

# Medicine & Science IN Sports & Exercise

The Official Journal of the American College of Sports Medicine

www.acsm-msse.org

**. . . Published ahead of Print**

## **Greater Effect of East vs. West Travel on Jet Lag, Sleep, and Team-Sport Performance**

Peter M Fowler<sup>1</sup>, Wade Knez<sup>1</sup>, Stephen Crowcroft<sup>2</sup>, Amy E Mendham<sup>3</sup>, Joanna Miller<sup>4</sup>,  
Charlie Sargent<sup>5</sup>, Shona Halson<sup>4</sup>, and Rob Duffield<sup>2</sup>

<sup>1</sup>Athlete Health and Performance Research Centre Aspetar Orthopaedic and Sports Medicine Hospital, Doha, Qatar; <sup>2</sup>Sport & Exercise Discipline Group, University of Technology Sydney, NSW, Australia; <sup>3</sup>Division of Exercise Science and Sports Medicine, University of Cape Town, South Africa; <sup>4</sup>Physiology, Australian Institute of Sport, Canberra, ACT, Australia; <sup>5</sup>Appleton Institute, Central Queensland University, Adelaide, SA, Australia

Accepted for Publication: 6 July 2017

**Medicine & Science in Sports & Exercise**® **Published ahead of Print** contains articles in unedited manuscript form that have been peer reviewed and accepted for publication. This manuscript will undergo copyediting, page composition, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered that could affect the content.

Copyright © 2017 American College of Sports Medicine

## **Greater effect of east vs. west travel on jet-lag, sleep and team-sport performance**

Peter M Fowler<sup>1</sup>, Wade Knez<sup>1</sup>, Stephen Crowcroft<sup>2</sup>, Amy E Mendham<sup>3</sup>, Joanna Miller<sup>4</sup>, Charlie Sargent<sup>5</sup>, Shona Halson<sup>4</sup>, Rob Duffield<sup>2</sup>

<sup>1</sup>Athlete Health and Performance Research Centre Aspetar Orthopaedic and Sports Medicine Hospital, Doha, Qatar.

<sup>2</sup>Sport & Exercise Discipline Group, University of Technology Sydney, NSW, Australia.

<sup>3</sup>Division of Exercise Science and Sports Medicine, University of Cape Town, South Africa.

<sup>4</sup>Physiology, Australian Institute of Sport, Canberra, ACT, Australia.

<sup>5</sup>Appleton Institute, Central Queensland University, Adelaide, SA, Australia.

### **Corresponding Author:**

Peter Fowler

Athlete Health and Performance Research Centre

Aspetar Orthopaedic and Sports Medicine Hospital

Sports City Street, Doha, Qatar

P.O. Box 29222

T: +974 4413 2196

F: +974 4413 2020

E: peter.fowler@aspetar.com

No conflicts of interest are declared. The research was solely funded by the corresponding authors' institution. The results of this study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The present study results do not constitute endorsement by the ACSM.

ACCEPTED

## ABSTRACT

**Purpose:** Determine the recovery timeline of sleep, subjective jet-lag and fatigue, and team-sport physical performance following east and west long-haul travel. **Methods:** Ten, physically-trained males underwent testing at 09:00 (AM) and 17:00 (PM) local time on four consecutive days two weeks prior to outbound travel (BASE), and the first four days following 21 h of outbound (WEST) and return (EAST) air travel across eight time-zones between Australia and Qatar. Data collection included performance (countermovement jump [CMJ], 20-m sprint and Yo-Yo Intermittent Recovery level 1 [YYIR1] test) and perceptual (jet-lag, motivation, perceived exertion and physical feeling) measures. In addition, sleep was measured via wrist activity monitors and self-report diaries throughout the aforementioned data collection periods. **Results:** Compared to the corresponding day at BASE, the reduction in YYIR1 distance following EAST was significantly different to the increase WEST on day 1 post-travel ( $p<0.001$ ). On day 2, significantly slower 20-m sprint times were detected in EAST compared to WEST ( $p=0.03$ ), with large effect sizes also indicating a greater reduction in YYIR1 distance in EAST compared to WEST ( $d=1.06$ ). Mean sleep onset and offset were significantly later and mean time in bed and sleep duration were significantly reduced across the four days in EAST compared to BASE and WEST ( $p<0.05$ ). Lastly, mean jet-lag, fatigue and motivation ratings across the four days were significantly worse in EAST compared to BASE and WEST ( $p<0.05$ ), and WEST compared to BASE ( $p<0.05$ ). **Conclusions:** Long-haul transmeridian travel can impede team-sport physical performance. Specifically, travel east has a greater detrimental effect on sleep, subjective jet-lag, fatigue and motivation. Consequently, maximal- and intermittent-sprint performance is also reduced following travel east, particularly within 72 h following arrival. **Keywords:** Soccer; team-sport; intermittent exercise; long-haul travel; travel fatigue; sleep disruption

## INTRODUCTION

Professional team-sport athletes regularly undertake long-haul transmeridian travel for competition, training camps and/or pre-season tours. Together with financial considerations, these demanding schedules dictate travel itineraries and consequently the proximity of arrival prior to the commencement of competition. Whilst optimal readiness to perform is required in the days following arrival, limited evidence exists describing the effect of an episode of long-haul travel on team-sport specific physical performance (1, 23). Consequently, inferences from an understanding of chronobiology obtained through stringently controlled laboratory studies are used to inform field-based travel strategies. For example, based on the premise it is easier to delay than advance circadian rhythms, in theory, jet-lag symptoms should be worse when travelling east compared to west (35). Whilst this has implications for athlete preparedness following travel, there is currently no information on the post-travel timeline of recovery of physical performance for team-sports, or a comparison of this timeline between east and west travel.

The interrelated effects of both jet-lag and travel fatigue are present following long-haul transmeridian travel, with increased daytime fatigue, reduced motivation and sleep disruption commonly observed (2, 12, 38). Upon arrival, endogenous circadian rhythms in body temperature and melatonin are misaligned with external cues at the destination (8, 24, 26). Until these rhythms align with the new time-zone; sleep, fatigue, motivation and ensuing physical performance may be negatively affected (23, 26). Moreover, a change in the rhythm of a morning nadir and late afternoon peak in physical performance may occur, with both physical and mental performance capacity reduced outside of this circadian peak 'window' (23).

Additionally, conditions encountered during travel, such as the uncomfortable seating arrangements, noise levels and timing of stopovers, may also disrupt sleep and exacerbate mood states (6, 11, 12). Whilst these demands may contribute to performance reductions in combination with circadian misalignment, data on the recovery timeline of and the time of day influence on sports-specific performance following an acute episode of long-haul travel remains limited.

Changes in the grip strength have consistently been reported following long-haul transmeridian travel in both athletic (24, 26) and non-athletic (8) populations. Specifically, a change in the performance rhythm of a morning nadir and a late afternoon peak (local time) occurs and grip strength is reduced outside of its circadian peak window (8, 24, 26). Reduced countermovement jump (CMJ) performance has also been observed following 24 h travel east across eight time-zones in national team skeleton athletes (5). However, whilst the use of grip strength and jump tests as performance measures may assist with the logistics of testing athletes around travel and competition, they have limited ecological relevance to physical performance in team-sports (23). As a consequence, the majority of current travel advice is based on stringently controlled laboratory-based research, which to date has had poor translation to high-performance athletes in the field (1, 34). For example, the rate of adaptation to a new time zone is estimated as half a day per hour of the time difference west and 1 day per hour of the time difference east (9, 27). Whilst these rates of adaptation have implications for team-sport physical performance, the timeline of performance recovery following travel in either direction is yet to be elucidated (9, 23, 27).

As a result of this limited understanding of the performance recovery timeline following long-haul transmeridian travel, many practitioners currently rely on personal experience or anecdotal evidence for travel schedules and training prescription following travel. Thus, the aim of the present study was to compare the timeline of recovery of sleep, subjective jet-lag, fatigue, and physical performance measures related to team-sports following east and west long-haul transmeridian travel. It was hypothesized that physical performance, sleep, jet-lag and fatigue would be worse following travel, and that east travel would cause greater disruption to these responses compared to west travel.

## **METHODS**

### **Participants**

Thirty students from a local University (Sydney, Australia) were screened through a general health questionnaire and an interview with a member of the research team for inclusion in the study. Eleven were excluded based on the following criteria; female, current smoker, sleep disorder, sleep medication use or illness, extreme morning or evening diurnal preference, insufficient fitness level (unable to obtain level 16 on the Yo-Yo Intermittent Recovery level 1 test), and shiftwork or transmeridian travel across more than two time-zones undertaken in the month prior to data collection. Of the 19 available participants, 10, healthy, physically trained males were recruited to participate (mean  $\pm$  standard deviation [SD]; age  $20.6 \pm 2.7$  y, height  $179.1 \pm 5.4$  cm and body mass  $77.05 \pm 7.83$  kg). All participant's had recent training history in a range of athletic events, including running, football, rugby and soccer and were involved in some form of physical (aerobic and strength) training at least 2-3 times per week. Prior to the commencement of the study, participants were informed of any associated risks and provided verbal and written informed consent. The study was approved by the Anti-Doping Lab Qatar Institutional Ethics Review Board (IRB no. EXT2014000003).

## Experimental Design

Participants completed a minimum of two familiarization sessions with all experimental measures and procedures. Performance data was collected at 09:00 (AM) and 17:00 (PM) local time (deemed ecologically relevant to training and competition) on four consecutive days in the two weeks prior to outbound travel as a baseline (BASE), and the first four days following long-haul transmeridian travel from Australia to Qatar (WEST, Figure 1). Following a 4-day wash-out, data was collected at the same time of day, two days prior to (PRE-EAST) and on the first four days following return travel from Qatar to Australia (EAST). In addition, sleep was measured throughout the aforementioned data collection periods and perceptual data was collected immediately prior to all performance testing sessions. Participants abstained from caffeine, alcohol and additional strenuous activity for 24 h prior to and during each data collection period. Considering the outside daytime temperatures in Qatar (~30-35°C) at the time of data collection (September/October) and the potential influence of heat acclimation on performance, participants' heat exposure was minimized to less than 1 h incidental passive heat exposure per day. Food and fluid intake was documented throughout in a food diary, with participants instructed to replicate their intake during BASE as closely as possible during WEST and EAST. Participants were provided with a standardized 1.5-2.0g/kg body mass of carbohydrate, including 600 ml of fluid (Gatorade™) immediately following all performance testing sessions. Prior to all performance testing, urine specific gravity (USG) was assessed (Digital Refractometer, Atago, WA) to determine hydration status from a midstream urine sample.



