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

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The present study examined effects of simulated air travel on physical performance. In a randomized crossover design, 10 physically active males completed a simulated 5-h domestic flight (DOM), 24-h simulated international travel (INT), and a control trial (CON). The mild hypoxia, seating arrangements, and activity levels typically encountered during air travel were simulated in a normobaric, hypoxic altitude room. Physical performance was assessed in the afternoon of the day before (D − 1 PM) and in the morning (D + 1 AM) and afternoon (D + 1 PM) of the day following each trial. Mood states and physiological and perceptual responses to exercise were also examined at these time points, while sleep quantity and quality were monitored throughout each condition. Sleep quantity and quality were significantly reduced during INT compared with CON and DOM ($P < 0.01$). Yo-Yo Intermittent Recovery level 1 test performance was significantly reduced at D + 1 PM following INT compared with CON and DOM ($P < 0.01$), where performance remained unchanged ($P > 0.05$). Compared with baseline, physiological and perceptual responses to exercise, and mood states were exacerbated following the INT trial ($P < 0.05$). Attenuated intermittent-sprint performance following simulated international air travel may be due to sleep disruption during travel and the subsequent exacerbated physiological and perceptual markers of fatigue.

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

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

Bullock et al., 2007). Furthermore, while the predominance of grip strength and jump tests as physical performance measures may assist with testing logistics, they have limited ecological relevance to most team sports, which require prolonged bouts of intermittent-sprint activity (Coutts et al., 2010).

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

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

Methods

Participants

Ten, physically active males were recruited to participate in the present study; mean (95% confidence intervals, CI); age 23.9 (22.2–25.6) years, body mass (BM) 79.2 (72.8–85.6) kg and estimated $\dot{V}O_{2max}$ 52.8 (50.4–55.2) mL/min. 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, participants completed three trials in a randomized order. The trials included; (a) a simulated 5-h domestic flight (DOM), similar to travel from Sydney to Perth, Australia; (b) 24 h of simulated international travel (INT), consisting of a 9- and 13-h flight separated by a 2-h stopover, replicating the demands of travel from Sydney, Australia to London, England; and (c) a control trial (CON) during which no simulated air travel was completed, but participants still reported to the laboratory (Fig. 1). Collection of baseline performance, physiological, and perceptual data occurred at a standardized time in the afternoon (16:00 h Australian Eastern Standard Time, AEST) of the day prior to each trial (D – 1 PM), followed 24 h later by the commencement of the simulated travel or CON trial, termed the day of travel (DT). Physiological and perceptual data were obtained immediately pre-, during, and post-simulated air travel, and at the same time points throughout the CON trial. Performance, physiological, and perceptual measures were again obtained at standardized times (09:00 and 16:00 h AEST) in the morning (D + 1 AM) and afternoon (D + 1 PM) of the day following the simulated travel and CON trial. This corresponded to 23:00 and 06:00 h London Time in the INT trial (Fig. 1). While these times attempted to standardize for the diurnal variation in physical performance (Drust et al., 2005), it is acknowledged that competition the day after international travel is unlikely. Therefore, the absence of measures on ensuing days is recognized as a limitation of the present study. Each trial was separated by 1 week to ensure adequate recovery time. Physical activity and nutritional intake were documented 24 h prior to the first trial and replicated for all subsequent trials. Participants abstained from caffeine, alcohol, and additional strenuous activity for 24 h before, during, and 24 h following all trials.

Simulated travel

Participants completed the DOM and INT trials as a group in a normobaric, hypoxic altitude room (Kinetic Performance Technologies, Canberra, Australia), with no exposure to natural light. The simulated altitude [2093 (2076–2110) m] via nitrogen dilution, temperature [20.2 (19.6–20.8) °C] and seating arrangement replicated what is typically encountered during an actual commercial flight (Hamada et al., 2002; Muhm et al., 2007). The chairs used (Cycloid Vibration Therapy Chair, Niagara, Meadowbrook, Australia) had a pitch and width of 117 and 90 cm, respectively. The fraction of inspired oxygen (F_IO_2) during simulated travel was 0.17 (0.16–0.18)%, as is representative of the F_IO_2 during actual airline travel (Coste et al., 2009). Activity was regulated to simulate the activity patterns of passengers during an actual commercial flight. Participants were instructed to remain seated at all times other than when using the bathroom, located in an adjacent room. Furthermore, lighting was dimmed [36 (18–54) lux] and raised [113 (103–123) lux], and meals/fluid were served to participants according to a typical commercial flight schedule. Specifically, a main meal similar in content and packaging to standard airline food was provided 30 min into the simulated DOM travel, and 30 min and 6.5 h into the first leg, and 30 min and 10.5 h into the second leg of the simulated INT travel. Additional fluid was offered at 2.5 h during the simulated DOM travel and 2.5 h, 4 h, and every subsequent hour during both legs of the simulated INT travel. Nutritional intake was documented by participants throughout all trials via dietary recall, which was analyzed using nutrient analysis software (FoodWorks®, Xyris Software Pty Ltd, Kenmore Hills, Australia).

