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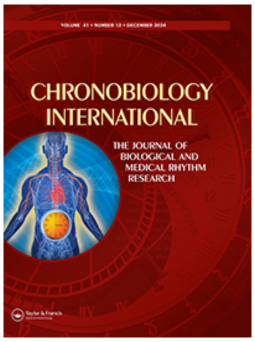

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Ben J. Edwards

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ORIGINAL ARTICLE

Effects of one-night of partial sleep loss on the circadian rhythm of temperature, subjective tiredness, alertness, and standing broad jump performance; is there a sex difference?

Ben J. Edwards

Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Liverpool, UK

ABSTRACT

Maximal gross-muscular performance shows a daily variation in adult males, however, effects of sleep loss on circadian rhythms of gross-muscular tasks with a high skill element such as the standing broad jump is less well established, and differences between biological sex may exist. Thirty-one males and 24 females volunteered. Participants were familiarised with tests before completing two conditions i) Normal (N) retires at 23:30, rising at 07:30 h the night before testing, and ii) Sleep deprivation (SD) retiring at 03:00, rising at 07:30 h, administered in a randomised counterbalanced-fashion. Participants having had 8- or 4.5-h opportunity to sleep, entered the laboratory at 08:00 h and sublingual temperatures, tiredness, and alertness were measured. Thereafter, volunteers completed a warm-up (3 jumps at 40, 60, and 80% max-effort) and then performed jumps. This schedule was replicated at 12:00, 16:00, 20:00, 24:00, and 04:00 h on the same day. Participants were more tired and less alert in the partial sleep deprivation condition, and time-of-day effects were evident in all variables with peaks in jump length coinciding with temperature and alertness (Φ15:44–18:24 h). Females, however, showed a preference for an ~1 h earlier peak in tiredness (mediated in the SD rather than N), with a lower mesor and/or amplitudes in alertness and jump performance than males. The results of the current investigation have important implications for athletes, particularly females suffering sleep loss, regarding strategies to cope with early peaks in tiredness and physical training demands.

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Oral temperature; all-out effort; sleep-restriction; circadian variations; gender

Introduction

Sleep is an important strategy for recovery in athletes during which time cellular restitution, growth, and repair occurs, as well as brain detoxification, consolidation of memories and immune function restoration (Edgar et al. 2021; Everson and Crowley 2004; Teece et al. 2021; Walsh 2019). The recommended amount of sleep, needed to promote optimal health in adults aged between 16 and 60 years old, is 7–9 h per night (American Academy of Sleep Medicine and Sleep Research Society; Watson et al. 2015). However, this recommendation for sleep may be an underestimation for athletes who are more susceptible to poor sleep quality and duration due to several constraints, such as training/competition demands, time-zone transition disturbing circadian rhythms, psychological issues, or environmental factors (Walsh et al. 2020).

Partial sleep loss or sleep deprivation is classed as a reduction of sleep per night, compared to that habitually taken in a 24-h period. Partial sleep deprivation can occur in three ways, 1) *sleep fragmentation*: preventing the normal progression and sequencing of sleep stages from being physiologically consolidated relative to time-in-bed; 2) *selective sleep stage deprivation*: a loss of specific physiological sleep stages, which can occur if sleep fragmentation is isolated to a specific sleep stage (such as when apnoeic episodes disrupt mostly one stage of sleep such as REM sleep, or when medications suppress a specific sleep stage); and lastly, 3) *sleep restriction or sleep debt*, which is characterised by reduced sleep duration (Banks and Dinges 2007). Reduced sleep over several days (hence, sleep disturbance by restriction) is a common occurrence in athletic and non-athletic populations, resulting in a reduction in sleep quality and quantity (Edwards et al. 2023; Gallagher et al. 2023). The effects of sleep loss on mental performance and cognitive function taken have been extensively investigated (Thun et al. 2015) and to a lesser extent so have some measures of sporting performance (Craven et al. 2022; Walsh et al. 2020). The effects of partial sleep deprivation on physical performance are equivocal depending on the complexity, duration, and type of the

