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

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

Keywords: Soccer, football, jet-lag, travel fatigue, physical performance, sleep

Abbreviations

AEST Australian Eastern Standard Time

CI Confidence intervals

CMJ Countermovement jump

CON Control trial

GMT Greenwich Mean Time

INT Intervention trial

YYIR1 Yo-Yo Intermittent Recovery level 1 test

Introduction

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

Symptoms of jet-lag result from the loss of synchrony between the endogenous (circadian rhythms in body temperature and hormone release) and exogenous (sleep and activity) components of the body clock, which occurs after rapidly crossing multiple time zones during transmeridian air travel (Forbes-Robertson et al. 2012; Reilly et al. 2007; Waterhouse et al.

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

Despite the detrimental effects of transmeridian air travel on physical performance (Chapman et al. 2012; Reilly et al. 2001), a paucity of interventions have been confirmed as beneficial for traveling athletes. Given the disruption of habitual sleep patterns is likely to occur during and following long-haul international air travel (Takahashi et al. 2002), which may reduce physical performance itself (Reilly and Edwards 2007; Skein et al. 2011), sleep hygiene recommendations that minimize this disruption may enhance performance recovery following international travel. Specific strategies include minimizing the use of electronic equipment prior to sleep and ensuring a cool, quiet and dark environment (Halson 2013). Though these strategies are

advocated to improve sleep in elite athletes (Halson 2013), it remains to be investigated as to whether they are effective at minimizing sleep disruption during and following international travel. Moreover, the correct timing of exposure to bright light is currently purported to be the most effective method of adjusting circadian rhythms (Forbes-Robertson et al. 2012). Consequently, the commercial availability of portable artificial bright light sources as a treatment for jet-lag has recently increased. Whilst evidence suggests these devices can adjust circadian rhythms (Wright et al. 2004), their effectiveness at enhancing the recovery of physical performance for team sports following transmeridian air travel is limited (Thompson et al. 2013).

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

Methods

Participants

Thirteen, physically active males were recruited to participate in the present study; mean and 95 % confidence intervals (CI); age 24.3 (19.6-29.0) y, body mass 73.8 (69.3-78.3) kg and estimated (Bangsbo et al. 2008) $\dot{V}O_2max$ 52.3 (50.4-54.2) ml·kg^{-1}·min^{-1}. At the time of testing, participants reported completing three or more physical training sessions per week, including sport-specific, cardiovascular and resistance training. However, it is recognized as a limitation of the present study that the participants were not all highly-trained team sport athletes, which may restrict the generalizability of the results. Prior to the commencement of the study, participants

were informed of any associated risks and provided verbal and written informed consent. The study was approved by the institutional Human Research Ethics Committee.

Experimental design

Following a minimum of two familiarization sessions with all experimental measures and procedures, including a detailed account of the respective exercise and simulated travel protocols, participants completed two trials in a randomized cross-over design. Each trial involved 24 h of simulated international travel, including 10 h and 12 h flights separated by a two hour 'stopover', thus, replicating the demands of travel from Sydney, Australia to London, England via Hong Kong. Trials were standardized and differed only by whether the artificial bright light and sleep hygiene interventions were utilized (INT) or not (CON). Collection of performance, physiological and perceptual data occurred in the morning at 08:00 and evening at 18:00, Australian Eastern Standard Time (AEST) on the day prior to travel, and in the morning at 07:00 and evening at 19:00 AEST for two days post-travel, which corresponded to 21:00 and 09:00 Greenwich Mean Time (GMT, London, England) (Figure 1). These specific times were selected to align with previous research (Reilly et al. 2001; Thompson et al. 2013) and to standardize for the diurnal variation in physical performance (Drust et al. 2005). Data were collected over five consecutive days for both trials, with each trial separated by a minimum of one week to ensure adequate recovery. Physical activity and dietary and fluid intake were documented 24 h prior to the first trial and replicated for the subsequent trial. Participants abstained from caffeine, alcohol and additional strenuous activity for 24 h before and during each trial.

