comparisons on the effects of different travel routes on fatigue, sleep, and jet lag responses is difficult (Fowler, Duffield & Vaile 2015; Kölling et al. 2017; Kraemer et al. 2016; Stevens et al. 2018). As players involved in any single national football team camp are required to travel from various locations, understanding travel responses to common routes can aid travel management strategies. Furthermore, the effects of the route may also be influenced by whether it involves travelling into or out of the national team (McCall et al. 2015). While poorer countermovement jump, jet lag and fatigue were reported after both outbound and return travel responses from a 6h flight, no comparisons were made between the two trip contexts, and only a single short-duration trip was reported (Kraemer et al. 2016). Larger data sets on longer travel are missing to inform national team footballers undertaking both outbound and return travel to clubs.

Further concerns for national team players include the departure/arrival time and how these factors may influence sleep and fatigue in the days following arrival. Arrival closer to sleep periods has previously been related to reduced jet lag and fatigue ratings in elite athletes (Waterhouse et al. 2002). However, these results consider only a single trip and do not cover the diversity of travel schedules experienced by national team footballers. Broader comparisons are needed across the range of arrival and departure times experienced by national team footballers. Accordingly, for a national football federation, understanding how travel route, context, and schedule influence player responses to travel will allow staff to better plan for athlete arrival/departure. This study aims to compare post-travel perceptual jet lag, fatigue, sleep, soreness, and stress ratings between different travel routes, schedules, and trip contexts.

4.3 Methods

Participants

Participants included 68 professional footballers (soccer) from a senior men's national team who were part of travelling squads between March 2018 and July 2022. Consent to use the data anonymously was obtained from the national football federation. All athletes provided consent for the collection and use of their data anonymously via national team contracts. Ethical approval was obtained from the institutional Human Ethics Committee (ETH20-5080).

Overview

The details of 796 flights were obtained and aligned with pre- and post-travel perceptual responses. Overall, 396 flights included pre- and post-travel perceptual scales, and 223 flights included perceived jet lag ratings. Perceptual ratings of fatigue, sleep, soreness, and stress (collectedly termed 'wellness') were obtained for two days prior to travel and up to three days after travel. Perceived jet lag ratings were obtained on the first three days after arrival from travel. All measures were obtained as part of national team monitoring procedures, with players required to complete a daily perceptual questionnaire via the organisation's athlete monitoring software on the athlete's smartphone. All players had previously used the questionnaire extensively. Trips were excluded if they did not include at least one pre- and all post-travel perceptual monitoring responses.

Travel Details

Travel details for each trip were obtained from booked travel schedules, with the arrival and departure times for each trip then verified using an online flight database (Flightera.com). Trips were classified based on 1) route, 2) context (into or out of national team), and 3) arrival and departure time. The travel route was classified based on the departure continent and arrival continent, based on the geographical location of the airport (not including land-based travel). Accordingly, the following categories were derived: I) Asia to Asia, II) Asia to Australia, III) Asia to Europe, IV) Australia to Asia, V) Europe to Asia, and VI) Europe to Australia. The arrival and departure times of each trip were grouped into categories of Morning (05:00-11:00), Lunch (11:00-17:00), Evening (17:00-23:00) and Night (23:00-05:00). Each trip was also categorised based on context with trips either being outbound (travelling into the national team), transition (travelling between national team matches/training camps), or return (travelling out of the national team). A player's age and number of national team appearances at the time of travel were also obtained from the federation databases and included in the analysis.

Perceptual Response Scales

Players completed a perceptual questionnaire every morning from two days before travelling to the national team through to three days after they left the national team. In this questionnaire, players provided subjective ratings of fatigue, sleep, soreness, and stress via a seven-point Likert scale. Descriptive anchors were included at scores of one, four and seven, with scores of 1 labelled as having “No” fatigue, soreness or stress and “Outstanding” sleep. Scores of 4 were labelled as “Moderate” fatigue, soreness or stress and “Average” sleep. Scores of 7 were labelled with “Maximal” fatigue, “Extreme” soreness, “Worst Possible” stress or “Horrible” sleep. The sum of all 4 scales for each day was also included in the analysis as a “Total

Wellness" score. For each trip, raw scores were converted into a change score by subtracting the latest score obtained prior to departure from the score on each day (Day 1 and Day 2 post-arrival).

These perceptual monitoring scales are frequently used in football teams to monitor responses to training, especially given the lack of available objective data for many national teams (McCall et al. 2015). Although these scales have been suggested to lack a conceptual framework (Jeffries et al. 2020), prior studies observed their responsiveness to training stress in both national (Noor et al. 2021) and club football teams (Thorpe et al. 2015). However, the limitations of these scales should be considered when interpreting results as travel may account for only a small proportion of variation in scores – which further necessitates the current study. Despite this, these scales represent a practical and frequently used tool in national teams to monitor athletes and can potentially aid in understanding travel responses in national teams (McCall et al. 2015).

Perceived Jet Lag Rating

Athletes completed a perceived jet lag rating every day for three days after travel. A modified version of the single-item jet lag rating from the Liverpool John Moore's University Jet Lag questionnaire (LJMJLQ) (Waterhouse et al. 2000) was used. Athletes were asked, "Do you have any jet lag or fatigue from your travel?" and answered on a 10-point rating scale with scores of 0 labelled as "None at all" and scores of 10 labelled as "Extreme". While jet lag is a bio-psychological and chronobiological concept, the LJMJLQ attempts to measure this perceptually, and the decision to include "travel fatigue" in this study was due to the inability to distinguish between symptoms of the two conditions. As such, this scale aimed to be a more specific measure of travel response compared to the aforementioned perceptual scales. For each trip, perceived jet lag ratings were obtained as a raw value and labelled by the day they were collected relative to arrival (i.e. +1, +2, +3).

Statistical Analysis

Travel details and perceptual monitoring scales were collated into a single excel spreadsheet and imported into R studio (R Core Team 2021). Perceptual monitoring scores for each day were labelled as Day 1 (D1), Day 2 (D2) or Day 3 (D3 – Perceived jet lag only) based on when the score was provided relative to arrival. Each outcome was aligned with the details of the prior travel. For all statistical tests, statistical significance was set at 0.05.

To analyse the influence of travel factors on the perceptual response to travel, linear mixed models were built for each outcome using the lme4 package (Bates et al. 2015). A numerical player identifier was included as a random effect within the model to account for the non-independence of outcomes. Models were built using a stepwise approach with the inclusion of fixed effects determined by statistical significance as measured by an F-test with Satterthwaite degrees of freedom approximation (Kuznetsova, Brockhoff & Christensen 2017). The model's Aikake Information Criterion and R^2 values were used to determine the overall fit of the model at each step. Once the final model had been built, assumptions of normality and homogeneity of variance were checked using QQ-plots and residual plots. Post-hoc pairwise comparisons between categorical variables were performed via estimated marginal means (Lenth 2021). Given the absence of significant interactions between variables, the mean value for each category was averaged out over levels of other variables.

4.4 Results

Model Details

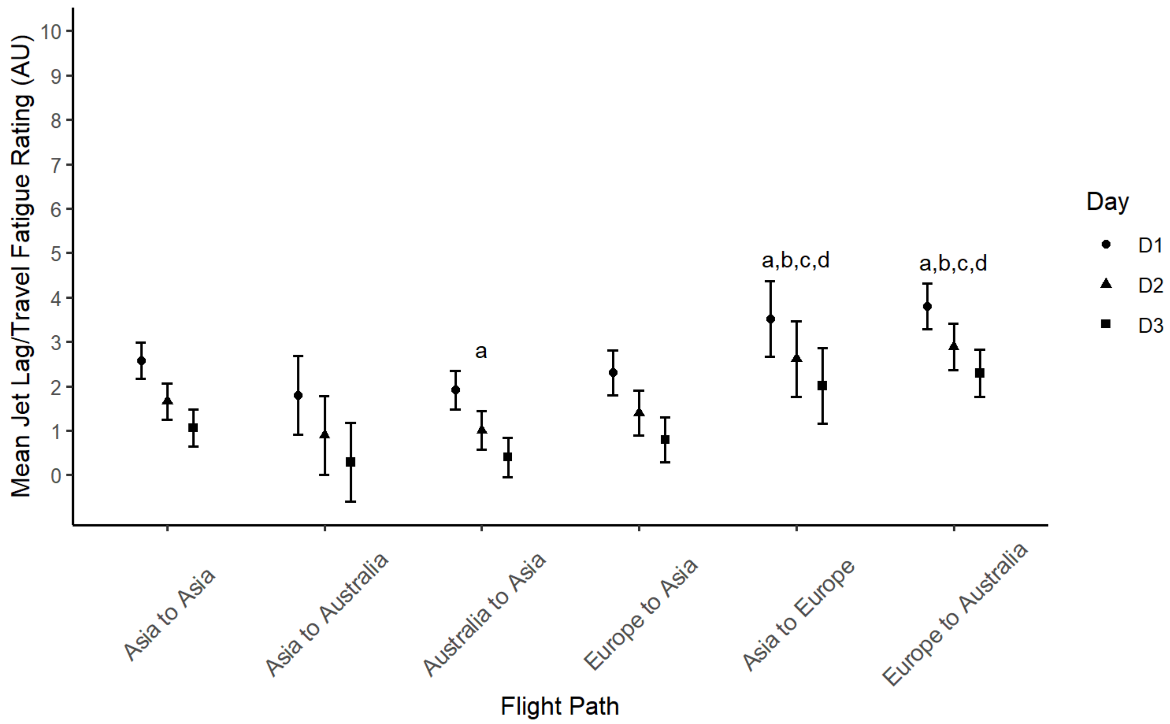
Details of the final models for each outcome variable are provided in Table 4.1. Based on R^2 values, perceived jet lag scores were most sensitive to the travel route, context, and arrival time (R^2 = 0.48). Conversely, perceptual "wellness" scales showed lower sensitivity (R^2 = 0.15 to 0.26), with fatigue showing the highest association with analysed travel variables.

Perceived Jet Lag

Travel routes from Asia to Europe (p=0.002 to 0.047) and Europe to Australia (p<0.001) produced significantly higher jet lag ratings than all other routes (Figure 4.1A). Travel from Australia to Asia resulted in lower perceived jet lag ratings than travel within Asia (p<0.001). Figure 4.1B shows that perceived jet lag was significantly higher following travel between national team matches compared to travel into the national team (p<0.001); however, no other differences were observed between trip types. Player age had a positive relationship with jet lag scores, with an increase in one unit (year) resulting in a 0.185 increase in perceived jet lag score (p<0.001). In contrast, for each national team appearance, a player's perceived jet lag score decreased by 0.023 (p=0.008).

Table 4.1. Final models detailing the relationship between travel scheduling factors and perceptual measures

Model	AIC	R^2	R^2 Fixed
Total Wellness ~ Flight Path + Day + Trip Type + Arrival Time + (1|Player Code)	3445.41	0.23	0.17
Fatigue ~ Flight Path + Day + Trip Type + Arrival Time + (1|Player Code)	2038.65	0.26	0.21
Sleep ~ Flight Path + Day + Arrival Time + Trip Type + (1|Player Code)	2426.79	0.22	0.13
Soreness ~ Flight Path + Arrival Time + Trip Type + Day + (1|Player Code)	1963.19	0.16	0.13
Stress ~ Flight Path + Departure Time + Arrival Time + Trip Type + (1|Player Code)	1193.08	0.15	0.07
Perceived Jet Lag ~ Day + Flight Path + Trip Type + Player Age + National Team Caps + (1|Player Code)	2380.37	0.48	0.31



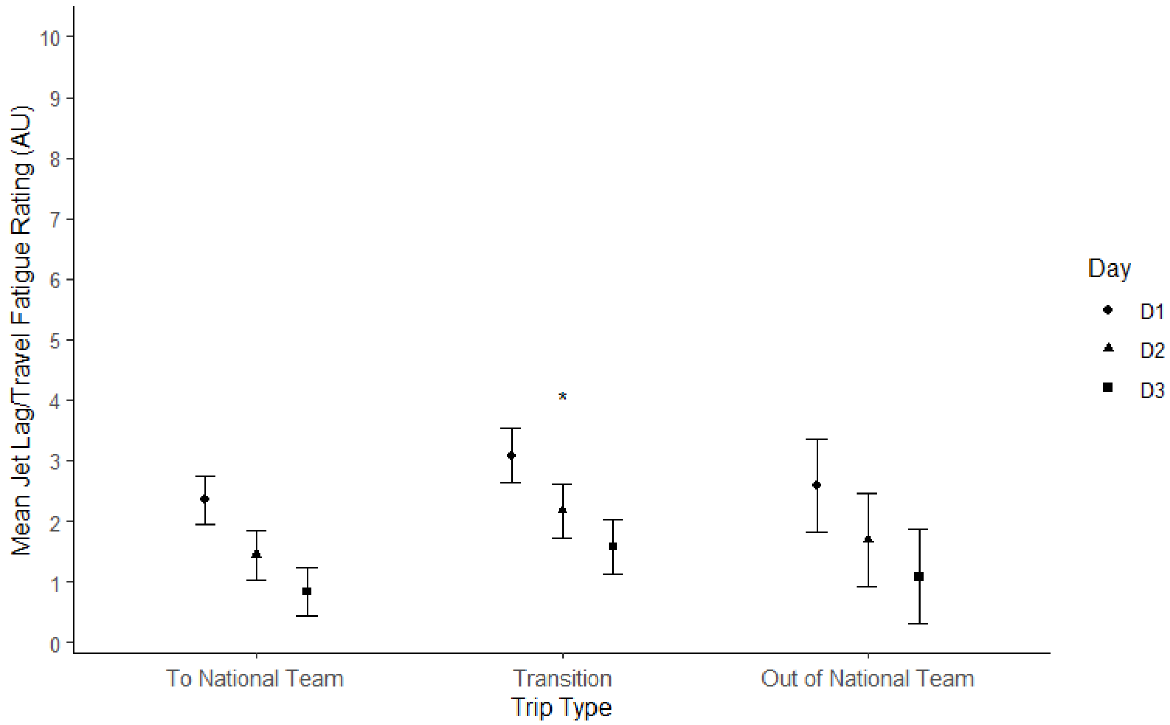


Figure 4.1. Mean change in perceptual perceived jet lag score by flight path and trip type (averaged out over day, player age and national team caps).

a – significantly different to Asia to Asia
b - significantly different to Asia to Australia
c - significantly different to Australia to Asia
d - significantly different to Europe to Asia
** - significantly different to travel To National Team*

Effects of Travel Route on Perceptual Wellness Scales

Travel route had a significant effect on all perceptual scales (Total wellness $p=0.005$; Fatigue $p<0.001$; Sleep $p<0.001$; Soreness $p=0.013$; Stress $p=0.036$). Pairwise comparisons between each route are shown in Figure 4.2. Europe to Australia travel resulted in poorer wellness compared to all other routes except Asia to Europe ($p<0.01$). Similarly, for fatigue ratings, Europe to Australia had significantly poorer scores than Asia to Asia, Australia to Asia and Europe to Asia ($p=0.004$ to 0.043). Asia to Europe travel resulted in poorer fatigue scores compared to Asia to Asia and Australia and Europe ($p=0.003$ to 0.047). Travel from Australia to Asia also caused poorer fatigue scores than travel from Asia to Asia ($p=0.013$). Poorer perceptual sleep ratings were observed after Europe to Australia compared to all other routes ($p<0.01$). Significantly worse changes in soreness scores were observed after both Europe to Australia and Asia to Europe travel compared to Asia to Asia ($p=0.068$; $p=0.045$) and Asia to Australia ($p=0.041$; $p=0.006$). Lastly, lower stress ratings occurred after travel from Europe to Asia compared to Asia to Australia ($p=0.014$), Asia to Europe ($p=0.004$) and Australia to Asia ($p=0.020$).

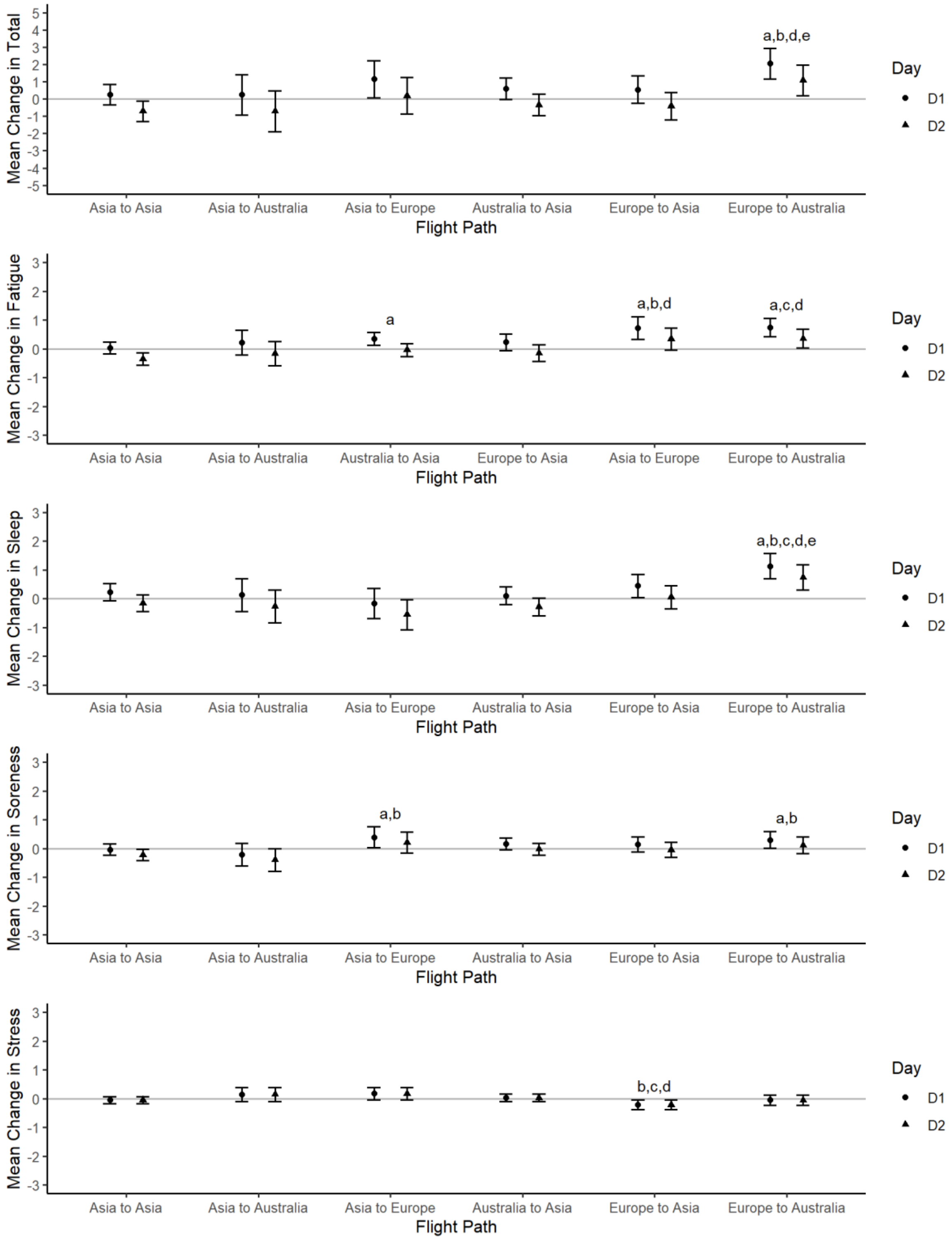


Figure 4.2. Mean change in perceptual wellness scores by flight path (values are averaged out over levels of other variables).

a – significantly different to Asia to Asia
b - significantly different to Asia to Australia
c - significantly different to Australia to Asia
d - significantly different to Europe to Asia
e - significantly different to Asia to Europe

Effects of Trip Type on Perceptual Wellness Scales

Figure 4.3 shows poorer scores were observed following travel out of the national team compared to travel into the national team and transition travel for total wellness (Into $p<0.001$; Transition $p<0.001$), fatigue (Into $p=0.002$; Transition $p<0.001$), sleep (Into $p=0.024$; Transition $p<0.001$), and soreness (Into $p=0.003$; Transition $p=0.004$). For stress ratings, poorer scores were observed after transition travel compared to travel into national team ($p=0.008$).

Effects of Arrival Time on Perceptual Wellness Scales

Compared to morning arrivals, lunch arrivals were associated with significantly better total wellness ($p<0.001$), fatigue ($p=0.006$), sleep ($p=0.050$), and soreness scores ($p<0.001$). Lunch arrivals also resulted in better total wellness ($p=0.008$) and soreness ($p=0.020$) compared to night arrivals. Similarly, evening arrivals resulted in better total wellness ($p=0.029$), fatigue ($p=0.013$) and soreness ($p<0.001$) scores compared to morning arrivals. However, compared to lunch arrivals, evening arrivals had poorer total wellness ($p=0.005$) and sleep scores ($p=0.002$). Lastly, stress scores were the worst after night arrivals compared to all other arrival times (Morning $p=0.008$; Lunch $p=0.003$; Evening $p=0.005$).