The hypoxic room, within which the simulated travel was completed, formed part of an altitude house. During the INT trial, all natural light and external influences were blocked out of the house. To simulate the change in time zones, all clocks in the testing area

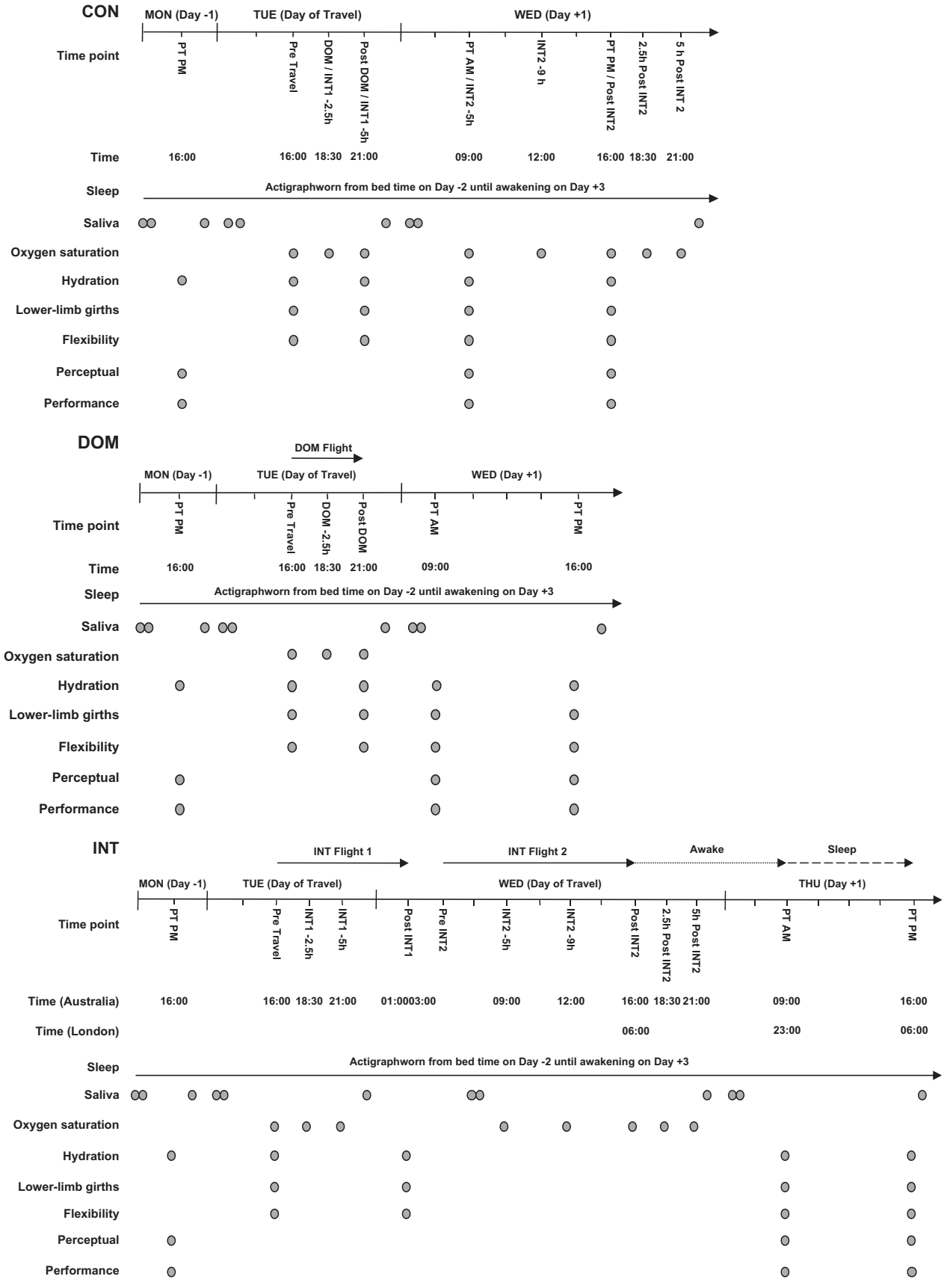


Fig. 1. Schematic outline of the study design illustrating the timing of performance, physiological and perceptual data collection, and the duration of the three conditions; simulated domestic air travel (DOM), simulated international air travel (INT), and no simulated air travel (CON).

were altered to show the destination time (London, England) from the beginning of the first leg of travel to the end of the trial. During the 2-h stopover, participants exited the house and were permitted to move around freely in normoxia, as they would at a stopover destination during actual travel. Furthermore, when the simulated INT travel was completed at 16:00 AEST on day 3, the corresponding time in London was 06:00 h. Therefore, to simulate a morning arrival in London, participants were required to remain awake overnight (AEST) in the altitude house with the lights on [164 (131–197) lux]. However, it is acknowledged as a limitation that this does not represent normal daylight. During this time, participants were permitted to move around freely in normoxia and were provided with breakfast, lunch, and dinner according to London time. During the CON trial, measures were obtained at the same time points; however, participants were not required to complete any simulated travel. Instead, participants were permitted to complete a normal sedentary day and only reported to the laboratory when measurements were required. While recorded, food and fluid intake were not controlled during this time period.