**** Insert Figure 1 near here ****

Simulated air travel

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

Meals similar in content and packaging to standard airline food were provided 1 h into and 2.5 h from the end of each leg of the simulated travel, whilst additional fluid was provided every two hours during each flight. Nutritional intake was documented by participants throughout all trials via dietary recall, which was analyzed using nutrient analysis software (FoodWorks®, Xyris Software Pty Ltd, Kenmore Hills, Australia). No significant differences existed between the INT and CON trials ($P<0.05$) for energy (KJ) and carbohydrate, protein, or fat intake (g/kg BM). To

simulate engine noise levels in the cabin during a commercial flight, air blowers (Side Channel Blower SE0120, BUSCH, Broadmeadows, VIC, Australia) were positioned in each room so that the noise level where participants sat was 80 decibels (Ozcan and Nemlioglu 2006). During the two hour stopover, participants exited the altitude room and were permitted to move around freely in normoxia.

Simulated time zone change

The hypoxic rooms in which the simulated travel was completed formed part of an altitude house. Natural light and external influences were blocked out of the house throughout each trial. From the beginning of the simulated travel, all clocks were altered to show the destination time (GMT, London, England). In addition, on completion of the simulated travel, participants' light-dark cycles and thus, eating and sleeping patterns were changed to London time for the rest of the trial. In an attempt to simulate day time in London, participants were required to remain awake overnight AEST in the altitude house with the lights on (167 (100-234) lux). However, it is acknowledged as a limitation that this doesn't represent normal daylight. During this time participants were permitted to move around freely in normoxia and were provided with breakfast, lunch, and dinner according to London time. To simulate night time in London, participants slept in the altitude house during the day time AEST. In order to limit potential exposure to incidental natural light, participants wore wrap-around sunglasses (Contractor Smoke Safety Glasses, Dewalt, Melbourne, Australia) when moving between the altitude house and the enclosed synthetic running track, where the performance tests were conducted and all natural light was blocked out.

Interventions

During the simulated travel, participants in the INT group were provided with noise cancelling headphones (Sennheiser HD 280 Pro, Sennheiser, Chatswood, Australia), a sleep mask (Sweet Dreams Eye Mask, Dream Essentials, Paradise Point, Australia) and a neck pillow (Traveller's Pillow, Therapeutic Pillow International, Cheltenham, Australia), and were instructed to sleep whenever possible. This aimed to increase comfort and the likelihood of sleep without pharmacological aids. Furthermore, participants' exposure to and avoidance of light was controlled during simulated travel. Specifically, artificial bright light emitting glasses (Re-Timer™, Bedford Park, SA, Australia) and wraparound sunglasses (Contractor Smoke Safety Glasses, Dewalt, Melbourne, Australia) were used from 02:00 - 05:00 and 05:00 - 08:00 AEST, respectively (Figure 1). The timing of exposure aimed to induce a phase delay in circadian rhythms to align participants' body clock with the new simulated time zone (GMT) and was derived from previous research on the phase response curve to light (Czeisler et al. 1989). Conversely, no assistance or advice was provided to the CON group, who self-selected their sleep patterns during the simulated travel. Participants in the INT group continued to use the light glasses and wraparound sunglasses at the same times for two days post-travel, to assist with circadian rhythm resynchronization following the simulated change in time zones and light-dark cycle. Overall, participants were exposed to 506 lux of blue-green 500 nm dominant wavelength, UV-free light at 12 mm for 3 h per day for three days during the INT trial, with each eye receiving 230 μW/cm^2 at the corneal surface. Light glasses with similar specifications have previously been reported to induce phase-shifts in circadian rhythms (Wright et al. 2004).

Sleep hygiene recommendations were also provided to participants during and for the two sleep periods following travel in the INT trial. These recommendations were based on evidence that exposure to excessive light and electronic stimuli can reduce sleep quality (Halson 2013), and aimed to induce the physiological state required for sleep onset. Specifically, in the hour prior to bed, participant's limited computer, TV and phone use and dimmed their bedroom lights. Cool (19.7 (19.1-20.3)°C), quiet and dark conditions were ensured throughout the sleep period. In contrast, the CON group was instructed to maintain normal behavior prior to bed and did not alter their room lighting or temperature. For both trials, participants shared the same room with the same group and the INT and CON groups were in separate rooms.

Experimental Procedures

Performance measures

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

performance tests until the end of the study, which included using a modified version of the YYIR1, with feedback regarding the level removed from the test audio mp3.