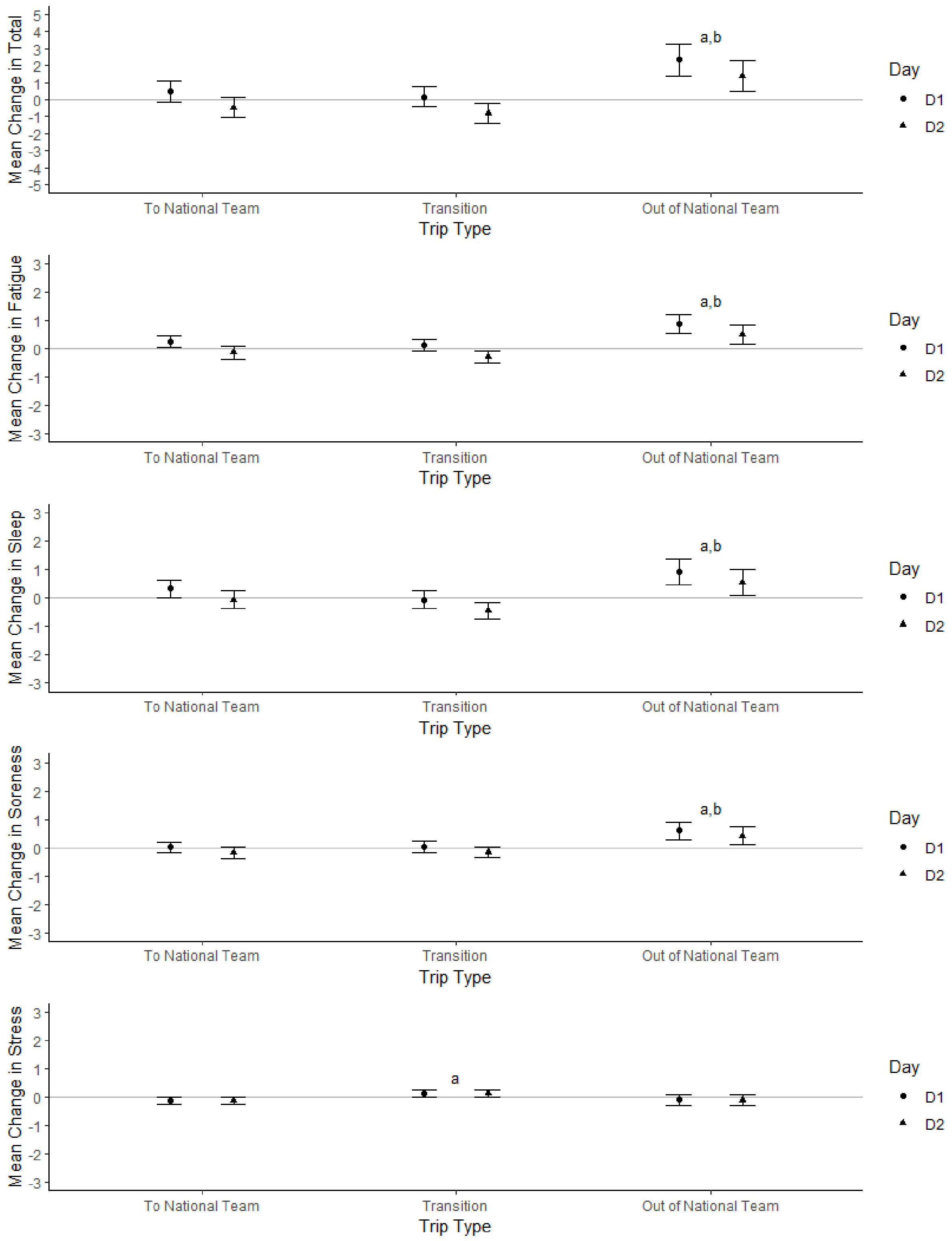


Figure 4.3. Mean change in perceptual wellness scores by trip type (values are averaged out over levels of other variables).
a – significantly different to travel To National team
b - significantly different to Transition

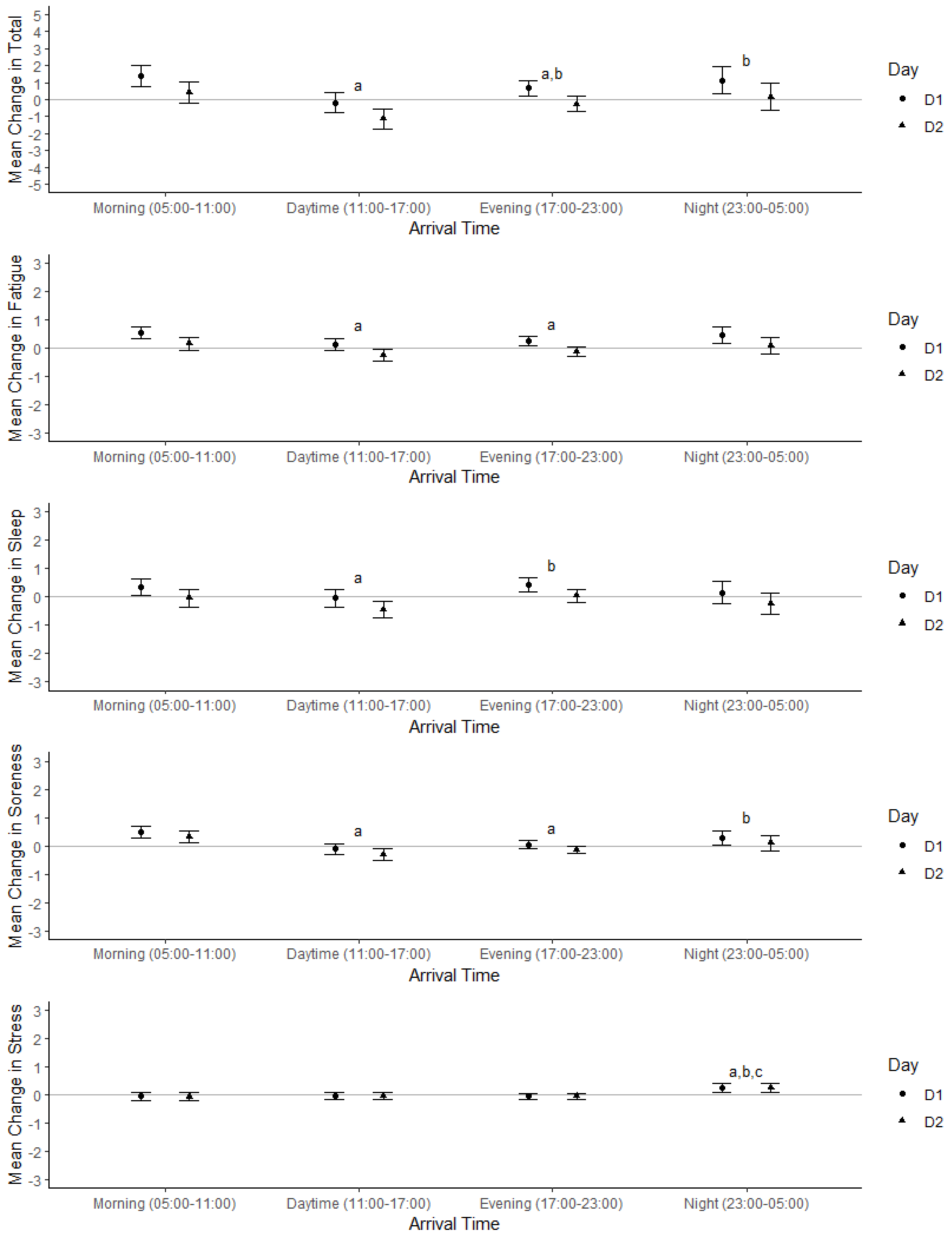


Figure 4.4. Mean change in perceptual wellness scores by Arrival Time (values are averaged out over levels of other variables).

a – significantly different to travel Morning
b - significantly different to travel Daytime
c - significantly different to travel Evening

4.5 Discussion

The current study identified travel-induced perceptual responses of jet lag, fatigue, sleep, soreness and stress from elite national team footballers based on travel routes, arrival/departure times, and trip contexts. Travel from Europe to Australia or Asia to Europe had the greatest impact on athlete perceptual responses. Travel responses were worse when returning to clubs than into or between national team matches. Arrival during the day (between 11:00-17:00) resulted in better perceptual responses. Whilst athlete ratings of fatigue, sleep, soreness, and stress are responsive to certain travel demands, a subjective jet lag scale represents a more responsive tool to monitor travel responses.

Importantly, this study showed that a perceptual jet lag rating has a better association with variations in travel demands than perceptual wellness measures. Although the full LJMUJLQ scale (Waterhouse et al. 2002) represents a more validated tool to monitor travel responses, this study highlighted a simplified version could be a practical and informative tool for national football teams. As expected, jet lag was worst following trips from Europe to Australia (Figure 1), representing eastward travel with the largest time zone change (Janse Van Rensburg et al. 2021). Prior studies show support, with detrimental jet lag symptoms following longer travel demands and eastward travel (Fowler, Duffield & Vaile 2015; Fowler et al. 2017a; Thornton et al. 2018). Interestingly, elevated jet lag was also observed following travel from Asia to Europe. As this route was common for athletes returning to their clubs, it is possible that accumulated travel fatigue from multiple long-haul flights in a short time may explain this (Samuels 2012), though further research is needed. A limitation of these comparisons, however, was that due to match scheduling and COVID-related venue changes, insufficient data existed from Australia to Europe trips, and thus, such trips were not included. Regardless, support in the form of jet lag mitigation strategies (Janse Van Rensburg et al. 2020) is recommended for athletes travelling from Europe to Australia or returning to Europe from Asia. Of note, elevated jet lag ratings were evident in older athletes and lower jet lag ratings in more experienced athletes. Prior studies have observed detrimental effects of age on jet lag symptoms (Fowler et al. 2017b; Moline et al. 1992); however, such findings are not consistent, with studies reporting positive (Waterhouse et al. 2002) or no effects of age (Becker, Penzel & Fietze 2015; Fowler et al. 2015a). The protective effect of experience has been previously observed amongst travelling footballers (Fowler et al. 2015a; Fowler et al. 2017b), and the development of travel management strategies is recommended for inexperienced players.

Although jet lag ratings likely provide a better indication of travel stress, perceptual wellness scales commonly collected in football teams showed some, albeit low, responsiveness to different travel bouts. Total wellness, fatigue, and sleep scores were worst following travel from Europe to Australia. As fatigue and impaired sleep are common symptoms of jet lag/travel fatigue (Janse Van Rensburg et al. 2021), these elevated ratings are likely explained by the large time zone change and eastward direction of travel. Prior research assessing Europe to Oceania travel observed no changes in objective sleep measures in professional Rugby 7s athletes in the 6 days following arrival (Leduc et al. 2021). The contrasting findings may relate to differences in the sensitivity of objective versus subjective sleep measures; alongside the authors suggesting travel management strategies implemented by the Rugby 7s athletes prevented sleep deficits (Leduc et al. 2021). All other routes included in this study appeared to have limited impact on perceptual responses; thus, priority should be with players undertaking travel from Europe to Australia and on return to Europe from Asia.

Regardless of travel route, athletes reported poorer perceptual fatigue, sleep, soreness, and total wellness scores after travel from the national team back to their club, which is a novel finding that has not been reported previously in national team athletes. Elevated jet lag and fatigue scores have been observed following the return journey of a round-trip domestic American travel schedule; however, comparisons were not reported between outbound and return travel

(Kraemer et al. 2016). As such, this study highlights that athletes may have additional difficulty in recovering from travel back to clubs following national team duties. The elevated ratings following return travel could be explained by the effects of prior training/match load from the national team duties (Noor et al. 2021). While data was not available for this study, it is likely that variations in physical load prior to travel will influence an athlete's wellbeing state (Noor et al. 2021) and, therefore, may interact with post-travel perceptual responses. Further exploration is necessary to examine the interaction between prior match load and travel demands on athlete recovery. Also of concern are the short timeframes between national team and club matches and the frequent need to travel almost immediately following matches. Such requirements may restrict opportunities for rest and recovery interventions following matches and future research should, therefore, explore how the time between match completion and travel departure influences post-match travel responses. Accumulated travel fatigue from the short-term congested travel schedules (i.e. national team athletes are often required to undertake up to 3 long-haul flights in space of two weeks) may also partially explain the poorer responses to return travel (Samuels 2012). However, given the lack of studies assessing responses of athletes to multiple long-haul trips in a short-time frame, this remains speculative. Regardless, this study highlights a need for travel and recovery interventions for athletes returning to their club following national duties.

An athlete's time of arrival should also be considered when travelling into and out of national teams. On the day after arrival, better fatigue and sleep ratings were evident when arriving around lunch (11:00-17:00) compared to the morning or evening. These findings are similar to those of Waterhouse et al. (2002), who reported better jet lag and fatigue scores in athletes and support staff arriving in the late afternoon compared to early morning following travel from Europe to Australia. Those authors suggested the longer period of wakefulness for the morning arrival group may have induced greater fatigue ratings (Waterhouse et al. 2002). The findings of the current study may also be explained by the additional time available for athletes to arrive at their hotel prior to attempting sleep, thus reducing the interruption of the sleep period on the night of arrival. Where logistically possible, travel schedules arriving during the middle of the day to later afternoon are recommended; however, this may not be feasible and ensuring athletes are provided with adequate sleep on the night of arrival is important.

While the findings of this study provide useful insight into monitoring travel in national football teams, several limitations need to be considered. Although data collection for this study occurred in an ecologically valid national team environment, limited control existed across what the athletes did before, during or after travel. Given that the perceptual scales used are likely influenced by other external factors (evidenced by low R2 values), caution should be taken when applying the study findings. The pre-travel baseline used for comparisons represents the measure from a single day and, as such, may be more susceptible to external influences. Lastly, perceptual jet lag ratings were obtained at a single time point during the day, and variations in scores may be expected if the ratings were performed at other points throughout the day (Waterhouse et al. 2000).

4.6 Practical Applications

- In national team footballers, subjective jet lag ratings are more responsive to variations in travel demands than perceptual wellness scales.
- Europe to Australia or Asia to Europe travel reduced perceptual ratings for this national team, and thus, additional travel management strategies may be required.
- Additional support for national team footballers may be required when travelling back to clubs following national team camps or when arriving later in the day.

4.7 Conclusions

This study has identified several trip-related factors that are likely to cause poorer perceptual responses to travel in national team footballers. Europe to Australia or Asia to Europe travel appears to be the most challenging for athletes from this national federation, and thus, additional support may be required for these trips. Return travel after a national team camp produced poorer ratings of fatigue, sleep, and soreness, and thus, further support may be required when returning athletes to clubs. Lunchtime arrivals (11:00-17:00) were the least detrimental to sleep and fatigue ratings, and where possible, trips should be scheduled to arrive during the day. Overall, the specific conditions of the trip should be considered, and travel management strategies should be individualised when planning for the transport of players in and out of national team camps.

Chapter 5: Study 3

Effects of Pre-Match Travel and Training on Physical and Technical Performance in International Football Matches.

Clements, E., Ehrmann, F., Clark, A., Jones, M., McCall, A. & Duffield, R. 2024, ' Effects of pre-match travel and training on physical and technical performance in international football matches.', *International Journal of Sports Physiology & Performance*, vol. 20, no. 1, pp.73-79.

5.1 Abstract:

Purpose: This study examined the relationship of pre-match travel and in-camp training on ensuing physical and technical match performance of footballers (soccer) competing for a national team.

Methods: Match-running and technical performance data were obtained from 68 national team footballers competing in international matches (n=108). Match performance data were aligned with confirmed travel durations, time zone change, travel direction, and the time between arrival and kick-off for the travel into the match. Additionally, in-camp training load from the 3 days prior to national team matches were also collated. Linear mixed models assessed relationships between travel and training measures with physical and technical match performance outcomes.

Results: Travel variables explained little variance in outcomes (R^2=0.02-0.16). Travelling eastward was associated with an increase in total (p=0.042) and very high-speed distance (p=0.030) in matches and a 5% decrease in pass accuracy (p=0.012). Greater time zone difference was associated with increased match decelerations (p=0.027) while arriving later for matches was associated with increased total (p=0.041) tackles. Increases in training high-speed distance were associated with increases in match high-speed distance (p=0.004) and number of decelerations (p<0.001). An increase in training total distance was associated with a decrease in match decelerations (p=0.002).

Conclusions: Pre-match travel appeared to have minimal effects on physical and technical performance in this national team. Training loads prior to matches may have some relationship with match running performance, and thus, readiness to train should be a priority for athletes arriving in national team camps.

5.2 Introduction

International football (soccer) matches require selected players to undertake travel directly from clubs into national team camps, often arriving with only a few days to recover and prepare for the match (Clements et al. 2023). Such situations can place significant stress on the athlete and may risk reduced physical and technical performance when playing for their national team and may also occur for some club teams (McCall et al. 2015). These performance concerns relate to the potential for increased physical and mental fatigue caused by jet lag, travel fatigue and disrupted sleep, which are common following extensive travel (Janse Van Rensburg et al. 2021). Additionally, with often only 2-5 days of camp to prepare for matches, training and preparation following travel into national team matches is challenging (Buchheit & Dupont 2018). Further understanding of the relationships between travel into national team matches and training load upon arrival with physical and technical match performance can assist athlete arrival plans for both club and national teams.

Given the short time to recover between arrival and competition for national team footballers, elevated fatigue and impaired sleep due to jet lag and travel fatigue may reduce an athlete's physical performance (Janse Van Rensburg et al. 2021). Previous studies in international football tournaments have observed varying effects of travel on match running, with reduced total distance covered in matches following eastward travel observed during the 2018 FIFA World Cup in Russia (Zacharko et al. 2022), though no effects of travel distance on total distance per minute, sprints per minute and high-speed distance per minute were observed in the 2014 FIFA World Cup in Brazil (Watanabe, Wicker & Yan 2017). Such studies, however, only focus on the final stages of these major tournaments, where players can arrive weeks in advance of matches, and pre-match travel demands are short. Qualifying stages for tournaments are often played within the domestic club season, and, as such, athletes are required to travel direct from club to national team, with these commitments delaying athlete arrival to only 2-5 days prior to matches. Studies assessing the effects of differing travel demands in international Rugby 7s have identified reduced total distance and distance >5m/s during tournament matches after long-haul (>5h) compared to short-haul (<5h) travel (Mitchell, Pumpa & Pyne 2017). In contrast, no effect of travel duration or number of time zones crossed on running performance was reported in other research on international Rugby 7s athletes (Ullersperger et al. 2022). Both studies, however, do not report the time between arrival and matches; thus, the effect remains unclear. Given the conflicting findings and lack of studies examining travel directly into international football (soccer) matches, it is still unclear how travel into a match will affect physical match running performance.

Extensive travel into a national team may reduce technical skill execution due to impairments in cognitive performance associated with jet lag, travel fatigue and sleep disruption (Rossiter, Warrington & Comyns 2022). Despite this, no studies have explored the effects of varying pre-match travel demands on technical performance in football. Fowler, Duffield and Vaile (2014) observed fewer goals conceded, more shots on goal and corners, and fewer opposition shots on goal and corners in home matches compared to away matches in the Australian domestic football (soccer) league. However, travel demands for such matches are relatively short (5.3 ± 2.2 h), and given the similar travel demands across all players, it is difficult to separate the effects of travel from those of away match-disadvantage. Research in Rugby 7s athletes identified significant reductions in several technical performance indicators such as passes, carries, clean breaks, defenders beaten, and metres gained, following both eastward and westward travel (24h, 12 time zones), with a more significant reduction from eastward trips and independent of away-match disadvantage (Lo et al. 2019a). Hence, further research is needed to determine the influence of pre-match travel demands on technical performance in national football teams.

Following travel into national team camp, athletes are required to train for 2-5 days in preparation for the matches while still recovering from the potential effects of travel. The combined influence of both travel and training stresses may induce additional fatigue and influence ensuing physical and technical match performance. Studies in club-based environments report positive relationships between running loads in training and the subsequent running performance in matches, though they are independent of travel demands (Guerrero-Calderón et al. 2021; Modric, Versic & Sekulic 2021; Silva & Nobari 2021; Springham et al. 2020). Additionally, despite the potential for both physical (Dambroz, Clemente & Teoldo 2022) and mental (Smith et al. 2018) fatigue to affect technical performance, the combined effects of travel and training prior to matches on technical performance have not been explored. Accordingly, this study comprises two aims, firstly, to identify the effect of travel duration, direction, time zone change, and the time between arrival and the match, on measures of physical and technical performance in national team matches. Secondly, to assess the influence of measures of external training load 3 days prior to matches on physical and technical match performance in national team footballers.

5.3 Methods

Participants

Participants were players competing for a senior male international football (soccer) team between October 2018 and March 2023. During this period, the team competed in qualifying matches for the 2022 FIFA World Cup and friendly matches after the tournament. Data was collected from 68 different athletes (mean age 25.4 ± 3.6y). Through individual contracts with the national football federation, athletes and the National Federation consented to the use of their anonymous data for research purposes. Ethical approval was obtained from the institutional human ethics committee (ETH22-7708).

Overview

Data was collected from players in each national team match during the study period (n=308). Goalkeepers, players who played <60 minutes in the match, or players who arrived >7 days before the match were excluded from the final dataset (n=103). Both physical and technical match-performance data was obtained for each player. Match performance data was aligned with their travel demands into the match and training load for 3 days prior to the match. To account for the effects of opposition quality, the FIFA ranking of each match opponent was obtained from a historical database at the time of the match. Start times for all matches were between 18:00h and 21:30h local time.

Training and Match Physical Data

Physical running data for matches and training was obtained using global positioning system (GPS) units (STATSports, Apex, Northern Ireland) worn between the players' scapulae using a customised vest. Each unit includes a gyroscope (10Hz), tri-axial accelerometer (100Hz) and magnetometer (10Hz). These devices have previously been validated for the measurement of speed and distance variables in team sports (Beato et al. 2018; Gimenez et al. 2020). All GPS units were managed by the sport scientist in camp, with all data downloaded and processed using the manufacturer's software package (STATSports Sonra, Apex, Northern Ireland). For both training and matches, the following variables were obtained: Total distance (TD), total high-speed distance (HSD) (19.8 – 25.2 $km{\cdot}h^{-1}$), total very high-speed distance (VHSD) (>25.2$km{\cdot}h^{-1}$), number of accelerations (>3$m{\cdot}s^{2}$), and number of decelerations (>3$m{\cdot}s^{2}$). These thresholds had been previously used by the national team based on FIFA guidelines and their frequent use in professional football (Akenhead & Nassis 2016; Rago et al. 2020). For matches, each variable was converted to a relative measure by dividing the raw value by the number of minutes the athlete played in the match. To quantify the total training load prior to matches, the sum of the total values for each day for 3 days prior to matches was calculated for each GPS metric (Akenhead & Nassis 2016). A 3-day sum was used as this best represented the amount of training days that most players took part in upon arrival into the national team. Data points where players elected not to wear a GPS unit (n=25) were excluded from the dataset for use in physical performance models (final dataset n=79). Additionally, due to a change in acceleration threshold during the study period and the unavailability of data prior to this change, data points prior to the change were not included in the match accelerations model (n=35).

Match Technical Data

Technical data from all national team matches were collated from a match statistics partner (Opta Data, Stats Perform, Sydney). The system used to measure technical data has been previously observed to have high inter-operator reliability (kappa value = 0.92-0.94) (Liu et al. 2013). A list of all variables obtained, and their definitions, can be found in Table 5.1. These variables were selected based on their commonality in a review of previous literature (Varley et al. 2017; Yi et al. 2019; Yi et al. 2018). Technical match data was not available for one match and thus was excluded from analysis (final dataset n =95).

