ORIGINAL ARTICLE

Effect of long haul travel on maximal sprint performance and diurnal variations in elite skeleton athletes

Nicola Bullock, David T Martin, Angus Ross, Doug Rosemond, Frank E Marino

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See end of article for authors' affiliations

Correspondence to:
Nicola Bullock, Department
of Physiology, Australian
Institute of Sport, PO Box
176, Belconnen, ACT 2616,
Australia; nicola.bullock@
ausport.gov.au

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Objective: To quantify the impact of eastward long haul travel on diurnal variations in cortisol, psychological sensations and daily measurements of physical performance.

Methods: Five elite Australian skeleton athletes undertook a long haul eastward flight from Australia to Canada (LH_{travel}), while seven elite Canadian skeleton athletes did not travel (NO_{travel}). Salivary cortisol was measured on awakening, 60 min and 120 min after awakening. Psychological sensations were measured with a questionnaire, and maximal 30 m sprints were performed once a day between 09:30 and 11:00 h local time.

Results: Compared with baseline, average (SD) resting salivary cortisol decreased by 67% immediately after long haul travel (23.43 (5.71) nMol/l) (mean $\pm$ 90% confidence interval) in the LH_{travel} group ($p=0.03$), while no changes were found in the NO_{travel} group ($p=0.74$). There were no significant differences in 30 m sprint time between baseline and post-flight tests in the LH_{travel} group ($p>0.05$). The LH_{travel} group perceived themselves as "jet lagged" for up to 2 days after the flight ($p=0.01$ for both midday lunch and evening dinner).

Conclusions: Despite a distinct phase change in salivary cortisol rhythmicity and the athletes perceiving themselves as "jet lagged", minimal disturbances in "one-off" maximal sprinting ability between 09:30 and 11:00 h local time were seen in a group of elite skeleton athletes after long haul eastward travel from Australia to Canada.

Elite athletes tend to undertake multiple extensive flights to North America, Europe, Asia and Australia for both competition and training, raising the question as to whether "jet lag" affects performance and, if so, for how long. Circadian dysrhythmia,¹ more commonly known as "jet lag", affects people who travel rapidly across three or more meridian time zones.² It arises from transient desynchronisation of the body clock, where a temporary mismatch arises between the timing of the endogenous circadian oscillator and biological rhythms. The main symptoms of "jet lag" have been defined as feeling tired in the new local daytime but unable to sleep at night, less able to concentrate and/or motivate oneself, and decreased mental and physical performance.³ These symptoms persist until the rhythms adjust to the new environment.^{3–6} The major factor determining the time for resynchronisation is the number of time zones crossed during the flight.⁷

Because circadian rhythms are driven internally after rapid transmeridian travel, optimal athletic performance may depend upon the time of competition relative to the circadian system.⁸ Peak performance in grip strength, minimal fatigue, maximal oxygen uptake and neuromuscular coordination are in parallel with the normal circadian "rhythms" acrophase of body temperature, which occurs between 16:00 and 20:00 h.⁹ Enhanced performance in laboratory-based tests was found in evening sessions compared with morning sessions in swimming and 30 s anaerobic capacity and 5 s peak power in a modified Wingate test.^{10–13} A 40 m sprint time in elite women hockey players crossing six time zones in a westward direction from Australia to Europe was significantly slower on days 4 and 6 after a flight than on pre-flight days. By day 8, performance had recovered and were similar to pre-flight values.¹⁴ Alterations in the mood states of vigor and fatigue have been noted on the first day after travel in elite women soccer players flying westward from the west coast of the USA to Taiwan, crossing eight time zones.¹⁵

Therefore, this study aimed at quantifying the impact of long haul eastward jet travel from the east coast of Australia to the Rocky Mountain region of Canada (resulting in an 8 h time difference) on diurnal variations in cortisol, feelings of wellness and multiple measurements of physical performance in elite skeleton athletes.