## Travel

The departure and arrival times for WEST (outbound travel) were 19:30 Australian Eastern Standard Time (AEST) and 08:55 the next day Arabia Standard Time (AST [AEST -8 h]). In total, there were three flights, with 21 h of travel (17 h total flight duration, 4 h total transit time) west across eight time-zones;

1. Sydney, Australia (19:30 local time) to Melbourne, Australia (21:05)
2. Melbourne, Australia (22:40) to Abu Dhabi, United Arab Emirates (06:45 + 1 day)
3. Abu Dhabi, United Arab Emirates (08:55) to Doha, Qatar (08:55)

The departure and arrival times for EAST (return travel) were 18:25 AST and 22:20 the next day AEST (AST +8 h). In total there were three flights, with 21 h of travel (17 h total flight duration, 4 h total transit time) east across eight time-zones;

1. Doha, Qatar (18:25 local time) to Abu Dhabi, United Arab Emirates (20:20)
2. Abu Dhabi, United Arab Emirates (22:20) to Perth, Australia (13:50 + 1 day)
3. Perth, Australia (16:00) to Sydney, Australia (22:20)

Participants travelled in economy class for all flights and were given no instructions by the research team regarding behaviors during travel (for example, when to eat and sleep, how much fluid to consume, and how often they should walk around the cabin). To match as closely as possible the duration (h) between arrival and initial testing in EAST and WEST, due to the differences in local arrival times, none of the measures outlined below were collected on day 1 at 09:00 in EAST.

## **Experimental Procedures**

### *Physical Performance*

All performance testing sessions in both locations were performed indoors on a basketball court in a temperate, air-conditioned environment (~20-25°C), with the same equipment and research team. A warm-up consisting of 5 min of standardized submaximal running followed by 10 min of general whole body movements was completed at the beginning of all performance testing sessions (33). Participants performed a countermovement jump (CMJ) test (33) at both 09:00 and 17:00, along with a 20-m sprint test and the Yo-Yo Intermittent Recovery level 1 (YYIR1) test (21) at 17:00 only. These tests are commonly utilized to assess the physical performance levels of team-sport athletes and participants were blinded from their results in all performance tests until the end of the study.

Jump height was measured using a linear position transducer (GymAware, Kinetic Performance Technologies, Canberra, ACT, Australia) sampling at 50 Hz, which was placed between the participant's feet on the floor and attached to a belt secured around their waist. The linear transducer transmitted displacement-time data to a hand held unit, which was subsequently analyzed using commercially available software (GymAware, Kinetic Performance Technologies, Canberra, ACT, Australia). Participants performed two sets of three maximal CMJ's using a self-selected depth, with a minimum of 3 min recovery between each set. Peak power (PP) and force (PF) and jump height were determined for each jump and after the removal of outliers (>3 SD's away from the mean) an average of the six jumps was calculated and used for analyses.

Three maximal 20-m sprints were performed with a minimum of 3 min recovery between each. Splits were measured at 5-m and 20-m using a single-beam infrared timing gate system (Microgate, Bolzano, Italy). The fastest 5-m and 20-m sprint times were included in ensuing analyses. YYIR1 performance was determined by total distance covered at the point of volitional exhaustion, which has been identified as a valid and reliable measure of team-sport physical performance capacity (21). A modified version of the YYIR1 was used with feedback regarding the level removed from the test audio mp3. Given the removal of audio feedback, a stopwatch was used to record the time elapsed at volitional exhaustion for each participant, which was later converted to total distance covered.

### *Sleep*

Sleep patterns were monitored using self-report diaries and wrist activity monitors (Actiwatch-64, Philips Respironics, Bend, OR). According to previously described methods, data from the sleep diaries and activity monitors were used to determine when participants were awake and asleep (30). All time was scored as wake unless: (i) the sleep diary indicated that the participant was lying down attempting to sleep and (ii) the activity counts from the monitor were sufficiently low to indicate that the participant was immobile (i.e. where the weighted activity count for an epoch fell below the defined threshold). In this study, sensitivity was set at medium which corresponds to a threshold activity count of 40 (36). When these two conditions were satisfied simultaneously, time was scored as sleep. This scoring process was conducted using a Philips Respironics' Actiwatch algorithm, which has been used to quantify sleep/wake behavior in airline pilots and long-haul truck drivers (7, 22). The following variables were derived from the sleep diary and activity monitor data;

- Time in bed (h:min): the period between going to bed and getting up.
- Sleep onset (hh:mm): the time at which a participant first fell asleep after going to bed.
- Sleep offset (hh:mm): the time at which a participant last woke before getting up.
- Sleep duration (h:min): the amount of time spent in bed asleep.
- Sleep efficiency (%): sleep duration expressed as a percentage of time in bed.
- Daytime nap duration (min): the amount of time spent in bed asleep during a daytime nap.
- Cumulative sleep duration (h:min): the sum of the sleep obtained at night and any sleep obtained the following day during a daytime nap(s).

**NB:** To isolate the impact of long-haul travel on night time sleep, participants were instructed to avoid day time napping throughout the study. Analysis of the sleep diaries and activity monitors indicated however that some participants were unable to avoid day time napping.

### *Perceptual*

Unless stated otherwise, all perceptual measures were entered into a Microsoft Excel spreadsheet on a laptop computer immediately prior to the physical performance testing. Each participant sat at a separate desk, had no access to previous responses, used an individual laptop and wore noise cancelling headphones to minimize external distractions and peer influence on their responses (4).

The Liverpool John Moore's University (LJMU) jet-lag questionnaire was used to assess participants' subjective ratings of jet-lag (38). The specific times of assessment for each sub-scale were: 1. jet-lag (1 question): 09:00 and 17:00; 2. sleep (5 questions): 09:00 only; 3. fatigue (1 question): 09:00 and 17:00; 4. diet (3 questions): 17:00 only; 5. mental performance and mood

(3 questions): 17:00 only; 6. bowel movement (2 questions): 17:00 only. Following a method previously outlined (34), data with a “negative outcome” were given a positive score and data with a “positive outcome” were given a negative score, before being pooled for summation into five categories: a. jet-lag, b. sleep, c. function (c.1. fatigue + c.2. mental performance and mood), d. diet and e. bowel movement. A greater overall value indicates worse symptoms (i.e. a positive number indicates a worse than ‘normal’ response and a negative number indicates a better than ‘normal’ response). At both 09:00 and 17:00, participants’ general level of motivation was assessed on a Likert scale from 0 (“none”) to 4 (“very motivated”) in 0.5-point increments. Lastly, approximately 30 min after the completion of the physical performance tests (17:00 only), a session rating of perceived exertion (sRPE) (10) and physical feeling (18) were obtained from participants.

### **Statistical Analysis**

Unless specified, data are presented as mean  $\pm$  standard deviation (SD). Normality of the observed data was assessed using quantile-quantile (Q-Q) plots and was deemed plausible in all instances, with data presented as mean  $\pm$  SD. Initially, comparisons between BASE Day 1 and PRE-EAST Day 1 were made for all variables using linear mixed models and standardized effect size ([ES] Cohen’s *d*) analysis. Since no significant ( $p < 0.05$ ) differences were observed and all effect sizes ([ES] Cohen’s *d*) were small ( $d < 0.40$ ), raw change in all performance variables on each of the four days following WEST and EAST were calculated from the corresponding day at BASE (i.e. day 1 EAST was compared to day 1 BASE). As such PRE-EAST measures were used as an internal control to ensure no training or fatigue effect had occurred prior to return travel. Raw values on each of the four days at BASE, WEST and EAST were used for all sleep

and perceptual variables. Differences between condition (travel direction) and interactions between condition and time (day and time of day) for the raw change in performance variables and raw values for sleep and perceptual variables were analyzed using linear mixed models. This type of analysis is preferred as it (i) allows for missing data, (ii) can accurately model different covariate structures for repeated measures data, and (iii) can model between-subject variability (37). The most appropriate model for each variable was chosen using the smallest Akaike's Information Criterion (AIC) in accordance with the principal of parsimony. Where significance was obtained ( $p < 0.05$ ), Least Significant Difference post-hoc tests were used. All statistical analysis was performed using SPSS (Version 21, IBM, Armonk, NY). Furthermore, standardized effect size analysis was used to interpret the magnitude of differences between conditions and over time. Due to the substantial amount of statistical analyses performed, only large ES's ( $d > 0.90$ ) are reported.

## RESULTS

To aid clarity, results are structured within each ensuing paragraph as follows; (a) differences between travel direction (BASE, WEST and EAST); (b) interactions between travel direction and day (1-4); (c) interactions between time of day (09:00 and 17:00) with travel direction and day. Of note, 09:00 and 17:00 *local time* would have corresponded to approximately 17:00 and 01:00 *body clock time* on day 1 following WEST and 01:00 and 09:00 *body clock time* following EAST (Figure 1).

## Physical Performance

Results for CMJ performance variables are presented in Table 1. A significant main effect of travel direction was observed for peak force ( $F_{1,84}=3.94$ ,  $p=0.04$ ), with a greater mean reduction across the four days in EAST compared to WEST ( $p=0.03$ ). Further, to be outlined below, significant interactions between travel direction, day and time of day were evident for both peak power ( $F_{5,86}=4.59$ ,  $p=0.001$ ) and peak force ( $F_{5,83}=4.70$ ,  $p=0.001$ ).

*AM testing (09:00 local time, ~17:00 WEST, ~01:00 EAST)*

a. Travel Direction:

A greater reduction in peak power was detected in WEST compared to EAST on day 2 ( $p>0.05$ ,  $d>0.90$ ).

b. Day:

Compared to day 1, a significantly greater reduction in peak force was observed on day 2 and 4 in WEST ( $p<0.05$ ).

*PM testing (17:00 local time, ~01:00 WEST, ~09:00 EAST)*

a. Travel Direction:

Though no significant differences were detected between travel directions, large ES indicated the increase in peak power and peak force on day 1 in WEST was different to the reduction observed in EAST ( $p>0.05$ ,  $d>0.90$ ).

b. Day:

The increase in peak power on day 4 was significantly different to the reduction on day 2 and 3 in WEST and EAST ( $p<0.05$ ). The increase in peak force on day 1 was significantly different to the reduction on day 2 and 3 in WEST ( $p<0.05$ ), and the reduction in peak force on day 3 was significantly different to all other days in WEST, and day 1 and 4 in EAST ( $p<0.05$ ).

c. Time of Day:

On day 3 the reduction in peak force at 17:00 was significantly greater than the reduction at 09:00 in WEST ( $p<0.05$ ). On day 4 the increase in peak power at 17:00 was significantly different to the reduction at 09:00 in both WEST and EAST, and the increase in peak force at 17:00 was significantly different to the reduction at 09:00 in WEST ( $p<0.05$ ).