Table 5.1. Operational definitions for technical performance stats derived by Opta

Outcome Variable	Definition
Total touches	A sum of all events where a player touches the ball, so excludes things like Aerial lost or Challenge lost.
Successful touches	Calculated as the difference between Total touches and Unsuccessful touches.
Unsuccessful touches	When the ball bounces off a player and there is no intentional pass, we award a touch. When a player mis-controls the ball with a poor touch, we award an unsuccessful touch. Also used for mishit shots which go backwards towards a player's own goal.
Total passes	Any intentional played ball from one player to another. Passes include open play passes, goal kicks, corners and free kicks played as pass – but exclude crosses, keeper throws and throw-ins.
Accurate Passes	A completed pass is a pass which goes to a teammate directly without a touch from an opposition player.
Inaccurate passes	Calculated based on the difference between total passes and accurate passes.
Pass Accuracy (%)	Calculated as the percentage of accurate passes to total passes.
Total shots	Calculated as the sum of shots on target and shots off target.
Shots on target	A shot on target is defined as any goal attempt that: • Goes into the net regardless of intent – For Goals only. • Is a clear attempt to score that would have gone into the net but for being saved by the goalkeeper or is stopped by a player who is the last-man with the goalkeeper having no chance of preventing the goal (last line block).
Shots off target	A shot off target is defined as any clear attempt to score that: • Goes over or wide of the goal without making contact with another player. • Would have gone over or wide of the goal but for being stopped by a goalkeeper's save or by an outfield player. • Directly hits the frame of the goal and a goal is not scored.
Total crosses	Any intentional played ball from a wide position intending to reach a teammate in a specific area in front of the goal.
Accurate crosses	An accurate cross is a cross that goes directly to a teammate without a touch from an opposition player.
Inaccurate crosses	Calculated as the difference between total crosses and accurate crosses.
Total tackles	A tackle is defined as where a player connects with the ball in a ground challenge where he successfully takes the ball away from the player in possession.
Won tackles	A tackle won is deemed to be where the tackler or one of their team-mates regains possession as a result of the challenge, or that the ball goes out of play and is "safe".
Interceptions	When a player intercepts any pass event between opposition players and prevents the ball reaching its target. Cannot be a clearance.
Clearances	This is a defensive action where a player kicks the ball away from their own goal with no intended recipient.
Turnovers	Loss of the ball through a mistake / poor control of the ball

Travel Details

Travel details of all flights prior to matches were obtained from booked travel schedules with details of the flight and scheduled arrival and departure times. The actual arrival and departure times of each flight were verified via an online flight database (flightera.com). The total travel duration was calculated as the total amount of time between aircraft departure and arrival at the final destination (including the length of stopovers). The direction of travel was determined based on the geographical locations of the cities of arrival and departure and labelled as either east or west. The time zone difference was calculated as the difference in time zone between the departure city and the arrival city at the time of arrival. The number of hours between arrival from travel and the national team match kick-off was also included for analysis. These travel variables were observed in the first study of this thesis to influence perceptual fatigue, jet lag and sleep ratings and thus may represent the travel stress of the athlete.

Statistical Analysis

Match physical and technical performance measures were aligned with travel and training load performed prior to each match. Data was imported into R Studio for analysis. For each match-running outcome variable, linear mixed models were built using the lme4 software package (Bates et al. 2015). To account for the non-independence of the observations, an anonymous player code and match ID (which accounts for the time of match and opposition) were included in the model as random effects. Additionally, playing position was included as a random effect to account for positional differences. Playing positions were categorised as Fullback, Central Defender, Central Midfielder, Wide Midfielder or Forward. Models were built using a forward stepwise approach with the fit of each fixed effect assessed through its statistical significance, the Aikake Information Criterion (AIC) value, and the R^2 values of the model. Assumptions of normality and homogeneity of variance were assessed post-hoc using QQ-plots and residual plots, and no issues were identified.

Technical performance (count data) outcomes were analysed using generalized linear mixed models with a Poisson link function. To account for differences in the number of minutes played in each match, technical outcomes were converted to rates (number of events per minute of play) by including the minutes played as an offset within the models. Where counts included large numbers and represented a normal distribution, linear mixed models were used (total touches, successful touches, accurate passes, inaccurate passes, pass accuracy). The random effects of player code, match ID and match position were included in all models.

5.4 Results

Travel and Training Loads

To provide context to pre-match travel demands in national team footballers, the distribution of flights by travel duration and the time between arrival and match start is shown in Figure 5.1. Travel ranged from 0.85h to 31h duration (mean:13.4h ±9.6h) across 0 to 11 time zones (mean 5.2 ±4.3) and included both east (N=75) and west (N=29) directions. Mean travel durations for each travel direction were 16.6h (±8.4) for eastward travel and 5.5h (±8.0) for westward travel. Athletes arrived on average 84.8 ±29.8h prior to the match and tended to arrive earlier when longer travel durations were required, with very few arrivals <40h before a match (95% of athletes arrived at least 48h prior to matches). The mean FIFA ranking of opposition teams was 93 (±45) and was lower (i.e. better teams) for trips involving eastward travel (76 ± 35) than westward travel (135 ± 39). Mean training loads over the first 3 days of arrival were 8701.5m (±2671.5) total distance, 314.7m (±173.7) high-speed distance, and 59.9m (±173.7) very high-speed distance. Mean accelerations (>3m·s^2) and decelerations were 89.5 (±34.7) and 66.6 (±28.7), respectively.

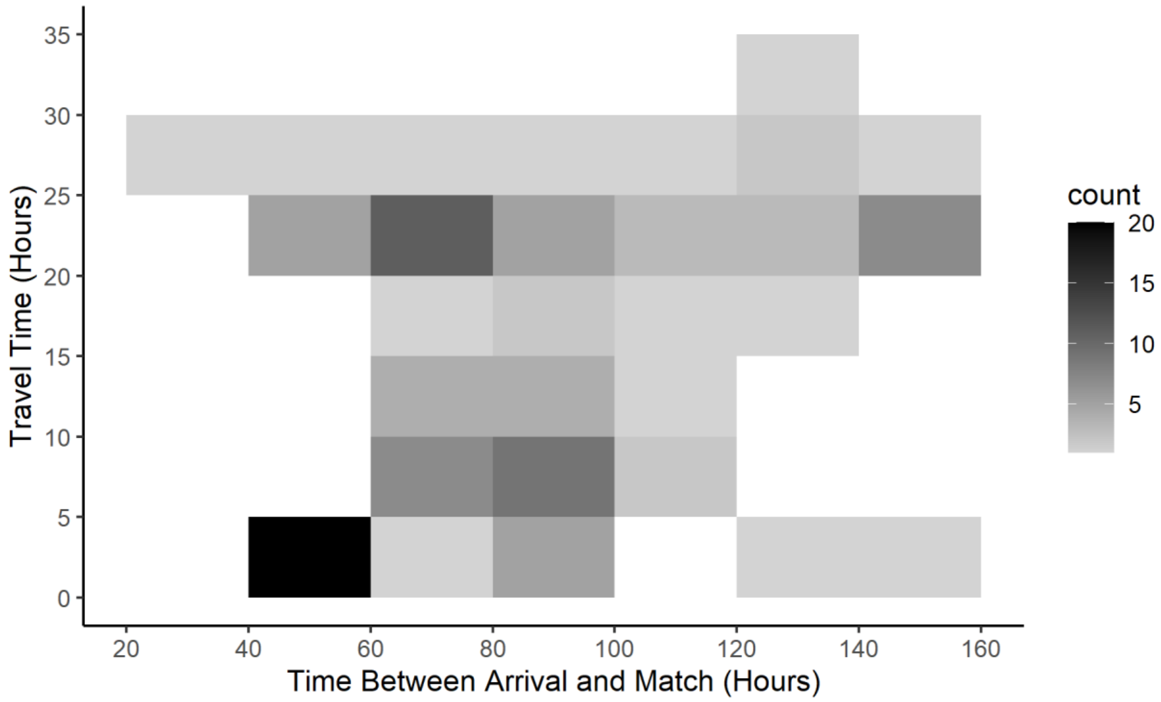


Figure 5.1. Distribution of flights based on the player's travel time and when they arrived relative to the match start time (n=103)

Physical Match Performance

Final model outputs and details of significant explanatory variables for physical match performance are shown in Table 5.2. Model R^2 conditional values were relatively high (R^2=0.84-0.89). However, R^2 marginal values were minimal (R^2=0.02-0.16), indicating that the random effects included within each model explained the majority of variance in each outcome. Athletes travelling eastward covered 3.003m/min more in total distance (p=0.042) and 0.336m/min more in very high-speed distance (p=0.030) compared to westward travellers. For each additional time zone crossed during travel, there was a significant increase of 0.008 decelerations per minute. (p=0.027). No other travel variables showed significant relationships with match running outcomes (p>0.05).

An influence of in-camp training loads was evident, with a 1m increase in training HSD associated with a 0.002m/min increase in match HSD/min (p=0.004) and a 0.0006 increase in the number of decelerations per minute (p<0.001). A 1km increase in training total distance was associated with a 0.028 decrease in decelerations per minute in the match (p=0.002).

Technical Match Performance

Final model outputs for technical performance outcomes are shown in Table 5.3. Only pass accuracy and total tackles had a significant relationship to any travel-based explanatory variables, and R^2 values were small (R^2=0.07 and R^2<0.01). Travelling eastward was associated with a 5% reduction in pass accuracy compared to athletes travelling westward to matches (p=0.012). Reductions in total tackles per minute were associated with arriving earlier to the match. For every hour prior to the match an athlete arrived, total tackles decreased by 0.7%.

Table 5.2. Final model outputs for significant variables explaining match GPS measures. All models included the player ID, match ID, and player position as random effects. Coefficients (and direction) for numerical explanatory variables represent the change in outcome per one unit change in the explanatory variable (units are displayed in brackets).

Outcome	R^2 Conditional	R^2 Marginal	Explanatory Variables	Coefficient	P value
Match TD per minute (m/min)	0.84	0.03	Travelling Eastward	3.003	0.042
Match HSD per minute (m/min)	0.89	0.03	Training HSD (m)	0.002	0.004
Match VHSD per minute (m/min)	0.85	0.02	Travelling Eastward	0.336	0.030
Match Acc per minute	0.83	0.00	-	-	-
Match Dec per minute	0.86	0.16	Training HSD (m)	0.0006	<0.001
			Total Distance (km)	-0.028	0.002
			Time Zone Difference (h)	0.008	0.027

TD – Total Distance
HSD – High-Speed Distance
VHSD – Very High-Speed Distance
Acc – Accelerations
Dec - Decelerations

Table 5.3. Final model outputs for variables explaining match technical performance measures. All outcome variables are expressed as relative measures per minute of match play. All models included the player ID, match ID, and player position as random effects.
** indicates use of a Poisson regression model.*

Outcome	R^2 Conditional	R^2 Marginal	Explanatory Variables	Change from Intercept (%)	P value
Total Touches	0.75	0			
Successful Touches	0.77	0			
Unsuccessful Touches*	0.43	0			
Total Passes	0.80	0			
Accurate Passes	0.80	0			
Inaccurate Passes	0.32	0			
Pass Accuracy (%)	0.27	0.07	Travelling Eastward	↓ 5%	p=0.0117
Total Shots*	0.80	0			
Shots on Target*	0.27	0			
Shots off Target*	0.12	0			
Total Crosses*	0.72	0			
Accurate Crosses*	0.53	0			
Inaccurate Crosses*	0.66	0			
Total Tackles*	0.02	<0.01	Time between arrival and match	↓ 0.7% per 1 hour	p=0.0409
Won Tackles*	0.05	0			
Interceptions*	0.40	0			
Clearances*	0.40	0			
Turnovers*	0.43	0			

5.5 Discussion

This study explored the effects of pre-match travel and in-camp training on ensuing physical and technical performance in international football matches. The effect of travel duration, direction and time between arrival and matches on physical and technical performance measures was minimal. Additionally, a small relationship between training load upon arrival and high-speed running quantities in matches was observed. Although pre-match travel may induce fatigue and poor sleep, normal match factors, such as opposition quality (Trewin et al. 2017), are likely to have had larger influence on physical and technical performance than travel demands. Further, for athletes arriving at least 48h prior to national team matches, travel did not appear to negatively impact match performance in this national team.

Small associations (R^2=0.02-0.16) between travel direction and match physical performance measures were observed in this study, with athletes travelling eastward covering a greater amount of total and very high-speed distance in matches compared to when travelling westward. While differences in physical performance may be expected based on travel demands, eastward travel would be expected to have a more negative effect on match performance than westward (Fowler et al. 2017a). These conflicting findings may, therefore, be better explained by competition scheduling and location factors, as athletes travelled eastward into matches against higher-quality teams (based on FIFA rankings). For example, FIFA ranking of opponents following eastward trips was 49.5 points lower (i.e. better teams) than that of westward trips. This aligns with prior club-based research where increases in match-running variables have been observed when competing against better-quality opposition (Trewin et al. 2017). Although it is unlikely full circadian resynchronisation would have occurred in the athletes in this study (Janse Van Rensburg et al. 2021), the lack of effects on physical performance could result from 95% of athletes arriving at least 48h in advance of matches and thus having time to recover from travel (Janse Van Rensburg et al. 2021). As such, it could be recommended, where possible, that athletes arrive a minimum of 48h prior to national team matches (or longer for greater travel demands) to minimise the risk of detrimental effects on performance from prior travel demands.

Although pre-match travel had minimal effect on physical match performance in this cohort, hastening the availability to train may be important, as small associations existed between training loads on arrival and subsequent match running outcomes. A small positive relationship was observed between the total high-speed distance completed in the three days prior to a match and the high-speed distance (R^2=0.03) and number of decelerations performed in the match (R^2=0.16). Previous club-based research has observed similar positive relationships between pre-match training and match running variables (Guerrero-Calderón et al. 2021; Modric, Versic & Sekulic 2021; Silva & Nobari 2021), while reduced match acceleration performance has also been linked to excessively high or low acute sprint loads in training (Springham et al. 2020). While previously this relationship has been related to a fitness-fatigue effect (Springham et al. 2020), the variations in training running loads in the current study may reflect adjustments in the tactical plans for the upcoming match. Teams are likely to attempt to train for the tactics they use in a match, and thus, position-based match tactics that require greater running loads may result in increased running loads during training. An additional finding of this study was that increases in total distance in training were related to reductions in match decelerations. While the reason for this is unclear, it may be related to the nature of distance covered, with players covering greater distances tending to do so at lower speeds. Regardless, these findings highlight the importance of athlete preparedness to train and compete in the congested schedule of a national team, and hence, some need to promote recovery from travel exists.

For the cohort in this study, pre-match travel demands and training loads upon arrival appeared to have minimal relationships with technical match performance. Travelling eastward to a match was associated with a small reduction in pass accuracy (R^2=0.07) when compared to travelling westward. Again, for athletes in this cohort, eastward travel required longer travel durations and potentially worse jet lag symptoms (Fowler et al. 2017a); however, this finding may also be related to the previously discussed increased opposition quality following eastward trips. This is consistent with prior research observing reductions in pass accuracy being associated with increased opposition quality in international youth football (Varley et al. 2017). Associations were also observed between the time between arrival and match and the total number of tackles, whereby players who arrived later (closer to the match) had more total tackles. However, as indicated by a marginal R^2 of less than 0.01, the strength of this association was minimal. As such, the findings of this study suggest match technical performance for this national team was unlikely to be affected by travel or training demands for athletes arriving at least 48h prior to matches.

Despite the novelty of this data to inform pre-match travel and training in national teams, there are several limitations that should be considered when interpreting these results. Firstly, these findings represent only a single national team and thus, variation in outcomes may be expected across other teams who may have different travel demands or strategies surrounding travel. Furthermore, due to the need to play at least 60 min in each match and the unavailability of GPS data for some athletes, a relatively small sample size of 103 data points was used. Additionally, only 2 of the 14 matches involved in this study were against higher-ranked teams and most matches resulted in a win (71%). As such, the impacts of travel and training on performance may have been masked by the superior quality of the analysed team compared to their opponents. Lastly, limited control was permitted over what athletes did before, during or after travel and thus, the use of jet lag management strategies was not controlled for, which may influence responses to travel.

5.6 Practical Applications

- Travel into international football matches had small effects on physical or technical performance of this national team, and thus, athletes should aim to arrive at least 40h in advance of matches.

- Small relationships existed between total training loads for 3 days prior to a match and match running performance, and thus, readiness to train should be a priority for athletes arriving at national teams.

5.7 Conclusions

In conclusion, this study examined the relationship of pre-match travel and the technical and physical performance of footballers competing in a national team. These findings show that travel into matches had only small effects on physical or technical match performance, with most of these athletes arriving at least 48h prior to matches. When earlier arrival is not possible, and travel durations are long, particular focus on interventions to assist in the alleviation of jet lag and manage sleep deficits could become more important. Additionally, small relationships existed between total and high-speed running in training and high-speed running in matches, thus suggesting readiness to train should be a priority for players arriving at national teams. Future studies should seek to add to these findings using other population groups and travel demands and explore the effects of travel where arrival at least 48h prior to matches is not possible.

Chapter 6: Study 4

Influence of Travel Demands and Match Load on Recovery Following Post-Match Travel in National Team Footballers.

Clements, E., Ehrmann, F., Clark, A., Jones, M., McCall, A. & Duffield, R. ' Influence of travel demands and match load on recovery following post-match travel in national team footballers.' *International Journal of Sports Physiology & Performance.* In review

6.1 Abstract

Purpose: This study investigated the relationship between travel demands and match loads on perceptual recovery, fatigue and sleep following post-match travel in national football teams. Additionally, the influence of travel demands and the time between match kick-off and travel departure on post-match recovery was examined.

Methods: Match-running load (via GPS) and travel data was collated from 79 male national team footballers. Post-match travel duration, direction, context, time zone difference, and time between kick-off and travel departure was collated. Athletes provided perceptual ratings of fatigue, soreness, sleep, stress, and recovery from 1-day pre-match through to 3 days after post-match travel. Linear mixed models assessed the influence of match load and travel on perceptual ratings for 3 days post-travel. Additional models assessed a standardised post-match timepoint of MD+3 to determine whether timing and extent of travel influenced recovery.

Results: Higher match-loads were associated with poorer recovery, fatigue, soreness, and sleep ($p=0.001$-0.032). Athletes reported poorer fatigue, soreness and recovery when travelling from national teams back to clubs compared to between national team matches ($p<0.001$). Travelling eastward was associated with poorer sleep ($p=0.004$). Longer periods between kick-off and travel departure were associated with poorer sleep on MD+3 ($p=0.003$).

Conclusions: Perceptual recovery, fatigue, sleep, and soreness following post-match travel were affected by both match load and travel demands. Greater match loads and eastward post-match travel may impair recovery. Additionally, departing later after a match was associated with poorer sleep on MD+3 due to arrival closer to that time point, without any effect on other recovery measures.

6.2 Introduction

National football (soccer) team athletes are often required to travel back to their clubs shortly after the completion of a national team match and then be prepared to compete again for their club team within 3 days (Gouttebarge, Brink & Kerkhoffs 2019). Hence, post-match travel is a concern for national football teams due to the physiological and physical stresses of travel, combined with the need to recover from match-play (Gouttebarge, Brink & Kerkhoffs 2019; Janse Van Rensburg et al. 2021; Rossiter et al. 2023). Further, travel stressors and the time required for travel may restrict the time available to undertake post-match recovery and affect recovery status. The combined effects of both match load and travel requirements are likely to have significant implications on fatigue, sleep, and recovery, potentially also impacting selection for their next club match (Janse Van Rensburg et al. 2021; Rossiter, Warrington & Comyns 2022). Understanding how match load and post-match travel influence perceived recovery, fatigue, sleep, and soreness can assist practitioners in planning for travel after both international and club matches.

International football windows are typically 9-11-day periods in which club football teams must release their athletes to national teams to compete in up to 2 international matches. Within these 9-day windows, players travel from clubs to national teams (often immediately after club matches), compete in 2 international matches with transition travel in between, and then return for their next club team fixture within a few days. Due to the condensed nature of these windows, athletes are often afforded only a few days to recover from both match loads and subsequent travel demands. Currently, very little research explores the combined effects of these two stresses on post-match recovery to guide subsequent player availability in any sport, but particularly for football. Kraemer et al. (2016) observed elevated blood recovery markers following a simulated team-sport match and 5h eastward trip in physically trained individuals; however, as both the travel and match load were the same for all participants, the influence of variations in these variables is unknown. Studies examining short-haul travel in Australian domestic football have reported no difference in post-match recovery (Fowler, Duffield & Vaile 2014) or perceptual wellness (Fowler et al. 2015c) between home and away matches, though only incorporated short-haul travel in a single club team. Further, the aforementioned studies address only a fraction of the possible travel demands a national team footballer may experience, and no studies compare the recovery responses of athletes across a broad range of travel demands. Although the second study of this thesis reported poorer perceptual fatigue, sleep, and soreness following travel out of a national team compared to travel into or between matches, the specific effects of different match loads and post-match travel demands on recovery are unknown. Detailed understanding of player responses to combined match and travel loads is therefore needed to better inform player availability and recovery when travelling between national team matches and when returning to club teams.

The need to travel to subsequent national team matches or return to club teams shortly after demanding national team matches may be suboptimal conditions for recovery, which may influence preparation and selection in subsequent matches. While the timeline of recovery from a professional football match is reported to range from 5-96h (Nédélec et al. 2012), the conditions of travel are often suggested to interfere with the recovery of athletes following matches and prolong this timeline. Whilst a common occurrence in modern fixtures, this is not ideal when only 3-5 days separate matches and include extensive travel. Despite this major concern, no research has investigated how player recovery differs based on post-match travel demands. A recent review of post-match recovery strategies highlighted sleep and nutrition as being particularly important for match recovery (Querido et al. 2022). Post-match travel, however, has been previously observed to reduce total sleep in Rugby 7's players (Smithies et al. 2021), while reductions in sleep during and after travel have frequently been reported by travelling athletes (Doherty et al. 2023; Fowler et al. 2017a; Fowler et al. 2017b; Fullagar et al. 2016). As such, it is possible that the post-match recovery of athletes may be impaired by travel-induced sleep loss. Additionally, travel demands may also reduce the time available for other recovery strategies, i.e., nutrition, cold-water immersion or massage, which have also been suggested to have beneficial effects on perceptual recovery (Querido et al. 2022). Due to the potential impacts of travel on post-match recovery, practitioners of national teams are also left to consider the best time to travel after a match. However, it is unclear whether travelling later and spending time recovering prior to travel will eventuate in better outcomes than travelling immediately post-match and recovering after travel. Given an athlete may be required to compete again within 3 days of their previous match, understanding how the timing and extent of travel influence post-match recovery will help inform the planning of travel schedules (e.g. when to depart) and guide post-travel recovery plans.

Based on the lack of research surrounding the relationships between match-load and travel, this study has two aims. Firstly, to describe the relationship of match load, travel duration, time zone change, and direction on the perceptual fatigue, sleep, soreness, and recovery status of national team footballers upon arrival from post-match travel. Secondly, to describe the influence of travel duration, time zone change, direction and time between match and travel departure on match recovery status 3 days after a match in national team footballers.

6.3 Methods

Subjects

Participants included 79 male international footballers (Age 25.0 ± 3.7) competing for a national football team between October 2018 and November 2023. Data was collected from each trip the players undertook for either the senior or under 23's national teams (n=258). Through contracts with the National Football Federation, all players provided consent for their data to be used anonymously for research purposes. Ethics approval was obtained from the institutional human ethics committee (ETH22-7708).