SUBJECTS AND METHODS

Participants

Twelve national team skeleton athletes (four Olympians, one Junior World Champion, four World Cup athletes and three America's Cup athletes) volunteered to participate in this study and had been training consistently in a structured elite programme for a minimum of 12 months (table 1). Five skeleton athletes were from Australia (four female and one male; LH_{travel}) while seven were residents of Calgary (six female and one male; NO_{travel}). All participants were informed of the procedures to be employed and gave their written consent before participation. The study was conducted with ethical approval from the Australian Institute of Sport. All Australian athletes had travelled overseas on long haul flights on numerous occasions for competition.

The first flight left Canberra, Australia at 06:50 h local time with Australian athletes changing flights four times, crossing

Table 1 Subject characteristics

Subjects	Age (years)	Height (cm)	Mass (kg)
LH _{travel} (n=5)	24.7 (6.0)	169.7 (4.6)	70.2 (11.7)
NO _{travel} (n=7)	31.2 (6.9)	170.8 (8.4)	70.9 (12.4)

Results are shown as mean (SD).

LH_{travel}, athletes who undertook long haul eastward jet travel; NO_{travel}, athletes who did not undertake any jet travel or time zone changes.

the International Date Line and arriving in Calgary, Canada at 13:50 h local time. The travel period lasted for a total of 24 h. Athletes were asked to refrain from sleep medication during the flights and throughout the duration of the study. All athletes underwent similar training, eating and sleeping schedules as they all shared rooms, ate together at the same restaurants and underwent similar training sessions at the same time of day.

Diurnal variation

Diurnal variations in the LH_{travel} group were monitored over 13 days. Baseline testing occurred 2 days before flying (days -2 and -1). At 06:45 h local time (Canada 06:45 h corresponded to 22:45 h Australia EST), athletes provided a saliva sample, which was immediately frozen and later analysed for cortisol. The maximum time difference between awakening at 06:45 h was 20 min. Athletes were asked to produce a midstream urine sample on awakening to assess hydration status. Urine samples were analysed within the hour using a digital urine refractometer (UG1, Atago, Tokyo). Further salivary samples were collected at 60 and 120 min after awakening, also for the determination of salivary cortisol. The awakening, 60 min and 120 min values were averaged to give a single value. During the 3 h salivary sampling period athletes were asked to drink only water, to abstain from drinking 10 min before sampling and to refrain from eating and brushing their teeth. Saliva and urine were collected on days -2, -1, 1, 2, 4, 7, 9 and 11. All salivary samples were collected by 09:00 h local time. The LH_{travel} athletes underwent similar light exposure, waking cycles and dietary habits in the baseline, travel and post-travel periods.

Jet lag questionnaire

The Liverpool John Moores University jet lag questionnaire was used, as previously described by Waterhouse *et al.*¹⁶ The LH_{travel} group filled in the questionnaire before breakfast (~09:00 h local time), lunch (~13:30 h local time) and dinner (~18:30 h local time) on days -1, 1, 2, 4, 7, 9 and 11. The questionnaire looked at subjective ratings of "jet lag", sleep duration and quality, ratings of feelings, concentration, motivation, irritability, hunger and tiredness. The NO_{travel} group filled out the questionnaire on days 2 and 9.

Physical tests

Maximal 30 m sprints were carried out once on days -2, -1, 1, 2, 4, 7 and 10 between 09:30 h and 11:00 h local time (09:30 h Canadian time was 01:30 h Australian time). Ambient temperature and relative humidity in Australia was 11°C and 70% and in Canada 16°C and 50%. A sprint competition warm-up was replicated at the beginning of every testing session and involved aerobic activity to raise muscle temperature followed by stretching, bounding, jumping and two 30 m accelerations at 90% effort. After the warm-up, two 30 m maximal sprints were carried out (5 min recovery between sprints). Sprints were measured at 5, 10, 15, 20, 25 and 30 m and recorded to the nearest 0.01 s using a laser device focused on the bottom of the athletes back by an experienced operator (LaVeg, 300c, Jenoptick, Germany). All athletes started the sprints with a two-point standing start in a stationary position 1 m before the start line. Athletes were instructed to hold the start position for a few seconds before starting and to continue accelerating past the 30 m mark to achieve maximal velocity in minimal time over 30 m. All sprints were conducted at an indoor running track. The fastest 30 m sprint time was used for analyses.