CONTACT Ben J. Edwards B.J.Edwards@ljmu.ac.uk Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Room 1.25 Tom Reilly Building, Byrom Street, Liverpool L3 3AF, UK

task (Souissi et al. 2003). As well as the timing of waking after the sleep loss in the solar day and individual differences in habitual sleep (Edwards et al. 2023). Gross muscular tasks such as grip strength that require less "time-on-task" are least affected by partial sleep restriction. In contrast, extended tasks or those of a repetitive nature such as Wingate's, sprints, or submaximal weightlifting (Bench press and back squat) are affected to a greater degree (Brotherton et al. 2019; Waterhouse et al. 2007). This is due to the high cognitive demand required to execute skill-based tasks, which have shown to be more sensitive under conditions of partial sleep loss. Ultimately altering mood states and numerous markers of cognitive function, such as reaction time, alertness, attention, and decision-making (Edwards et al. 2023; Walsh et al. 2020). The standing broad jump is an example of all out-performance task, which requires attention to land with both feet on the ground and has shown a diurnal variation and circadian rhythm in men (Bougard and Davenne 2012; Reilly and Down 1986; Reilly et al. 2007). Hence, there is a cognitive component to this task, also, unlike other all-out performance efforts which require ~24 h to recover, it is thought recovery from the broad jump is quick with low residual fatigue. This allows multiple measures to be taken or performance to be undertaken over the solar day to establish a circadian rhythm, with recovery between trials (such as every 4 h for 24 h). Partial sleep deprivation before such a protocol would increase the homeostatic drive compared to a control condition which should reduce performance in the later stages of the protocol (20:00–04:00 h) and change the circadian rhythm if the broad jump has a large cognitive component. We have previously applied this type of protocol to hand-eye tasks such as darts and simple motor tasks (Edwards and Waterhouse 2009; Edwards et al. 2008).

Interindividual factors, such as chronotype (a person's natural predisposition to be awake or asleep at certain times) or ability to shrug off fatigue (flexibility/rigidity of sleep habits), can influence effects following sleep loss (Durmer and Dinges 2005; Stolarski et al. 2021). The effects of partial sleep deprivation on sex differences, however, are unequivocal due to little research into this area. Similarly, although circadian rhythms in many components of physical performance have been investigated in men, there is limited information on females (Drust et al. 2005). Elliott-Sale et al. (2021) reported that the exclusion of women as participants in general exercise physiology and exercise research was due to i) the confounding effect of female hormone fluctuations on measurements, Ii) because they can be more expensive than men to study due to the extra time (e.g. repeated measures across a menstrual cycle), and iii) resources (e.g. blood samples for the determination of ovarian steroid levels) needed to produce high-quality data. However, recent work suggests that in females who are on a monophasic pill, any phase of the pill cycle can be chosen as exercise performance was consistent across the oral contraceptive pill user cycle (Elliott-Sale et al. 2021).

When polysomnography, hence, sleep is directly measured, sleep efficiency and quality (shorter latencies, fewer nocturnal awakenings, less stage 1 sleep, and deeper sleep) have been consistently found to be better in women than men is known is sleep in women (Redline et al. 2004; Silva et al. 2019). In contrast to this, subjective sleep reports suggest women have a higher need for sleep but generally sleep less with greater non-restorative sleep (Roberts et al. 2021), with more reported sleep disturbances (Schaal et al. 2011). Hence, may be more susceptible to sleep restriction, with knock-on effects on circadian rhythms than males. Where sex differences in sleep have been attributed to females' shorter intrinsic circadian period (Duffy et al. 2011), greater risk for insomnia but not apnoea or snoring (Zhang and Wing 2006) and hormonal fluctuations across the menstrual cycle (Baker and Lee 2018).

The present study was therefore undertaken to directly address some of these issues. The purpose of this study was to determine the effects of one-night partial sleep deprivation (SD, opportunity to sleep for 4.5 h) compared to normal (N, opportunity to sleep for 8 h) on the circadian rhythm of the broad jump and whether biological sex has an effect in participants otherwise living regular and conventional sleep–wake schedules. It is hypothesised that in males and females (taking a monophasic birth control pill) participants exhibit a similar significant circadian rhythm in temperature like that of alertness and jumps performance, with the daily profile of tiredness being the reciprocal to that of alertness. Further, a 4.5 h SD condition will negatively change profiles of tiredness and alertness and performance, and there will be no difference in these profiles for males and females.

Materials and Methods

Participants

Thirty-one males and 24 females (*n* = 55), who identified gender and biological sex as the same, were classified as "recreationally active" by the "Participant Classification Framework" (McKay et al. 2021) volunteered for the study. Mean±SD: age 20.7 ± 0.7 vs 21.4 ± 1.8 yrs; body mass 59.8 ± 8.4 vs 78.7 ± 10.5 kg; height