20-m sprint and YYIR1 results are presented in Figure 2. A significant interaction between travel direction and day was observed for 20-m sprint ( $F_{6,49}=3.46$ ,  $p=0.006$ ) and YYIR1 ( $F_{6,39}=5.96$ ,  $p<0.001$ ), respectively.

*PM testing (17:00 local time, ~01:00 WEST, ~09:00 EAST)*

a. Travel Direction:

A significantly slower 20-m sprint time was detected on day 2 in EAST compared to WEST ( $p=0.03$ ). On day 1 the reduction in YYIR1 distance in EAST was significantly different to the increase in WEST ( $p<0.001$ ). Large ES indicated a greater reduction in YYIR1 distance in EAST compared to WEST on day 2 ( $d=1.06$ ). Conversely, the increase in YYIR1 distance on day 4 in EAST was greater than WEST ( $d=1.00$ ).



b. Day:

5-m sprint time was significantly slower on day 1 and 2 compared to day 4 in EAST ( $p<0.05$ ), with large ES also suggesting it was slower on day 3 ( $d=1.25$ ). Similarly, 20-m sprint time was significantly slower on day 1 and 2 compared to day 3 and 4 in EAST ( $p<0.05$ ). The reduction in YYIR1 distance on day 1 and 2 in EAST was significantly different to the increase on day 3 and 4 ( $p<0.05$ ), whereas the increase in YYIR1 distance on day 1 was significantly greater than day 2 and 4 in WEST ( $p<0.05$ ).

## Sleep

Results for all sleep variables are presented in Table 2. A significant main effect of travel direction was observed for time in bed ( $F_{2,71}=15.57$ ,  $p<0.001$ ), sleep onset ( $F_{2,70}=36.69$ ,  $p<0.001$ ), sleep offset ( $F_{2,67}=4.75$ ,  $p=0.012$ ) and sleep duration ( $F_{2,70}=13.03$ ,  $p<0.001$ ). A significant interaction between travel direction and day was detected for sleep onset ( $F_{11,49}=4.00$ ,  $p<0.001$ ), sleep offset ( $F_{11,41}=5.78$ ,  $p<0.001$ ) and sleep duration ( $F_{11,48}=2.11$ ,  $p=0.037$ ).

a. Travel Direction:

Mean sleep onset and offset were significantly later and mean time in bed and sleep duration were significantly reduced across the 4 days in EAST compared to BASE and WEST ( $p<0.05$ ). Sleep onset and sleep offset were significantly later and time in bed and sleep duration were significantly reduced on the day of arrival in EAST compared to WEST ( $p<0.05$ ). Similarly, sleep onset was significantly later and time in bed and sleep duration were significantly reduced on day 1 and 2 in EAST compared to BASE and WEST ( $p<0.05$ ). Sleep onset was also significantly later on day 4 in EAST compared to BASE and WEST ( $p<0.05$ ). Large ES suggested sleep offset was later on day 2 and 3 in WEST compared to BASE and sleep efficiency was reduced on day 1 in WEST and EAST compared to BASE ( $d>0.90$ ).

b. Day:

In WEST, sleep onset was significantly earlier and time in bed and sleep duration were significantly greater on the day of arrival compared to all other days ( $p<0.05$ ). Similarly, time in bed and sleep duration were significantly greater on the day of arrival compared to day 1 and 2 in EAST ( $p<0.05$ ). Moreover, sleep onset was significantly earlier on day 3 compared to day of arrival and day 4, sleep offset was significantly later on day of arrival compared to all other days, and time in bed and sleep duration were significantly greater on day 4 compared to day 1 and 2 in EAST ( $p<0.05$ ). Sleep onset and offset were significantly later on day 4 compared to all other days in BASE ( $p<0.05$ ).

Across the 4 days, a total of 2 naps were recorded in BASE and EAST, and 8 naps in WEST. Mean nap duration across the 4 days was  $35 \pm 11$  min,  $59 \pm 11$  min and  $73 \pm 4$  min for BASE, WEST and EAST, respectively. However, the interaction between travel direction and day for cumulative sleep duration was no different compared to the aforementioned results for sleep duration.

## **Perceptual**

### *Jet-lag*

Results for jet-lag and function ratings are presented in Figure 3. A significant main effect of travel direction was observed for jet-lag ( $F_{2,147}=45.29$ ,  $p<0.001$ ), function ( $F_{2,185}=15.18$ ,  $p<0.001$ ) and diet ( $F_{2,190}=7.06$ ,  $p=0.001$ ). Specifically, mean jet-lag and function ratings across the 4 days were significantly worse in EAST compared to BASE and WEST, and WEST compared to BASE ( $p<0.05$ ). Conversely, mean diet ratings were significantly worse in WEST ( $3.3 \pm 2.5$  AU) compared to BASE ( $2.2 \pm 2.2$  AU) and EAST ( $1.9 \pm 2.1$  AU) ( $p<0.01$ ).

*AM testing (09:00 local time, ~17:00 WEST, ~01:00 EAST)*

a. Travel Direction:

Jet-lag was significantly worse in WEST compared to BASE on day 1 and 2 ( $p<0.05$ ), EAST compared to BASE on day 2-4 ( $p<0.05$ ), and EAST compared to WEST on day 3 ( $p<0.05$ ). Large ES indicated that jet-lag was still elevated on day 4 in EAST and WEST compared to BASE ( $d>0.90$ ). Function ratings were significantly worse on day 2 in EAST compared to BASE and WEST ( $p<0.05$ ). Large ES indicated that sleep ratings were worse on day 1 and 4 in BASE ( $3.7 \pm 4.1$  and  $3.3 \pm 4.8$  AU) compared to WEST ( $0.7 \pm 3.0$  and  $0.9 \pm 3.2$ ,  $d>0.90$ ), on day 4 in BASE compared to EAST ( $0.8 \pm 3.7$  AU,  $d=1.11$ ) and on day 2 in EAST ( $4.8 \pm 5.1$  AU) compared to WEST ( $2.0 \pm 2.5$  AU,  $d=1.06$ ).

b. Day:

Jet-lag ratings were significantly lower on day 4 compared to day 1 and 2 in EAST ( $p<0.05$ ). Large ES also suggested jet-lag was lower on day 4 compared to day 1 and 2 in WEST ( $p>0.05$ ;  $d>0.90$ ). Sleep ratings were significantly better on day 4 compared to 2 ( $p=0.02$ ) in EAST.

*PM testing (17:00 local time, ~01:00 WEST, ~09:00 EAST)*

a. Travel Direction:

Jet-lag was significantly worse in WEST compared to BASE on day 1 and 2 ( $p<0.05$ ) and EAST compared to BASE and WEST on day 1-3 ( $p<0.05$ ). Large ES indicated that jet-lag was still elevated on day 4 in EAST and WEST compared to BASE ( $d>0.90$ ). Function ratings were significantly worse on day 1 in EAST compared to BASE and WEST, on day 2 in EAST compared to BASE and on day 3 in EAST and WEST compared to BASE ( $p<0.05$ ). Large ES also indicated function was worse on day 2 in WEST compared to BASE ( $d=1.32$ ). Diet ratings were significantly worse on day 1 and 2 in WEST ( $4.3 \pm 3.2$  and  $4.0 \pm 2.8$ ) compared to EAST ( $2.2 \pm 2.2$  and  $2.0 \pm 1.7$ ) and BASE ( $2.5 \pm 1.5$  and  $2.2 \pm 2.6$ ) ( $p<0.05$ ), and bowel movement ratings were significantly worse on day 1 in EAST compared to BASE ( $1.6 \pm 2.5$  vs.  $0.2 \pm 0.3$  AU,  $p=0.01$ ).

b. Day:

Jet-lag ratings were significantly lower on day 3 and 4 compared to day 1 in EAST ( $p<0.05$ ). Large ES also suggested jet-lag was lower on day 4 compared to day 1 and 2 in WEST ( $p>0.05$ ;  $d>0.90$ ). Function ratings were significantly better on day 4 compared to all other days in EAST ( $p<0.01$ ), and on day 3 compared to day 1 in WEST ( $p=0.03$ ). Bowel movement ratings were significantly better on day 3 ( $0.2 \pm 0.5$  AU) and 4 ( $0.2 \pm 0.6$  AU) compared to day 1 ( $1.6 \pm 2.5$  AU) in EAST ( $p<0.05$ ). Lastly, diet ratings were significantly better on day 3 and 4 ( $2.5 \pm 2.2$  and  $2.2 \pm 2.4$  AU) compared to day 1 and 2 ( $4.3 \pm 3.2$  and  $4.0 \pm 2.8$  AU) in WEST ( $p<0.01$ ).

c. Time of Day:

On day 4 function ratings were significantly better at 17:00 compared to 09:00 in EAST ( $p<0.01$ ).

*Motivation, RPE and Physical Feeling*

Results for RPE and physical feeling are presented in Figure 2, with results for motivation presented in Figure 3. A significant main effect of travel direction was identified for motivation ( $F_{2,190}=34.12$ ,  $p<0.001$ ), with mean motivation across the 4 days significantly reduced in EAST compared to BASE and WEST, and WEST compared to BASE ( $p<0.05$ ). A significant main effect of travel direction was evident for physical feeling ( $F_{2,70}=3.97$ ,  $p=0.023$ ), with mean ratings across the 4 days significantly worse in EAST compared to BASE ( $p=0.007$ ).

*AM testing (09:00 local time, ~17:00 WEST, ~01:00 EAST)*

a. Travel Direction:

Motivation was significantly reduced on day 1 in WEST compared to BASE ( $p=0.04$ ), day 2 in EAST compared to BASE and WEST ( $p<0.05$ ), and day 3 and 4 in EAST compared to BASE ( $p<0.05$ ).

b. Day

Motivation was significantly lower on day 3 compared to day 2 in WEST ( $p<0.05$ ).