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

Physiological measures

Participants' sleep was monitored using self-report diaries and wrist activity monitors (Philips Respironics, Bend, OR) worn on the same wrist during each trial for two days prior to, during

and two days following the simulated travel. According to methods previously described (Sargent et al. 2014), data from the sleep diaries and activity monitors was used to determine when participants were awake and asleep. The following dependent variables were derived; sleep duration (h): the amount of time spent in bed asleep; sleep efficiency (%): sleep duration expressed as a percentage of time in bed; and the number of wake bouts (Sargent et al. 2014). Total sleep duration (h) during the sleep hygiene intervention period was also calculated for each trial, by summating individual sleep durations from during-travel, day 1 and day 2.

Oxygen saturation was recorded whilst seated with a pulse oximeter (Nonin 4000 Avant Bluetooth Pulse Oximeter, Nonin, North Plymouth, MN) immediately prior to, 1 h after 'take-off', half-way through, 1 h prior to 'landing' and immediately following each leg of the simulated travel. To assess urine specific gravity, a midstream urine sample was collected and analyzed (Refractometer 503, Nippon Optical Works, Co., Tokyo, Japan) immediately prior to all performance testing sessions, and immediately before the first leg and after the second leg of the simulated travel. Heart rate was measured (Polar Team[2], Polar Electro, Kempele, Finland), continuously throughout the 5′-5′ test and was analyzed using customized manufacturers software (Polar Team System[2], Polar Electro, Kempele, Finland). Heart rate during and recovery following the test was calculated according to a method previously described (Buchheit et al. 2011). The typical error for these measures in the present study was 6 (4-9) beats per minute and 4 (3-6) beats per minute, respectively.

Perceptual measures

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

Statistical Analysis

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

Results

Performance measures

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

**** Insert Figure 2 near here ****

Physiological measures

No significant differences existed between conditions for any physiological measure ($P>0.05$). Sleep duration was significantly reduced during travel compared to all other time points in both trials (Table 1; $P<0.01$), while total sleep duration was almost significantly greater during the INT compared with the CON trial ($P=0.06$). Perceived sleep quality was significantly worse

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during travel compared to all other time points in both trials (Table 1; *P*<0.01). Compared to baseline, perceived sleep quality was significantly and almost significantly better on day 1 (*P*=0.03) and day 2 (*P*=0.06), respectively, in the INT trial.

**** Insert Table 1 near here ****

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

**** Insert Table 2 near here ****

Perceptual measures

Whilst vigour was significantly greater the morning of day 2 in the INT compared to the CON trial (*P*=0.04; Table 3), no other significant differences existed between conditions for any perceptual measure (*P*>0.05). Compared to the morning and evening baseline, subjective jet-lag was significantly greater at all other time points and sleep ratings were significantly worse on

day 1 in both trials (Fig. 3A and B; $P<0.05$). In contrast, sleep ratings were significantly better the morning of day 2 in the CON trial ($P<0.05$) and the morning and evening of day 2 in the INT trial ($P<0.05$). Function ratings were significantly worse the evening of day 1 compared to the morning and evening baseline in both trials (Fig. 3C; $P<0.05$). Additionally, function ratings were significantly worse the morning of day 1 and the evening of day 2 compared to baseline in the CON trial ($P<0.05$). Conversely, in the INT trial, function ratings were almost significantly better the morning of day 2 compared to the morning of day 1 ($P=0.09$) and evening of day 2 ($P=0.07$). Lastly, bowel movement ratings were significantly worse the evening of day 1 compared to the morning baseline in the CON trial (Fig. 3D; $P<0.01$).

 **** Insert Figure 3 near here ****

No significant effects of time were identified for anger, depression or tension in either trial ($P>0.05$) and therefore given the extent of already data presented, no data is presented for these variables. Compared to baseline, confusion and fatigue were significantly greater the evening of day 1 and the evening of day 1 and 2, respectively, in both trials (Table 3; $P<0.05$). Moreover, fatigue was significantly greater the morning of day 1 compared to baseline in the CON trial ($P<0.05$). Vigour was significantly lower the evening of day 1 compared to pre-travel in the CON trial ($P<0.05$), and the morning baseline and pre-travel in the INT trial (Table 3; $P<0.05$). Lastly, compared to baseline, session rating of perceived exertion was significantly greater, and physical feeling was significantly worse, the evening of day 1 and 2 in both trials (Table 3; $P<0.05$).