Experimental procedures

Physical performance

Prior to the collection of physical performance data, a warm-up consisting of the 5′-5′ test (Buchheit et al., 2011), involving 5 min of standardized submaximal 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 on an enclosed synthetic running track in temperate conditions. Participants completed a countermovement jump (CMJ) test (Taylor et al., 2010), followed by the Yo-Yo Intermittent Recovery level 1 test (YYIR1; Krustrup et al., 2003), to assess neuromuscular and intermittent-sprint performance, respectively. Jump height, peak power, and peak velocity for the concentric phase of the CMJ were measured using a linear position transducer (GymAware, Kinetic Performance Technologies, Canberra, Australia) sampling at 50 Hz, attached to a 1.5-m-long, 0.5-kg aluminum bar held firmly across the shoulders during each jump. The typical error (TE) of these measures in the present study was 1.8 (1.4–2.5) cm, 420 (328–584) W and 0.15 (0.12–0.21) m/s 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 TE of 145 (113–202) m in the present study.

Physiological measures

Sleep patterns were assessed using actigraphy watches (ReadiBand™, Fatigue Science, Honolulu, Hawaii, USA) worn on participants' nondominant wrist for three days prior to and following each trial. Actimeter records were analysed using customized manufacturers software (Sleep Analyzer, Fatigue Science) for quantity and quality of sleep. Oxygen saturation was recorded while seated with a pulse oximeter (Nonin 4000 Avant Bluetooth Pulse Oximeter, Nonin, North Plymouth, Minnesota, USA) for 10 min immediately prior to, continuously throughout, and for 10 min immediately following the simulated DOM and INT travel, and at matched time points during the CON trial. Additional readings were recorded for 10 min at 2.5 and 5 h after the simulated INT travel and at the same time during the CON trial. Data was subsequently downloaded using device specific software and a mean oxygen saturation value was obtained at specific time points (Fig. 1). To assess urine specific gravity (USG), a midstream urine sample was collected immediately prior to all performance testing sessions, immediately before and after the simulated DOM and INT travel, and at matched time points during the CON trial (Refractometer 503, Nippon Optical Works, Co., Tokyo, Japan). To obtain an indication of lower limb muscle swelling, mid-thigh and mid-calf girths were measured (Lufkin®, Apex Tool Group, Apex, North Carolina, USA) in duplicate at the same time points as USG, except for prior to the performance tests at baseline. Measurement sites were standardized based on those previously described for the mid-thigh and mid-calf (Norton et al., 1996). Heart rate (HR) was measured (Polar Team^2, Polar Electro, Kempele, Finland), continuously throughout the 5′-5′ and YYIR1 tests, and was analyzed using customized manufacturers software (Polar Team System 2, Polar Electro). HR during (HRex) and recovery (HRR) following the 5′-5′ test (Buchheit et al., 2011), and maximum HR (HRmax) during the YYIR1 was recorded. The TE for HRex and HRR in the present study was 5 (4–7) beats per minute (bpm) and 9 (7–13) bpm, respectively.

Saliva collection and analysis

Saliva samples were collected via passive drool immediately upon and 30 min post-waking and immediately prior to bed, 1 day prior to (D – 1), the day(s) of (DT) and 1 day following (D + 1) the simulated travel and CON trial. For all collections, participants remained seated and refrained from ingesting any fluid for 10 min prior. Participants were instructed to swallow and then, while making minimal orofacial movement, dribble saliva into a sterile vial for a minimum of 3 min or until 1 mL was collected. Saliva samples were sealed and stored in a −20 °C freezer until analyzed. Cortisol concentration was determined according to the manufacturer's instructions provided in the respective assay kits (ELISA, Demeditec Diagnostics, Kiel, Germany), by enzyme-linked immunosorbent assay, and using a microplate reader (VICTOR^3, PerkinElmer Inc, Waltham, Massachusetts, USA) and associated software (WorkOut 2.5, Dazdaq Ltd, Brighton, England). Intra-assay coefficients of variation were less than 5% for all analyses.

Perceptual measures

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

Statistical analysis

Data are presented as mean (95% CI). The TE of measurement was determined using a commercially available Excel spreadsheet for calculations of reliability (http://www.sportsci.org/resource/stats/xrely.xls). For YYIR1 and CMJ performance, and mid-calf and mid-thigh girth, the effect of time and trial was assessed by fitting a linear mixed model to the absolute change from baseline. For all other variables, a linear mixed model was fitted to the raw data. Specifically, time and trial, and their interaction were fitted as fixed effects to determine whether there was a difference in the effect of trial over time. In addition, participant and trial (within participant) were fitted as random effects to account for the possible correlation within participants and

within trial within participants. Statistical significance was accepted at $P < 0.05$. Where a significant effect was observed, a Tukey's *honestly significant difference* post-hoc test was used to determine differences between means. Analyses were performed using JMP statistical software (JMP Pro v 10.0, SAS, Cary, North Carolina, USA).

Results

Physical performance

No significant differences were observed between trials in YYIR1 performance at D + 1 AM ($P > 0.05$). However, participants covered significantly less distance at D + 1 PM following the INT trial compared with the DOM and CON trials ($P < 0.01$; Fig. 2(a)). No significant differences were detected between trials for CMJ height (Fig. 2(b)), peak power (Fig. 2(c)), or peak velocity (Fig. 2(d); $P > 0.05$).

Physiological measures

Sleep duration and efficiency were significantly reduced, and the duration of awakenings was significantly greater during the INT trial compared with the first night following the DOM and CON trials ($P < 0.01$; Table 1). No significant differences existed between trials for sleep latency or number of awakenings ($P > 0.05$).