*PM testing (17:00 local time, ~01:00 WEST, ~09:00 EAST)*

a. Travel Direction

Motivation was significantly reduced on day 1 and 2 in EAST compared to BASE and WEST ( $p<0.05$ ), and day 3 in EAST compared to BASE ( $p<0.05$ ). Large ES also suggested motivation was reduced on day 3 in EAST compared to WEST ( $d=1.08$ ).

b. Day

Motivation was significantly lower on day 3 compared to day 1 in WEST ( $p=0.04$ ), and significantly better on day 4 compared to day 1-3 in EAST ( $p<0.05$ ). Physical feeling was significantly worse on day 1 and 2 in EAST compared to BASE ( $p<0.05$ ) and large ES indicated worse physical feeling in EAST on day 2 compared to WEST ( $d=0.97$ ) and on day 3 compared to BASE and WEST ( $d>0.90$ ). RPE was significantly higher on day 4 compared to 1 at BASE ( $p=0.04$ ), with large ES suggesting it was also higher on day 3 compared to 1 ( $d=1.05$ ). Physical feeling was significantly better on day 4 compared to 1 in EAST ( $p=0.01$ ), with large ES indicating it was better on day 4 compared to all other days ( $d>0.90$ ).

### c. Time of Day

Motivation was significantly lower at 17:00 compared to 09:00 on day 2 in WEST ( $p=0.03$ ).

### Hydration

Across the 4 days, mean USG was significantly lower in WEST ( $1.012 \pm 0.006$ ) compared to BASE ( $1.016 \pm 0.007$ ) and EAST ( $1.019 \pm 0.007$ ) ( $p<0.05$ ), and BASE compared to EAST ( $p<0.05$ ). USG was significantly lower in WEST ( $1.014 \pm 0.007$ ) and EAST ( $1.014 \pm 0.007$ ) compared to BASE ( $1.019 \pm 0.006$ ) on day 1 ( $p<0.05$ ), BASE ( $1.015 \pm 0.008$  and  $1.015 \pm 0.007$ ) and WEST ( $1.013 \pm 0.006$  and  $1.011 \pm 0.005$ ) compared to EAST ( $1.020 \pm 0.006$  and  $1.021 \pm 0.007$ ) on day 2 and 3 ( $p<0.05$ ), and WEST ( $1.018 \pm 0.004$ ) compared to BASE ( $1.017 \pm 0.008$ ) and EAST ( $1.018 \pm 0.008$ ) on day 4 ( $p<0.05$ ). USG was significantly greater on day 1 compared to day 2 and 3 in BASE ( $p<0.05$ ), yet significantly reduced on day 1 compared to day 2 and 3 in EAST ( $p<0.05$ ).

### DISCUSSION

The present study investigated the effects of 21 h air travel across seven times-zones, both west and east, on sleep, subjective jet-lag, fatigue and motivation, and physical performance related to team-sports. Results indicated west travel had negligible effects on sleep, fatigue and intermittent-sprint performance. Conversely, sleep quantity and intermittent-sprint performance were reduced up to day 2, alongside increased perceived fatigue and reduced motivation up to day 4 following travel east. Irrespective of travel direction, reduced maximal-sprint and CMJ performance were evident up to day 3 and 4 following travel, respectively. As such, the present study indicates performance deficits in lower-body power are evident up to 96 h post-travel in

either direction. Though, within the initial 72 h, sleep, fatigue and both maximal- and intermittent-sprint performance are disturbed to a greater extent following east travel. Accordingly, practitioners should be aware that 72 h post long-haul travel may be required prior to the restoration of optimal readiness to train or compete.

Training and competition can occur within 24-48 h following long-haul travel for elite team-sport athletes. A novel finding of the present study was therefore the reduction of intermittent-sprint performance on day 1 and 2 following east, but not west travel. This is despite the time of day (17:00 local time) corresponding to more 'unfavorable' body clock time in west compared to east travel (~01:00 vs. ~09:00 on day 1). Reduced and unchanged intermittent-sprint performance has previously been reported on day 1 following 24 h of simulated travel, with sleep duration on the night of arrival the main difference between the two studies (12, 14). Thus, reduced sleep duration observed in the first 3 nights following east travel could explain the reduction in YYIR1 performance in the present study. Comparable to previous simulated (12, 14) and actual travel studies (15, 38), subjective ratings of fatigue and motivation were exacerbated following travel in the present study, particularly east. In part, these altered subjective responses as a consequence of either circadian misalignment, sleep disruption and/or the demands of travel could also explain the reduction of intermittent-sprint performance (12, 31). Whilst east and west travel had similar flight schedules and durations, the change in time-zones meant a difference in local arrival time. This could also have contributed to the intermittent-sprint performance reduction following east but not west travel, as there was a greater duration (~15 h) between arrival time and initial performance testing in west compared to east. Other detrimental consequences of travel that could impact performance are the low cabin

humidity and potential risk of hypohydration (17). However, though USG across the 4 days was lower following west travel compared to baseline and east travel, results indicated participants were adequately hydrated (USG <1.020) across all data collection periods (25). In summary, whilst west long-haul transmeridian travel with a morning arrival appears to induce negligible changes in intermittent-sprint capacity, east travel with an evening arrival should be of concern to athletes and practitioners.

Reductions in CMJ performance were evident up to day 4 following both east and west travel in the present study. The timeline of recovery was different to the other measures of physical performance, with the greatest differences following both east and west travel compared to baseline on day 3, instead of day 1. Interestingly, the return of CMJ performance to baseline levels coincided with greater motivation on day 4 at 17:00 compared to 09:00 local time following both east and west travel. In national team skeleton athletes, CMJ height was reduced following similar travel demands, but only on day 1 where testing occurred at ~01:00 body clock time (5). If circadian misalignment was the expected cause of CMJ performance impairments in the present study; (1) a change in the performance rhythm of a morning nadir and a late afternoon peak would have occurred; (2) east travel would have likely had a greater effect on performance compared to west travel; (3) performance would have been reduced outside of its circadian peak window (23). Though testing following west travel at 09:00 (particularly day 1 post-arrival) corresponded with the time of peak performance (~17:00 body clock time), there were negligible differences in CMJ performance between testing times (09:00 vs. 17:00) and travel directions (east vs. west). The absence of these differences could be due to the nullification of circadian influence from a thorough warm-up (33, 35), fatigue from travel, sleep disruption



and/or previous exercise (35), or sensitivity of the CMJ test. Hence, whilst results from the present study suggest a 96 h recovery timeline for explosive lower-body power following both east and west long-haul travel, the time of day (local or body clock) does not appear to be influential.

Reduced 5- and 20-m sprint performance was also observed up to day 3 following both east and west travel. Similar to intermittent-sprint performance, a greater reduction in 20-m sprint performance was detected on day 2 following east compared to west travel. This is again despite the time of day (17:00 local time) corresponding to a more unfavorable body clock time following west travel (~01:00 on day 1) and suggests that the time of day influence on performance post-travel may not be as integral as previously purported (26, 27). In the same aforementioned group of skeleton athletes, no change in 30-m sprint performance was observed following similar travel demands (3), which was attributed to the competitive training environment and/or the athlete's high levels of motivation. Given the differences between testing and competition environments, motivational issues may explain the performance decrements noted in the present study (3, 29, 35). Regardless, compared to intermittent-sprint capacity, the greater levels of neuromuscular fatigue, as indicated by reductions in both CMJ and 20-m sprint performance, is of concern for athletes following both east and west long-haul travel.

Based on an understanding of chronobiology, delayed sleep onset and early waking are anticipated following long-haul travel east and west, respectively (9, 35, 40). More prolonged sleep disruption following east travel is also expected, since circadian rhythms adjust quicker to a delay than an advance (9, 35, 40). To date however, limited data exists on the impact of long-

haul transmeridian travel on sleep patterns in passengers. Hence, a novel finding of the present study was that while there was no impact of travel west on post-travel sleep patterns, sleep duration was reduced for 3 days following east travel due to a later sleep onset and reduced time in bed. Conversely, in academics travelling to conferences, reduced sleep quantity and quality, and earlier sleep onset and waking were reported for 3 days following east travel, whilst delayed sleep onset and waking were reported for 5 days following west travel, with no changes in sleep quantity or quality (32). Considering the delayed waking following west travel was attributed to that specific cohorts lack of commitments (32), the anticipated early waking in west could have been masked in the present study by morning testing requirements, akin to training or competition demands. An average of only ~6.5 h sleep per night was obtained at baseline, which is recognized as below the recommended 7-9 h (19). Thus, a greater impact of travel, particularly west may have been observed in individuals with better sleep habits. Subtle yet important differences in sleep architecture may also have been detected through polysomnography which was unavailable in the present study (2, 36). Lastly, since napping is a frequently reported symptom following long-haul transmeridian travel, it could also be argued that different results may have been observed in the present study if participants were not instructed to avoid napping.

A common occurrence following long-haul travel overnight is that on the night of arrival the homeostatic factor of sleep regulation overrides the circadian factor and sleep quantity and/or quality increases (13, 16, 35). This is likely due to sleep disruption during travel, as a result of the flight schedule (e.g. enforced waking by a stopover) and/or an uncomfortable sleeping position (9, 12, 14). Compared to all subsequent days, increased sleep duration was evident on the night of arrival following west travel due to an earlier sleep onset and increased time in bed.

Though it cannot be determined whether this was due to reduced sleep duration during travel, as limitations exist for accurately assessing sleep during travel via actigraphy and/or self-report diaries. Conversely, sleep duration was reduced on the day of arrival following east travel due to an evening arrival (22:20 local time), which is typical due to an advance in time-zones and has previously been reported to disrupt sleep in professional football players (11, 15). Results from the present study suggest that a combination of travel demands, particularly the flight schedule and circadian misalignment disrupted sleep following east travel.

The theoretical rate of realignment of circadian rhythms following transmeridian travel is half a day per hour of the time difference west and one day per hour of the time difference east (27). It was therefore anticipated that subjective jet-lag ratings would be more prominent and persistent following east compared to west travel. Whilst this hypothesis can be accepted, the attenuation of jet-lag ratings was faster than expected for both west (2 instead of 3-4 days) and east travel (4 instead of 7 days), which is consistent with data from other field-based studies (8, 15). In the only other study to investigate the impact of travel direction on jet-lag ratings, more prominent and persistent symptoms were also identified following east travel across 8 time-zones compared to west travel across 6 time-zones in elite gymnasts (24). Furthermore, it was hypothesized that subjective jet-lag would be worse at 09:00 h following west travel and 17:00 h following east travel, since this would have corresponded to ~01:00 h body clock time on the first day following arrival. However, this was not consistently observed, which similar to CMJ performance, could be because the circadian influence is nullified by other factors in field-based studies, such as fatigue from travel, sleep disruption and/or previous exercise (35). Indeed, jet-lag ratings are strongly associated with the level of perceived fatigue assessed at the same time (42). For example, increased subjective jet-lag ratings were unexpectedly reported by

professional football players for 5 days following long-haul travel north across 1 time-zone (12). Results suggested this was due to sleep disruption induced by an early departure time and evening competition, together with fatigue following competition rather than circadian rhythm misalignment (12).