1.67 ± 0.09 vs 1.81 ± 0.06 m) and habitual total sleep time = 8.6 ± 1.4 vs 8.1 ± 0.9 h. Our primary outcome was the diurnal variation of distance jumped; in adult males, this has shown to have a difference between 08:00 and 17:00 h of 12 cm (206 ± 4.9 vs 218 ± 5.8 cm, Reilly et al. 2007). Using the G*Power 3.1.9.6 software (Faul et al. 2007), it was estimated that with a diurnal difference of 12 cm and SD of 5.5 cm (08 to 20 h, Reilly et al. 2007); hence, an effect size of 2.18 that four participants would facilitate the detection of a statistically significant difference between morning and evening jumps where $p < 0.05$ and 95% power with a one-tailed paired t-test (where evening gross muscular performance is normally greater than morning, actual power = 94%). To the best of my knowledge, there are no investigations concerning diurnal variations in broad jump performance in an adult female population; and the nearest we could find was countermovement jump with an unknown phase of the menstrual cycle where between 07:00–09:00 h and 17:00–19:00 h of 3.92 cm (26.91 ± 4.32 vs 30.83 ± 5.31 cm, Klaus-Karwisch et al. 2023). It was estimated that with an effect size of 0.80, 19 participants would facilitate the detection of a statistically significant difference between morning and evening jumps where $p < 0.05$ and 95% power with a one-tailed paired t-test (where evening gross muscular performance is normally greater than morning, actual power = 95.6%). I took the more conservative approach and recruited 31 male and 24 female participants to allow for dropout, all were recruited from the student population of the University Sport Science department. The criteria for selection hence *inclusion criteria*, were non-smoking or vaping, injury-free with no diagnosed sleep disorders, not undertaking shiftwork or travel outside the local time-zone in the past month. Further, participants had to habitually retire between 22:00–23:30 h and rise at 06:00–07:30 h and agree to retire to bed at 23:30 or 03:30 h and rise at 07:30 h. Hence, the control sessions are not too dissimilar to their natural sleep patterns (Edwards et al. 2024). *Additional inclusion criteria specifically for the females* was self-reported menstrual function and use of the oral monophasic contraceptive pill (for at least 3 months) containing an estrogen component, paired with one of eight progestins (established by a questionnaire; Low Energy Availability in Females Questionnaire [LEAF-Q]; Melin et al. 2014), with participants being allocated sessions at any time of their oral contraceptive cycle with ~7 d recover like the men. The LEAF questionnaire is used to identify those female athletes who may be at risk of oligomenorrhoea/functional hypothalamic amenorrhoea and impaired bone health, a syndrome called the female athlete triad (Triad) and includes questions on injuries, gastrointestinal as well as reproductive functions. None of the participants were receiving any pharmacological treatment other than contraception for the females (including non-steroidal anti-inflammatory drugs, NSAIDs), with no injuries and taking no supplements throughout the study period (Edwards et al. 2024). Habitual caffeine consumption was assessed using the caffeine consumption questionnaire (CCQ), and those with >150 mg per day were excluded (Landrum 1992). Further, all participants expressed no preference for training regarding time-of-day by a weekly self-reported 2-week training diary. The circadian chronotype of the participants was assessed using a composite "morningness questionnaire" by Smith et al. (1989). The participants' mean "chronotype" score on a 13–52 scale for males and females was 31 ± 6 vs 32 ± 7; hence, all the participants were "intermediate types. A circadian-type inventory questionnaire by Folkard et al. (1979) was administered to determine the languidness/vigorous and flexibility/rigidity of participants. The female and male mean scores were 46.2 ± 6.5 vs 41.7 ± 7.8 and 42.2 ± 6.4 vs 39.6 ± 7.8 for languidness (L)/vigour (V) and flexibility (F)/rigidity (R), respectively. Vigorous types are generally more alert than languid types across the day and report needing less sleep. Flexible types are less influenced by circadian and wakefulness factors and need less sleep compared to rigid types (Di Milia et al. 2005). Hence, vigorous and flexible types would best cope with sleep loss. That said, the females' values were 29.2% V and 70.8% L vs males 38.7% V and 61.3% L; and 8.3% R and 91.7% F vs 29% R and 71% F according to the definitions of the questionnaire. Participants were required to arrive fast and abstain from alcohol, caffeine and exercise 24 h preceding a testing session (Edwards et al. 2024). All participants gave their written informed consent. The study was conducted in accordance with the Local Ethics Committee at JMU, the ethical standards of the journal and complied with the Declaration of Helsinki.