Oxygen saturation was significantly lower during the DOM and INT trials compared with the CON trial ($P < 0.05$; Fig. 3(a)). Furthermore, oxygen saturation remained significantly suppressed immediately following the second leg of the INT trial, when compared with the same time point in the CON trial ($P < 0.05$).

Compared with pre-travel, USG was significantly lower post-travel, in the DOM [1.023 (1.019–1.027) vs 1.012 (1.010–1.014); $P < 0.05$] and INT [1.020 (1.016–1.024) vs 1.008 (1.006–1.010); $P < 0.01$] trials. However, there were no significant differences between trials ($P > 0.05$). Change in mid-calf girth was significantly greater post-travel in the INT compared with the CON trial ($P < 0.05$; Table 2). Conversely, change in mid-calf girth was significantly lower at D + 1 PM, following the INT trial compared with the CON trial ($P < 0.05$). Compared with baseline, mid-thigh girth

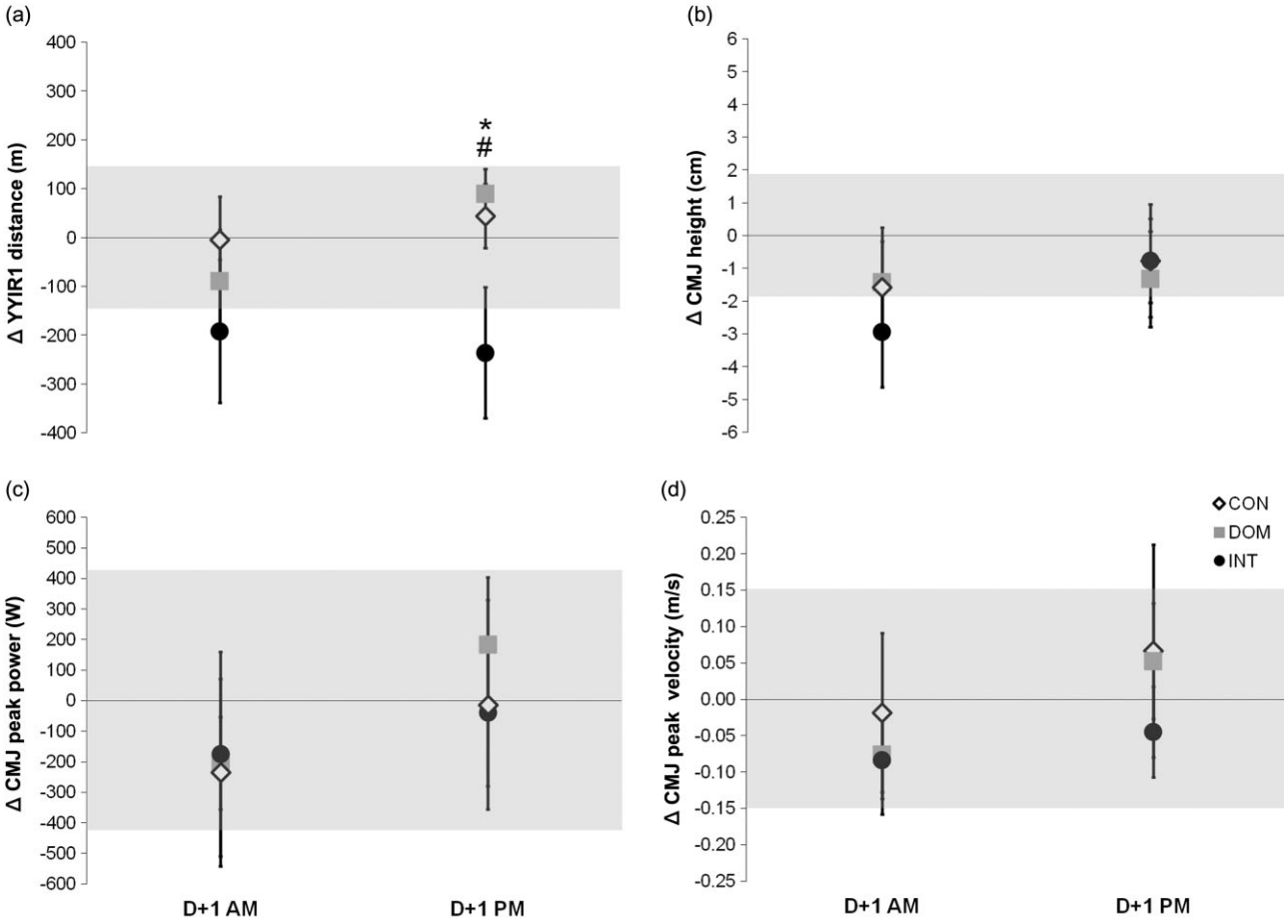


Fig. 2. Effect of simulated air travel on intermittent-sprint and neuromuscular performance. Mean change from baseline (95% CI) in the YYIR1 (a) and CMJ height (b), peak power (c), and peak velocity (d) in the morning (D + 1 AM) and afternoon (D + 1 PM) of the day following the CON (white diamond), DOM (gray square) and INT (black circle) trials. #Significantly different to CON ($P < 0.01$).*Significantly different to DOM ($P < 0.01$). Gray shaded area indicates typical error of the measure.