Increased fatigue along with reduced motivation and tolerance to exercise were identified up to day 3 following east compared to west travel. These differences align with the reduced sleep duration observed for the first 3 nights following east travel, and previous observations that sleep disruption itself can exacerbate subjective ratings of fatigue, motivation and tolerance to exercise (31). Together with the impact of sleep disruption on perceived fatigue, prolonged inactivity and exposure to mild hypoxia during air travel may also contribute (6). Yet, since the duration of travel (excluding stopovers) was similar for east and west, any differences in perceived fatigue are likely to be attributed to circadian rhythm misalignment and/or sleep disruption. Previous research suggests that individuals are unable to maintain performance in sustained or repeated exercise bouts following sleep loss due to difficulties in maintaining the motivation to perform at a high intensity (28, 31). Therefore, the cascade of travel-induced changes observed following east travel (reduced sleep duration together with exacerbated perceived fatigue and motivation) may explain the reduction of intermittent-sprint performance.

In the present study the participant population was relatively homogenous from a training and physical performance perspective, chronotype was accounted for and a statistical technique that models for inter-individual variation was utilized. Despite this, a common theme was the large inter-individual variation in results, which may have masked potential differences between east

and west travel. For example, when mean group reductions in performance were observed post-travel, there were some individuals that performed better and vice-versa. This variation in travel-induced responses could be due to age, flexibility of sleeping habits and previous travel experience (15, 39). In addition, the variation in motivation may have been larger in the present participant population compared to professional athletes (3, 29, 35). Regardless, significant inter-individual variation in the disruption of body temperature circadian rhythms to 24 h of west travel across 10 time-zones has previously been reported, with 50 - 69% phase-delays, 20 - 38% phase-advances and 11 - 19% unchanged (8). Thus, further research investigating the cause of this variation and utilizing more progressive statistics to assess changes at an individual rather than a group level is warranted.

In conclusion the present study is the first to compare the impact of east and west long-haul travel on integrated measures related to physical performance for team-sports. Results suggest a greater impact of east travel on sleep, subjective jet-lag, fatigue and motivation, and maximal- and intermittent-sprint performance, particularly within the first 48 - 72 h following arrival. Though, despite including 'pre-east' measures as an internal control, it is recognized as a limitation of the present study that it was not a counterbalanced design. It is also acknowledged that actual team-sport performance requires more than activity from a single muscle or group of muscles, for example, neural control, central decision-making and motivation (29). Nonetheless, the present study provides coaches and practitioners with novel information on the timeline of recovery specific to team-sport physical performance following east and west long-haul travel. This data can help to inform decisions on travel schedules in relation to competition and when to return to full training following travel. For example, a practical recommendation from the

present study would be that team-sport athletes should aim to arrive a minimum of 96 h prior to competition following both east and west long-haul travel for optimal performance. However, due to their demanding schedules, this is not always feasible. Thus, future research developing interventions that have field-based efficacy for reducing the impact of long-haul transmeridian travel, particularly on sleep is warranted.

ACCEPTED

## **ACKNOWLEDGEMENTS**

The authors would like to thank the participants for their time and enthusiasm, and gratefully acknowledge the allocation of resources provided by the Aspire Zone Foundation, Aspetar Orthopaedic and Sports Medicine Hospital, and University of Technology Sydney in support of this project. The authors would also like to thank Adulaziz Farooq and Lauren Banting for their assistance with statistical analysis.

## **DECLARATIONS**

No conflicts of interest are declared. The research was solely funded by the corresponding authors' institution. The results of this study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The present study results do not constitute endorsement by the ACSM.

## REFERENCES

1. Atkinson G, Batterham AM, Dowdall N, Thompson A, van Drongelen A. From animal cage to aircraft cabin: an overview of evidence translation in jet lag research. *Eur J Appl Physiol.* 2014;114(12):2459-68. doi: 10.1007/s00421-014-3026-3.
2. Beaumont M, Batejat D, Pierard C, et al. Caffeine or melatonin effects on sleep and sleepiness after rapid eastward transmeridian travel. *J Appl Physiol.* 2004;96(1):50-8. doi: 10.1152/japplphysiol.00940.2002. PubMed PMID: 12959951.
3. Bullock N, Martin DT, Ross A, Rosemond D, Marino FE. Effect of long haul travel on maximal sprint performance and diurnal variations in elite skeleton athletes. *Br J Sports Med.* 2007;41(9):569-73. doi: 10.1136/bjsm.2006.033233. PubMed PMID: 17473002.
4. Carnes AJ, Petersen JL, Barkley JE. Effect of Peer Influence on Exercise Behavior and Enjoyment in Recreational Runners. *J Strength Cond Res.* 2016;30(2):497-503. doi: 10.1519/JSC.0000000000001064. PubMed PMID: 26813634.
5. Chapman DW, Bullock N, Ross A, Rosemond D, Martin DT. Detrimental effects of West to East transmeridian flight on jump performance. *Eur J Appl Physiol.* 2012;112(5):1663-9. doi: 10.1007/s00421-011-2134-6. PubMed PMID: 21874551.
6. Coste O, Van Beers P, Touitou Y. Impact of hypobaric hypoxia in pressurized cabins of simulated long-distance flights on the 24 h patterns of biological variables, fatigue, and clinical status. *Chronobiol Int.* 2007;24(6):1139-57. doi: 10.1080/07420520701800702. PubMed PMID: 18075804.



7. Darwent D, Roach G, Dawson D. How well do truck drivers sleep in cabin sleeper berths? *Appl Ergon*. 2012;43(2):442-6. doi: 10.1016/j.apergo.2011.06.019. PubMed PMID: 21820102.
8. Edwards BJ, Atkinson G, Waterhouse J, Reilly T, Godfrey R, Budgett R. Use of melatonin in recovery from jet-lag following an eastward flight across 10 time-zones. *Ergonomics*. 2000;43(10):1501-13. doi: 10.1080/001401300750003934.
9. Forbes-Robertson S, Dudley E, Vadgama P, Cook C, Drawer S, Kilduff L. Circadian disruption and remedial interventions: effects and interventions for jet lag for athletic peak performance. *Sports Med*. 2012;42(3):185-208. doi: 10.2165/11596850-000000000-00000. PubMed PMID: 22299812.
10. Foster C, Daines E, Hector L, Snyder AC, Welsh R. Athletic performance in relation to training load. *Wis Med J*. 1996;95(6):370-4. PubMed PMID: 8693756.
11. Fowler P, Duffield R, Howle K, Waterson A, Vaile J. Effects of northbound long-haul international air travel on sleep quantity and subjective jet lag and wellness in professional Australian soccer players. *Int J Sports Physiol Perform*. 2015;10(5):648-54. doi: 10.1123/ijsp.2014-0490. PubMed PMID: 25569181.
12. Fowler P, Duffield R, Vaile J. Effects of simulated domestic and international air travel on sleep, performance, and recovery for team sports. *Scand J Med Sci Sports*. 2015;25(3):441-51. doi: 10.1111/sms.12227. PubMed PMID: 24750359.
13. Fowler PM, Duffield R, Lu D, Hickmans JA, Scott TJ. Effects of Long-Haul Transmeridian Travel on Subjective Jet-Lag and Self-Reported Sleep and Upper Respiratory Symptoms in Professional Rugby League Players. *Int J Sports Physiol Perform*. 2016;11(7):876-84. doi: 10.1123/ijsp.2015-0542. PubMed PMID: 26788986.

14. Fowler PM, Duffield R, Morrow I, Roach G, Vaile J. Effects of sleep hygiene and artificial bright light interventions on recovery from simulated international air travel. *Eur J Appl Physiol.* 2015;115(3):541-53. doi: 10.1007/s00421-014-3043-2. PubMed PMID: 25387805.
15. Fowler PM, McCall A, Jones M, Duffield R. Effects of long-haul transmeridian travel on player preparedness: Case study of a national team at the 2014 FIFA World Cup. *J Sci Med Sport.* 2017;20(4):322-7. doi: 10.1016/j.jsams.2016.08.021. PubMed PMID: 28109712.
16. Fullagar HH, Duffield R, Skorski S, et al. Sleep, Travel, and Recovery Responses of National Footballers During and After Long-Haul International Air Travel. *Int J Sports Physiol Perform.* 2016;11(1):86-95. doi: 10.1123/ijsp.2015-0012. PubMed PMID: 25946072.
17. Hamada K, Doi T, Sakurai M, et al. Effects of hydration on fluid balance and lower-extremity blood viscosity during long airplane flights. *JAMA.* 2002;287(7):844-5. doi: 10.1001/jama.287.7.844-a. PubMed PMID: WOS:000173922500022.
18. Hardy CJ, Rejeski WJ. Not what, but how one feels: The measurement of affect during exercise. *J Sport Exerc Psychol.* 1989;11(3):304-17.
19. Hirshkowitz M, Whiton K, Albert SM, et al. National Sleep Foundation's sleep time duration recommendations: methodology and results summary. *Sleep Health.* 2015;1(1):40-3. doi: 10.1016/j.sleh.2014.12.010.
20. Horne JA, Ostberg O. A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *Int J Chronobiol.* 1976;4(2):97.