**** Insert Table 3 near here ****

Discussion

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

Effects of simulated travel

Results from the present study indicate simulated air travel had negligible effects on intermittent-sprint performance, though further research involving actual international travel is required to confirm these findings. Conversely, slower sprint times were evident in the evening of day 1 and 2 post-travel, which is contrary to previously reported effects of transmeridian air travel on maximal-sprint performance (Bullock et al. 2007). Similar to previous research (Chapman et al. 2012), reductions in unloaded CMJ height were also evident in the evening of day 1 and 2 following travel. Considering sprint times and jump height were reduced in the evening GMT, which corresponded to the morning AEST, simulated travel may have augmented the performance reduction often observed in the morning compared to the evening (Drust et al. 2005). This could be a result of the simulated change in light-dark cycle, which meant that

following simulated travel, wakefulness prior to testing in the morning AEST was greater than normal. Though reduced eight-choice reaction time has previously been identified following transmeridian air travel (Reilly et al. 2001), there were no meaningful changes in two- or four-choice reaction time in the present study. Such findings may imply that long-haul air travel affects complex (decision making), but not simple (psychomotor speed) reaction time (Reilly et al. 2001). Whilst this may indicate that decision making could be affected during team sport training and competition following international air travel, further research utilizing more sport-specific reaction time measures, such as reactive agility, is required to substantiate this.

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

(Ozcan and Nemlioglu, 2006), however, similar to a commercial flight (Ozcan and Nemlioglu, 2006), noise levels of 80 decibels were endured during simulated travel in the present study.

Sleep disruption can induce a physiological stress response (Meerlo et al. 2008) and therefore, maintaining wakefulness in a state of sleep debt may require increased sympathetic activation and hence, cardiovascular activity, particularly during exercise (Meerlo et al. 2008). In the present study, the heart rate response to sub-maximal exercise was unchanged following travel, which may suggest that sleep disruption did not induce substantial physiological stress. However, considering the present study is the first to report such findings and other physiological stress markers were not measured, further research is required to confirm this. Evidence suggests that as a result of the low cabin humidity during actual air travel, an increased loss of moisture via respiration may occur, resulting in hypohydration (Simons and Krol 1996) which could impact subsequent exercise performance (Maughan 2003). Therefore, given hydration status improved post-simulated travel, the inability to simulate low cabin humidity is acknowledged as a logistical limitation of the present study. Furthermore, as testing occurred at similar body clock times pre- and post-travel, the detrimental physiological consequences of jet-lag (Forbes-Robertson et al. 2012; Reilly et al. 2007; Waterhouse et al. 2007) are unlikely to have occurred. Though the lack of physiological markers of circadian rhythms in the present study, such as melatonin and body temperature, means this is difficult to ascertain. Instead, symptoms of travel fatigue which are predominantly perceptual (Reilly et al. 2007; Waterhouse et al. 2007) may have been present.

Subjective jet-lag post simulated travel was comparable to levels previously reported following transmeridian air travel (Reilly et al. 2001; Thompson et al. 2013). Furthermore, sleep and

function ratings, which resemble symptoms of travel fatigue, were worse post-travel, whereas, diet and bowl movement ratings, which would only be affected if circadian rhythms were disrupted (Reilly et al. 2007), were relatively unchanged. These findings indicate the presence of travel fatigue, but not jet-lag following simulated travel. A change in the light-dark cycle was simulated in the present study, which would have resulted in the misalignment of the timing of external factors, such as sleep and activity with body clock time post-travel. However, testing occurred at a similar body clock time pre- and post-travel, with only a difference in the duration of wakefulness prior to testing. This may explain why the detrimental consequences of jet-lag are unlikely to have occurred in the present study. Additionally, increased perceptual strain prior to and during exercise was evident following travel in the present study. Since restricted sleep has been associated with similar responses (Reilly and Edwards 2007; Skein et al. 2011), it is likely that sleep disruption during simulated travel caused the reported increase in perceived fatigue. Together with reduced effects of simulated travel on 5 m compared to 20 m sprint times and loaded compared to unloaded CMJ height, these results suggest that the decrease in lower-body power detected in the present study, may have been due to increased subjective fatigue and thus, reduced motivation rather than a decline in skeletal muscle contractile function. However, it must be recognized that without an explicit measure of skeletal muscle contractile function, such a conclusion cannot be confirmed in the current study.