The NO_{travel} athletes underwent the same physical test on days 2 and 9 only, as these athletes were involved in a respective national team training camp. The NO_{travel} athletes were tested on a synthetic outdoor track between 10:00 h and 11:30 h (15°C, 2 m/s wind speed) during a national team

testing session. Before the session the NO_{travel} athletes had given saliva samples on awakening, 60 min and 120 min after awakening. As these athletes were not living on site they did not present to the laboratory, but were asked to freeze the saliva sample immediately after collection and store the urine sample at 2–8°C.¹⁷ Urine and saliva samples were returned to the investigators, with the urine analyses occurring ~4 h after the sample collection. Saliva samples were kept frozen (-5 to -10°C) until analysis.

Throughout the testing period immediate feedback was given to the athletes, and individual athlete's results from each test were communicated to the entire group. This was intentional to encourage competition between them.

Methods of analysis

Unstimulated whole mixed saliva was collected by passive drool into a commercially available 6 ml tube. Athletes were in a seated position and were requested to provide saliva over a 3 min period. Samples were immediately frozen at -20°C and later transported to Australia on dry ice. Samples remained frozen until analysis.

Salivary cortisol was measured using a commercially available luminescence immunoassay (IBL, Hamburg, Germany), according to the manufacturer's instructions. Saliva samples were thawed at room temperature before centrifugation at 5000 rpm and 4°C for 5 min to remove any particulate matter. All samples were analysed in duplicate and results accepted if the coefficient of variation between the duplicates was <10%. All samples from individual subjects were analysed on the same plate. A series of six standards ranging in concentration from 0.0 to 110 nmol/l and two quality controls were included on each plate. Briefly, 20 µl of saliva was incubated with 100 µl of enzyme conjugate in a microtitre plate for 3 h at room temperature. The wells were then washed four times before the addition of 50 µl of substrate solution to each well. The luminescence units were then counted using a Victor³ 1420 Multilabel Counter (PerkinElmer, Massachusetts, USA). Cortisol concentrations in samples were determined by extrapolation against the standard curve using Workout 2.0 Software (Dazdaq Ltd, East Sussex, UK). The limit of detection for salivary cortisol was 0.41 nmol/l. The interassay variability was 3.4% for high (~32 nmol/l) and 10.7% for low (~4.5 nmol/l) controls, respectively.

Data analysis

All analyses were performed using Statistica for Windows, version 5.5 (StatSoft Inc, Tisa, USA). Results are expressed as the mean and 90% confidence intervals (90% CI). Cortisol, 30 m sprint and urine specific gravity on days -2 and -1 were averaged to give an overall baseline result (day 0). Paired *t* tests were used to compare the effect of travel against the baseline value. Significance was set at *p* = 0.05. The within-subject standard deviation was calculated using the standard deviation of the difference between the two baseline days for the LH_{travel} divided the square root of two ($SD_{within} = Stdev \Delta / \sqrt{2}$).¹⁸ The two testing sessions (days 2 and 9) were used to calculate the SD_{within} for the NO_{travel} group.

RESULTS

Diurnal variation

Figure 1 shows the daily salivary cortisol concentrations for individual athletes and the average for the LH_{travel} group. The SD_{within} was 4.4% for the LH_{travel} group and 7.9% for the NO_{travel} group. The salivary cortisol concentrations significantly decreased in the LH_{travel} group by 67% at day 1 after flight compared with baseline (*p* = 0.03). Two-day post-flight concentrations remained suppressed by 47% compared with

Figure 1 Individual and mean (dashed line) $\pm 90\%$ CI cortisol response for the long haul travel group (LH_{travel}). *Significantly different from baseline values, $p < 0.05$.

baseline values, although this difference was not significant ($p = 0.17$). No significant differences were found between salivary cortisol on days 4, 7, 9 and 11 and the baseline value ($p > 0.05$). No differences were found in mean ($\pm 90\%$ CI) salivary cortisol between the two samples collected from the NO_{travel} group (18.29 (2.44) and 19.15 (3.42) nmol/l; $p = 0.74$).