21. Krstrup P, Mohr M, Amstrup T, et al. The Yo-Yo Intermittent Recovery test: physiological response, reliability, and validity. *Med. Sci. Sports Exerc.* 2003;35(4):697-705. doi: 10.1249/01.mss.0000058441.94520.32. PubMed PMID: 12673156.
22. Lamond N, Petrilli RM, Dawson D, Roach GD. Do short international layovers allow sufficient opportunity for pilots to recover? *Chronobiol Int.* 2006;23(6):1285-94. doi: 10.1080/07420520601062387.
23. Leatherwood WE, Dragoo JL. Effect of airline travel on performance: a review of the literature. *Br J Sports Med.* 2012;47(9):561-7. doi: 10.1136/bjsports-2012-091449.
24. Lemmer B, Kern RI, Nold G, Lohrer H. Jet lag in athletes after eastward and westward time-zone transition. *Chronobiol Int.* 2002;19(4):743-64. PubMed PMID: 12182501.
25. Popowski LA, Oppliger RA, Patrick LG, Johnson RF, Kim JA, Gisolf C. Blood and urinary measures of hydration status during progressive acute dehydration. *Med. Sci. Sports Exerc.* 2001;33(5):747-53.
26. Reilly T, Atkinson G, Budgett R. Effect of low-dose temazepam on physiological variables and performance tests following a westerly flight across five time zones. *Int J Sports Med.* 2001;22(3):166-74. doi: 10.1055/s-2001-16379. PubMed PMID: 11354518.
27. Reilly T, Atkinson G, Edwards B, et al. Coping with jet-lag: A position statement for the European College of Sport Science. *Eur J Sport Sci.* 2007;7(1):1-7. doi: 10.1080/17461390701216823.

28. Reilly T, Piercy M. The effect of partial sleep deprivation on weight-lifting performance. *Ergonomics*. 1994;37(1):107-15. doi: 10.1080/00140139408963628. PubMed PMID: 8112265.
29. Reilly T, Waterhouse J. Sports performance: is there evidence that the body clock plays a role? *Eur J Appl Physiol*. 2009;106(3):321-32. doi: 10.1007/s00421-009-1066-x. PubMed PMID: 19418063.
30. Sargent C, Lastella M, Halson SL, Roach GD. The validity of activity monitors for measuring sleep in elite athletes. *J Sci Med Sport*. 2016;19(10):848-53. doi: 10.1016/j.jsams.2015.12.007. PubMed PMID: 26794719.
31. Skein M, Duffield R, Edge J, Short MJ, Mundel T. Intermittent-sprint performance and muscle glycogen after 30 h of sleep deprivation. *Med. Sci. Sports Exerc*. 2011;43(7):1301-11. doi: 10.1249/MSS.0b013e31820abc5a. PubMed PMID: 21200339.
32. Takahashi M, Nakata A, Arito H. Disturbed sleep-wake patterns during and after short-term international travel among academics attending conferences. *Int Arch Occup Environ Health*. 2002;75(6):435-40.
33. Taylor K-L, Cronin J, Gill ND, Chapman DW, Sheppard J. Sources of variability in isoinertial jump assessments. *Int J Sports Physiol Perform*. 2010;5(4):546-58.
34. Thompson A, Batterham AM, Jones H, Gregson W, Scott D, Atkinson G. The Practicality and Effectiveness of Supplementary Bright Light for Reducing Jet-Lag in Elite Female Athletes. *Int J Sports Med*. 2013;34(7):582-9.

35. Thun E, Bjorvatn B, Flo E, Harris A, Pallesen S. Sleep, circadian rhythms, and athletic performance. *Sleep Med Rev.* 2015;23:1-9. doi: 10.1016/j.smr.2014.11.003. PubMed PMID: 25645125.
36. Tonetti L, Pasquini F, Fabbri M, Belluzzi M, Natale V. Comparison of two different actigraphs with polysomnography in healthy young subjects. *Chronobiol Int.* 2008;25(1):145-53. doi: 10.1080/07420520801897228.
37. Vandenberg TJ, Hopkins WG. Monitoring acute effects on athletic performance with mixed linear modeling. *Med. Sci. Sports Exerc.* 2010;42(7):1339-44. doi: 10.1249/MSS.0b013e3181cf7f3f.
38. Waterhouse J, Edwards B, Nevill A, et al. Do subjective symptoms predict our perception of jet-lag? *Ergonomics.* 2000;43(10):1514-27. doi: 10.1080/001401300750003943.
39. Waterhouse J, Edwards B, Nevill A, et al. Identifying some determinants of "jet lag" and its symptoms: a study of athletes and other travellers. *Br J Sports Med.* 2002;36(1):54-60. PubMed PMID: 11867494.
40. Waterhouse J, Reilly T, Atkinson G, Edwards B. Jet lag: trends and coping strategies. *Lancet.* 2007;369(9567):1117-29. doi: 10.1016/s0140-6736(07)60529-7. PubMed PMID: 17398311.

## FIGURE LEGENDS

**Figure 1** Schematic outline of the study design including the timeline of data collection (A), estimated body clock time data was collected on the first day following WEST and EAST (B), and specific details of the measures, travel and washout (C).

**Figure 2** Mean  $\pm$  SD changes from BASE in sprint (A and B) and YYIR1 (C) performance in WEST (black circles) and EAST (white circles). Grey shaded area indicates the typical error of the measure. Mean  $\pm$  SD responses for sRPE (D) and physical feeling (E) during BASE (grey circles), WEST and EAST. <sup>1</sup>EAST significantly different to WEST ( $p<0.05$ ); <sup>2</sup>EAST significantly different to BASE ( $p<0.05$ ); <sup>3</sup>Significantly different to day 1 and 2 in EAST ( $p<0.05$ ); <sup>4</sup>Significantly different to day 1 in WEST ( $p<0.05$ ); <sup>5</sup>Significantly different to day 1 in BASE and EAST ( $p<0.05$ ); <sup>6</sup>Significantly different to day 3 and 4 in EAST ( $p<0.05$ ); <sup>a</sup>Large ES for EAST different to WEST ( $d>0.90$ ); <sup>b</sup>Large ES for EAST different to BASE and WEST ( $d>0.90$ ); <sup>c</sup>Large ES for difference to day 3 in EAST ( $d>0.90$ ) <sup>d</sup>Large ES for difference to day 2 and 3 in BASE ( $d>0.90$ ); <sup>e</sup>Large ES for difference to all other days in EAST ( $d>0.90$ ).

**Figure 3** Mean  $\pm$  SD for jet-lag (A), function (B) and motivation (C) during BASE (grey circles), WEST (black circles) and EAST (white circles). <sup>1</sup>EAST significantly different to WEST ( $p<0.05$ ); <sup>2</sup>EAST significantly different to BASE and WEST ( $p<0.05$ ); <sup>3</sup>EAST and WEST significantly different to BASE ( $p<0.05$ ); <sup>4</sup>EAST significantly different to BASE ( $p<0.05$ ); <sup>5</sup>WEST significantly different to BASE ( $p<0.05$ ); <sup>6</sup>Significantly different to 09:00 h in EAST ( $p<0.05$ ); <sup>7</sup>Significantly different to all other days in EAST ( $p<0.05$ ); <sup>8</sup>Significantly different to day 1 and 2 in EAST ( $p<0.05$ ); <sup>9</sup>Significantly different to day 1 in EAST ( $p<0.05$ );

<sup>10</sup>Significantly different to day 1 in WEST ( $p<0.05$ ); <sup>11</sup>Significantly different to day 2 in EAST ( $p<0.05$ ); <sup>12</sup>Significantly different to day 2 in WEST ( $p<0.05$ ). <sup>a</sup>Large ES for EAST different to WEST ( $d>0.90$ ); <sup>b</sup>Large ES for EAST and WEST different to BASE ( $d>0.90$ ); <sup>c</sup>Large ES for difference to all other days in BASE ( $d>0.90$ ); <sup>d</sup>Large ES for difference to day 1 and 2 in WEST ( $d>0.90$ )