Table 1. Mean (95% CI) for sleep volume and quality for the CON, DOM, and INT trials for the 2 days prior to travel (D – 2 and D – 1), the day of travel (DT), and the 2 days following travel (D + 1 and D + 2)

	D – 2	D – 1	DT	D + 1	D + 2
Sleep duration (h)					
CON	7.2 (6.2–8.2)	7.1 (6.3–7.9)	6.7 (5.8–7.6)	7.6 (6.7–8.5)	7.0 (6.3–7.7)
DOM	7.1 (5.8–8.4)	6.9 (6.0–7.8)	6.7 (5.9–7.5)	6.6 (6.0–7.2)	7.6 (6.4–8.8)
INT	6.4 (5.5–7.3)	6.9 (5.7–8.1)	2.5 (1.7–3.3)*†	12.6 (11.2–14.0)*†	5.6 (4.0–7.2)
Sleep latency (min)					
CON	27 (14–40)	26 (12–40)	12 (9–15)	17 (11–23)	18 (12–24)
DOM	14 (13–15)	16 (7–25)	17 (8–26)	18 (7–25)	16 (10–22)
INT	26 (15–37)	29 (19–39)	15 (5–25)	15 (6–24)	33 (9–57)
Sleep efficiency (%)					
CON	80 (70–90)	82 (75–89)	86 (78–94)	83 (77–89)	83 (75–91)
DOM	82 (70–94)	83 (77–89)	85 (77–93)	86 (78–92)	85 (78–92)
INT	81 (73–89)	82 (75–89)	55 (45–65)*†	87 (82–93)	81 (71–91)
Number of awakenings					
CON	5 (2–8)	4 (2–6)	4 (2–6)	3 (1–5)	5 (2–8)
DOM	4 (0–8)	4 (2–6)	3 (1–5)	4 (2–6)	5 (2–8)
INT	4 (1–7)	4 (2–6)	4 (2–6)	5 (3–7)	4 (1–7)
Duration of awakenings (min)					
CON	14 (6–22)	10 (5–15)	7 (4–10)	11 (5–17)	13 (9–17)
DOM	8 (2–14)	9 (7–11)	11 (8–14)	9 (4–14)	10 (7–13)
INT	9 (3–15)	11 (8–14)	29 (18–40)*†	9 (5–13)	6 (3–9)

*Significantly different to CON ($P < 0.01$).
†Significantly different to DOM ($P < 0.01$).

was significantly greater immediately following the INT trial and at D + 1 AM ($P < 0.05$; Table 2). However, there were no significant differences between trials ($P > 0.05$).

Compared with baseline [148 (140–156) bpm], HRex was significantly increased at D + 1 AM [156 (147–165) bpm; $P < 0.05$) and D + 1 PM [158 (149–167) bpm; $P < 0.01$] following the INT trial. There were no significant differences between trials for HRex, and no significant effects of time or trial, or associated interaction for HRR and HRmax ($P > 0.05$). As no significant differences were observed between immediately upon and 30 min post-waking salivary cortisol concentrations ($P > 0.05$), a mean of the two values was calculated and analyzed. A significant diurnal variation was apparent, with increased values identified in the morning and reduced values in the evening ($P < 0.01$; Fig. 3(b)). Moreover, following the INT trial, cortisol concentrations were significantly lower in the morning on D + 1 compared with D – 1 and DT ($P < 0.05$). However, there were no significant differences between trials ($P > 0.05$).

Perceptual measures

Compared to baseline, whole-body fatigue was significantly greater at D + 1 AM ($P < 0.01$) and D + 1 PM ($P < 0.05$) following the INT trial, which was significantly different to the CON trial at D + 1 AM ($P < 0.05$; Table 3). Muscle soreness was significantly increased at D + 1 PM following the DOM trial compared with baseline ($P < 0.01$), though this was not significantly different to the INT or CON trial ($P > 0.05$). There were no significant differences between trials for anger and confusion ($P > 0.05$), though compared with baseline, anger was significantly greater at D + 1 AM ($P < 0.01$) and confusion was significantly greater at D + 1 AM ($P < 0.01$) and PM ($P < 0.05$) following the INT trial. Depression ($P < 0.05$) and fatigue ($P < 0.01$) were both significantly greater at D + 1 AM following the INT trial compared with the DOM and CON trials. Compared with baseline, vigor was significantly lower at D + 1 AM following the INT trial ($P < 0.05$).

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

Nutrition

Energy (kJ) intake was significantly greater ($P < 0.05$) on the day of travel during the INT trial [17 180 (16 187–18 173) kJ] compared with the CON trial [13 274 (11 112–15 463) kJ]. Carbohydrate intake (g/kg BM) was also significantly greater ($P < 0.01$) on the day of travel during the INT trial [6.4 (5.8–7.0) g/kg BM] compared with the DOM [4.2 (3.8–4.6) g/kg BM] and CON [3.8 (3.0–4.6) g/kg BM] trials. No other significant differences existed between trials for energy