Methodology

Data was collected from each national team player travelling after a national team match (including travel both between national team matches and back to clubs). Participants were required to complete a perceptual questionnaire every day when in the national team camp and up to 3 days following their return to their club. Players were also required to provide a perceived recovery status rating from the day prior to each match through to 3 days after the match. Each player's perceptual scores were aligned with their match loads and post-match travel details. To accomplish aim 2, perceptual outcome scores were collated from a standardised post-match time point of match day +3 (MD+3). This time point was selected as all players had completed post-match travel requirements by this point, and it allowed for a standardised time point for comparison that could align with the earliest possible club match. Baseline scores for both aims 1 and 2 were obtained the morning before a match (MD). Perceptual outcomes were converted to change scores by subtracting the baseline score from the raw value.

Travel Details

Travel details for each post-match flight were obtained from booked travel schedules provided by national team managers. Actual departure and arrival times for each flight were verified via an online flight database (Flightera.com). Travel duration (Mean: 14.51h ± 4.10, Range: 1.08h - 32.98h) was calculated as the total time between airport departure and arrival at the final destination airport (including the duration of stopovers but not travel to and from the airport). The recovery time between matches and travel was calculated as the length of time in hours between match kick-off and aircraft departure due to the availability of match start time (Mean:

24.34h ± 12.11, Range: 4.83h - 76.33h). The number of time zones crossed during travel was measured as the difference in time zone between departure and destination locations at the time of travel (Mean: 5.56 ± 2.25, Range: 0 – 14). The direction of the flight was labelled as either eastward or westward based on the flight path. The travel context was categorised as being either transition (travel between two national team matches) or return (travel out of the national team back to club teams). These travel variables were identified in the first two studies of this thesis to be associated with post-travel perceptual fatigue and sleep. Athletes stayed in team hotels during camp periods (i.e. after transition travel), while following return travel, athletes typically stayed in their own accommodation at their respective club teams.

Match Load

Global positioning system (GPS) devices measured the running loads of players during each match. Players wore a GPS unit (STATSports, Apex, Northern Ireland) worn between the players' scapulae using a customised vest. Each unit includes a gyroscope (10Hz), tri-axial accelerometer (100Hz) and magnetometer (10Hz). Satellite quality was filtered for using HDOP values of <1. These devices have previously been validated for the measurement of speed and distance variables in team sports (Beato et al. 2018; Gimenez et al. 2020). The following measures were obtained for each player from each match: Total distance (TD), total high-speed distance (HSD) (19.8 – 25.2 $km \cdot h^{-1}$), total very high-speed distance (VHSD) (>25.2$km \cdot h^{-1}$), number of accelerations (>3$m \cdot s^{2}$), and number of decelerations (>3$m \cdot s^{2}$).

Perceptual Measures

Players completed a perceptual monitoring questionnaire every morning during the national team camp and for 3 days after the completion of the camp. The questionnaire included 4 subjective rating scales on a 7-point Likert scale. Players were asked to rate their current level of fatigue, soreness, sleep quality, and stress as used previously in this thesis. A "Total

Wellness" score was calculated from the sum of each of the individual scales. Athletes were also asked to complete the Perceived Recovery Status Scale (PRSS) (Laurent et al. 2011) each day from the day before a match through to 3 days after the match. This scale is a 10-point scale requiring players to rate their current perception of their recovery status, with scores of 10 relating to being very well recovered and scores of 0 relating to being very poorly recovered. Athletes completed all perceptual monitoring scales via the federation's athlete monitoring software (Smartabase Athlete, Fusion Sport Pty Ltd) installed on their own smartphones.

While the authors acknowledge the validity of perceptual wellness scales to monitor athletes can be questioned (Jeffries et al. 2020), these scales have previously been observed to be responsive to variations in match load (Evans et al. 2022; Noor et al. 2021; Oliveira et al. 2023). Additionally, these scales were observed in the previous chapters of this thesis to be responsive to variations in travel demands, including travel duration, time zone difference and travel direction. Given the challenges associated with athlete monitoring in national football teams (Buchheit & Dupont 2018), these tools represent a practical way to monitor athlete responses to both match and travel stresses.

Statistical Analysis

All perceptual monitoring scales were aligned with the prior travel details and match GPS measures in an Excel spreadsheet. For aim 1, perceptual scores were labelled as either Day (D) 1, D2 or D3, based on the timing of the score relative to arrival from travel. All data was imported into R Studio (version: 2023.6.0.421) for analysis. Linear mixed models were created for each perceptual outcome variable (Bates et al. 2015). Models were built using a forward step-wise approach with the inclusion of each fixed effect determined by statistical significance ($p<0.05$), measured via F-tests with Satterthwaite degrees of freedom approximations using the lmertest package (Kuznetsova, Brockhoff & Christensen 2017). Where multiple effects were deemed statistically significant, the AIC value and the R^2 values of the model were used to determine order. Where fixed effects were correlated (i.e. all match load variables and travel duration/time zone difference), only one of the strongest of the two variables was included to control for multicollinearity within models. The following fixed effects were tested for each model: day, travel duration, time zone difference, travel direction, travel context, match total distance (m), match HSD, match VHSD, match ACC, and match DEC. All players were assigned an anonymous identification number, which was included as a random effect within the model to account for variation between participants. The national team camp from which the data came was also coded as a random effect.

For aim 2, perceptual measures taken on MD+3 were used as outcomes for separate linear mixed models. Models were built using the same methods described for Aim 1. Models were built using the same fixed and random effects as those listed above, with the additional included fixed effect of the recovery time.

6.4 Results

Model Outcomes

Details of the final selected models for each outcome are presented in Table 6.1. Overall, the model R^2 values showed fatigue (R^2 Marginal=0.21) and recovery (R^2 Marginal=0.22) scales to be the most responsive to combined travel and match stresses.

Table 6.1. Model outputs for changes in wellness and recovery scales from baseline (MD or MD-1) and post-travel (arrival +1, +2, +3). Coefficient values represent the change in outcome variable per one unit increase in the explanatory variable (1 for categorical variables).

Outcome	R^2M	R^2C	Explanatory Variables	Coefficient	P values
Fatigue	0.21	0.33	*Intercept*	0.555	
(n=258)			D2	-0.485	<0.001
			D3	-0.656	<0.001
			Trip Type: Return	0.491	<0.001
			Match Decelerations	0.002	0.031
Soreness	0.09	0.21	*Intercept*	0.405	
(n=258)			D2	-0.248	0.001
			D3	-0.453	<0.001
			Trip Type: Return	0.297	<0.001
			Match Decelerations	0.002	0.023
Sleep	0.10	0.29	*Intercept*	-0.070	
(n=258)			Match VHSD	0.003	<0.001
			D2	-0.351	0.002
			D3	-0.430	<0.001
			Travel Direction: East	0.429	0.004
			Recovery Time	0.014	0.003
Stress	0.02	0.21	*Intercept*	0.015	
(n=258)			Match Accelerations	0.002	0.008
Total	0.13	0.32	*Intercept*	1.482	
(n=258)			D2	-1.074	<0.001
			D3	-1.590	<0.001
			Match Decelerations	0.012	<0.001
			Trip Type: Return	0.529	0.007
Recovery	0.22	0.40	*Intercept*	-0.890	
(n=181)			D2	0.667	<0.001
			D3	1.086	<0.001
			Trip Type: Return	-0.629	<0.001
			Match VHSD	-0.002	0.032

Post-Travel Perceptual Outcomes

Athletes reported poorer ratings of fatigue ($p<0.001$), soreness ($p<0.001$), total wellness ($p=0.007$), and recovery ($p<0.001$) following return travel than when they travelled between national team matches (Figure 6.1). Travelling eastward resulted in significantly poorer sleep responses than travelling westward ($p=0.004$), while, regardless of travel context, travelling later after the match also had a negative effect on sleep ratings 3 days following arrival ($p=0.003$) (Figure 6.2). No significant effects existed for any other travel variable on perceptual makers ($p>0.05$).

The strongest associated match load measure differed between perceptual outcome variables. Increases in match VHSD had a negative effect on sleep ($p<0.001$) and recovery ($p=0.032$) scores. A greater number of decelerations in matches resulted in poorer ratings of fatigue ($p=0.031$), soreness ($p=0.023$), and total wellness ($p<0.001$). Greater match accelerations were also associated with poorer stress ratings ($p=0.008$).

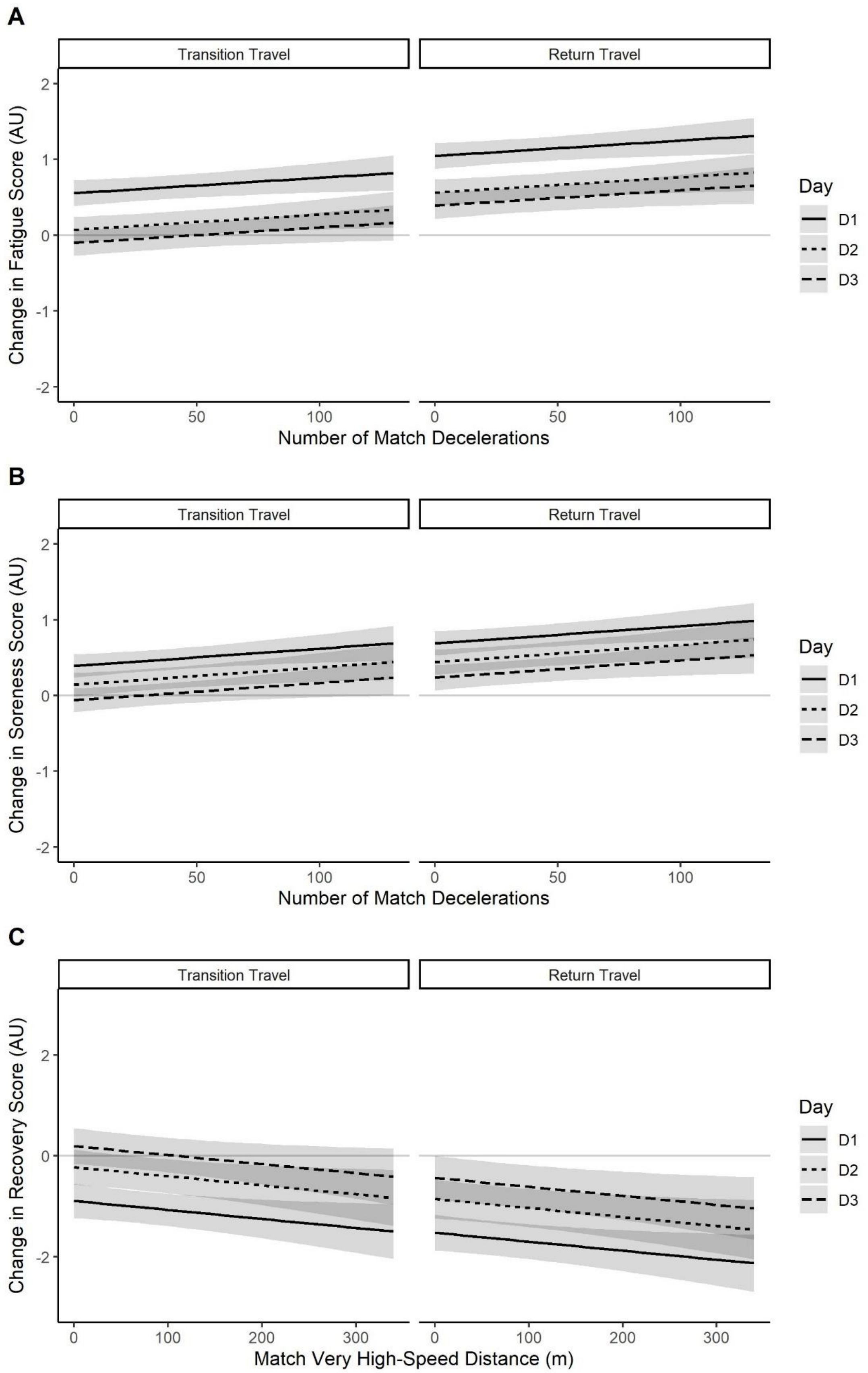


Figure 6.1. Change in A) Fatigue, B) Soreness, and C) Recovery scores between pre-match to post-travel based on travel type, match decelerations and match very-high-speed distance. Shaded areas represent the 95% confidence intervals.

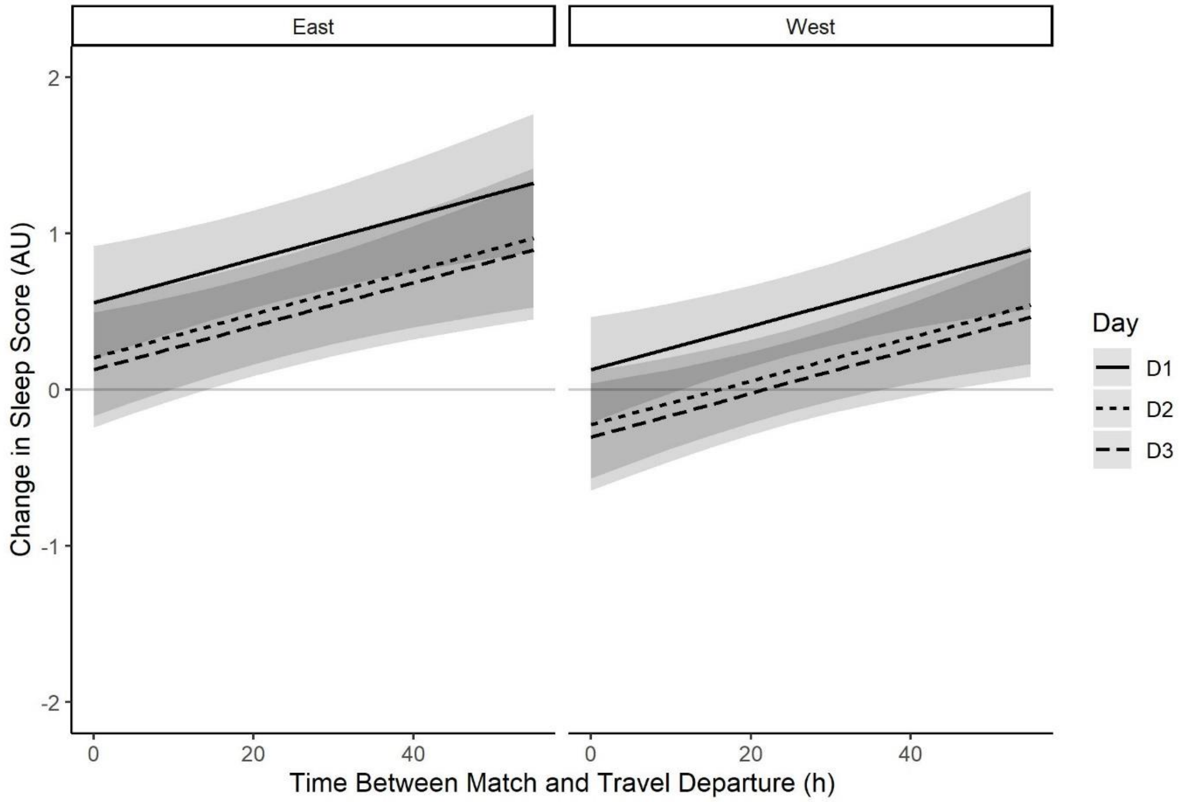


Figure 6.2. Change in sleep scores from pre-match to post-travel based on the time between match kick-off and travel departure, as well as the travel direction. Shaded areas represent the 95% confidence intervals.

Match Day +3 Perceptual Outcomes

Final model outcomes for MD+3 perceptual measures are shown in Table 6.2. Travelling eastward after matches was associated with poorer fatigue ($p=0.002$), sleep ($p=0.032$), total wellness ($p=0.015$), and recovery ($p<0.001$) ratings when compared to travelling westward. Athletes also reported poorer sleep ($p=0.003$) and total wellness scores ($p=0.023$) the later after the match they travelled. Perceptual recovery ratings were worse when travelling for longer durations ($p=0.003$). At MD+3, greater VHSD in matches was associated with poorer sleep ($p=0.019$) and total wellness scores ($p=0.030$). No other effects of match load were observed at MD+3.

Table 6.2. Model outputs for the difference in wellness and recovery scales from baseline (MD or MD-1) and 3 days post-match (MD+3). Coefficient values represent the change in outcome variable per one unit increase in the explanatory variable (1 for categorical variables).

Outcome	R^2M	R^2C	Explanatory Variables	Coefficient	P values
Fatigue	0.05	0.22	*Intercept*	0.525	
(n=228)			Travel Direction: East	0.432	0.002
Soreness	0.00	0.09	*Intercept*	0.404	
(n=228)					
Sleep	0.09	0.22	*Intercept*	-0.333	
(n=228)			Recovery Time	0.024	0.003
			Travel Direction: East	0.502	0.032
			Match VHSD	0.003	0.019
Stress	0.00	0.22	*Intercept*	0.083	
(n=228)					
Total	0.08	0.35	*Intercept*	0.368	
(n=228)			Travel Direction: East	1.030	0.015
			Recovery Time	0.032	0.023
			Match VHSD	0.005	0.030
Recovery	0.15	0.36	*Intercept*	-0.204	
(n=168)			Travel Direction: East	-0.853	<0.001
			Travel Duration	-0.065	0.003

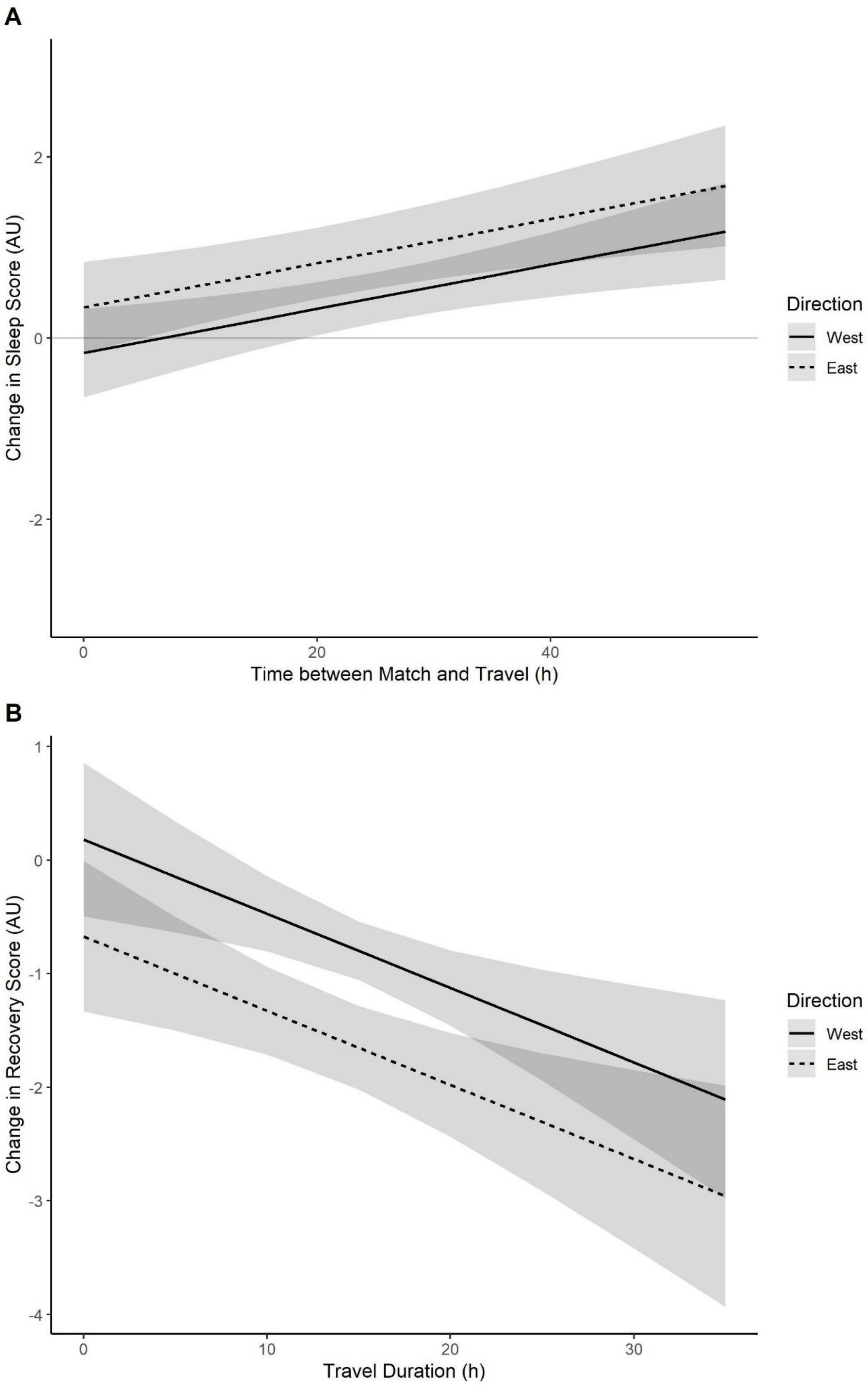


Figure 6.3. Change in Sleep and Recovery scores from MD to MD+3 based on travel direction, the time between match kick-off and travel departure, and the duration of travel. Shaded areas represent the 95% confidence intervals.

6.5 Discussion

The current study explored the relationship of match load and travel demands with perceptual fatigue, sleep and recovery responses of professional footballers following national team matches. Perceptual ratings of recovery, fatigue, soreness, and sleep were influenced by both match external load and the post-match travel demands. Greater match acceleration, deceleration, and high-speed running load were associated with poorer recovery, fatigue, soreness, and sleep, and these measures were also reported to be worse following travel back to clubs compared to travel between national team matches. Additionally, players who travelled eastward after matches reported poorer sleep and recovery than those travelling westward. Further, players with longer travel durations reported poorer perceptual recovery on MD+3, and players who travelled later after a match reported poorer sleep on MD+3 than those who travelled earlier.

The findings of this study indicate that the perceptual fatigue, sleep, and recovery state of national team footballers upon arrival from post-match travel showed small associations (R^2=0.02-0.22, as context an R^2 of 1.0 represents all variation in the outcome value is explained by the model and its fixed effects) with high-speed running loads undertaken in the prior match and the travel demands after matches. Greater high-speed loads (measured as either high-speed distance, very high-speed distance or acceleration/deceleration counts) were negatively associated with all perceptual recovery measures. These findings concur with recent works in both senior (Oliveira et al. 2023) and junior (Evans et al. 2022) professional footballers reporting negative associations between increased high-intensity running and perceptual fatigue, soreness, energy, and sleep on MD+1 (Oliveira et al. 2023) and MD+2 (Evans et al. 2022) respectively. However, similar to the findings in a recent systematic review on perceptual responses to training and match load (Duignan et al. 2020), the variation in scores explained by these models was relatively low (R^2 conditional = 0.04-0.22), indicating that other factors are likely to also have influence on perceptual scores. Regardless, this study is the first to show that pre-travel match loads, specifically high-speed loads, continue to influence an athlete's perceptual recovery status following arrival from post-match travel. As such, high-speed match loads should be considered when planning for the expected arrival status of athletes. Further, these findings emphasise the importance of sharing match load information between clubs and national teams to better inform athlete status and availability upon return to clubs.