Experimental Design

The 55 participants attended a university gymnasium on seven occasions (dry temperature, humidity, barometric pressure and ambient light were 19–20°C, 35–45%, 750–760 mmHg and ~750 lux, respectively or all sessions). Participants were familiarised with the standing broad jump over 24 h (see Familiarisation section), before completing two conditions separated by 7 d for the participants. Experimenatal sessions were 1) Normal (N) retires at 23:30 and rising at 07:30 h, and 2) Partial sleep deprivation (SD) retiring at 03:00 and rising at 07:30 h, which were administered in a counterbalanced fashion (Figure 1). Sublingual temperatures (Omron, Eco Temp Intelli IT MC-280B oral-thermometer, Brighton, UK), tiredness, and alertness (0–10 cm Visual analogue scale) were measured at 08:00, 12:00, 16:00, 20:00, 24:00, and 04:00 h. Thereafter, volunteers performed three broad jumps with 2-min between each jump and the best jump was recorded. Ten stations were set up in the room with a standing long jump distance marked on the floor, with a researcher noting the landing position of each jump and noting down jump length; ~5 participants were allocated for each station. Each participant completed with a minimum of 7 d between experimental trials to ensure washout between trials. All experiments were completed between the months of October to December (Autumn to Winter in the UK) to ensure the individual's exposure to sunlight in the mornings when entering the laboratories was <80 lux (Light-watch, Neurotechnologies, Cambridge, UK), with sunrise and sunset range from start to the end of the experiment being 07:02 to 08:06 h and 16:01 to 18:37 h, respectively.

Protocol and Measurements

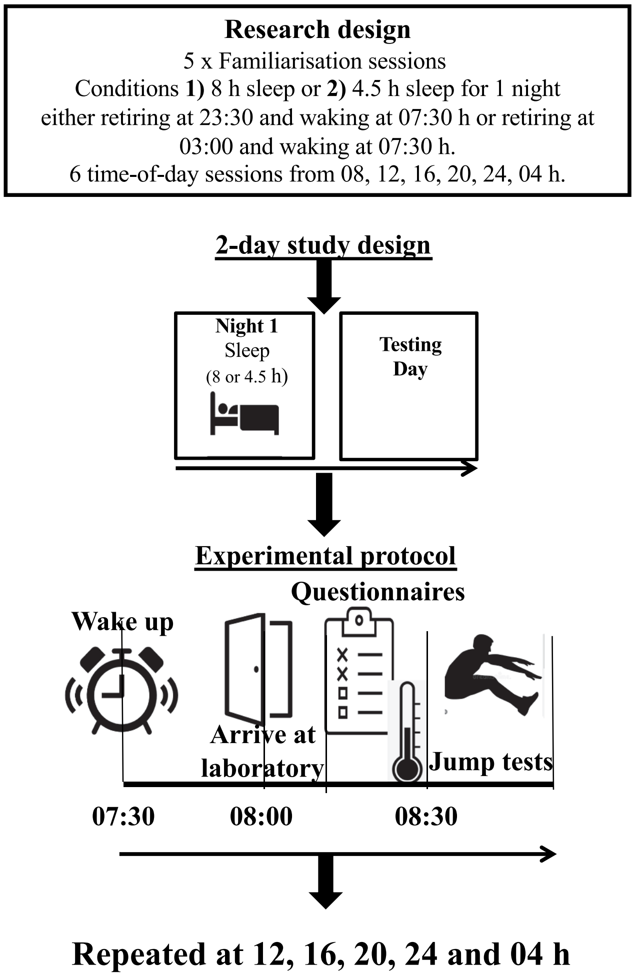
During recruitment, participants were asked questions to see if they met the inclusion criteria, and for the females, they were asked to self-report the type of oral contraceptive pill, if they still had bleeds and how long they had been on the pill for.

Familiarisation: Participants arrived at the gymnasium at 08:00 h (having slept normally) and completed a mock run-through of the experiment. They then returned at 12:00, 16:00 and 20:00 h to return the next morning at 08:00; and it was the two 08:00 h data sets that were used for analysis. During these five sessions, participants were trained as aids to the primary researcher in collecting data on their fellow participants. Volunteers were accepted as familiarised when broad jump performance varied by no more than a coefficient of variance of 5% to reduce the chances of a learning effect affecting performance. The random error between the second and last reliability trials was heteroscedastic, and the data were therefore expressed as 95% ratio limits of agreement. The 95% ratio limits of agreement for the jump performance sessions at 08:00 h were investigated for the 55 participants; these were */ 1.097 (about 9.7%) and a coefficient of variance of 4.95%, indicating little measurement error (Nevill and Atkinson 1997). Paired *t*-test showed no difference ($p = 0.490$), and practically, this was a 0.4% increase in distance jumped. One week after these preparatory tests, volunteers underwent the experimental data collection sessions.