Effects of travel interventions

Use of artificial bright light alongside sleep hygiene recommendations had no effect on performance recovery following simulated air travel. However, the frequency of performance measures and lack of physiological markers of circadian rhythms are recognized as limitations of

the present study, as this made it difficult to detect whether, if as intended, the artificial bright light intervention delayed circadian rhythms. Previous research also reports negligible effects of artificial bright light on performance recovery following transmeridian air travel (Thompson et al. 2013), which could be due to limited consensus on optimal protocols (Forbes-Robertson et al. 2012). For example, compared to the individual use of light glasses for 3 h per day in the present study, light boxes shared between two people for 45-60 min per day have previously been utilized (Thompson et al. 2013). Furthermore, considering bright light exposure at the wrong time may cause circadian rhythm shifts in the opposite direction (Gronfier et al. 2004), avoidance of incidental light at specific times is essential. Yet, previously no restrictions have been placed on exposure to additional light (Thompson et al. 2013). Consequently, further research is required to determine optimum protocols for utilizing bright light to resynchronize circadian rhythms and thus, enhance performance recovery following transmeridian air travel.

Total sleep duration was almost significantly greater in the INT trial, which suggests that assistance with comfort during travel and sleep hygiene recommendations may help with reducing the sleep debt accumulated from long-haul air travel. Despite increased sleep quantity during the INT trial, no subsequent effects on the recovery of performance or physiological fatigue were evident post-travel. Given the absence of supporting literature, further research into the efficacy of optimizing sleep hygiene on sleep during and following travel is required, especially when there are disruptions to circadian rhythms in body temperature and melatonin, which regulate sleep.

Increased jet-lag symptoms and perceptual fatigue, together with reduced vigour were evident following simulated travel in the CON trial, indicating that artificial bright light together with sleep hygiene recommendations may attenuate travel fatigue following long-haul air travel. Given the restorative effects of sleep on alertness following sleep restriction (Belenky et al. 2003), increased sleep quantity during the INT trial may explain these results. Moreover, considering artificial bright light has been reported to be ineffective at reducing subjective jet-lag symptoms following transmeridian air travel (Thompson et al. 2013), sleep hygiene recommendations are likely to have had a greater impact on perceptual recovery in the present study. Whilst a placebo effect of the interventions shouldn't be discounted, reduced travel fatigue did not translate into enhanced recovery of physical performance following simulated travel. Therefore, the interventions utilized in the present study are unlikely to enhance team sport physical performance following international air travel.

In conclusion, sleep disruption resulting from conditions during travel may have increased perceptual fatigue and suppressed lower-body power post-travel. Whilst attenuating sleep disruption through increased comfort during travel and sleep hygiene recommendations may assist with reducing travel fatigue, no subsequent effect on the recovery of team sport physical performance was identified. Therefore, practitioners should consider utilizing interventions that minimize sleep disruption in order to reduce travel fatigue following long-haul air travel. However, the authors acknowledge that the main limitation of simulating international air travel was that testing occurred at a similar body clock time pre- and post-travel. Moreover, no physiological markers of circadian rhythms were obtained, making detection of altered circadian rhythms difficult. Consequently, though results from the present study suggest that artificial

bright light had negligible effects on performance, physiological and perceptual responses, given the simulated travel environment, further research into its impact on circadian rhythm resynchronization and team sport physical performance recovery following actual transmeridian air travel is warranted.

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Conflicts of interest

The authors report no conflicts of interest.

References

Australian Institute of Sport (2000) Physiological Tests for Elite Athletes. Gore C and Tanner R (eds). Second ed. Human Kinetics, Champaign, IL.

Bangsbo J, Iaia FM, Krustrup P (2008) The Yo-Yo Intermittent Recovery Test. A Useful Tool for Evaluation of Physical Performance in Intermittent Sports. Sports Med 38: 37-51.

Belenky G, Wesensten NJ, Thorne DR, Thomas ML, Sing HC, Redmond DP, Russo MB, Balkin TJ (2003) Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: A sleep dose-response study. J Sleep Res 12: 1-12.