In addition to the influence of match load, both post-match travel direction and the context of travel appeared to influence an athlete's post-arrival state. Athletes travelling eastward after a match reported significantly poorer sleep scores post-arrival compared to those travelling westward. This finding concurs with Fowler et al. (2017a), who identified reductions in sleep duration and time in bed following eastward travel across 8 time zones compared to westward travel of the same extent. The reduction in sleep quality in this study may be explained by delayed sleep onset as a result of jet lag, with morning commitments potentially limiting the capability to make up for the delayed onset of sleep; though we recognise neither sleep onset nor wake time was recorded in this study. As such, athletes with prolonged travel eastwards, especially overnight after a national team match, may require additional time to sleep or strategies to improve sleep quality following arrival. Travel context, as either transition between national team matches or returning to clubs, also appeared to influence the perceptual state upon arrival. Fatigue, soreness and recovery ratings were lower following travel back to club teams compared to travel between national team matches. This finding was also previously observed in the study 2 of this thesis where perceptual fatigue, sleep, soreness, and total wellness scores were lower up to 3 days after travel out of national teams compared to travel into national teams or between national team matches. This may relate to athletes returning to clubs at the end of a national team camp having experienced multiple national team matches and travel bouts in a relatively short period of time. Accordingly, for players transitioning back to club teams from national teams, additional strategies to maintain sleep during travel are highly recommended (Janse Van Rensburg et al. 2020), while recovery interventions that can be implemented during periods of (Querido et al. 2022) may further benefit the athlete.

Due to the potential need to compete again within 3 days after national team matches, a secondary aim of this study was to explore how long after a match travel occurred and the effects on post-match recovery 3 days after a national team match. Longer travel demands in this study appeared to affect perceptual recovery from matches, with athletes reporting poorer perceptual recovery scores on MD+3 when post-match travel demands were longer. This is a novel finding, as no other studies have compared an athlete's post-match recovery at a standardised time point based on differing post-match travel requirements, recognising players travel at different times following the match. Poorer recovery ratings when required to travel longer durations may, in part, be associated with reductions in sleep duration and quality that have been frequently reported during long-haul travel (Doherty et al. 2023; Fowler et al. 2017a; Fowler et al. 2017b; Fullagar et al. 2016). However, as sleep duration or quality during travel was not recorded in this study, further research is necessary. In addition to the duration of travel, post-match fatigue, sleep, and recovery ratings on MD+3 were worse in athletes who travelled east than those who travelled west. As discussed previously, eastward travel is likely to result in delayed sleep onset caused by jet lag, which has previously been observed to reduce sleep duration (Fowler et al. 2017a). Reductions in sleep because of this may further exacerbate feelings of fatigue from matches and impair post-match perceived recovery status. Based on the findings of this study, it appears that longer post-match travel durations, particularly in an eastward direction, may impair recovery from national team match play and result in poorer ratings of recovery 3 days after a match. This poses a concern for athletes who are required to compete within 3 days after their national team match, and recovery tools that can be applied during travel are recommended.

A concern amongst practitioners of national football teams often revolves around whether it is better to travel immediately after a match or wait and allow athletes time to recover from the match prior to travelling. Athletes in this study reported poorer sleep on MD+3 when travelling later out of the match compared to earlier, while the timing of travel had no effect on any other perceptual recovery measures. Better sleep scores on MD+3 when departing earlier after a match may be related to having more time to adapt to the destination time zone and recover from sleep deficits associated with long-haul travel. As such, if athletes are required to compete again shortly after a match, travelling earlier may allow adaptation of sleep schedules to occur earlier. However, as this is the first study to explore the relationship between the timing of travel relative to a match and match recovery, further research is needed to support this finding.

While the findings of this study may inform practitioners of the influence of travel and match load on perceptual recovery after national team matches, several limitations should be considered. The population used within this study represented only a single national team, and thus, variation may be expected from other national teams who are likely to have their own unique travel demands and strategies. Additionally, as evidenced by low R^2 values, the variation in perceptual recovery measures used in this study is only explained to a small extent by travel and match-related factors. Other influences on perceptual recovery from matches and travel are likely to exist and should be considered when monitoring athletes travelling post-match. Furthermore, this research only considers air travel requirements as data was not available for other forms of transport. Lastly, the design of this study meant that the research team had no control over what the athletes did before, during or after travel, nor over the use of recovery strategies post-match.

6.6 Practical Applications

- Elevated high-speed match-running demands are likely to affect perceptual fatigue, sleep and soreness ratings following travel after national team matches.
- Athletes may require additional support following travel back to clubs after national team matches due to poorer perceptual recovery, fatigue, and soreness than travel between national team matches.
- Perceptual recovery on MD+3 following travel is negatively impacted by longer post-match travel durations, while travelling later after the match may have negative impacts on sleep on MD+3.

6.7 Conclusions

In conclusion, this study was the first to determine the combined influence of travel and match demands on perceptual recovery, fatigue and sleep following post-match travel. Increased high-speed match running in the prior national team match was associated with poorer perceptual recovery, fatigue, sleep and soreness upon arrival from travel. Additionally, travelling from the national team back to the club was associated with poorer ratings of recovery, fatigue and soreness compared to travelling between national team matches, while travelling eastward was associated with poorer sleep ratings. In addition, the perceptual recovery status on day 3 after a national team match appeared to be negatively affected by longer post-match travel demands. Lastly, travelling later after a match was associated with poorer sleep ratings at MD+3. When monitoring the athletes travelling after national team matches, practitioners should be aware of both prior match loads and travel demands of their athletes. Additionally, for athletes who are required to compete again within 3 days of their prior national team match, travel-friendly recovery strategies are recommended to maximise post-match recovery.

Chapter 7: Study 5

Mobile Phone Applications for Managing Jet Lag: A Review of Jet Lag Apps for Travelling Athletes.

7.1 Abstract:

Purpose: For athletes undertaking travel, mobile phone applications (apps) represent a portable tool to guide the implementation of interventions to reduce the effects of jet lag. This study reviewed apps currently available to manage jet lag and identified the type and timing of interventions recommended. A secondary aim compared respective app interventions to assess their similarities for a simulated travel bout.

Methods: A systematic search was undertaken of the Apple App and Google Play stores to identify apps focused on managing jet lag. Data was extracted from apps, which included descriptive information, intervention methodologies, and specific recommendations. Further, a simulated long-haul travel bout was entered into each app to determine the schedule of interventions recommended. Simple Matching Coefficients (SMC) were used to assess the similarity of intervention schedules between apps.

Results: Twelve apps were identified, and the most common method of intervention delivery was by recommendation schedules (33%). The recommended interventions by apps included sleep timing adjustments (42%), timed light avoidance/attainment (33%), and guided acupressure treatments (33%). Peer-reviewed research did not exist for any apps. For a long-haul flight, intervention schedules showed large variation between apps, with mean SMCs of 58% (±18) for light schedules and 78% (±9) for sleep schedules. Post-travel showed SMCs of 57% (±14) for light schedules and 93% (±3) for sleep schedules.

Conclusions: Considerable variation exists in the recommendations of travel apps and their schedules of application. Athletes and practitioners seeking to use travel apps should consider evidence-based guidelines for jet lag interventions when interpreting or using these apps.

7.2 Introduction

As observed in the prior works of this thesis, jet lag and travel fatigue following travel are likely to induce fatigue, reduce sleep quality and impair the recovery of athletes travelling for national football teams. Based on this, interventions to hasten adaptations to new time zones and manage fatigue from travel are commonly recommended in travelling athletes (Rossiter et al. 2023). However, based on principles of chronobiology, the implementation of many jet lag interventions requires carefully planned timing, as incorrect scheduling can not only render an intervention ineffective but may have an opposing effect on the adaptation to the new time zone (Janse Van Rensburg et al. 2021). In national team environments, providing effectively timed interventions for athletes can be challenging, as practitioners must manage the individual plans for many athletes, sometimes travelling from a variety of different locations (Clements et al. 2023). For example, up to 25 different travel plans may be needed for players into and out of national team duties, which places logistical and time challenges on practitioners already preparing of the demands of the international window. To help with this challenge, applications (apps) on mobile devices represent a practical tool to implement interventions for the management of jet lag in a user-friendly and portable format. As such, an in-depth review of the content provided by such apps is needed to assist practitioners wishing to identify appropriate apps and tools to support their travelling athletes. Although several mobile apps exist with a focus on jet lag treatment, the information provided by such apps is unclear and is likely to vary between apps, making it difficult to select an app that meets the needs of athletes.

Current recommendations for travelling athletes focus on the timed manipulation of drivers of circadian rhythms, most commonly light, sleep, and melatonin, to promote faster adaptation to the new time zone and preserve sleep (Janse Van Rensburg et al. 2021). Such interventions have been effective in both lab- (Van Maanen et al. 2016) and field-based studies using athletes (Fowler et al. 2020); however, careful planning and strict adherence to protocols are generally required. One of the challenges of implementing such protocols in high-performance sporting environments is the complexity of managing the intervention schedules of multiple athletes, each with their own travel demands and sleep patterns. Furthermore, in national football teams, athletes often travel independently of their support team and thus the adherence to intervention protocols must be athlete driven. Apps for jet lag management may represent an effective medium to individualise and implement travel interventions for athletes. However, the content provided by such apps, or the manner of its delivery has not been reviewed and therefore the alignment with current evidence-based guidelines is unclear.

While applications for jet lag present a practical tool to provide tailored information and guidance to athletes, the control and regulation of mobile apps is minimal, and thus, the information provided can vary significantly. Although limited research exists in athletic contexts, the content of mobile apps to treat various health conditions has been previously explored. In a review of weight management apps, significant variation in practices implemented between apps and a low level of adherence to evidence-based practices was reported (Rivera et al. 2016). Likewise, in diabetes self-management apps, several components of clinical guidelines for diabetes self-management were lacking from the apps available (El-Gayar et al. 2013). While several mobile apps have been designed to treat symptoms of jet lag and travel fatigue, there has been no examination of the content provided, nor how the content aligns with current evidence-based guidelines, to guide the use of apps for travelling athletes. Given the complexities of circadian realignment strategies and the potential for detrimental effects on performance if jet lag (or travel fatigue) is poorly managed, further research is needed to assist practitioners looking to identify tools to assist their travelling athletes. Accordingly, this study has two aims. Firstly, to review current apps available to manage jet lag and identify their interventions and recommendations. Secondly, to compare the interventions of apps for a simulated travel bout and assess their similarity.

7.3 Methodology

Systematic Search

A systematic search was undertaken in October/November of 2023 to identify apps with a focus on managing jet lag and its symptoms. Both the Google Play and Apple App stores were searched using the following search terms: "jet lag", "jetlag", and "travel fatigue". Each term was searched in both app stores, and all results were screened. Screening was conducted based on the title of the app, the in-store app description and any screenshots of the app included in the store description. For an app to be included in the final review, the following criteria had to have been met: (1) The app had a focus on managing jet lag or fatigue from travel, (2) the app provided recommendations for the user to undertake before, during or after travel, (3) the app was written in English or had an English translation. If it was unclear whether an app met the inclusion criteria, the app was downloaded for further assessment.

Once the final selection of included apps was determined, the apps were downloaded onto either an IOS (Apple iPhone 6s, Software 15.8.1) or Android (Google Pixel 4, Android 13 Software) device. Where apps had versions existing on both the Apple App Store and Google Play store, the app was downloaded and reviewed on the IOS device.

Data Extraction

Data was extracted from each app by two independent reviewers, with disagreements resolved by a third reviewer. Two custom app information extraction tables were developed; one focused on descriptive information relating to the app, and another focused on the recommendations provided by the app. The following descriptive information was obtained from each app: 1) App Name, 2) App Developer, 3) Platform (IOS and/or Android), 4) Last update, 5) Payment model, and 6) User rating on both Apple App and Google Play Stores. The apps were also coded for the delivery method in which they provided recommendations. The following delivery methodology categories were established based on the initial screening of apps: intervention schedule, guided acupressure, guided audio, timed light flashes, and sleep alarm.

The second information extraction table focused on the information and methods provided by the app. The following information was obtained from each app: 1) Timing of interventions, 2) Intervention recommendations, 3) Whether the app asked for the user's chronotype, 4) Whether the app asked for the user's sleep/wake times, and 5) Whether the app was peer-reviewed. The timing of interventions was categorised as either pre-flight, during flight, or post-flight based on when recommendations were provided relative to the flight (recommendations during layovers were considered during flight). All intervention recommendations used by the app were obtained and coded based on the following codes: seek light, avoid light, sleep, nap, sleep alarm (the app provided a self-adjusting sleep alarm), consume melatonin, consume caffeine, avoid caffeine, consume meal, guided audio, compression stockings, electrostimulation, acupressure, and exercise. To determine whether an app had been peer-reviewed, the app name, along with the search terms “mobile” and “travel OR jet lag,” was searched in two databases (Google Scholar and PubMed).

Trip Comparisons

For the second aim comparing the recommendations between apps, a single common trip was entered amongst the 4 intervention scheduling apps (Timeshifter, Flykitt, Gowwiz, and Perform Away). The trip used was a two-legged trip including a flight from London (GMT time zone) to Singapore (Dep. 19:55h, Arr. 17:45h, Duration. 13h50min), a 1h40min layover, and then a 2nd flight from Singapore to Sydney (AEDT time zone) (Dep. 19:25h, Arr.06:15h, Duration. 7h50min). The total duration of the trip was 23h 20min, and the time zone difference between departure and arrival locations was +11h. The start time for each schedule in the app was standardised to begin from 8 am on the morning of the first travel day. The normal wake time for each app was set to 07:00, and the normal bedtime was set to 23:00. A chronotype of neither morning nor evening type was used (when required by the app). The recommendations of each app for each hour across two 48h periods were obtained, with the first period starting from 07:00 (departure time zone) on the morning of the first travel day and the second period starting from 07:00 (arrival time zone) on the first day after arrival in the new destination. Based on what the included apps provided, the following recommendations (and their timing) were extracted for each hour: consume caffeine, avoid caffeine, seek light, avoid light, sleep, nap, consume meal, and consume melatonin.

To examine the variation between intervention schedules provided by apps, the similarity of schedule was compared between each app using the simple matching coefficient (SMC) (Verma & Aggarwal 2020). For both during-travel and post-travel schedules, a separate SMC was calculated for both light therapy recommendations and sleep-related recommendations for each possible pairing of apps. The SMC in intervention schedules was calculated as the number of times an hour time block provided the same recommendation from the two apps. SMC score was converted to a percentage by multiplying by 100. Higher percentages, therefore, represented a greater similarity between app recommendations. The mean and standard deviation of similarity scores were then calculated across all possible combinations of apps to provide an idea of the overall similarity between app schedules.

7.4 Results

App Descriptive Information

Descriptive information for all identified apps is presented in Table 7.1, with 12 apps meeting the inclusion criteria. Of the 12 apps, 4 existed on both Android and IOS systems, 3 were Android exclusive, and 5 were IOS exclusive. 10 of the 12 included apps had received an update within the last 12 months. Payment models for apps varied, with 6 apps requiring no cost, 2 apps requiring a one-time purchase, 2 apps providing payment per-trip options, and 3 apps offering a subscription service. Only 2 apps had received over 100 reviews on either mobile store, and 6 apps had no user reviews. The most reviewed app across both Android and IOS systems was Timeshifter, with an average user rating of 4.6/5 (Apple Store) and 4.3/5 (Google Play Store). The methodology used to treat jet lag varied, with 4 apps providing intervention schedules, 3 apps providing guided acupressure treatments, and 2 apps providing sleep-adjusting alarms. Other treatment methodologies included guided audio and timed light flashes from the phone torch.

Table 7.1. App descriptive information.

App Name	Developer	Platform	Last Update (Android)	Last Update (IOS)	Payment	User Rating (IOS)	User Rating (Android)	App Methodology
Timeshifter	Timeshifter Inc.	IOS, Android	16/12/2022	19/12/2022	Yearly Subscription or Per Trip Payment	4.6 (145)	4.3 (667)	Intervention Schedule
Uplift	Uplift Ventures	IOS, Android	21/09/2023	22/09/2023	Monthly or Yearly Subscription	5 (117)	2.3 (117)	Guided Acupressure
Flykitt	Kitt Bio Inc.	IOS	N/A	21/09/2023	Per Trip Payment	4.6 (42)	N/A	Intervention Schedule, Supplement kit
ByeByeJetLag	Pina De Rosa	IOS, Android	30/12/2022	3/01/2023	One time purchase	5 (23)	N/A	Guided Audio
Jet Lag Fix	Young Design Labs	IOS	N/A	5/12/2023	Monthly Subscription	4.3 (8)	N/A	Guided Acupressure
Gowwiz	Gowwiz	IOS, Android	15/08/2023	18/08/2023	One time purchase	5 (1)	N/A	Intervention Schedule
Jet Lag Buster	Ruval Enterprises	Android	30/03/2023	N/A	Free	N/A	N/A	Timed Light Flashes
Gentle Jet Lag	Dr Alexander Rieger	Android	23/08/2023	N/A	Free	N/A	N/A	Sleep Schedule
Jet Lag Helper	Coding with Jaz	Android	18/07/2022	N/A	Free	N/A	N/A	Guided Acupressure
Fight Jet Lag	Zajno Inc.	IOS	N/A	28/10/2020	Free	N/A	N/A	Sleep Schedule
Jetlag - Time zone	EDGAR ROSSANT	IOS	N/A	21/09/2023	Free	N/A	N/A	Sleep Schedule, Meal Schedule
Perform Away	Institut national du sport du Quebec	IOS	N/A	11/09/2023	Free	N/A	N/A	Intervention Schedule

Interventions & Methods

Details of each app's intervention methods are shown in Table 7.2. The timing of interventions by apps included 58% of apps providing pre-flight interventions, 50% providing interventions during travel, and 66% of apps providing post-flight interventions. The timing of interventions was unclear in one of the apps. The most common interventions were "going to sleep" (42%) or "adjusting scheduled sleep time" (42%). Specifically, timed naps were also recommended by 17% of apps. Light therapy interventions were also common, with 33% providing recommendations to "avoid light" at certain times and 25% providing recommendations to "seek light" at certain times. Timed melatonin consumption was recommended by 25% of apps, and timed caffeine consumption was recommended by 17% of apps. Only 1 app (8%) recommended avoiding caffeine consumption at certain times. Of the apps, 33% recommended the use of acupressure treatments to manage jet lag symptoms. Other interventions provided by apps included scheduled meal timings (17%), timed exercise (8%), and the consumption of supplements designed to manage symptoms (8%). The collection of information relating to the user's chronotype and sleep/wake behaviour varied between apps. For example, information relating to the user's normal sleep and wake times was obtained by 50% of apps and only 25% of apps requested information about the user's chronotype. Lastly, no peer-reviewed and published research existed regarding the effectiveness of any of the apps included in this review.

Table 7.2. Details of app functionality and features.

App Name	Timing of Treatments	Intervention Recommendations	Ask for chronotype?	Ask for sleep/wake times?	Peer Reviewed?
Timeshifter	Pre-flight, During flight, Post-flight	Seek Light, Avoid Light, Sleep, Nap, Consume Caffeine, Avoid Caffeine, Consume Melatonin	Yes	Yes	No
Uplift	Post-flight	Acupressure	No	No	No
Flykitt	Pre-flight, During flight, Post-flight	Meal Timing, Consume Caffeine, Avoid Light, Sleep, Adjust Bed Time, Consume Melatonin, Wear light blocking glasses, Electrostimulation, Compression Stockings	No	Yes	No
ByeByeJetLag	During flight, Post-flight	Guided Audio	No	No	No
Jet Lag Fix	Pre-flight, During flight, Post-flight	Acupressure	No	No	No
Gowwiz	Pre-flight, During flight, Post-flight	Adjust Bed Time, Seek Light, Sleep, Nap	Yes	Yes	No
Jet Lag Buster	Unclear	Scheduled Light Flashes (phone torch)	No	No	No
Gentle Jet Lag	Pre-flight	Adjust Bed Time	No	No	No
Jet Lag Helper	Unclear	Acupressure	No	No	No
Fight Jet Lag (JetLag)	Post-flight	Adjust Bed Time, Consume Melatonin	No	Yes	No
Jetlag - Time zone (Jetlag)	Pre-flight	Meal Timing, Adjust Bed Time	No	Yes	No
Perform Away	Pre-flight, During flight, Post-flight	Other, Seek Light, Avoid Light, Sleep, Compression Stockings, Electrostimulation	Yes	Yes	No

Trip Comparisons

The timings of intervention recommendations by the apps on the day of travel are shown in Figure 7.1. The similarity percentage for light and sleep-related schedules is shown in Table 7.3. During travel, the average similarity between apps was 58% (±18) for light schedules and 78% (±9) for sleep schedules. Two apps recommended seeking light in the morning of travel (Timeshifter 7:00 AM- 4:00 PM, Gowwiz 7:00 AM - 8:00 AM GMT), while one app recommended avoiding light in the evening prior to departure (Flykitt 5:00 PM - 7:00 PM GMT). Light schedules during the flight differed between all 4 apps. Light schedules during travel included seeking light from 2:00 AM - 2:00 PM GMT (Timeshifter), avoiding light from 3:00 AM - 5:00 AM GMT and seeking it from 5:00 AM - 7:00 AM GMT (Gowwiz), avoiding light from 4:00 AM - 7:00 AM GMT and again from 10:00 AM - 12:00 PM GMT (Flykitt), and lastly seeking light from 2:00 AM - 5:00 AM GMT and avoiding it from 5:00 AM - 8:00 AM GMT (Perform Away). Immediately following arrival in Sydney (6:00 AM AEDT), one app recommended to seek light from 11:00 AM AEDT onwards, while two apps recommended to seek light after 2:00 PM AEDT (3:00 AM GMT). Lastly, one app recommended to avoid light from 5:00 - 6:00 PM AEDT. Sleeping during the initial hours of the flight was recommended by 3 of the 4 apps (8:00P M up to 2:00 AM GMT), while two of the four apps also recommended sleeping in the latter stages of the flight (Timeshifter 3:00 PM - 6:00 PM GMT; Flykitt 12:00 PM - 5:00 PM GMT). One app recommended the use of a nap following arrival (8:00 AM - 11:00 AM AEDT).

Table 7.3. Simple Matching Coefficient percentage between app intervention schedules.