Sprinting parameters

The post-travel 30 m sprint time in the LH_{travel} group was not significantly different from baseline values (4.12 (0.08) s; SD_{within} 0.19%) (fig 2). For the NO_{travel} group the average sprint times (4.44 (0.22) s; SD_{within} 0.40%) were significantly different between the two trials, with performance decreasing by 2.5% ($p = 0.05$). The sprints were further analysed in 5 m splits, with the 0–5 m segment discarded from this analysis as it was deemed unreliable owing to the high variability between athletes' running styles (changes in the position of the upper body during the start). For all other splits no significant differences were found in comparison with the pre-travel test ($p > 0.05$).

Urine specific gravity

No significant differences were found in urine specific gravity for the LH_{travel} group on any day after the flight (mean (90% CI) 1.02 (0.01); SD_{within} 0.02%; $p > 0.05$). No significant differences were found between samples in the NO_{travel} group (1.02 (0.01); SD_{within} 0.12%; $p = 0.64$).

Questionnaire results

Before lunch ($\sim 13:00$ h local time) and dinner ($\sim 18:30$ h local time) the LH_{travel} group rated themselves "jet lagged" on days 1, 2 and 4 compared with baseline ($p < 0.05$). In addition, before lunch on day 7 the LH_{travel} group still rated themselves as "jet lagged" ($p < 0.05$). Before dinner on day 11 the LH_{travel} group were feeling "better" and less irritable than at baseline ($p = 0.02$; $p = 0.04$, respectively). No differences were seen in hunger, motivation, concentration and tiredness for the LH_{travel} group; no significant differences were found in any of the Canadian athletes (NO_{travel}).

DISCUSSION

The present data indicate that the abrupt time zone change in the LH_{travel} group disrupted the normal cortisol circadian rhythm. Although athletes perceived themselves as "jet lagged", we did not observe any detrimental effects of eastward long haul travel on maximal 30 m sprinting. By establishing rigorous baseline values, a competitive environment and using

Figure 2 Individual and mean (dashed line) $\pm 90\%$ CI for 30 m sprint for the long haul travel group (LH_{travel}).

"elite" status athletes, the current study deals with many previously identified limitations of existing "jet lag" studies.²

Cortisol baseline values were comparable with those previously reported in healthy subjects.¹⁹ On day 1 after flight the salivary cortisol concentrations were similar among all athletes in the LH_{travel} group as shown by the small confidence interval. However, during the first 4 days after the flight, salivary cortisol concentrations varied to a greater extent between athletes, as shown by the larger confidence interval. These findings suggest that rates of resynchronisation of the circadian rhythms differed between athletes. This is in accord with findings of 1.7–6.0 days for complete resynchronisation after eastward air travel across six time zones.²⁰ In the current study, only on the ninth day after flight were the mean and 90% CIs similar to baseline levels, which suggests that the resynchronisation process had been completed. These results are in keeping with the estimates of 1 day needed for each time zone crossed to readjust the circadian rhythms to the new environment.⁷

Non-significant differences were found in 30 m sprint times before and after travel for the LH_{travel} group. Similarly, others have observed diurnal variations in peak and mean power, as determined by a Wingate test.²¹ Yet, in the same study the stair run and standing broad jump tests exhibited weak circadian rhythmicity.²¹ The rhythms in performance of the stair run and broad jump were low in amplitude; however, the 2–3% variation would have marked effects in competition.²¹ Conversely, sprint times slowed by 8–12% in military personnel travelling westwards across a 6-hour time zone change.²² However, many of the military personnel had not engaged in any consistent physical training for 3–6 months before deployment, thus the increased sprint times might potentially be attributed to fatigue and muscle damage rather than jet lag.

Nerve conduction velocity and metabolic enzyme reaction rates are all influenced by the acrophase and nadir of body temperature, which in turn affects some types of performance.²³ Therefore, it is plausible that the competition-specific warm-up undertaken before each physical testing session negated any negative effects of core temperature on performance. The competition-specific warm-up was used to enhance the ecological validity of the study to replicate as far as possible a competition environment and allow for the best possible performance. Reilly and Down suggested that the stair run and jumps before the Wingate tests might have inducted a sufficient warm-up stimulus to the active muscles to help override an inherent rhythm in muscle function. They also postulated that when pre-experimental warm-up is insufficient to raise core temperature to the optimal level then the circadian

What is already known about this topic

Optimal athletic performance may depend upon the time of competition relative to the circadian system.