Measurements and Protocol for the Experimental Sessions

Measurement Procedures

On arrival to the gymnasium, participants were asked to rest in a supine position for 30-min before the tests (Figure 1). Thereafter, they inserted an oral thermometer (Omron, Eco Temp Intelli IT MC-280B oral-thermometer, Brighton, UK) under the tongue having not consumed water for 2 h before the measure. Two values of sublingual temperatures were taken 2-min apart and if there was a discrepancy and third was taken. During the resting period, participants gave ratings of "alertness" and "tiredness" on a 0–10 cm scale "0" meaning no and "10" maximal, by putting a cross on the scale with a sharp pencil (this was measured by a rule and the score expressed to 1 mm). Thereafter, volunteers performed three broad jumps with 2-min between each jump and the longest jump was recorded at 08:00, 12:00, 16:00, 20:00, 24:00, and 04:00 h. The procedure for the long jump entailed three warm-up



Research design
5 x Familiarisation sessions
Conditions **1)** 8 h sleep or **2)** 4.5 h sleep for 1 night
either retiring at 23:30 and waking at 07:30 h or retiring at 03:00 and waking at 07:30 h.
6 time-of-day sessions from 08, 12, 16, 20, 24, 04 h.

Figure 1. Schematic representation of the protocol undertaken by participants in the investigation.

jumps at 30, 50, and 80% of perceived max effort. The athlete stood behind a line marked on the ground (with tape) with feet slightly apart. A two-foot take-off and landing technique was required, and the participant was asked to swing the arms and bend the knees to provide forward drive. The volunteer was given verbal encouragement to jump as far as possible, landing on both feet without falling backwards. The participant lined up both toes on the jump mat and the researcher marked where their back heel fell on landing. The jump was measured from the toes to the back heel of the back foot and recorded in cm and mm using standard metal tape (Freedman, 10 m Fiberglass tape, UK). Participants were asked to come for the 08:00 h session fasted and eat immediately after this session and consume food lunch after the 12:00 h session and dinner meal at 17:00 h before the start of the 20:00 h session (Edwards et al. 2024). In all sessions, the participants retired at around 22:30 h or 03:30 h and rose around 06:30 h, having had a text message to which they had to respond. Compliance was high, with all confirming within 2 mins, they had adhered to the schedule as assessed by the text response and verbal check in the morning and evening of the experimental sessions. The volunteers were free to live a "normal life," between sessions sleeping at home at night and attending lectures and doing light office work in the day. They were asked to refrain from any other training or heavy exertion for the 48 h before the experiments or during them. Participants recorded the type, amount, and timing of the food they ate for the period of 24 h before the day of the first session and were asked to replicate this diet for the days before the second experimental condition. Water and non-caffeinated/non-alcoholic, calorie-free beverages were allowed ad libitum up to a total volume of 3 L per day.

Statistical Analysis

Data were analysed using the Statistical Package for Social Sciences version 29 (SPSS, Chicago, IL, USA). All data were checked for normality using the Shapiro-Wilk test. General linear models were used for all measurements collected. To correct sphericity violations the degrees of freedom were corrected using Greenhouse-Geisser ($\varepsilon < 0.75$) or Huynh-Feldt ($\varepsilon > 0.75$). Bonferroni pairwise and graphical comparisons were made where the main effects were found. This was supplemented by single and group cosinor analyses using a period of Tau = 24 h (Nelson et al. 1979). The parameters derived from this analysis were mesor (M: a time series mean), the amplitude (A: half the distance from the peak to the trough of the fitted curve), and the acrophase (Φ: time-of-peak of the fitted curve). The significance of the fitted curve was determined by comparing its variance with the total variance using a F-test. The bathyphase (time of minimum of the fitted curve, 12 h difference from the acrophase) was derived. Significance was set at $p < 0.05$. Effect sizes were calculated from Cohen's d if two groups had similar standard deviations and were of the same size (such as main effects for time-of-day and Sleep), if different sample sizes Hedges' g, which provides a measure of effect size weighted according to the relative size of each sample was used (SEX). The magnitude of the ES was classified as trivial (≤0.2), small (>0.2–0.6), moderate (>0.6–1.2), large (>1.2–2.0), and very large (>2.0) based on guidelines from Batterham and Hopkins (2006). The results are presented as the mean ± the standard deviation throughout the text unless otherwise stated. Ninety-five percent confidence intervals are presented where appropriate as well as the mean difference between pairwise comparisons.