During Travel

Light Recommendations				**Sleep Recommendations**			
	Gowwiz	Flykitt	Perform Away		Gowwiz	Flykitt	Perform Away
Timeshifter	47%	29%	47%	Timeshifter	65%	86%	-
Gowwiz		76%	78%	Gowwiz		82%	-
Flykitt			71%	Flykitt			-
		Mean:	58% (±18)			**Mean:**	78% (±9)

Post Travel

Light Recommendations				**Sleep Recommendations**			
	Gowwiz	Flykitt	Perform Away		Gowwiz	Flykitt	Perform Away
Timeshifter	61%	49%	41%	Timeshifter	96%	-	94%
Gowwiz		71%	43%	Gowwiz		-	90%
Flykitt			76%	Flykitt		-	-
		Mean:	57% (±14)			**Mean:**	93% (±3)

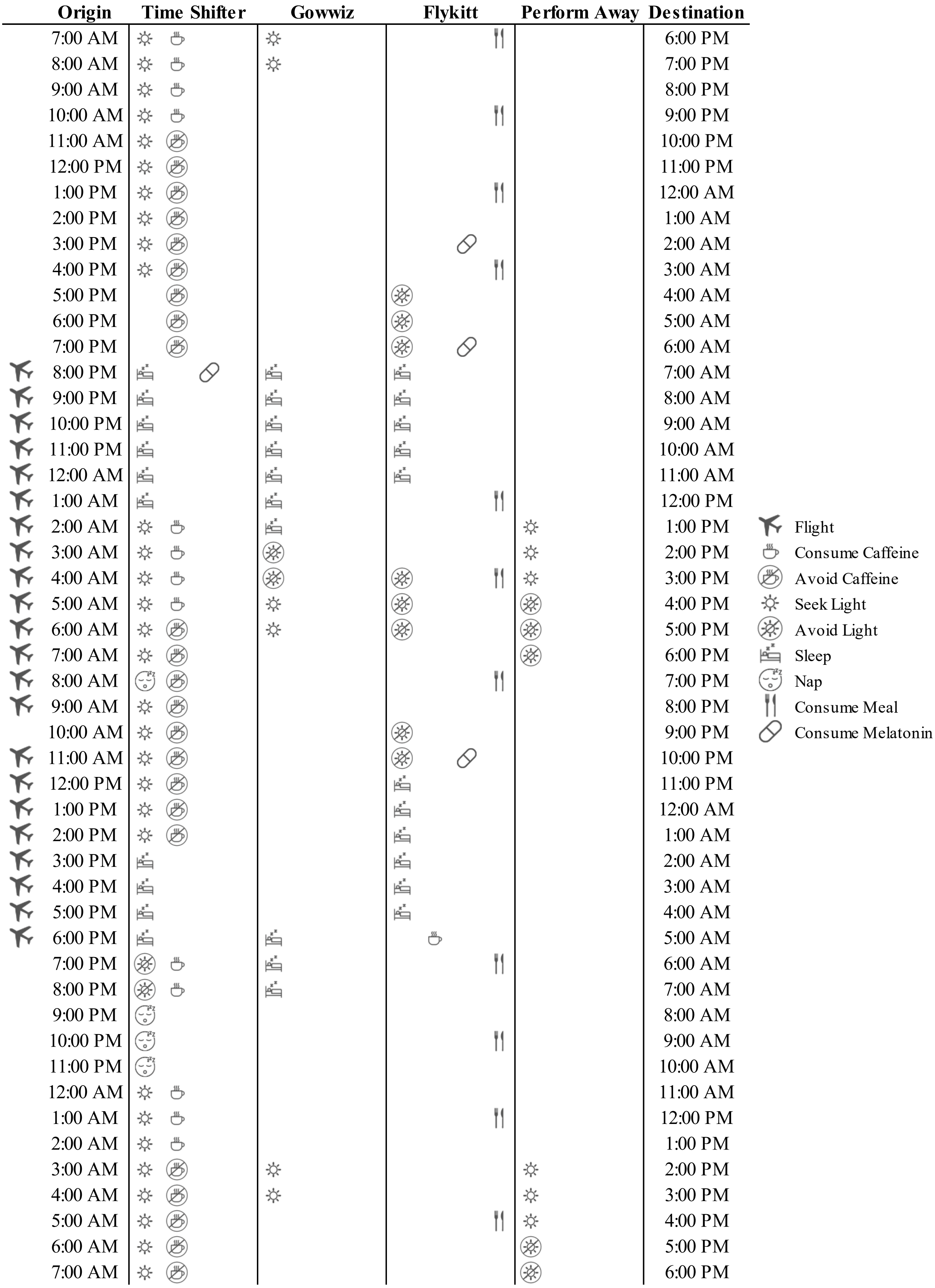


Figure 7.1. Comparison of recommendations between apps on the day of a flight from London to Sydney (+11 time zones).

Post-travel intervention schedules are shown in Figure 7.2. On the day after arrival, the average similarity between apps was 57% (±14) for light schedules and 93% (±3) for sleep schedules. Two of the included apps recommended avoiding light at the start of the day (Timeshifter until 10:00 AM AEDT; Gowwiz until 1:00 PM AEDT), while two apps provided no morning light guidelines. One app recommended to seek light in the early evening (4:00 PM - 7:00 PM AEDT) before avoiding light from 7:00 PM until sleep. Three of the four apps recommended avoiding light prior to sleep periods. Post-travel sleep periods were similar between 3 of the apps, while one app provided no sleep guidelines following arrival. The start of sleep ranged from 10:00 PM to 1:00 AM AEDT. All three apps that provided sleep schedules recommended waking at 7:00 AM AEDT.

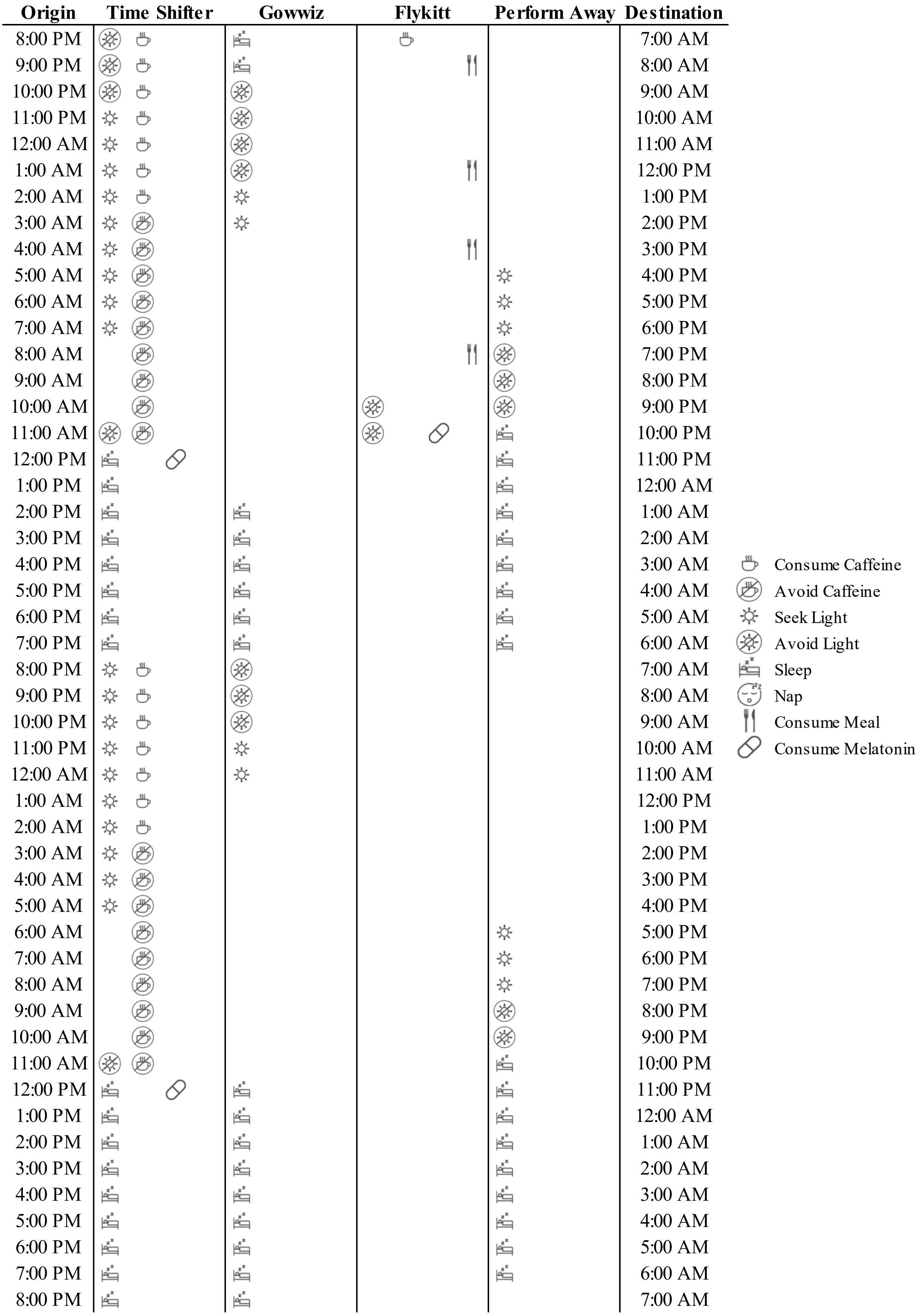


Figure 7.2. Comparison of recommendations between apps for first two days after arrival (starting 2 days after departure) from a London to Sydney flight (+11 time zones)

7.5 Discussion

This review analysed the current mobile apps available to manage jet lag and its symptoms and assessed the recommendations that may be provided to travelling athletes. Although mobile apps to combat symptoms of jet lag and travel may be useful tools, practitioners should be aware of the differing recommendations and interventions that are provided as significant variations exist in the treatment methodology and delivery provided by apps. The most common recommendations for jet lag and travel fatigue symptoms were adjustment of sleep routines, scheduled light exposure/avoidance, acupressure treatments, and the scheduled consumption of melatonin or caffeine. Of note, there is a complete lack of published and peer-reviewed research to support the effectiveness of any current apps that aim to combat jet lag, especially for travelling athletes. Additionally, despite the timing of interventions being crucial to jet lag treatment, the provided treatment schedules varied considerably between apps. Athletes and practitioners seeking to use mobile applications to manage jet lag should undertake their own research and consider their own needs.

As an overall summary, 12 different apps existed at the time of review, though a large variation existed between designs and the popularity of the apps. The most common method of delivery for jet lag interventions was through prescribed treatment schedules (4/12 apps), which provided users specific times to undertake certain actions that either assist in adapting to a change in time zone or alleviate symptoms of jet lag. Another common method of delivery was through a simple sleep schedule (3/12 apps), which provided users with guidance on when to sleep and adjust their sleep times but did not include any other recommendations. The use of such scheduling recommendations in apps is supported by research evidence demonstrating that the manipulation of circadian zeitgebers, including light and sleep, can help induce faster phase shifts following travel across multiple time zones (Roach & Sargent 2019). Interestingly, another common method of jet lag management provided by apps was guided acupressure treatments (3/12 apps). Given the absence of peer-reviewed research supporting the use of acupressure to manage symptoms of jet lag, such apps require careful consideration if used by travelling athletes.

Current recommendations for athletes travelling for competition often focus on the manipulation of light exposure/avoidance to hasten the adaptation to a new time zone (Janse Van Rensburg et al. 2021). Light therapy was used as a tool to manage jet lag by 5 of the 12 apps; however, of the 5 apps, only 3 provided schedules of when to both seek and avoid light. One app only recommended when to seek light, and one app only recommended when to avoid light. This is a concern as incorrectly timed light exposure may have the opposite effect on circadian adaptation (Arendt 2009; Mitchell et al. 1997). The use of light schedules to hasten the adaptation to a change in time zone has been one of the most widely researched methods to manage jet lag (Janse Van Rensburg et al. 2020). Several laboratory studies have reported successfully speeding the adaptation to a new time zone using correctly timed light exposure (Van Maanen et al. 2016). Additionally, a combined intervention that included sleep hygiene and light therapy strategies was also shown to be effective in improving post-travel physical performance in a field-based study using trained individuals travelling 21h east across 8 time zones (Fowler et al. 2020). However, several field-based studies have also reported no impact of light therapy on physical performance responses following travel of 7h across 5 time zones (Thompson et al. 2012) and 24h of simulated travel and 11h time zone change (Fowler et al. 2015b). Of the 5 apps that provided light schedules, all 5 obtained information about the user's sleep-wake schedules, and 3 also obtained information about the user's chronotype. This information may be important for the apps to tailor the recommendations to the user's own circadian rhythm in the absence of a more accurate circadian marker; however, it is unclear how this information is used by the apps to adjust scheduling. As light-based interventions are one of the most well researched methods to treat jet lag, athletes travelling could consider the use of one of the apps that include light-scheduling in their treatment methodology.

Due to the importance of sleep for athletic performance (Walsh et al. 2021), strategies that aim to minimize disruptions to sleep both during and after travel are commonly recommended for travelling athletes. Of the 12 apps reviewed, 7 included the adjustment of sleep times or sleep schedules as a part of their jet lag management. The current recommendation for travelling athletes is to move scheduled bed time up to 1h per day towards the direction of sleep in the new time zone (Janse Van Rensburg et al. 2021). In addition to sleep adjustments for the new time zones, it is also recommended to maximise sleep when possible during travel and consider a "sleep window" based on departure time zones (Janse Van Rensburg et al. 2021). Only 3 apps provided guidance on when to sleep during flights, with all three apps suggesting sleep during the initial stages of travel (biological night). In addition to night time sleep, strategic napping has also been observed to have potential benefits on cognitive performance in jet-lagged athletes (Petit et al. 2018), while several studies have also reported positive effects of napping on physical performance, cognitive performance and perceptual fatigue in sleep-restricted athletes (Lastella et al. 2021). Despite this, only 2 apps included naps as a strategy to manage jet lag and travel fatigue symptoms. As such, while sleep adjustments post-travel were commonly used in apps, only a few apps also provided guidance on when to sleep during travel and when to nap after travel.

Although field-based studies in athletic populations are limited, the consumption of exogenous melatonin is an effective strategy to reduce jet lag in adults and adjust circadian rhythms (Janse Van Rensburg et al. 2020). Despite this, only three apps recommended the consumption of melatonin to manage jet lag, with only two of those apps providing individualised guidance on the time of consumption based on travel details. The lack of melatonin guidance by apps is likely due to the limitations of prescribing pharmaceutical medication without specific knowledge of the individual's circadian rhythms, and thus, the risk of negative side effects. Given that poorly timed melatonin consumption may have a negative effect on sleepiness and adaptation to a new time zone, practitioners should seek medical advice prior to the use of melatonin (or any pharmacological intervention) to confirm the app recommendations for alignment with current guidelines (Janse Van Rensburg et al. 2021). In addition to exogenous melatonin, caffeine consumption has also previously been observed to improve alertness following travel in healthy populations (Janse Van Rensburg et al. 2020), though inappropriate timing may have negative impacts on sleep (Beaumont et al. 2004). As such, the consumption and avoidance of caffeine is a commonly recommended guideline for travelling athletes (Janse Van Rensburg et al. 2021). Only 2 apps assessed in this study recommended the consumption of caffeine at certain times after travel; however, only one app provided specific guidance on when caffeine should be avoided.

Other less common interventions provided by some of the apps included adjustments in meal timings, wearing compression stockings during travel, and electrical stimulation devices during travel. Meal timing adjustments were provided by 2 of the included apps. Although evidence is limited (Janse Van Rensburg et al. 2020), one randomised control trial in flight crew has identified setting regular meal times following travel to reduce ratings of perceptual jet lag (Ruscitto & Ogden 2017). Two of the apps included in this review also included instruction to use compression stockings and electrical stimulation during travel. Previous studies assessing the use of compression wear during travel have observed improvements in physical performance, subjective alertness, fatigue and soreness when compared to control groups following travel of 6h (Kraemer et al. 2016) and 9h (Broatch et al. 2019) duration. While no travel-specific studies exist for the use of electrical-stimulation, previous research has identified positive effects on post-exercise perceptual muscle soreness (Malone, Blake & Caulfield 2014). As such, while the use of these additional interventions may provide some support to travelling athletes, further research is needed to support their usefulness and justify such recommendations in jet lag management apps.

The secondary aim of this study was to compare the treatment schedules across multi-intervention apps and identify the level of similarity in the recommendations provided. Despite identical travel and individual profile details being input into the 4 compared apps, recommendations provided by apps varied considerably. On average, light therapy schedules provided by apps showed only 58% (±18) similarity during travel and 57% (±14) similarity post-travel. Given that the effectiveness of light in adjusting circadian rhythms is dependent on the appropriate timing of light attainment and avoidance (Bin, Postnova & Cistulli 2019), the variation observed between apps further highlights concerns about what information would be provided to travelling athletes. The timing of sleep windows showed similarity between apps with SMCs of 78% (±9) during travel and 93% (±3) after arrival. The greater similarity in sleep schedules likely reflects the similar strategy employed by apps, with apps appearing to focus on sleeping to the departure time zone during travel and adjusting sleep to the arrival time zone immediately post-arrival. Although a sleep hygiene intervention including this strategy produced greater sleep duration during travel in athletes (Fowler et al. 2020), optimal sleep strategies during travel are still unclear, and further research is required to justify this strategy employed by most of the apps. Regardless, due to the variability between app information, further research is needed to identify the effectiveness of each different app's management plan to reduce jet lag in travelling athletes.

7.6 Conclusions

In summary, the findings of this study highlight that although several apps exist with the potential to manage jet lag in travelling athletes, there is considerable variation in the information and recommendations provided. The most common app formats included providing intervention schedules, guided acupressure treatments, and self-adjusting sleep alarms. The most commonly employed recommendations to manage jet lag were sleep schedules, light therapy, acupressure, and melatonin consumption. There remains a lack of supporting peer-reviewed evidence on the effectiveness of apps to reduce symptoms of jet lag and/or travel fatigue. Lastly, within apps that provided multi-intervention management schedules, significant variation existed between light therapy guidelines, highlighting the need for further evidence to identify the effectiveness of apps in reducing jet lag in athletes. For practitioners seeking to manage jet lag in their athletes, apps that include guidance on both light and sleep time adjustments may be useful, while the inclusion of other interventions such as melatonin, caffeine, and napping may provide additional benefit (Janse Van Rensburg et al. 2021). However, practitioners should consider their own needs and the current scientific research when selecting an app to use for their athletes.

Chapter 8: Discussion

8.1 Overview

Travel is a frequent and recurring dilemma for national football teams (Clements et al. 2023) given the potential for detrimental effects on athlete preparation, performance and recovery (Rossiter, Warrington & Comyns 2022). For national teams, this raises concerns about athletes' arrival into camp, ensuing preparation for international matches, post-match travel, and recovery upon returning to club teams. For each national team camp, athletes within a national team are required to travel to and from various locations, thus having their own individual travel demands. As a practical example, flights for a team of 24 players in one camp window ranged from <1h across no time zones to 26h across 10 time zones, with players based across Europe, Asia, North America, and Australia. Therefore, the diverse nature of travel demands within a single team requires individualised planning that addresses the specific travel each individual athlete experiences.

From a research perspective, while comparisons have been made between extremes of long and short-haul travel (Fowler, Duffield & Vaile 2015; Mitchell, Pumpa & Pyne 2017; Thornton et al. 2018), the effects of trips across the full range of travel durations, time zone differences, flight schedules, and flight paths are unclear. Further, current research on travelling athletes has focused predominantly on singular trips without comparisons between different flights, and hence, limited research exists using a diversity of flights and travel demands (Rossiter, Warrington & Comyns 2022). Additionally, the current focus of travel research on physical performance outcomes and detailed measures of sleep and jet lag (Rossiter, Warrington & Comyns 2022) is impractical for national football teams where often only simple perceptual measures and in-camp physical performance data are available (McCall et al. 2015). For practitioners working with national teams, a more detailed understanding of how specific trips and travel factors influence perceptual fatigue, sleep, and recovery, as well as physical and technical match performance, will assist in identifying athletes at risk of poorer responses to travel and guide interventions and strategies to minimise the effects.

8.2 Variations in Travel Demands and their Influence on Perceptual Wellbeing

The extent and nature of the travel undertaken largely influences the specific effects of travel on an athlete. Negative effects of travel can result from multiple mechanisms, including jet lag, travel fatigue, and sleep disruption, with the extent of each being influenced by different factors associated with the trip (Janse Van Rensburg et al. 2021). Despite this, due to a lack of studies assessing large quantities of different flights in the same cohort, the nuanced effects of different travel factors are difficult to apply to practical settings, given the diversity of travel demands encountered. For national football teams, monitoring responses to travel is often undertaken using perceptual scales that can be completed before, during and after players are in camp (McCall et al. 2015). Therefore, the first two studies of this thesis explored the perceptual responses of international footballers across a broad range of travel situations as part of national team duties. The effects of each observed travel factor and the perceptual well-being measures they affect will be discussed below.

8.2.1 Travel Duration and Time Zone Change

Larger time zone differences are expected to contribute to greater symptoms of jet lag, while longer travel durations may increase feelings of travel fatigue and have a greater impact on sleep schedules (Fowler, Duffield & Vaile 2015; Thornton et al. 2018). The first study of this thesis identified that national team footballers who travelled across 9 or more time zones reported significantly poorer perceptual fatigue, sleep, and soreness on the first 2 days after arrival than those travelling across <6 time zones. For athletes travelling across <9 time zones, fatigue scores were significantly greater on the first day of arrival compared to the second, suggesting that for flights with smaller time zone durations, perceptual fatigue scores recovered quickly once settled into the new environment. In contrast, the fatigue and sleep scores of athletes travelling across 9 or more time zones remained elevated on Day 2 compared to baseline and were not significantly different to Day 1.

The sustained increase in fatigue and decreased sleep quality reported in athletes travelling 9 or more time zones suggest an effect of jet lag, with athletes requiring more time to adapt to the larger time zone change. Such a finding is similar to prior works comparing 24h vs 5h of simulated travel in physically trained populations (Fowler, Duffield & Vaile 2015) and travel across 1 time zone vs 6-11 time zones in wheelchair basketball athletes (Thornton et al. 2018). These studies both observed greater perceived fatigue and reduced vigour after the long-haul journey compared to the short-haul. In study 1, the greater effect of a 9 time zone change and faster recovery of smaller time zone changes is a novel finding. These findings highlight that while longer travel demands are expected to produce poorer perceived fatigue and sleep responses, this effect is most pronounced once athletes travel across 9 or more time zones and thus strategies to manage symptoms of jet lag and hasten adaptation are likely necessary for these individuals.