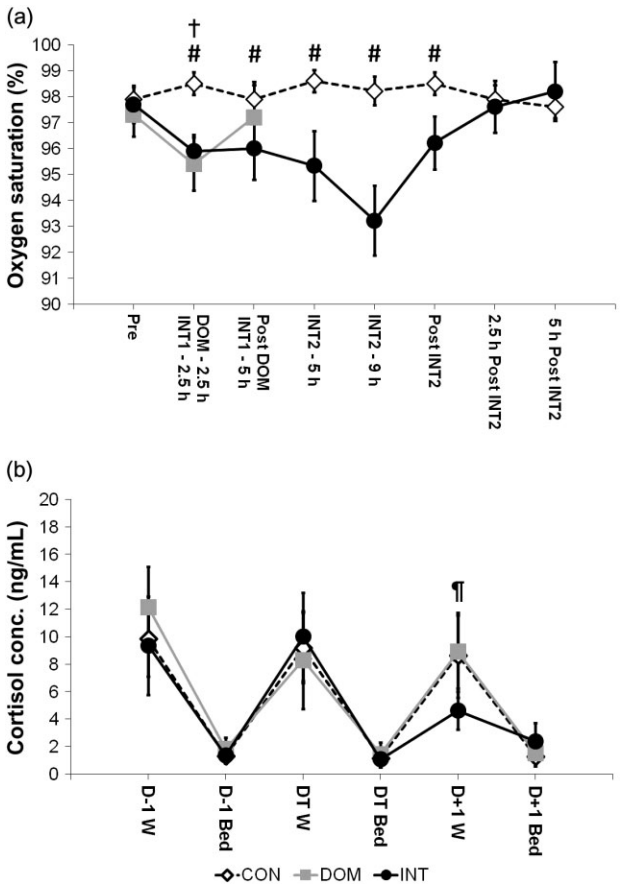


Fig. 3. Physiological responses to simulated air travel. Mean (95% CI) oxygen saturation (a) and salivary cortisol concentration (b) for the CON (dotted line and white diamond), DOM (solid gray line and square) and INT (solid black line and circle) trials. Salivary cortisol concentration was measured immediately upon and 30 min post-waking (W), and immediately prior to bed (Bed) on the day before (D – 1), the day of (DT) and the day after (D + 1) each trial. ¶Significantly different from in the morning on D – 1 and DT in the INT trial ($P < 0.05$). †DOM significantly different to CON ($P < 0.01$). #INT significantly different to CON ($P < 0.05$).

Table 2. Mean change from baseline (95% CI) in lower body limb girths for the CON, DOM, and INT trials, immediately post-travel (Post-Travel) and the morning (D + 1 AM) and afternoon (D + 1 PM) of the day after travel

	Post-Travel	D + 1 AM	D + 1 PM
Mid-calf girth (cm)			
CON	–0.2 (–0.4, 0.0)	–0.4 (–0.6,–0.2)	–0.1 (–0.3, 0.1)
DOM	–0.1 (–0.3, 0.1)	–0.5 (–0.6,–0.4)	–0.4 (–0.5, –0.3)
INT	0.3 (0.1, 0.5)†	–0.3 (–0.5,–0.1)	–0.6 (–0.9,–0.3)†
Mid-thigh girth (cm)			
CON	–0.2 (–0.5, 0.1)	–0.3 (–0.6, 0.0)	–0.1 (–0.4, 0.2)
DOM	–0.2 (–0.5, 0.1)	–0.3 (–0.6, 0.0)	–0.2 (–0.7, 0.3)
INT	0.1 (0.0, 0.2)*	0.0 (–0.2,0.2)*	–0.3 (–0.6, 0.0)

*Significantly different to D + 1 PM ($P < 0.05$).
†Significantly different to CON ($P < 0.05$).

(kJ), carbohydrate, protein, or fat (g/kg BM) intake ($P > 0.05$).

Discussion

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

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

While YYIR1 performance was reduced following INT travel, no significant effects on leg power were detected. Conflicting results exist in the literature, with some research reporting no change (Lagarde et al., 2001; Bullock et al., 2007) and others a reduction (Chapman et al., 2012) in leg power following international transmeridian air travel. These contrasting findings may be a result of the interindividual variation in responses to the duration and direction of travel (Waterhouse et al., 2002), along with the type, sensitivity, timing, and frequency of the tests conducted (Lagarde et al., 2001; Bullock et al., 2007). These factors could help explain the findings of the present study, especially given the relatively large TE observed for CMJ peak power and velocity. A reduction in YYIR1 performance with minimal change in CMJ performance, suggests the suppression of intermittent-sprint ability may not relate to reduced contractile function following prolonged travel,

Table 3. Mean (95% CI) mood states for the CON, DOM, and INT trials, prior to performance testing in the afternoon of the day before travel (D – 1 PM) and the morning (D + 1 AM) and afternoon (D + 1 PM) of the day after travel