Results

Resting Sublingual Temperature Subjective Rating of Tiredness and Alertness

Participants reported higher subjective tiredness and lower values of alertness in the SD condition than N (mean difference 0.60 cm, $p = 0.004$, CI = 0.21 to 1.00 cm and 0.63 cm, $p = 0.001$, CI = 0.26 to 1.01 cm, respectively; Table 1). This agrees with the changes in mesor values for N and SD for the circadian rhythms of tiredness and alertness (Table 2). There was no main effect for sex (Tables 1 and 3). There was a significant time-of-day effect in all variables, where temperature and alertness values peaked between 16:00–20:00 h ($p < 0.05$; acrophases Φ15:44 to 18:24 h). Tiredness, however, was lowest at 16:00 h and peaked at 04:00 h (Φ 03:42 to 03:46 h, Figure 2). Both males and females showed a significant circadian rhythm in temperature, tiredness and alertness (Table 3 and Figure 4). There was a significant interaction between time-of-day and sex for tiredness, alertness where pairwise comparisons showed female values were better at 08:00 h than the males (lower tiredness 1.29 cm, CI = 0.24 to 2.35 cm, $p = 0.017$; higher alertness 1.19 cm, CI = 0.13 to 2.25 cm, $p = 0.028$), and the profiles were lowest and highest, respectively, from 12:00 to 16:00 h compared to 16:00 h in the males. For tiredness, this resulted in the acrophase (Φ) peaking 1:06 h:min earlier in the females than males ($p = 0.001$). For alertness, cosinor analysis showed mesor and amplitude values to be higher in the males than in females (0.54 cm and 0.74 cm, respectively, Table 3). Lastly, a significant

Table 1. Statistical significance for main effects and interactions are given for temperature, tiredness, alertness, and broad jump variables; for experimental conditions (SD 4 vs 8 h), in males and females measured over 6 times of day.

Variable	Main effect for SD		Main effect for Sex		Main effect for Time-of-day		Interaction
Temperature (°C)	$p = 0.442$	ES = 0.03, OP = 11.8%	$p = 0.757$	ES = 0.07, OP = 6.1%	**$p < 0.001$**	**ES = 0.66, OP = 100%**	$p = 0.458$ TOD*SEX $p = 0.489$ SD*TOD $p = 0.411$ SD*TOD*SEX
Tiredness (0–10 cm VAS)	**$p = 0.004$**	**ES = 0.21, OP = 84.7%**	$p = 0.706$	ES = 0.04, OP = 6.6%	**$p < 0.001$**	**ES = 1.64, OP = 100%**	**$p = 0.012$ TOD*SEX** $p = 0.249$ SD*TOD **$p = 0.049$ SD*TOD*SEX**
Alertness (0–10 cm VAS)	**$p = 0.001$**	**ES = 0.22, OP = 90.8%**	$p = 0.729$	ES = 0.03, OP = 6.3%	**$p < 0.001$**	**ES = 1.80, OP = 100%**	**$p = 0.002$ TOD*SEX** *$p = 0.086$ SD*TOD* $p = 0.116$ SD*TOD*SEX
Broad Jump (cm)	$p = 0.397$	ES = 0.02, OP = 13.4%	**$P < 0.001$**	**ES = 1.92, OP = 100%**	**$p < 0.001$**	**ES = 0.34, OP = 100%**	**$p = 0.022$ TOD*SEX** $p = 0.900$ SD*TOD $p = 0.690$ SD*TOD*SEX

$p < 0.05$ is indicated in bold and a trend where $0.05 < p < 0.1$ is indicated in italics, ES = effect size (either Cohen's d or Hedge's g) and OP = observed power.

Table 2. Cosinor analysis for variables for normal (N) and partial sleep deprivation (SD) conditions.

	Mesor (M)	Amplitude (A)	Acrophase (Φ, Decimal h)	Acrophase (Φ, h:min)	%R	Significance (p-value)
Temperature (°C)						
N	36.03	0.34	18.44	18:26	99.17	$p < 0.0001$
SD	36.01	0.30	17.86	17:52	97.64	$p < 0.0001$
Tiredness (0–10 cm VAS)						
N	5.10	2.99	3.68	03:40	94.74	$p < 0.0001$
SD	5.70*	2.96	3.82	03:49	97.99	$p < 0.0001$
Alertness (0–10 cm VAS)						
N	4.97*	2.80	16.14	16:08	94.29	$p < 0.0001$
SD	4.27	2.80	16.35	16:21	98.41	$p < 0.0001$
Broad Jump (cm)						
N	165.44	8.06	16.93	16:56	95.57	$p = 0.005$
SD	164.56	8.57	16.96	16:58	98.18	$p = 0.003$

*Represents a significant difference for mesor. $p < 0.05$ is indicated in bold and a trend where $0.05 < p < 0.1$ is indicated in italics.

Table 3. Cosinor analysis parameters and significance for variables for females (F) and males (M), as well as statistical significance between females and males.