8.2.2 Travel Direction

Based on principles of chronobiology, travelling eastward is expected to produce more significant and longer-lasting symptoms of jet lag (Janse Van Rensburg et al. 2021). Study 1 in this thesis identified that across 355 different flights, eastward travel was associated with poorer perceptual sleep and fatigue ratings in national team athletes. Previously, a comparison between an 8h eastward time zone difference and 8h westward time zone difference found a reduction in sleep and poorer jet lag and function ratings in eastward travel for physically trained individuals (Fowler et al. 2017a). As such, the findings of this thesis provide further support for the detrimental effect of eastward travel on athlete sleep and fatigue by comparing a broader range of travel demands. The cause of poorer sleep quality and elevated fatigue following eastward travel in the footballers observed in this study is unclear. Slower circadian adaptation is expected to an eastward time zone change (Janse Van Rensburg et al. 2021); hence, across the 3 days measured, the internal circadian rhythms and sleep routines of athletes travelling eastward may have been further out of alignment with time cues of the external environment with the external environment. Additionally, Fowler et al. (2017a) found athletes to report delayed sleep onset and reduced time in bed following eastward compared to westward travel. As such, it is also possible that athletes in the current national team research experienced poorer perceived sleep quality due to difficulties attaining sleep combined with a lack of time in the morning to make up for delayed sleep onset. As such, practitioners working with national teams should be aware of players' sleep patterns when travelling eastward and develop strategies to improve sleep quality following travel.

8.2.3 Flight Path

For national teams where players are located at clubs in a variety of different countries, monitoring responses to common flight paths may represent a practical way to consider the influence of multiple travel variables. Within the second study of this thesis, flight paths from Europe to Australia and Asia to Europe were associated with poorer perceptual jet lag and fatigue ratings, while Europe to Australia flights were also associated with poorer sleep. The poorer jet lag, fatigue, and sleep ratings associated with Europe to Australia travel align with the first study's findings, whereby larger time zone changes and eastward travel were associated with similar changes in perceptual ratings. Given that this flight path commonly occurred prior to matches, practitioners should aim for athletes to arrive as early as possible to adapt to the new time zone, improve sleep and alleviate fatigue. Where early arrivals are not possible, providing interventions to maintain sleep during travel and improve alertness and fatigue on arrival may be important for limiting impacts on training and performance (Janse Van Rensburg et al. 2020).

Interestingly, athletes in this study also reported poorer jet lag and fatigue when travelling from Asia to Europe. This was unexpected as this travel does not involve as great a time zone shift and occurred in a westward direction. However, the difficulties associated with this flight schedule likely highlight the importance of other contextual factors surrounding travel. This flight path predominantly occurred at the end of a national team camp after players had competed in two international matches, undergone multiple travel bouts, and spent up to two weeks away from home. Given that perceptual sleep ratings were unaffected by this flight path, it is plausible that accumulated fatigue from the national team camp may explain this finding. Similar fixture congestion of 2 and 3 games in a single week has been reported to produce poorer subjective wellness and recovery scores in both junior (Hattersley et al. 2018) and senior professional footballers (Lundberg & Weckström 2017). Although accumulated travel is expected to increase fatigue in athletes (Janse Van Rensburg et al. 2021), the only study to explore the effects of frequent travel reported no differences in perceptual wellness between home vs away matches in the late season phases, suggesting season-long accumulated travel fatigue did not contribute to poorer subjective wellness scores (Fowler et al. 2015c). However, travel demands in the previous study were short (<5h) and spread across an entire season, making comparisons to the acute long-haul travel congestion observed in this study difficult. As such, while flight paths may be used to monitor travelling national team athletes, consideration should still be given to other contextual factors surrounding the trip.

8.2.4 Arrival/Departure Time

The departure and arrival times of flights may have implications for the sleep windows of travelling athletes and influence the extent of sleep disruption before, during and after travel.

National team footballers observed in this thesis reported better sleep on the 2 days after a daytime (11:00-17:00) arrival when compared to a morning (05:00-11:00) or evening (17:00-23:00) arrival. Additionally, daytime arrivals were associated with reduced fatigue compared to morning arrivals. Similar findings were reported in Olympic athletes and support staff following a 24h flight, with participants who arrived in the early afternoon reporting less jet lag and fatigue on the first two days on arrival compared to those who arrived at 06:00 (Waterhouse et al. 2005). The authors of this study suggested that the longer duration between normal nighttime sleep for those who arrived in the morning may have extended periods of sleep deprivation and contributed to greater jet lag and fatigue. While this may explain the poorer responses following morning arrival in our study, it conflicts with the negative effects of evening arrivals that were also observed. The negative effect of evening arrivals could be attributed to additional requirements following arrival that further delay the bedtime of athletes and thus impact sleep quality. However, further research is needed to explore this, and it is likely highly individualised to the context and the person. These findings suggest that a middle-of-day or early afternoon arrival may be optimal for athletes travelling for national teams. If flight schedules do not permit this, practitioners with national teams should consider using daytime naps following morning arrivals or extending sleep periods in the morning following evening arrivals.

8.2.5 Travel Context

For national football teams, concerns arise not only from players travelling into camp but also between camps/matches and return travel to clubs. A novel finding of this thesis was that following travel back to clubs at the end of national team camps, athletes reported greater fatigue, soreness and poorer sleep than when travelling to national teams or between national team matches. This finding may reflect an accumulation of fatigue that athletes may experience by the end of a national team camp. During national team windows, players will often play 2 games within the space of ~5 days, and thus, acute fixture congestion may partially explain the poorer perceptual scores at the end of camps. Supporting this, poorer soreness and recovery status ratings were observed in youth footballers after a 2 match game week compared to a single-match game week (Hattersley et al. 2018), while a 3 match game week resulted in poorer soreness compared to a one-match game week in senior professional footballers (Lundberg & Weckström 2017). In addition to the match demands, athletes at the end of national team windows may experience up to 3 flights in a two-week window, potentially imposing an effect of travel fatigue accumulation. Although travel fatigue has been suggested to accumulate over multiple trips (Janse Van Rensburg et al. 2021), currently, no research exists comparing responses to multiple travel bouts in short time frames. Thus, further research is needed to support this view. Together, these findings highlight the need to provide additional support to athletes departing national teams; in particular, interventions to improve sleep and recovery during travel may be useful to improve post-match recovery and strategies to manage accumulated travel demands may also be important.

8.2.6 Age/Experience

Although the effects of a travel bout are influenced by the nature of travel, the response to each trip will also differ between individuals. This thesis identified the age and playing experience of the individual to be associated with travel responses. For example, this thesis observed older athletes travelling with the national team to report greater subjective jet lag than younger athletes, while those with more national team appearances (and therefore greater national team travel experience) reported less subjective jet lag. Age has previously been suggested to have a negative effect on jet lag symptoms (Moline et al. 1992); however, the individuals within our study were much younger (mean age 28.2 ±3.5) than the older group these suggestions are based upon (37-52 years). In similarly aged professional footballers, no association of age on jet lag symptoms was reported following a 10h flight across 1 time zone (mean age 27±2)

(Fowler et al. 2015a) or a 19h flight across 11 time zones (mean age 26±4) (Fowler et al. 2017b). However, despite differences in the effects of age, both prior studies reported a similar effect of having greater match experience on reduced symptoms of jet lag after travel. As such, our findings on the association between national team caps and jet lag symptoms further emphasise the importance of educating inexperienced athletes on strategies to manage travel related stresses. This may be of particular importance to those working with junior national teams, in which youth athletes may have little travel experience both inside and outside of national team environments. Further, variation in individual response may also be expected based on an individual's chronotype (Janse Van Rensburg et al. 2021; Rossiter et al. 2023), however, such data was not available from athletes in this thesis.

8.2.7 Which perceptual scales can be used to monitor travel responses?

The first two studies of this thesis have identified several travel and individual-related factors that contribute to poorer perceptual responses to travel. A summary of the factors affecting each perceptual variable is conceptually represented in Figure 8.1. Based on analyses undertaken in studies 1 and 2, perceptual fatigue and sleep quality scales appeared to be the most responsive to variations in travel demands. Poorer fatigue and sleep responses were observed with longer travel demands, particularly with time zone changes >9h, or after Europe to Australia travel. Further, these scores were also worse on Day 1 after arrival when athletes arrived in the early morning or late evening. Travel direction also affected sleep quality, with poorer sleep observed after eastward trips. As such, where perceptual wellness scales are used to monitor national team footballers following periods of travel, the scales of perceived fatigue and sleep quality are recommended as the most informative to monitor. However, it is important to recognise such scales' limitations, as they lack a conceptual framework and have limited validation research (Jeffries et al. 2020). Additionally, such scales are likely to be influenced by other non-travel-related factors, as evidenced by the relatively low R^2 values (0.07-0.26) of models in our studies. Thus, caution should be taken when interpreting outcomes. However, despite the concerns around single-item perceptual scales, they are widely used throughout elite athletic populations (McCall et al. 2015; McGuigan et al. 2021; Neupert et al. 2022). As such, our research may further assist the interpretation of athlete responses and has demonstrated that these scales are indeed responsive to variations in travel demands and may provide insight into how an athlete responds to travel.

Adding a single item perceived jet lag scale may provide important value for national football teams as R^2 values (0.15-0.46) of models in study 2 indicated this scale to be more responsive to variations in travel than other perceptual wellness measures. Poorer perceived jet lag scores may be expected when athletes undergo greater time zone changes, as observed by the increase in perceived jet lag following Europe to Australia travel (9-10 time zones) compared to all other flight paths. In addition, this scale was associated with age and national team experience, with older and less experienced players reporting poorer jet lag scores. The R^2 value of the subjective jet lag model of 0.48 was much higher than the 0.07-0.26 observed for models on perceptual wellness scales in both studies 1 and 2. As such, this scale may represent a more specific measure of travel response in national team athletes. Although the use of a single-item version of the Liverpool John Moore University's Jet Lag Scale may oversimplify symptoms of jet lag (Waterhouse et al. 2002), the full version of the scale is unlikely to achieve compliance with national team athletes due to the time burden required to complete the scale regularly. As such, the findings of our study are useful in that they identify a simplified single-item version of the scale will provide better insight into travel responses than perceptual wellness scales alone and remain a practical and easy-to-implement tool for national football teams.

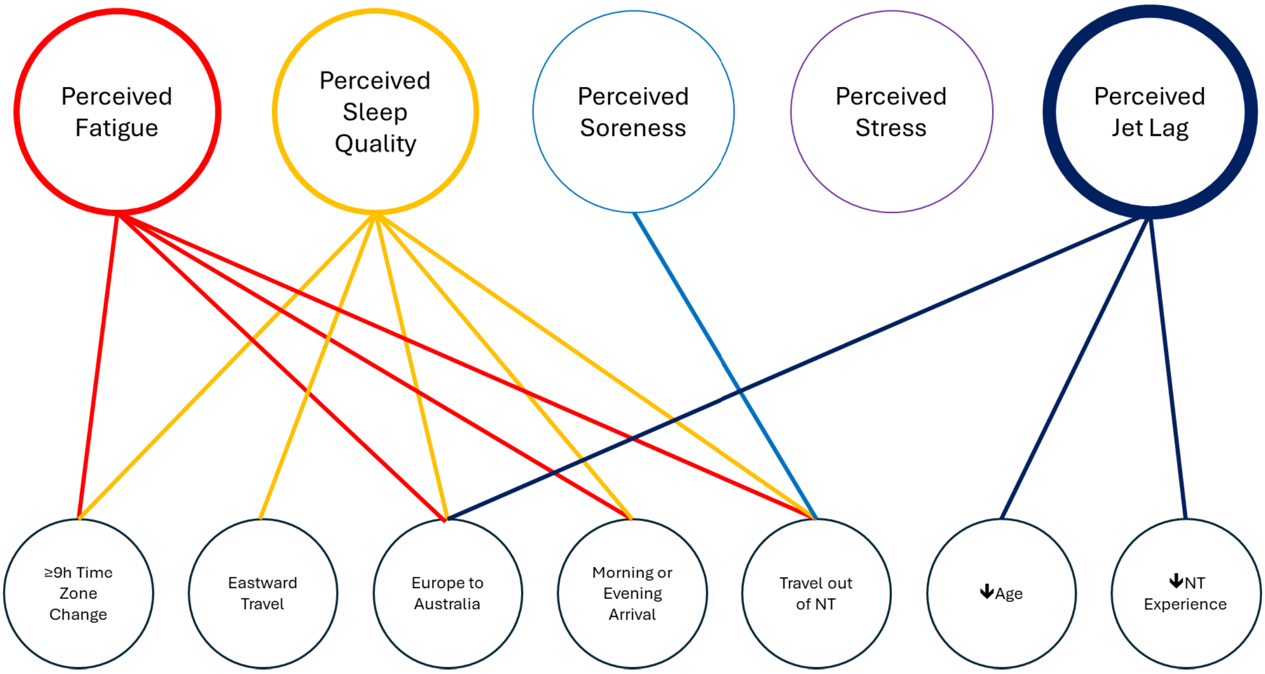


Figure 8.1. Travel and individual factors that negatively influence perceptual responses to travel in professional footballers.
NOTE: Thickness of circles around outcome variables conceptually represents an increased magnitude of R^2 (explained variance).

8.3 Camp Arrival – Travel and Training Concerns for Match Performance

Congested fixture scheduling is common for international footballers, and thus, only short (≈3-day) windows often exist between an athlete's arrival at a match location and the match. Given that travel can have negative effects on measures of physical and cognitive performance (Rossiter, Warrington & Comyns 2022) and detrimental effects on fatigue, sleep, and jet lag were also observed in the first two studies of this thesis, identifying whether pre-match travel demands affect match performance is of interest to national team practitioners. While travel has been frequently suggested to impair the match performance of athletes, evidence for this effect is limited.

Currently, research on the effects of travel on football performance has been limited to home and away comparisons in domestic football leagues where travel demands are short. Poorer technical and tactical performance was observed in away matches (Travel Duration 3.1h-7.5h) compared to home matches in the Australian domestic league; however, the authors suggest this was largely attributable to away match disadvantage, as fatigue and sleep ratings of athletes were similar (Fowler, Duffield & Vaile 2014). Likewise, reduced high-intensity and sprint distance were observed in Brazilian domestic footballers in matches requiring travel >520km; however, travel demands were short, and the extent to which away disadvantage influenced these findings is unclear. In international Rugby tournaments, reductions in several key technical performance indicators have been observed following eastward long-haul travel, though they have not yet been reported in football contexts. Therefore, prior research in this area does not represent the context of national football teams, whereby travel can vary considerably between individuals competing within the same match. Accordingly, study 3 of this thesis aimed to leverage the large flight dataset available to identify whether variations in travel duration, direction, and the time between arrival and a match, would influence the physical and technical performance of athletes competing in international football matches.

8.3.1 Pre-match Travel and Match Performance

Eastward travel in our study was associated with increased total and high-speed running distance completed in matches. These findings contrast with observations in Rugby 7s players, where reductions in running performance measures were observed in tournaments requiring eastward travel compared to no travel (Ullersperger et al. 2022). Following an eastward trip, greater fatigue may be expected, as observed in studies 1 and 2, due to the additional challenges associated with advancing circadian rhythms (Forbes-Robertson et al. 2012). However, increased match-running performance, particularly high-speed distance, as observed in our study, is inconsistent with a fatigue effect associated with jet lag symptoms. Furthermore, additional analysis revealed that match day fatigue, sleep and soreness scores were similar between eastward and westward flights. While further research is needed, the lack of negative effect on match running in our data may also be influenced by the arrival time of the athletes. Recovery of intermittent sprint performance has previously been observed to take 2 days after travel of 21h duration. In contrast, maximal sprint and countermovement jump have been reported to return to baseline by day 4 and 3, respectively (Fowler et al. 2017a). Although the arrival timeframe of the previously mentioned Rugby 7s study is unclear, athletes within our study arrived at least 40h (≈2 days) in advance of matches for shorter travel demands and earlier if longer travel was required. As such, it is possible that athletes in our study had sufficient time to recover from travel demands to a level where match performance was unaffected.

An alternative explanation to the differences in match performance between directions in the current thesis may be that more players tended to travel eastward into matches against better-quality opposition (Mean FIFA Rankings: Eastward travel; 76 ± 35, Westward Travel; 135 ± 39). This is supported by prior works identifying greater opposition quality to be associated with increased match running (Trewin et al. 2017). As such, for the travel demands and timelines of athletes in our study, travel was unlikely to influence match-running performance.

Although match-running performance measures were greater after eastward travel, the pass accuracy of athletes was reduced. This observed reduction in pass accuracy is similar to reports in international Rugby tournaments, where reductions in ball carries, metres gained, and total passes were associated with eastward but not westward travel (24h across 12 time zones) (Lo et al. 2019a). Furthermore, in the same population group, eastward travel was associated with fewer wins and fewer points scored (Lo et al. 2019b). Previous research, therefore, suggests that an impairment in technical performance may occur as a result of greater jet lag symptoms from eastward travel. However, the reduction in passing accuracy observed in our research may also be influenced by greater opposition quality following eastward travel, with previous research in football reporting greater opposition quality to be associated with poorer pass accuracy (Varley et al. 2017). The lack of difference in match-day fatigue, sleep and soreness scores between travel directions in our population further supports this. As such, while reductions in technical performance were observed after eastward travel, further research is required to affirm whether this effect is related to jet lag and fatigue from travel.

8.3.2 Post-Arrival Training and Match Performance

Although travel into matches appeared to have minimal effect on match performance, small associations existed between training loads on arrival and match-running performance. Greater total high-speed distance loads on the three days after arrival from travel were associated with greater total- and high-speed distance covered in matches. This finding is consistent with previous works in club environments, where positive relationships between pre-match training loads and match-running loads have been observed (Guerrero-Calderón et al. 2021; Modric, Versic & Sekulic 2021; Silva & Nobari 2021). While this finding may be partially associated with variations in pre-match training loads to reflect tactical variations in matches, it also highlights the importance of assisting players to recover from travel demands into camp and hasten training readiness. Interestingly, in a separate study using the same population group as this thesis, elevated subjective fatigue ratings were associated with reductions in high-speed training load following arrival into the national team camp, while training loads were also lowest in the first two days following travel (Gould et al. 2024) Such findings likely highlight a periodised approach from national team staff to reduce training loads while athletes recover from travel-related fatigue. Given studies 1 and 2 identified elevated fatigue on arrival from various travel demands, strategies to manage symptoms of fatigue following extensive travel demands into national teams may prove useful in promoting readiness to train. Overall, where significant pre-match travel demands are expected, ensuring athletes are able to manage jet lag and maintain sleep is essential for the appropriate accumulation of training loads.

8.3.3 When to arrive for national team matches

Ensuring adequate time to recover from travel demands and prepare for upcoming matches is necessary for national team performance; however, the effect of arrival times on match performance has previously not been explored. Reductions in countermovement jump performance have previously been reported up to 4 days post a 21h flight across 8 time zones, while maximal sprint ability was reduced up to 3 days after, and intermittent sprint ability up to 2 days after in physically trained individuals (Fowler et al. 2017a). Likewise, in a similar population, sprint and countermovement jump performance was reduced for 2 days after a 24h simulated travel bout (Fowler, Duffield & Vaile 2015). However, our study observed limited effects of travel on physical and technical match performance in international footballers, with these athletes arriving at least 40h in advance of matches, and often earlier for longer travel demands. The first two studies of this thesis observed sleep and fatigue ratings to return to baseline by day 2 after arrival for flights across ≤9 time zones. This is consistent with previous research where sleep and fatigue were reported to be at baseline by 48h post travel following a 22.6h journey (Stevens et al. 2018), a 21.5h journey (Doherty et al. 2023), and 24h of simulated travel (Fowler, Duffield & Vaile 2015). Although we observed perceptual jet lag to remain elevated on day 3 after the longest travel demands (>9 time zones), athletes on these trips tended to arrive earlier, and the lack of difference in match-day perceptual wellness scores between different travel demands suggests these athletes arrived with sufficient time to recover from travel. As such, these findings suggest that the athletes in our study arrived early enough for travel demands to have minimal impact on performance in international football matches, with most athletes arriving at least 40h in advance of matches or earlier for longer travel demands.

8.3.4 Summary – Considerations for Athlete Arrival in National Teams

This thesis has contributed several novel findings that may inform practitioners and assist in decision-making surrounding arrival in national football teams prior to matches. The primary aim for most flights should be ensuring athletes arrive at least 48h in advance of matches; however, earlier arrivals may be required for longer trips (e.g. Europe to Australia). Doing so appears to allow time to recover from poorer sleep and increased fatigue and limit detrimental effects on match performance, whilst respecting the club demands that may limit earlier arrival. Once travel schedules are established, practitioners should be aware of athletes whose travel requirements will likely result in poorer perceptual well-being (Table 8.1). Specifically, this includes athletes who are required to travel eastward, have longer time zone differences, or are arriving in the late evening or early morning, as these athletes may experience more significant detrimental effects of travel on sleep and fatigue. Assisting these athletes to overcome these symptoms will promote readiness to train, with the appropriate accumulation of training loads potentially influencing physical match performance. Lastly, given pre-travel match loads were observed to impact fatigue, sleep and soreness post-travel, information regarding prior match load, either from club or national team matches, should also be used to inform training and recovery plans surrounding athlete arrival.

Table 8.1. Travel Factors that influence the arrival state of athletes travelling into national football teams.

Travel Factor	Potential Effect on Athlete
Time zone change ≥ 9h	↑ Fatigue ↓ Sleep
Eastward Travel	↓ Sleep
Early Morning Arrival (05:00-11:00)	↑ Day1 Fatigue ↓ Day1 Sleep
Evening arrival (17:00-23:00)	↓ Day1 Sleep
Night arrival (23:00-05:00)	↑ Day1 Fatigue
Travel out of the national team	↑ Fatigue ↑ Soreness ↓ Sleep
Large high-speed match load pre-travel	↑ Fatigue ↑ Soreness ↑ Stress ↓ Sleep ↓ Recovery Status

8.4 Post-Match Travel

Travel is a common occurrence within 24h after a national team football match, and thus, athletes are placed under significant physical and physiological stress from the combination of match load and travel demands back to clubs. This scenario is likely to impact fatigue and recovery timelines, and, given that subsequent club-based matches can occur within 2-3 days, it may impact player availability and selection decisions. Despite this, current research has not explored the impact of match loads and subsequent travel on professional footballers' recovery, fatigue and sleep. As such, the 4th study of this thesis aimed to identify the influence of pre-travel match load and travel demands on athlete recovery and fatigue.

8.4.1 Post-Match Travel – Factors influencing perceptual fatigue and recovery

Understanding the influence of prior match load and travel demands on post-match fatigue and recovery may inform recovery strategies and player availability following post-match travel. Match high-speed running loads appear to influence athlete recovery upon arrival, with elevated match load being associated with poorer perceived recovery, fatigue, soreness and sleep responses. In previous work, match high-speed running demands have been observed to be negatively associated with MD+1 fatigue, soreness and sleep measures in male professional footballers (Oliveira et al. 2023), and MD+2 energy, stress, and total wellness scores in academy footballers (Evans et al. 2022). The athletes in our study arrived back at home locations ≈38.9h (± 12.3) after match kick-off; thus, the findings of this study align with the perceptual recovery timelines of these prior works. In our athletes, perceptual soreness and recovery scores were also worse when athletes were travelling back to their club when compared to between national team matches. For many of these return trips, athletes would have competed in two international matches in the space of ~5 days and undergone multiple travel bouts, and as such, accumulated fatigue from match congestion and travel demands may explain these findings. Poorer soreness and recovery status ratings were observed in male youth footballers for up to 72h after a 2-game match week compared to a 1-game match week (Hattersley et al. 2018), while a 3-match week resulted in poorer soreness compared to a 1-match week in male professional footballers (Lundberg & Weckström 2017). For national team footballers, the short-term accumulation of multiple travel bouts may also contribute to this; however, as no studies exist exploring the effects of accumulated travel on recovery, further research is needed to support this theory.