		D – 1 PM	D + 1 AM	D + 1 PM
Whole-body fatigue	CON	2.3 (1.7–2.9)	3.0 (2.3–3.7)	3.4 (2.4–4.4)
	DOM	3.3 (2.5–4.0)	4.3 (3.7–4.9)	4.4 (3.9–4.9)
	INT	3.2 (2.4–4.0)	5.0 (4.0–6.0)*†	4.6 (3.9–5.3)*
Muscle soreness	CON	2.3 (1.7–2.9)	1.9 (1.4–2.4)	3.7 (3.0–4.4)
	DOM	2.6 (1.9–3.3)	3.2 (2.8–3.6)	4.6 (3.9–5.3)*
	INT	2.9 (2.0–3.8)	3.4 (2.7–4.1)	4.1 (3.2–5.0)
Anger	CON	0.8 (0.0–1.6)	0.7 (0.0–1.4)	0.6 (0.0–1.2)
	DOM	1.8 (0.2–3.4)	0.7 (0.0–1.4)	0.2 (0.2–0.6)
	INT	0.2 (0.0–0.4)	3.1 (1.5–4.7)*	1.6 (0.0–3.2)
Confusion	CON	0.8 (0.0–1.6)	0.7 (0.0–1.4)	0.4 (0.0–0.8)
	DOM	0.8 (0.1–1.5)	0.1 (0.0–0.2)	0.2 (0.0–0.4)
	INT	0.0 (0.0–0.0)	2.4 (0.5–6.3)*	1.9 (0.1–3.7)*
Depression	CON	0.8 (0.0–1.6)	0.6 (0.0–1.2)	0.4 (0.0–0.8)
	DOM	0.9 (0.0–1.8)	0.7 (0.0–1.4)	0.8 (0.0–1.6)
	INT	0.2 (0.0–0.4)	3.1 (1.2–5.0)*†‡	0.9 (0.0–1.8)
Fatigue	CON	3.1 (0.9–5.3)	3.7 (1.2–6.2)	6.1 (4.1–8.1)
	DOM	4.8 (2.5–7.1)	6.7 (4.2–9.2)	8.4 (6.1–10.7)
	INT	2.4 (1.5–3.3)	13.4 (12.7–14.1)*†‡	10.1 (8.0–12.2)
Tension	CON	0.6 (0.0–1.3)	0.3 (0.3–0.6)	1.0 (0.1–1.9)
	DOM	1.6 (0.7–2.5)	1.1 (0.2–2.0)	1.7 (0.8–2.6)
	INT	1.1 (0.0–2.2)	2.0 (0.4–3.6)	0.8 (0.0–1.6)
Vigor	CON	6.9 (4.6–9.2)	6.3 (3.6–9.0)	5.7 (3.4–8.0)
	DOM	7.0 (4.8–9.2)	4.7 (2.9–6.5)	4.8 (3.0–6.6)
	INT	6.4 (4.6–8.2)	1.9 (0.5–3.3)*	4.1 (2.7–5.5)

*Significantly different to baseline ($P < 0.05$).
†Significantly different to CON ($P < 0.05$).
‡Significantly different to DOM ($P < 0.05$).

but to other physiological or perceptual mechanisms. Moreover, no change in CMJ or intermittent-sprint performance was identified following simulated DOM travel. To date, only one other investigation has reported the effects of domestic air travel on physical performance, highlighting no change in handgrip strength or leg power (McGuckin et al., 2014). However, given the limited information available, further research is required to confirm this.

Limited research exists on the effects of domestic and international air travel on the quality and quantity of sleep in passengers. Thus, another notable finding from the present study was the reduction in sleep quantity and quality observed during INT travel. Similarly low sleep quantities (2–5 h) have previously been self-reported by passengers during international transmeridian air travel (Waterhouse et al., 2002), with environmental factors, such as comfort (Waterhouse et al., 2004, 2007) and exposure to mild hypoxia (Coste et al., 2004) purported as contributors to sleep disruption. Interestingly, the magnitude of the reduction in oxygen saturation observed during simulated air travel in the present study was similar to values previously reported during actual air travel (Geertsema et al., 2008). Moreover, oxygen saturation may have remained suppressed immediately following INT compared with CON due to the prolonged duration of INT travel and thus, exposure to mild hypoxia, though further research is required to confirm this observation. Reduced subjective sleep quality has previously been reported following domestic air travel (Richmond et al., 2007). Considering no effects of DOM travel were evident for objective sleep quantity or quality in the present study, domestic air travel *per se* may not affect sleep patterns. Instead, sleeping in unfamiliar surroundings may explain the aforementioned reduction in perceived sleep quality (Richmond et al., 2007).

Maintaining wakefulness in a state of sleep debt requires increased sympathetic activation, particularly if physically challenged (Meerlo et al., 2008). Since an increase in sympathetic activity is associated with elevated cardiovascular activity (Meerlo et al., 2008), this may explain the increase in HR detected during a standardized submaximal exercise bout, in the morning and afternoon of the day following simulated INT travel. Given the present study is the first to report such responses, further research is required to confirm elevated sympathetic activity resulting from prolonged travel. Reduced cortisol concentrations have been identified in response to acute sleep deprivation, which may be related to increased fatigue and sleepiness, and decreased physical and mental activity (Meerlo et al., 2008). In the present study, reduced cortisol levels were evident in the morning of the day following simulated INT travel, where fatigue and sleepiness were high, and

physical and mental activity were low. A reduction in cortisol concentration in conjunction with an increase in submaximal HR responses could imply an increase in physiological fatigue following simulated INT travel. This may explain why during the YYIR1, HRmax did not differ, but distance covered was reduced, perceived exertion was increased, and physical feeling was worse. However, further research is required to confirm these findings.