	Mesor (M)	Amplitude (A)	Acrophase (Φ, Decimal h)	Acrophase (Φ, h:min)	Sex (p-value)	Sex differences (p-value)
Temperature (°C)	F: 36.07 M: 36.00	F: 0.26 M: 0.36	F: 18.13 M: 18.20	F: 18:08 M: 18:12	F: $p = 0.009$ M: $p < 0.0001$	M: $p = 0.480$ A: $p = 0.415$ Ac: $p = 0.969$
Tiredness (0–10 cm)	F: 5.34 M: 5.45	F: 2.87 M: 3.11	F: 3.11* M: 4.21	F: 03:06 M: 04:13	F: $p < 0.0001$ M: $p < 0.0001$	M: $p = 0.567$ A: $p = 0.383$ Ac: $p = 0.001$
Alertness (0–10 cm)	F: 4.32 M: 4.86*	F: 2.38 M: 3.12*	F: 16.14 M: 16.31	F: 16:08 M: 16:19	F: $p < 0.0001$ M: $p < 0.0001$	M: $p = 0.005$ A: $p = 0.007$ Ac: $p = 0.682$
Broad Jump (cm)	F: 136.02 M: 187.43*	F: 6.96 M: 9.60	F: 16.02 M: 17.46	F: 16.01 M: 17:28	F: $p = 0.033$ M: $p = 0.0002$	M: $p < 0.0001$ A: $p = 0.512$ Ac: $p = 0.464$

*Represents a significant difference. $p < 0.05$ is indicated in bold and a trend where $0.05 > p < 0.1$ is indicated in italics.

interaction for SD*SEX*TOD* was found ($p = 0.049$, Table 1), where profiles of tiredness in the N condition are lowest at 16:00 h in both sexes; however, there was a difference in profiles where for females in the SD condition values are lowest at 12:00 and males at 16:00 h. Cosinor analysis showed an earlier acrophase in tiredness and alertness in females after SD compared to N (1.63 h and 1.88 h) with a change in mesor for tiredness and alertness (1.42 cm and −1.46 cm; Table 4).

Performance Broad Jump

There was no main effect for the SD condition compared to N for jump performance, such that the values were similar ($p > 0.05$). There was a main effect for sex where males jumped further than the females (51.4 cm, CI = 37.8 to 65.1 cm; $p < 0.001$, Tables 1 and 3). A time-of-day effect was found where general pairwise comparisons showed jump performance peaked ~20:00 h ($p < 0.05$; acrophase ~16:44 h). Both males and females

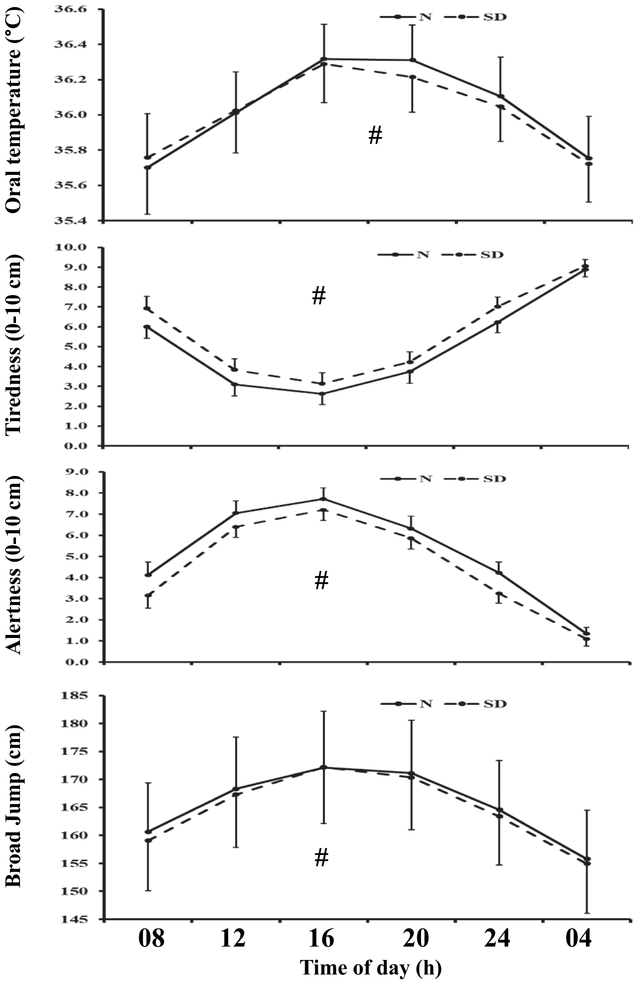


Figure 2. Mean (95%CI) values for oral temperature, tiredness, alertness, and broad jump for normal (N) and partial sleep deprived (SD) conditions for the six times-of-day.