Buchheit M, Voss SC, Nybo L, Mohr M, Racinais S (2011) Physiological and performance adaptations to an in-season soccer camp in the heat: associations with heart rate and heart rate variability. Scand J Med Sci Sports 21: 477-485.

Bullock N, Martin DT, Ross A, Rosemond D, Marino FE (2007) Effect of long haul travel on maximal sprint performance and diurnal variations in elite skeleton athletes. Br J Sports Med 41: 569-573.

Chapman DW, Bullock N, Ross A, Rosemond D, Martin DT (2012) Detrimental effects of West to East transmeridian flight on jump performance. Eur J Appl Physiol 112: 1663-1669.

Coste O, Beaumont M, Batejat D, Van Beers P, Charbuy H, Touitou Y (2004) Hypoxic depression of melatonin secretion after simulated long duration flights in man. J Pineal Res 37: 1-10.

Coste O, Van Beers P, Touitou Y (2009) Hypoxia-induced changes in recovery sleep, core body temperature, urinary 6-sulphatoxymelatonin and free cortisol after a simulated long-duration flight. J Sleep Res. 18: 454-465.

Czeisler CA, Kronauer RE, Allan JS, Duffy JF, Jewett ME, Brown EN, Ronda JM (1989) Bright light induction of strong (type 0) resetting of the human circadian pacemaker. Science 244: 1328-1333.

Drust B, Waterhouse J, Atkinson G, Edwards B, Reilly T (2005) Circadian rhythms in sports performance - an update. Chronobiol Int 22: 21-44.

Forbes-Robertson S, Dudley E, Vadgama P, Cook C, Drawer S, Kilduff L (2012) Circadian disruption and remedial interventions: effects and interventions for jet lag for athletic peak performance. Sports Med 42: 185-208.

Foster C, Daines E, Hector L, Snyder AC, Welsh R (1996) Athletic performance in relation to training load. Wis Med J 95: 370-374.

Galambos SA, Terry PC, Moyle GM, Locke SA, Lane AM (2005) Psychological predictors of injury among elite athletes. Br J Sports Med 39: 351-354.

Geertsema C, Williams AB, Dzendrowskyj P, Hanna C (2008) Effect of commercial airline travel on oxygen saturation in athletes. Br J Sports Med 42: 877-881.

Gronfier C, Wright KP, Jr., Kronauer RE, Jewett ME, Czeisler CA (2004) Efficacy of a single sequence of intermittent bright light pulses for delaying circadian phase in humans. Am J Physiol Endocrinol Metab 287: E174-181.

Halson SL (2013) Sleep and the elite athlete. Sports Science 26: 1-4.

Hardy CJ, Rejeski WJ (1989) Not what, but how one feels: The measurement of affect during exercise. J Sport Exerc Psychol 11: 304-317.

Krustrup P, Mohr M, Amstrup T, Rysgaard T, Johansen J, Steensberg A, Pedersen PK, Bangsbo J (2003) The yo-yo intermittent recovery test: physiological response, reliability, and validity. Med Sci Sports Exerc 35: 697-705.

Lagarde D, Chappuis B, Billaud PF, Ramont L, Chauffard F, French J (2001) Evaluation of pharmacological aids on physical performance after a transmeridian flight. Med Sci Sports Exerc 33: 628-634.

Leatherwood WE, Dragoo JL (2012) Effect of airline travel on performance: a review of the literature. Br J Sports Med 47: 561-567.

Maughan R (2003) Impact of mild dehydration on wellness and on exercise performance. Eur J Clin Nutr 57: S19-S23.

Meerlo P, Sgoifo A, Suchecki D (2008) Restricted and disrupted sleep: effects on autonomic function, neuroendocrine stress systems and stress responsivity. Sleep Med Rev 12: 197-210.

Ozcan HK, Nemlioglu S (2006) In-cabin noise levels during commercial aircraft flights. Canadian Acoustics 34: 31-35.

Pierard C, Beaumont M, Enslen M, Chauffard F, Tan DX, Reiter RJ, Fontan A, French J, Coste O, Lagarde D (2001) Resynchronization of hormonal rhythms after an eastbound flight in humans: effects of slow-release caffeine and melatonin. Eur J Appl Physiol 85: 144-150.

Reilly T, Atkinson G, Budgett R (2001) Effect of low-dose temazepam on physiological variables and performance tests following a westerly flight across five time zones. Int J Sports Med 22: 166-174.