ACCEPTED

Figure 1

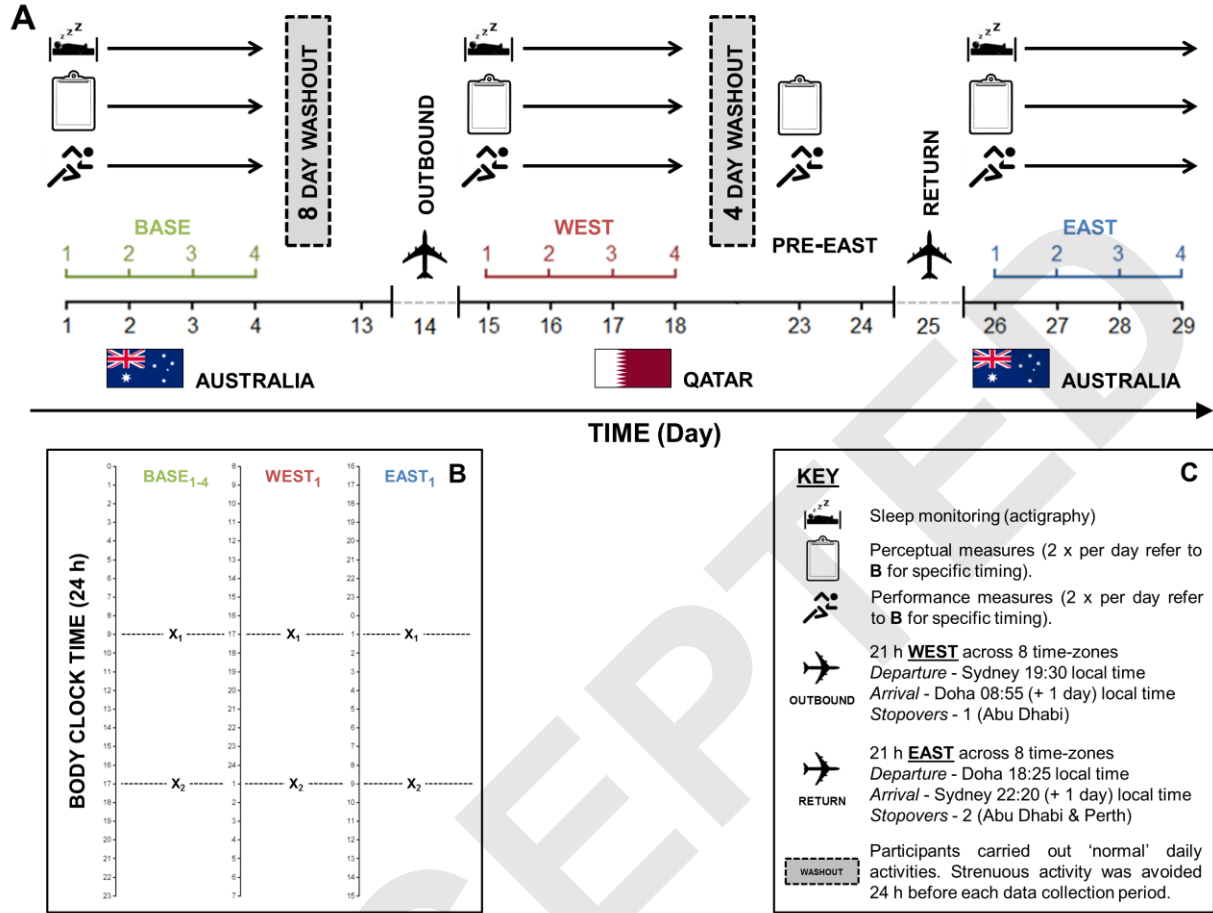




Figure 2

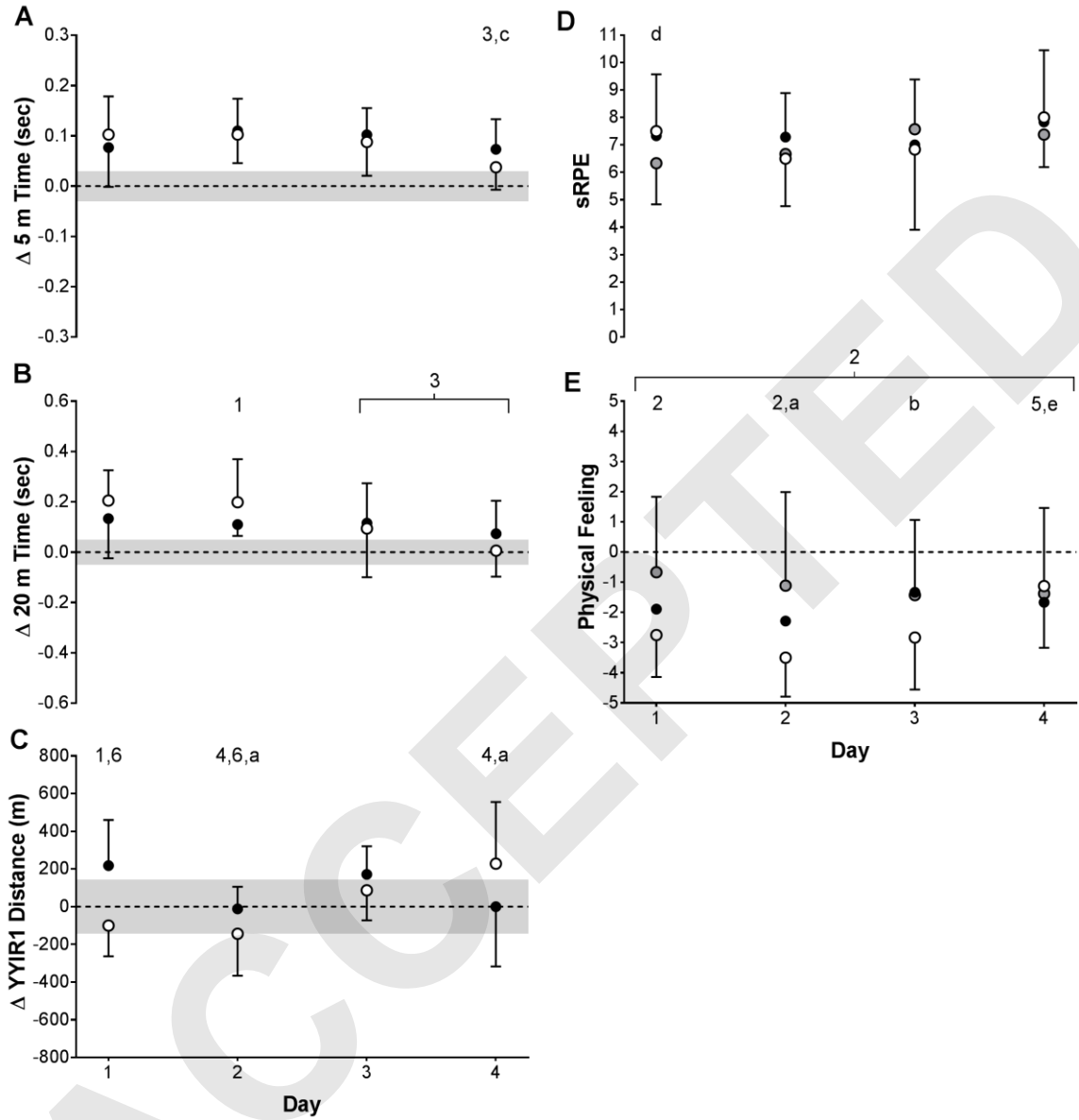
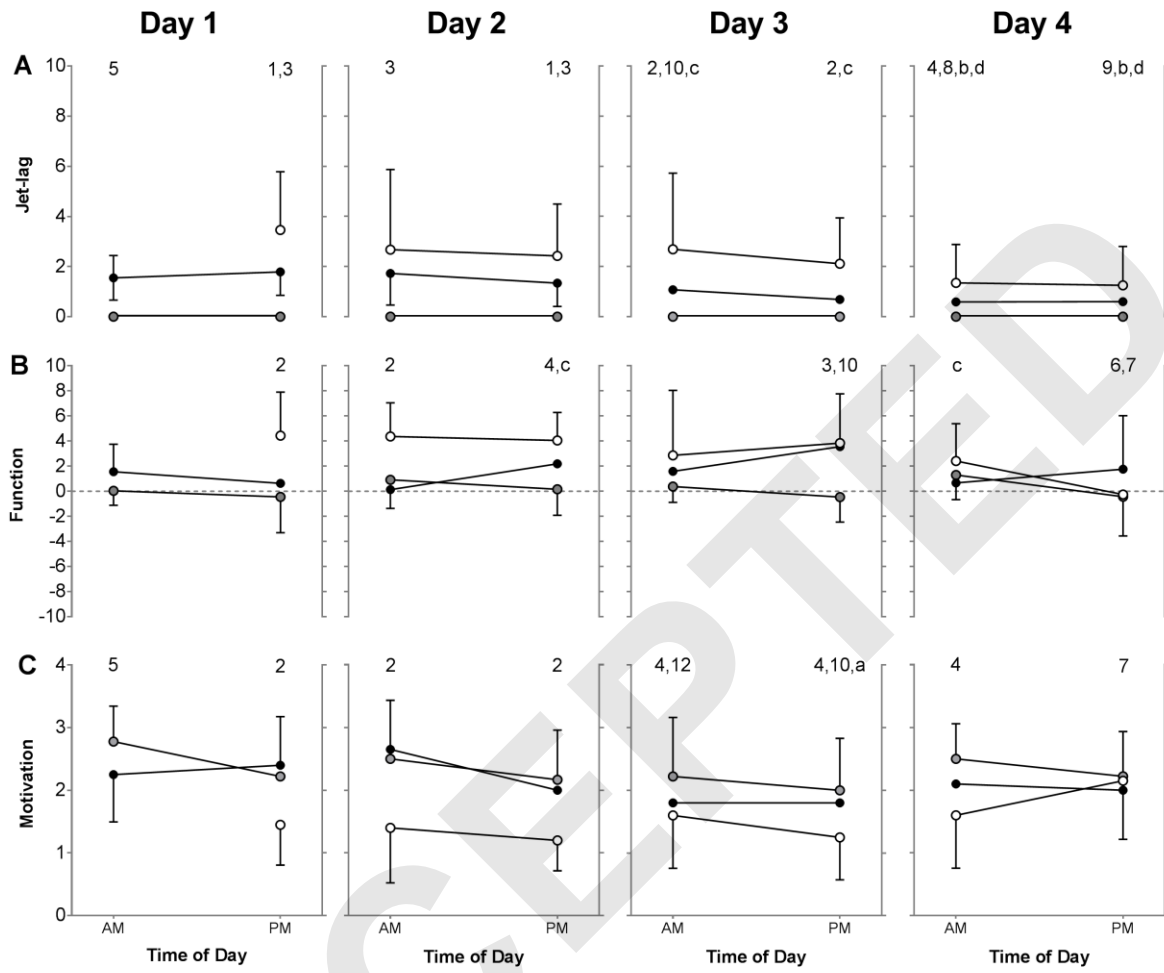


Figure 3



**Table 1** Change from BASE in CMJ performance variables in WEST and EAST. Data presented as mean  $\pm$  SD and range (minimum

	Day	1		2		3		4		09:00
		Time	09:00	17:00	09:00	17:00	09:00	17:00	09:00	
$\Delta$ Peak Power (W) <sup>#</sup>	WES T	-98 $\pm$ 457	60 $\pm$ 400	-447 $\pm$ 354 <sup>a,e</sup>	-227 $\pm$ 651	-80 $\pm$ 431	-308 $\pm$ 337	-454 $\pm$ 310 <sup>c</sup>	222 $\pm$ 479 <sup>2,5,f</sup>	-270 $\pm$ 136
		1392 (-523 - 869)	1416 (-664 - 752)	1197 (-882 - 315)	2162 (-1759 - 403)	1494 (-803 - 691)	1062 (-880 - 182)	904 (-971 - -67)	1350 (-244 - 1106)	1840 (-971 -
TE 295	EAST	-198 $\pm$ 377 <sup>a</sup>	-120 $\pm$ 287	-394 $\pm$ 637	-135 $\pm$ 358	-443 $\pm$ 584 <sup>b</sup>	-331 $\pm$ 364	177 $\pm$ 637 <sup>2,5,c</sup>	-196 $\pm$ 185	
		1386 (-878 - 508)	965 (-543 - 422)	1955 (-1653 - 302)	1156 (-592 - 564)	1763 (-1399 - 364)	1250 (-815 - 435)	1960 (-698 - 1262)	1379 (-815 -	
$\Delta$ Peak Force (N) <sup>*,†,#</sup>	WES T	-13 $\pm$ 158 <sup>d</sup>	29 $\pm$ 124 <sup>5,f</sup>	-182 $\pm$ 147 <sup>8,c</sup>	-109 $\pm$ 185	-100 $\pm$ 92	-244 $\pm$ 137 <sup>2,4</sup>	-187 $\pm$ 141 <sup>8,e</sup>	40 $\pm$ 205 <sup>2,f</sup>	-121 $\pm$ 79
		456 (-267 - 189)	396 (-149 - 247)	477 (-469 - 8)	527 (-366 - 161)	314 (-244 - 70)	438 (-443 - -5)	446 (-410 - 36)	551 (-191 - 360)	658 (-469 -
TE 100	EAST	-72 $\pm$ 148 <sup>a</sup>	-156 $\pm$ 148	-143 $\pm$ 168	-148 $\pm$ 126	-267 $\pm$ 87 <sup>7,c</sup>	-179 $\pm$ 136	-58 $\pm$ 187	-162 $\pm$ 67	
		442 (-341 - 101)	494 (-413 - 81)	465 (-393 - 72)	329 (-343 - -14)	307 (-367 - -60)	394 (-375 - 19)	621 (-361 - 260)	494 (-413	
$\Delta$ Height (cm)	WES T	-0.9 $\pm$ 2.8	-1.0 $\pm$ 2.2	-2.1 $\pm$ 2.2	-2.4 $\pm$ 4.2	-1.9 $\pm$ 2.8	-3.0 $\pm$ 1.9	-1.2 $\pm$ 2.6	-1.9 $\pm$ 2.5	-1.5 $\pm$ 1.5
		8.9 (-3.5 - 5.4)	6.9 (-3.6 - 3.3)	7.0 (-4.2 - 2.8)	14.3 (-10.0 - 4.3)	8.0 (-6.3 - 1.7)	5.9 (-6.5 - -0.6)	6.9 (-5.1 - 1.8)	5.9 (-5.1 - 0.8)	11.7 (-6.3 -
TE 1.1	EAST	-1.6 $\pm$ 2.9	-1.6 $\pm$ 3.1	-1.6 $\pm$ 3.3	-1.9 $\pm$ 3.5	-1.8 $\pm$ 2.5	-0.7 $\pm$ 2.0	-0.9 $\pm$ 2.6	-1.4 $\pm$ 2.5	
		9.6 (-6.1 - 3.5)	9.1 (-5.0 - 4.1)	12.0 (-7.7 - 4.3)	11.7 (-6.1 - 5.6)	8.1 (-5.2 - 2.9)	5.2 (-2.8 - 2.4)	7.1 (-4.0 - 3.1)	11.7 (-6.1 -	