In addition to match loads, travelling eastward after matches was associated with poorer sleep quality scores on arrival. Greater jet lag symptoms are expected following eastward travel (Janse Van Rensburg et al. 2021), and shorter sleep duration has been previously observed in physically trained individuals following an 8h eastward time zone change, when compared to equivalent westward travel (Fowler et al. 2017a). Similarly, reduced total sleep time was observed in travelling academics following eastward but not westward travel with time zone changes from 7-11 hours (Takahashi, Nakata & Arito 2002). Our research findings, therefore, build on the evidence for additional challenges to sleep that may be expected following a significant eastward time zone shift after a match. For practitioners working with national teams, this reduction in sleep quality following eastward post-match travel is significant as sleep loss may negatively affect recovery from match loads (Kölling et al. 2016; Rae et al. 2017). As such, strategies to assist athletes in maintaining sleep quality in the days after an eastward post-match trip may help promote better recovery from international matches (Fowler et al. 2020).

8.4.2 Does travel impair match-recovery?

In national football teams, requirements to travel (often long-haul) soon after matches are common, creating suboptimal conditions for recovery from international matches and potentially slowing the recovery process. To assess match recovery, our study compared the match day +3 responses of athletes based on travel demands, with this timepoint selected as it represents one of the earliest possible timeframes for subsequent (club) matches. Athletes within the 4th study reported poorer perceived recovery status on match day +3 when they were required to travel for longer durations post-match. This is a novel finding as prior research has yet to compare athletes' match-recovery based on different travel demands. While an increase in markers of muscle damage has been observed following a 5h flight after a simulated team sport match (Kraemer et al. 2016), only a single common flight was observed. Thus, the influence of travel on this response is unknown. Although recovery responses to travel have not been previously explored, reductions in sleep duration have been consistently reported during flights of >18h duration (Doherty et al. 2023; Fowler, Duffield & Vaile 2015; Fowler et al. 2017a; Fullagar et al. 2016; Stevens et al. 2018). Such reductions in sleep may potentially negatively affect recovery from football matches. As further evidence, reduced overall recovery ratings were observed in Olympic rowers following a night of reduced sleep during a training camp (Kölling et al. 2016), while being limited to half of normal sleep duration after a training session was associated with increased sleepiness, decreased, motivation and decreased physical performance in trained cyclists (Rae et al. 2017). As such, strategies to maintain sleep quantity and quality may be essential in promoting the recovery of athletes required to travel for long durations after international football matches.

In addition to the longer travel duration, eastward travel was associated with poorer fatigue and recovery status ratings on MD+3. While recovery responses to travel directions have not been reported, greater sleep duration reductions have been observed for 3 days following eastward compared to westward travel across 8 time zones (Fowler et al. 2017a). This is consistent with subjective sleep quality responses observed in our first study, with poorer sleep quality after arrival observed following eastward compared to westward trips. These findings suggest that poorer sleep following arrival from eastward travel may impair post-match recovery and highlight the need for interventions that target the maintenance of sleep following eastward travel. Overall, the findings of our study suggest long-haul travel, particularly in eastward directions, may cause slower recovery following matches, with reduced recovery ratings observed 3 days after the international match. Therefore, additional time to recover from matches may be necessary for these athletes, while interventions to maintain sleep and promote recovery during travel are recommended.

8.4.3 When should athletes depart?

In addition to identifying the effects of specific travel demands on post-match recovery, this thesis also explored whether the amount of time between a match and travel departure influenced recovery. As schematically represented in Figure 8.2, leaving later after a match reduced sleep quality on MD+3 but had no other effect on perceptual recovery measures. Reduced sleep following later departures is likely a result of having spent less time in the new destination and, therefore, having had less time to adjust to time zone changes and settle into the new environment. As such, the implication here is that where additional matches are required shortly following travel, departing sooner after the first match may assist athletes in adapting sooner and alleviating potential sleep difficulties earlier. If there is sufficient time between matches, later departures had no other effect on perceptual recovery measures. Thus, decisions on whether to travel immediately or spend time recovering prior to travel may be dictated by other factors such as available facilities and player preference. However, as this is the first research to compare match recovery responses between different travel demands, further research is needed to support these findings.

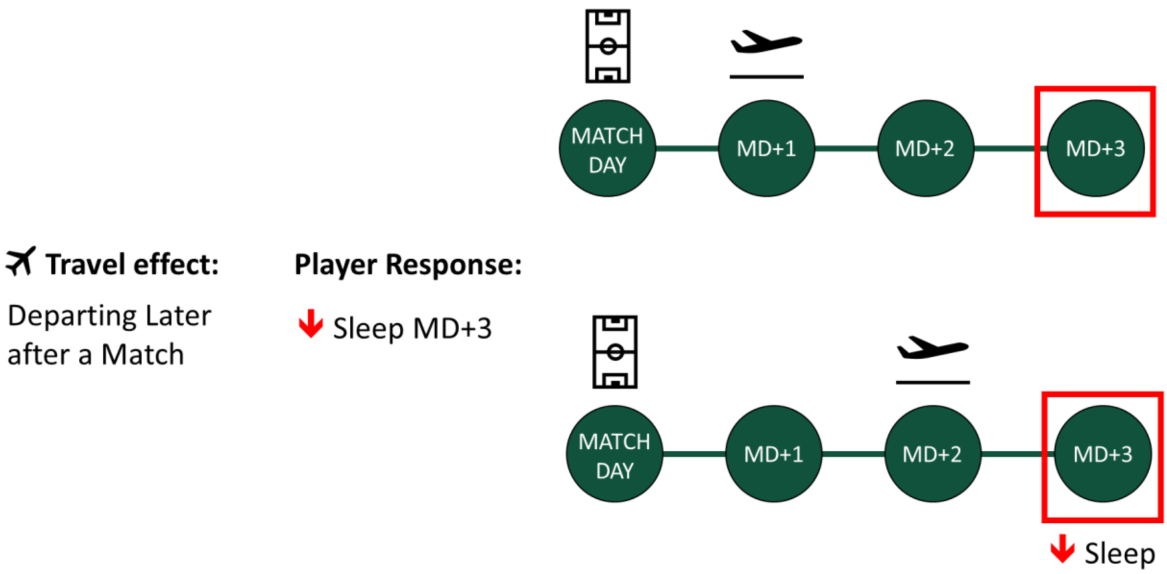


Figure 8.2. Schematic representation of the influence of time of departure on perceptual sleep quality

8.5 Jet Lag Mobile Applications and their potential use for national teams

The first 4 studies of this thesis have highlighted the importance of providing individually tailored advice to each athlete travelling for national team competition. In turn, supporting travelling athletes is an important process for practitioners, although the logistical and time challenges to produce individual travel advice for each player may not be possible. Further, as players are often required to travel without support staff, the development, dissemination and compliance of this guidance can be difficult. As a potential supporting mechanism, mobile phone applications focused on jet lag and travel management may represent a practical and accessible tool for national teams, as individualised guidelines could theoretically be provided without direct interaction with support staff. However, mobile phone applications are poorly regulated, and no prior research has reviewed the content provided by such apps or how they align with current evidence-based recommendations. Accordingly, the final study of this thesis aimed to review all available jet lag and travel management mobile applications and explore the strengths and limitations regarding their potential use for national football teams.

8.5.1 Overview of Current Applications to Manage Jet Lag in Athletes

At the time of review, 12 apps were identified with a focus on managing jet lag, with large variations in the content and methodology used. The most common method of content delivery used by mobile apps was intervention schedules (4/12 apps), with apps delivering specific times to undertake sleep-related actions and light-based jet lag treatments. These apps represent the most promising method to manage jet lag in travelling athletes, with current guidelines recommending sleep and light interventions (Janse Van Rensburg et al. 2020). Several other app methodologies existed, including acupressure treatments and timed light flashes from the phone torch. Given that no peer-reviewed research exists to support such interventions, these apps are not recommended for national team athletes. As such, while several apps exist for travelling athletes, practitioners should check the content provided by a specific app before its use and ensure that the methodologies employed by the app are supported by current evidence-based research.

8.5.2 Limitations of Current Applications

While several apps were identified with underlying theories supported by current peer-reviewed research, no peer-reviewed evidence exists assessing the effectiveness of any specific app. The use of light- and sleep-based interventions similar to those employed by the reviewed apps has received mixed support from the scientific literature. Fowler et al. (2020) reported improved physical performance post-travel when using a combined light and sleep hygiene intervention in physically trained participants travelling 21h across 8 time zones (Fowler et al. 2020). However, other studies have reported no effect of similar interventions following travel of 7h across 5 time zones (Thompson et al. 2012) and 24h of simulated travel with an 11h simulated time zone change (Fowler et al. 2015b). Given that the effectiveness of light-based therapy to alleviate jet lag is dependent on the appropriate timing of the attainment and avoidance of light (Bin, Postnova & Cistulli 2019), a major limitation of current mobile apps, therefore, is the lack of peer-reviewed research supporting the specific schedules provided by any of the included apps. Furthermore, large variation existed between the schedules provided by apps, with light schedules sharing only 58% (±18) average similarity during travel and 57% (±14) average similarity post-travel. In comparison, sleep schedules shared 78% (±9) during travel and 93% (±3) after arrival. This variation between apps further highlights the need for practitioners to check app interventions and ensure that the schedules provided align with evidence-based recommendations. Given concerns about the information provided in unregulated travel apps, players, coaches, and support staff need to further understand the expected travel responses based on trip demands to guide appropriate interventions. A summary of these responses and findings of this thesis are provided in the following chapter.

Chapter 9: Summary & Practical Applications

9.1 Thesis Aims

Travelling into and out of international camps and matches is a complicated challenge for practitioners of national football teams, as athlete travel demands within a single tournament can vary from short-domestic trips to long-haul transmeridian journeys (Clements et al. 2023). While several studies have reported detrimental effects of travel on physical performance, perceptual wellness, and sleep (Rossiter, Warrington & Comyns 2022), these studies provide insight into only a single flight. Due to differences in methodologies between studies, comparisons between a range of travel demands make it difficult to inform athletes, coaches and support staff. As such, it is currently unclear when travel becomes detrimental to athlete preparation, performance and recovery. Further, most research relating to travel has focused on physical performance measures and detailed measures of sleep and jet lag, which are impractical for national football teams, where athletes are often based outside of their representative country. Current national team practices require simple monitoring scales that athletes can regularly complete remotely (McCall et al. 2015). The challenges associated with national football teams and the lack of applicable literature have formed the basis for the five studies in this thesis.

This thesis aimed to explore different travel-related variables and their respective association with measures of perceptual well-being, physical and technical match performance, and post-match recovery. The first two studies aimed to explore how different travel variables are associated with perceptual jet lag, fatigue, sleep, soreness, and stress in the first 3 days after arrival from travel. Specifically, study 1 aimed to identify the effects of time zone difference and travel direction, while study 2 explored the effects of flight path, arrival/departure time, and the travel context (outbound, transition or return). Study 2 also aimed to identify whether athlete age or national team experience influenced responses to travel demands. Following this, study 3 aimed to explore travel into national team matches and its effects on physical and technical match performance. Specifically, this study aimed to identify whether variations in travel duration, time zone difference, travel direction, or the time between arrival and the match influenced running or technical performance outcomes. To finalise explorations on the effects of different travel demands, study 4 focused on variations in post-match travel and the influence on perceptual recovery from international matches and subsequent travel demands. This study analysed whether variations in travel duration, time zone difference, travel direction, and the time between the match and travel departure influenced perceptual recovery, fatigue and sleep measures both relative to arrival (first 3 days post-arrival) and a standardised post-match time point (Match Day +3). Finally, athletes are often required to travel independently for national football teams; hence, study 5 sought to review currently available mobile phone applications for managing jet lag and travel fatigue, assess their content provided, and evaluate their usefulness for travelling national team athletes.

9.2 Key Findings

The below represents a summary of the key outcomes of each study:

Study 1

- An increase in the number of time zones crossed during travel had a negative effect on perceptual fatigue, sleep, soreness and total wellness scores.
- Significantly worse perceptual fatigue and sleep scores were observed when crossing >9 time zones compared to travel crossing <6 time zones.
- Perceptual fatigue and sleep scores remained elevated 2 days after travel across >9 time zones; however, for shorter travel demands, fatigue and sleep returned to baseline by day 2
- Travelling in an eastward direction resulted in poorer perceptual sleep scores than travelling in a westward direction.

- R^2 values for models were low (0.07-0.18), indicating that the variance in perceptual wellness scores explained by travel-related factors is low.

Study 2

- A single-item perceived jet lag scale resulted in higher R^2 values (0.48) than all perceptual wellness scales (0.15-0.26), thus, representing a more appropriate tool for monitoring travel responses.
- Europe to Australia travel resulted in poorer perceived jet lag, fatigue, and sleep scores than other travel routes.
- National team footballers reported poorer perceptual fatigue, sleep quality, and soreness when travelling from national teams to clubs, compared to travel into national teams or between national team locations.
- Poorer perceived fatigue was observed on the day after travel when athletes arrived in the morning (05:00-11:00) or night (23:00-05:00), while perceptual sleep ratings were worse following morning (05:00-11:00) or evening (17:00-23:00) arrivals.

Study 3

- Athletes tended to arrive at least 40h in advance of matches and tended to arrive earlier for longer travel demands.
- In this study, travel appeared to have minimal effect on footballers' physical or technical match performance.
- Eastward travel was associated with an increase in total and high-speed distance covered during matches and a reduction in pass accuracy; however, this is likely due to differences in opposition quality between travel directions.

- Increases in training high-speed distance were associated with increases in match high-speed distance and decelerations.

Study 4

- Increased high-speed match load prior to travel was associated with poorer perceptual recovery, fatigue, sleep, and soreness on the first 3 days after arrival from post-match travel.
- Athletes travelling eastward after a match reported poorer perceived sleep quality for the first 3 days after arrival.
- Longer post-match travel demands were associated with poorer perceptual recovery status on match day +3.
- Eastward travel was associated with poorer perceived sleep quality, fatigue, and recovery status on match day +3.
- Departing later after a match was associated with a reduction in perceived sleep quality on match day +3 compared to travelling earlier after a match.

Study 5

- Currently, no mobile phone applications focused on managing jet lag are supported by peer-reviewed research.
- The most common formats of mobile applications to manage jet lag were via intervention schedules, guided acupressure treatments, and self-adjusting sleep alarms.
- Adjustments to sleep schedules, timed light avoidance/attainment, acupressure treatments, and timed melatonin consumption were the most common recommendations of jet lag mobile applications.

- Within intervention scheduling apps, large variation exists between the schedules and timing of interventions provided for a single flight.

9.3 Practical Applications

Based on the above summary of findings, the following practical applications have been identified:

- Practitioners should be aware of athletes with the following travel demands, and additional support to maintain sleep both during and after travel and manage symptoms of jet lag is recommended:
    - Time zone change >9h
    - Eastward travel direction
    - Europe to Australia travel
    - Travel from the national team to club
    - Arrival in the morning after overnight travel (05:00-11:00) or evening/night (17:00-05:00)
- For practitioners seeking to monitor athlete responses to travel, using a single-item perceived jet lag scale represents a more specific tool to monitor responses to travel than perceptual wellness measures alone.
- When planning for pre-match travel, aiming to have athletes arrive at a minimum of 40h in advance of matches for shorter trips and earlier for longer travel requirements may help minimise the effects of travel on match performance.
- Following matches, athletes with longer post-match travel demands, especially in an eastward direction, may require additional time to recover from international football matches, and interventions to maintain sleep during travel are recommended.
- If subsequent matches are scheduled within 3-4 days after a national team match, athletes should travel sooner after the match to ensure adequate time to minimise the effects of jet lag and travel fatigue on sleep prior to matches.

- Caution is advised when using mobile applications to manage jet lag in travelling athletes as significant variation exists between apps, and no peer-reviewed research exists supporting their effectiveness. Practitioners should assess the content provided by apps individually and determine whether they align with travel strategies.

9.4 Future Research Directions

Recommendations for future research to build upon the findings of this thesis include:

- Future research should explore the responses to different travel demands in other population groups, particularly female athletes.
- To support travel planning for national teams, comparisons between flight classes (e.g. Economy, Business, etc.) may provide insight into whether better flight conditions improve athlete fatigue, sleep, and recovery responses.
- As this study observed poorer athlete fatigue and sleep responses at the end of national team camps, further research into the effects of multiple trips in a short period and accumulated travel load on perceptual fatigue, sleep, and performance may help better understand the travel contribution to this effect.
- Explorations on the association between travel demands and injury occurrence may further support post-travel planning and injury prevention during national team transitions.
- As the majority of athletes arrived more than 40h in advance of matches in our study, identifying the effects on match performance for arrivals closer to matches may assist in decision-making for worst-case scenario travel.
- Peer-reviewed research is needed to assess the effectiveness of mobile applications in improving post-travel jet lag, fatigue, and sleep in travelling athletes.

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Appendices

Appendix A –Ethics Approval Letter: "The Influence of Travel Duration, Direction and Demands on Fatigue and Stress in National Team Football Players"

Dear Applicant

Re: ETH20-5080 - "The Influence of Travel Duration, Direction and Demands on Fatigue and Stress in National Team Football Players"

Thank you for your response to the Committee's comments for your project. The Committee agreed that this application now meets the requirements of the National Statement on Ethical Conduct in Human Research (2007) and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application.

You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy.

Your approval number is UTS HREC REF NO. ETH20-5080.

Approval will be for a period of five (5) years from the date of this correspondence subject to the submission of annual progress reports.

The following standard conditions apply to your approval:

- Your approval number must be included in all participant material and advertisements. Any advertisements on Staff Connect without an approval number will be removed.

- The Principal Investigator will immediately report anything that might warrant review of ethical approval of the project to the Ethics Secretariat (Research.Ethics@uts.edu.au).

- The Principal Investigator will notify the UTS HREC of any event that requires a modification to the protocol or other project documents, and submit any required amendments prior to implementation. Instructions on how to submit an amendment application can be found here.

- The Principal Investigator will promptly report adverse events to the Ethics Secretariat. An adverse event is any event (anticipated or otherwise) that has a negative impact on participants, researchers or the reputation of the

University. Adverse events can also include privacy breaches, loss of data and damage to property.

- The Principal Investigator will report to the UTS HREC annually and notify the HREC when the project is completed at all sites. The Principal Investigator will notify the UTS HREC of any plan to extend the duration of the project past the approval period listed above through the progress report.

- The Principal Investigator will obtain any additional approvals or authorisations as required (e.g. from other ethics committees, collaborating institutions, supporting organisations).

- The Principal Investigator will notify the UTS HREC of his or her inability to continue as Principal Investigator including the name of and contact information for a replacement.

This research must be undertaken in compliance with the Australian Code for the Responsible Conduct of Research and National Statement on Ethical Conduct in Human Research.

You should consider this your official letter of approval. If you require a hardcopy please contact the Ethics Secretariat.

If you have any queries about your ethics approval, or require any amendments to your research in the future, please don't hesitate to contact the Ethics Secretariat and quote the ethics application number (e.g. ETH20-xxxx) in all correspondence.

Yours sincerely,

Prof Beata Bajorek

Chairperson

UTS Human Research Ethics Committee

C/- Research Office University of Technology Sydney

E: Research.Ethics@uts.edu.au

Ref: E38

Appendix B - Ethics Approval Letter: "Identifying travel and match related factors influencing performance and recovery in national team footballers."

Dear Applicant

Re: ETH22-7708 - "Identifying travel and match related factors influencing performance and recovery in national team footballers."

Thank you for your response to the Committee's comments for your project. The Committee agreed that this application now meets the requirements of the National Statement on Ethical Conduct in Human Research (2007) and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application.

You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy.

Your approval number is UTS HREC REF NO. ETH22-7708.

Approval will be for a period of five (5) years from the date of this correspondence subject to the submission of annual progress reports.

The following standard conditions apply to your approval:

- Your approval number must be included in all participant material and advertisements. Any advertisements on Staff Connect without an approval number will be removed.
- The Principal Investigator will immediately report anything that might warrant review of ethical approval of the project to the Ethics Secretariat.
- The Principal Investigator will notify the Committee of any event that requires a modification to the protocol or other project documents, and submit any required amendments prior to implementation. Instructions on how to submit an amendment application can be found here.
- The Principal Investigator will promptly report adverse events to the Ethics Secretariat. An adverse event is any event (anticipated or otherwise) that has a negative impact on participants, researchers or the reputation of the University. Adverse events can also include privacy breaches, loss of data and damage to property.
- The Principal Investigator will report to the UTS HREC or UTS MREC annually and notify the Committee when the project is completed at all sites. The Principal Investigator will notify the Committee of any plan to extend the duration of the project past the approval period listed above.

- The Principal Investigator will obtain any additional approvals or authorisations as required (e.g. from other ethics committees, collaborating institutions, supporting organisations).
- The Principal Investigator will notify the Committee of his or her inability to continue as Principal Investigator including the name of and contact information for a replacement.

This research must be undertaken in compliance with the Australian Code for the Responsible Conduct of Research and National Statement on Ethical Conduct in Human Research.

You should consider this your official letter of approval. If you require a hardcopy please contact the Ethics Secretariat.

If you have any queries about your ethics approval, or require any amendments to your research in the future, please don't hesitate to contact the Ethics Secretariat and quote the ethics application number (e.g. ETH20-xxxx) in all correspondence.

Yours sincerely,
The Research Ethics Secretariat

On behalf of the UTS Human Research Ethics Committees
C/- Research Office
University of Technology Sydney
E: Research.Ethics@uts.edu.au

Ref: E38

Appendix C – Football Australia Data Consent Letter

23 June 2023

Human Research Ethics Committee
University of Technology Sydney
Broadway Campus, Sydney

To Human Research Ethics Committee,

As Head of Medical for Football Federation Australia, this document serves as an approval letter for Ewan Clements to conduct research using Australian Men's National Team travel, physical running load, technical performance data and perceptual wellness data obtained by Football Australia's National Teams Unit. Approval is granted on the condition that participant anonymity is maintained and reasonable measures are taken to keep confidentiality of personal information.

If you have any queries please feel free to contact me at Mark.Jones@footballaustralia.com.au

Yours Sincerely,

Production Note:
Signature removed
prior to publication.

Dr Mark Jones

Head of Medical Services

Football Australia