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

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

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

Perspectives

This is the first study to indicate a detrimental impact of international air travel on intermittent-sprint performance. However, similar to previous research, the present study identified minimal disturbances in leg power (Lagarde et al., 2001; Bullock et al., 2007), and confirmed that short-haul air travel has negligible effects on physical performance (McGuckin et al., 2014). Furthermore, this is the first study to observe a reduction in sleep quantity and quality in passengers during air travel through objective measures. Previous research suggests that the inability to maintain performance during intermittent-sprint exercise following sleep disruption may be due to difficulty in sustaining the motivation to perform at high intensities (Reilly & Edwards, 2007; Skein et al., 2011). This is supported by the findings of the present study, where time to volitional exhaustion was reduced, yet perceived exertion was increased and physical feeling was worse during intermittent-sprint exercise following simulated international air travel. Therefore, by minimizing sleep disruption during air travel, practitioners may subsequently reduce the impact of travel fatigue on intermittent-sprint performance. However, research into the development and implementation of effective interventions is required.

Key words: Soccer, travel fatigue, intermittent-sprint performance, mild hypoxia, mood.

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Conflicts of interest

The authors report no conflicts of interest.

References

Beaumont M, Batejat D, Pierard C, Van Beers P, Denis JB, Coste O, Doireau P, Chauffard F, French J, Lagarde D. Caffeine or melatonin effects on sleep and sleepiness after rapid eastward transmeridian travel. J Appl Physiol 2004: 96: 50–58.

Buchheit M, Voss SC, Nybo L, Mohr M, Racinais S. 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 2011: 21: 477–485.

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: 569–573.

Cesarone MR, Belcaro G, Errichi BM, Nicolaides AN, Geroulakos G, Ippolito E, Winford M, Lennox A, Pellegrini L, Myers KA, Ricci A, Hans C, Simeone E, Bavera P, Dugall M, Moia M, Stuard S. The LONFLIT4–Concorde Deep Venous Thrombosis and Edema Study: prevention with travel stockings. Angiology 2003: 54: 143–154.

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: 1663–1669.

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

Coste O, Beers PV, Bogdan A, Charbuy H, Touitou Y. Hypoxic alterations of cortisol circadian rhythm in man after simulation of a long duration flight. Steroids 2005: 70: 803–810.

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

Coutts AJ, Quinn J, Hocking J, Castagna C, Rampinini E. Match running performance in elite Australian Rules Football. J Sci Med Sport 2010: 13: 543–548.

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

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: 1501–1513.

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: 185–208.

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

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

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

Hamada K, Doi T, Sakurai M, Matsumoto K, Yanagisawa K, Suzuki T, Kikuchi N, Okuda J, Miyazaki H, Okoshi H. Effects of hydration on fluid balance and lower-extremity blood viscosity during long airplane flights. JAMA 2002: 287: 844–845.

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

Hooper SL, Mackinnon LT, Howard A, Gordon RD, Bachmann AW. Markers for monitoring overtraining and recovery. Med Sci Sports Exerc 1995: 27: 106–112.

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

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

Lemmer B, Kern RI, Nold G, Lohrer H. Jet lag in athletes after eastward and westward time-zone transition. Chronobiol Int 2002: 19: 743–764.

McGuckin TA, Sinclair WH, Sealey RM, Bowman P. The effects of air travel on performance measures of elite Australian rugby league players. Eur J Sport Sci 2014: 14: S116–S122.

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

Muhm JM, Rock PB, McMullin DL, Jones SP, Lu IL, Eilers KD, Space DR, McMullen A. Effect of aircraft-cabin altitude on passenger discomfort. N Engl J Med 2007: 357: 18–27.

Norton K, Whittingham N, Carter L, Kerr D, Gore C, Marfell-Jones M. Measurement techniques in anthropometry. Anthropometrica 1996: 1: 25–75.

Pierard C, Beaumont M, Enslen M, Chauffard F, Tan DX, Reiter RJ, Fontan A, French J, Coste O, Lagarde

D. Resynchronization of hormonal rhythms after an eastbound flight in humans: effects of slow-release caffeine and melatonin. Eur J Appl Physiol 2001: 85: 144–150.

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: 166–174.

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

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

Richmond LK, Dawson B, Stewart G, Cormack S, Hillman DR, Eastwood PR. The effect of interstate travel on the sleep patterns and performance of elite Australian Rules footballers. J Sci Med Sport 2007: 10: 252–258.

Samuels CH. Jet lag and travel fatigue: a comprehensive management plan for sport medicine physicians and high-performance support teams. Clin J Sport Med 2012: 22: 268–273.

Sinnerton S, Reilly T. Effects of sleep loss and time of day in swimmers. Biomech Med Swimming 1992: 6: 347.

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: 1301–1311.

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

Van Dongen HP, Maislin G, Mullington JM, Dinges DF. The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. Sleep 2003: 26: 117–129.

Waterhouse J, Edwards B, Nevill A, Carvalho S, Atkinson G, Buckley P, Reilly T, Godfrey R, Ramsay R. Identifying some determinants of 'jet lag' and its symptoms: a study of athletes and other travellers. Br J Sports Med 2002: 36: 54–60.

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

Waterhouse J, Reilly T, Edwards B. The stress of travel. J Sports Sci 2004: 22: 946–965.

Winter WC, Hammond WR, Green NH, Zhang Z, Bliwise DL. Measuring circadian advantage in Major League Baseball: a 10-year retrospective study. Int J Sports Physiol Perform 2009: 4: 394–401.