TE Typical Error. \*Significant main effect for travel direction ( $p < 0.05$ ); †Significant interaction between travel direction and interaction between travel direction, day and time of day ( $p < 0.05$ ). <sup>1</sup>EAST significantly different to WEST ( $p < 0.05$ ); <sup>2</sup>Significantly different to ( $p < 0.05$ ); <sup>4</sup>Significantly different to all other days ( $p < 0.05$ ); <sup>5</sup>Significantly different to day 2 and 3 ( $p < 0.05$ ); <sup>7</sup>Significantly different to ( $p < 0.05$ ); <sup>8</sup>Significantly different to day 1 ( $p < 0.05$ ). <sup>a</sup>Large ES for EAST different to WEST ( $d > 0.90$ ); <sup>b</sup>Large ES for difference to <sup>c</sup>Large ES for difference to all other days ( $d > 0.90$ ); <sup>d</sup>Large ES for difference to day 1 and 2 ( $d > 0.90$ ); <sup>e</sup>Large ES for difference to Large ES for difference to day 2 and 3 ( $d > 0.90$ ).

**Table 2** Sleep patterns, quantity and quality during BASE, WEST and EAST. Data presented as mean  $\pm$  SD and range (minimum - maximum).

Day	Arrival	1	2	3	4	
<b>Time in Bed (h:min)*</b>						
<b>BASE</b>		07:14 $\pm$ 01:01 03:16 (05:21 - 08:37)	07:33 $\pm$ 01:23 04:34 (04:46 - 09:20)	07:22 $\pm$ 00:55 03:15 (05:52 - 09:07)	07:48 $\pm$ 01:00 03:09 (06:05 - 09:14)	03:01 (05:59)
<b>WEST</b>	08:33 $\pm$ 00:50 <sup>3</sup> 02:30 (07:11 - 09:41)	07:21 $\pm$ 00:32 01:39 (06:40 - 08:19)	07:22 $\pm$ 00:42 02:01 (06:20 - 08:21)	07:11 $\pm$ 00:23 01:12 (06:37 - 07:49)	07:48 $\pm$ 00:20 <sup>d</sup> 00:57 (07:16 - 08:13)	01:11 (06:58)
<b>EAST</b>	07:20 $\pm$ 00:40 <sup>1</sup> 02:06 (06:14 - 08:20)	06:13 $\pm$ 01:27 <sup>2,4</sup> 04:31 (03:06 - 07:37)	06:11 $\pm$ 01:43 <sup>2,4</sup> 04:49 (03:33 - 08:22)	06:38 $\pm$ 01:27 04:29 (04:00 - 08:29)	07:06 $\pm$ 01:20 <sup>5</sup> 03:21 (05:47 - 09:08)	02:30 (05:13)
<b>Sleep Onset (hh:mm)*,†</b>						
<b>BASE</b>		23:09 $\pm$ 01:11 03:16 (21:42 - 00:58)	22:57 $\pm$ 01:27 04:53 (21:00 - 01:53)	23:00 $\pm$ 01:06 04:12 (21:00 - 01:12)	23:57 $\pm$ 01:19 <sup>3</sup> 04:04 (22:02 - 02:06)	04:17 (21:14)
<b>WEST</b>	22:00 $\pm$ 00:52 <sup>3</sup> 02:31 (21:05 - 23:36)	23:12 $\pm$ 00:43 01:46 (22:27 - 00:13)	23:23 $\pm$ 00:41 02:01 (22:29 - 00:30)	23:27 $\pm$ 00:35 01:44 (22:41 - 00:25)	23:02 $\pm$ 00:19 00:58 (22:27 - 23:25)	01:32 (22:23)
<b>EAST</b>	00:57 $\pm$ 01:13 <sup>1</sup> 03:01 (23:51 - 02:52)	00:11 $\pm$ 01:23 <sup>2</sup> 03:51 (22:55 - 02:46)	00:24 $\pm$ 01:38 <sup>2</sup> 04:17 (22:52 - 03:09)	23:40 $\pm$ 01:43 <sup>4</sup> 05:10 (21:50 - 03:00)	00:36 $\pm$ 01:25 <sup>2</sup> 03:55 (23:08 - 03:03)	03:28 (23:10)
<b>Sleep Offset (hh:mm)*,†</b>						
<b>BASE</b>		06:16 $\pm$ 00:41 02:19 (04:51 - 07:10)	06:18 $\pm$ 00:27 01:37 (05:43 - 07:20)	06:08 $\pm$ 00:36 02:03 (05:13 - 07:16)	07:34 $\pm$ 01:37 <sup>3</sup> 04:20 (05:45 - 10:05)	01:23 (05:55)
<b>WEST</b>	06:34 $\pm$ 00:21 01:14 (05:44 - 06:58)	06:32 $\pm$ 00:27 01:12 (05:47 - 06:59)	06:44 $\pm$ 00:15 <sup>c</sup> 00:46 (06:22 - 07:08)	06:37 $\pm$ 00:30 <sup>c</sup> 01:34 (05:56 - 07:30)	06:51 $\pm$ 00:21 01:00 (06:31 - 07:31)	00:50 (06:15)
<b>EAST</b>	08:14 $\pm$ 01:20 <sup>1,3</sup> 04:10 (06:59 - 11:09)	06:24 $\pm$ 00:28 01:28 (05:51 - 07:19)	06:33 $\pm$ 00:29 01:18 (05:59 - 07:17)	06:15 $\pm$ 00:42 02:15 (05:19 - 07:34)	07:39 $\pm$ 01:38 <sup>3</sup> 04:13 (05:27 - 09:40)	02:06 (06:13)

Sleep Duration (h:min)\*:†

<b>BASE</b>		06:25 ± 01:06	06:18 ± 01:16	06:20 ± 00:50	06:38 ± 00:45	
		03:24 (04:35 - 07:59)	04:33 (03:53 - 08:26)	03:16 (04:53 - 08:09)	02:36 (05:11 - 07:47)	03:08 (05:03)
<b>WEST</b>	07:36 ± 01:00 <sup>3</sup>	06:24 ± 00:36	06:22 ± 00:47	06:15 ± 00:29	06:53 ± 00:55	
	02:43 (06:23 - 09:06)	01:58 (05:25 - 07:23)	02:28 (05:24 - 07:52)	01:36 (05:38 - 07:14)	02:20 (05:39 - 07:59)	02:00 (05:44)
<b>EAST</b>	06:27 ± 00:49 <sup>1</sup>	05:24 ± 01:18 <sup>2,4</sup>	05:18 ± 01:38 <sup>2,4</sup>	05:50 ± 01:27	06:13 ± 01:28 <sup>5</sup>	
	02:39 (04:52 - 07:31)	03:56 (02:38 - 06:34)	04:48 (03:07 - 07:55)	04:22 (03:16 - 07:38)	03:38 (04:50 - 08:28)	02:45 (04:27)

Sleep Efficiency (%)

<b>BASE</b>		90.3 ± 3.1	85.7 ± 3.5	88.9 ± 3.7	87.4 ± 4.2	
		9.5 (84.4 - 93.9)	11.9 (79.5 - 91.5)	12.5 (83.4 - 96.0)	13.0 (79.9 - 92.9)	
<b>WEST</b>	88.7 ± 4.0	87.2 ± 5.1 <sup>b</sup>	86.4 ± 4.3	87.2 ± 3.7	87.8 ± 8.4	
	11.9 (82.0 - 93.9)	16.9 (80.2 - 97.1)	13.6 (80.5 - 94.2)	9.9 (83.1 - 93.0)	19.9 (77.4 - 97.3)	
<b>EAST</b>	88.4 ± 5.4	86.9 ± 3.3 <sup>b</sup>	86.8 ± 9.9	88.5 ± 3.3	87.7 ± 4.2	
	17.6 (78.2 - 95.9)	9.8 (81.8 - 91.5)	31.1 (63.7 - 94.8)	8.9 (84.9 - 93.8)	12.0 (82.8 - 94.8)	

\*Significant main effect for travel direction ( $p < 0.05$ ); †Significant interaction between travel direction and  
<sup>1</sup>EAST significantly different to WEST ( $p < 0.05$ ); <sup>2</sup>EAST significantly different to BASE & WEST ( $p < 0.05$ );  
different to all other days ( $p < 0.05$ ); <sup>4</sup>Significantly different to day of arrival ( $p < 0.05$ ); <sup>5</sup>Significantly different to  
( $p < 0.05$ ).<sup>a</sup>Large ES for EAST different to WEST ( $d > 0.90$ ); <sup>b</sup>Large ES for EAST and WEST different to BASE ( $d > 0.90$ );  
<sup>c</sup>Large ES for WEST different to BASE; <sup>d</sup>Large ES for difference to all other time points ( $d > 0.90$ ).