What this study adds

"One-off" alactic sprinting ability between 09:30 and 11:00 h local time in elite athletes was not impaired by eastward long haul travel when full warm-up procedures were employed.

rhythms in short-term muscle performance may follow the pattern of the body temperature.²¹

No changes in motivation were reported by the athletes in the LH_{travel} group. The lack of change in motivation as well as the physical performance measures might in part be attributed to the group being elite athletes. A unique competitive environment was created by sharing individual athletes' performance results with the entire group. Furthermore, the athletes in the LH_{travel} group were still competing against each other for places on the Australian World Cup skeleton team. Because a competitive environment was created, the ecological validity of this study was enhanced for athletes travelling to compete overseas in maximal intensity alactic sprinting tasks. Possibly, this competitive environment contributed to the reduced impact of the suggested negative effects of long haul travel on circadian rhythms.

Several characteristics of individual subjects might alter their rate of adjustment to a time zone transition. A circadian rhythm of arousal has been shown with the acrophase ~11:30–14:00 h and the nadir ~03:00 h. This arousal circadian rhythm can be a major predictor of athletic performance, with the acrophase coinciding with periods of highest performance.⁷ Athletes have been shown to exhibit a more positive mood profile than non-athletes and are generally more extroverted and have a stable personality.²⁴ Therefore, it is possible that they may be able to cope with the demands of travel better than non-athletes. However, it is unknown if long haul travel has similar psychological consequences on athletes and non-athletes.²

The athletes in the LH_{travel} group perceived themselves as "jet lagged" before lunch and evening meals on days 1, 2 and 4 after flight. This pattern is similar in those flying eastwards from the UK to Australia undergoing a 10 h time zone change, with "jet lag" most marked on the first day after flight and decreasing thereafter, but remaining significantly greater than baseline on day 6.¹⁶ The LH_{travel} group did not demonstrate any major differences in indices of concentration and hunger. Unlike the aforementioned study, concentration, motivation and irritability were reported as disrupted for up to 4 days after travel.¹⁶

Unfortunately, for the current study the sample size was limited owing to the individual nature of skeleton competition and the related small squad sizes. Possibly, the lack of change in some performance tests might be a type II error.²⁵ Additionally, performance tests were only carried out once a day, and nothing is known about how performance would be affected in the afternoon and evening. It has been suggested that exercise of short duration may lead to a lack of sensitivity to jet lag consequences and not show significant deleterious effects.²⁶ Circadian rhythms in muscular activity may not always be detectable, and measurement error associated with

repeated ergometric assessments is higher than the underlying circadian rhythms in muscle performance when dynamic ergometric tests are used in measurements of anaerobic power and capacity.¹² No differences were found in the questionnaire responses in the NO_{travel} group. It is also possible that the questionnaire results might be biased as it was not possible to blind athletes to travel.

In conclusion, "one-off" daily alactate sprinting ability between 09:30 and 11:00 h local time in a group of elite skeleton athletes was not significantly impaired by eastward long haul travel when full warm-up procedures were followed. In contrast, salivary cortisol, displayed a typical time course response to the change in time zones, with athletes reporting being "jet lagged" for up to 7 days after travel.

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Authors' affiliations

Nicola Bullock, David T Martin, Department of Physiology, Australian Institute of Sport, Belconnen, ACT, Australia

Frank E Marino, School of Human Movement Studies, Charles Stuart University, Bathurst, NSW, Australia

Angus Ross, New Zealand Academy of Sport, Dunedin, New Zealand

Doug Rosemond, Department of Biomechanics, Australian Institute of Sport, Belconnen, ACT, Australia

Conflict of interest: None declared.

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COMMENTARY

It is refreshing to read scientific research based on elite level athletes and, in particular, dealing with such an important issue in modern sport. The problems of long haul flight across several time zones require elucidation if athletes are to be managed effectively. This paper contributes to our understanding of this area.

Robert U Newton

Edith Cowan University, Western Australia, Australia;
r.newton@ecu.edu.au

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