Reilly T, Atkinson G, Edwards B, Waterhouse J, Åkerstedt T, Davenne D, Lemmer B, Wirz-Justice A (2007) Coping with jet-lag: A position statement for the European College of Sport Science. Eur J Sport Sci 7: 1-7.

Reilly T, Edwards B (2007) Altered sleep-wake cycles and physical performance in athletes. Physiol Behav 90: 274-284.

Reilly T, Waterhouse J, Burke LM, Alonso JM (2007) Nutrition for travel. J Sports Sci 25 S125-134.

Sargent C, Halson S, Roach GD (2014) Sleep or swim? Early-morning training severely restricts the amount of sleep obtained by elite swimmers. Eur J Sport Sci 14: S310-315.

Savourey G, Launay JC, Besnard Y, Guinet A, Travers S (2003) Normo- and hypobaric hypoxia: are there any physiological differences? Eur J Appl Physiol 89: 122-126.

Simons R, Krol J (1996) Jet leg, pulmonary embolism, and hypoxia. The Lancet 348: 416.

Skein M, Duffield R, Edge J, Short MJ, Mundel T (2011) Intermittent-sprint performance and muscle glycogen after 30 h of sleep deprivation. Med Sci Sports Exerc 43: 1301-1311.

Takahashi M, Nakata A, Arito H (2002) Disturbed sleep–wake patterns during and after short-term international travel among academics attending conferences. Int Arch Occup Environ Health 75: 435-440.

Taylor KL, Cronin J, Gill ND, Chapman DW, Sheppard J (2010) Sources of variability in iso-inertial jump assessments. Int J Sports Physiol Perform 5: 546-558.

Thompson A, Batterham A, Jones H, Gregson W, Scott D, Atkinson G (2013) The Practicality and Effectiveness of Supplementary Bright Light for Reducing Jet-Lag in Elite Female Athletes. Int J Sports Med 34: 582-589.

Waterhouse J, Edwards B, Nevill A, Atkinson G, Reilly T, Davies P, Godfrey R (2000) Do subjective symptoms predict our perception of jet-lag? Ergonomics 43: 1514-1527.

Waterhouse J, Reilly T, Atkinson G, Edwards B (2007) Jet lag: trends and coping strategies. The Lancet 369: 1117-1129.

Wright HR, Lack LC, Kennaway DJ (2004) Differential effects of light wavelength in phase advancing the melatonin rhythm. J Pineal Res 36: 140-144.

Wyatt JK, Cecco AR-D, Czeisler CA, Dijk D-J (1999) Circadian temperature and melatonin rhythms, sleep, and neurobehavioral function in humans living on a 20-h day. Am J Physiol Regul Integr Comp Physiol 277: R1152-R1163.

Figure Legends

Fig. 1 Schematic outline of the study design illustrating the timing of performance, physiological and perceptual data collection, and the timing of exposure to artificial bright light in the INT trial. Light and dark grey shaded areas indicate light exposure (02:00 - 05:00 AEST) and avoidance (05:00 - 08:00 AEST), respectively

Fig. 2 Effect of simulated international air travel and intervention on performance responses. Mean (95% CI) distance covered in the YYIR1 (**A**), 5 m sprint time (**B**), 20 m sprint time (**C**) unloaded and loaded CMJ height (**D**), and two- and four-choice reaction time (**E**) during the INT (solid black line and square) and CON (dashed line and white circle) trials. [#]Significantly different to the morning baseline (CON) ($P<0.05$). [*]Significantly different to the morning and evening baseline (INT) ($P<0.05$). [†]Significantly different to the morning and evening baseline ($P<0.05$)

Fig. 3 Effect of simulated international air travel and intervention on subjective jet-lag symptoms. Mean (95% CI) subjective jet-lag (**A**), sleep ratings (**B**), function ratings (**C**), diet ratings (**D**) and bowel movement ratings (**E**) during the INT (solid black line and square) and CON (dashed line and white circle) trials. [#]Significantly different to the morning and evening baseline ($P<0.05$). [*]Significantly different to the morning and evening baseline (INT) ($P<0.05$). [†]Significantly different to the morning and evening baseline (CON) ($P<0.05$). [α]Significantly different to the morning baseline (CON) ($P<0.01$)