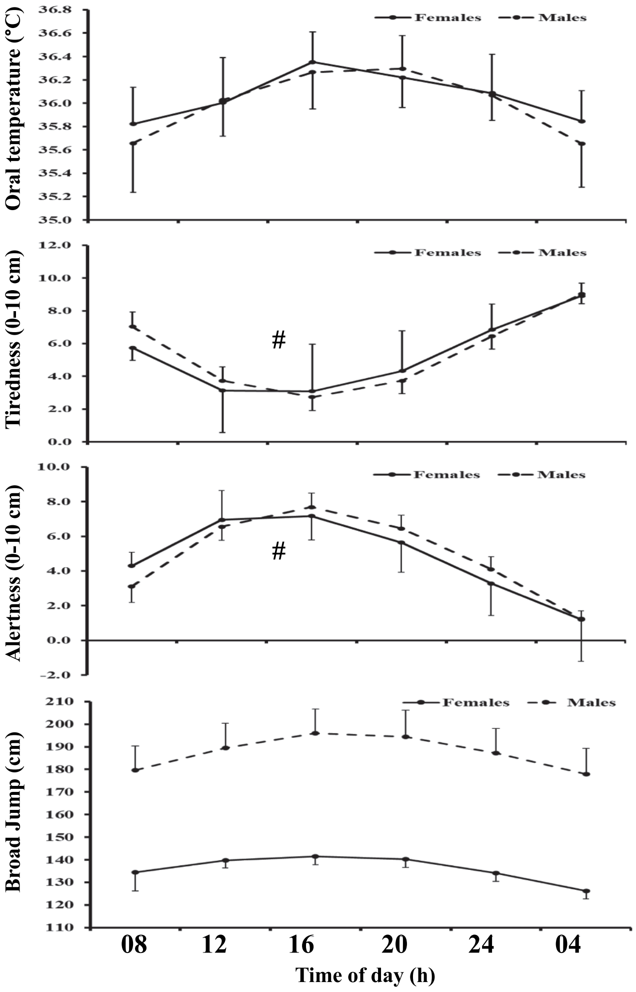


Figure 3. Mean (95%CI) values for oral temperature, tiredness, alertness, and broad jump for females and males for the six times-of-day. Significant interactions are denoted by #.

showed a significant circadian rhythm in the broad jump (Tables 3, 4 and Figure 3). There was a significant interaction between time-of-day and sex where the mesor for jump distance was higher in the males than females (51.4 cm, Table 3). There were no other significant interactions (Figure 4, Table 1).

Table 4. Cosinor analysis for variables for males (M) and females (F) for normal (N) and partial sleep deprivation (SD) conditions.

	Mesor	Amplitude	Acrophase (Decimal H)	Acrophase (H:Min)	(p-value)
Temp. (°C)	F: 36.06	F: 0.29	F: 18.80	F: 18:48	F: $p = 0.005$
N	M: 36.01	M: 0.39	M: 18.30	M: 18:18	M: $p < 0.001$
SD	F: 36.01	F: 0.28	F: 18.31	F: 18:19	F: $p = 0.039$
	M: 35.98	M: 0.34	M: 18.04	M: 18:02	M: $p < 0.001$
Tire. (0–10 cm)	F: 5.11	F: 2.56	F: 03.38	F: 03:23	F: $p < 0.001$
N	M: 5.16	M: 3.27	M: 04.00	M: 04:00	M: $p < 0.001$
SD	F: 6.53*	F: 3.05	F: 05.01*	F: 05:01	F: $p < 0.001$
	M: 5.73*	M: 2.96	M: 04.44	M: 04:26	M: $p < 0.001$
Alert. (0–10 cm)	F: 4.99	F: 2.59	F: 15.22	F: 15:13	F: $p < 0.001$
N	M: 5.18	M: 3.25	M: 16.21	M: 16:13	M: $p < 0.001$
SD	F: 3.54*	F: 3.08 *	F: 17.10*	F: 17:06	F: $p < 0.001$
	M: 4.53*	M: 3.00	M: 16.42	M: 16:25	M: $p < 0.001$
Jump (cm)	F: 136.06	F: 6.42	F: 16.06	F: 16:04	F: $p = 0.045$
N	M: 188.18*	M: 9.52	M: 17.38	M: 17:23	M: $p < 0.001$
SD	F: 135.98	F: 7.51	F: 15.99	F: 15:59	F: $p < 0.001$
	M: 186.68*	M: 9.68*	M: 17.54*	M: 17.32	M: $p < 0.001$

*Represents a significant difference for condition (N or SD) and gender (F or M).

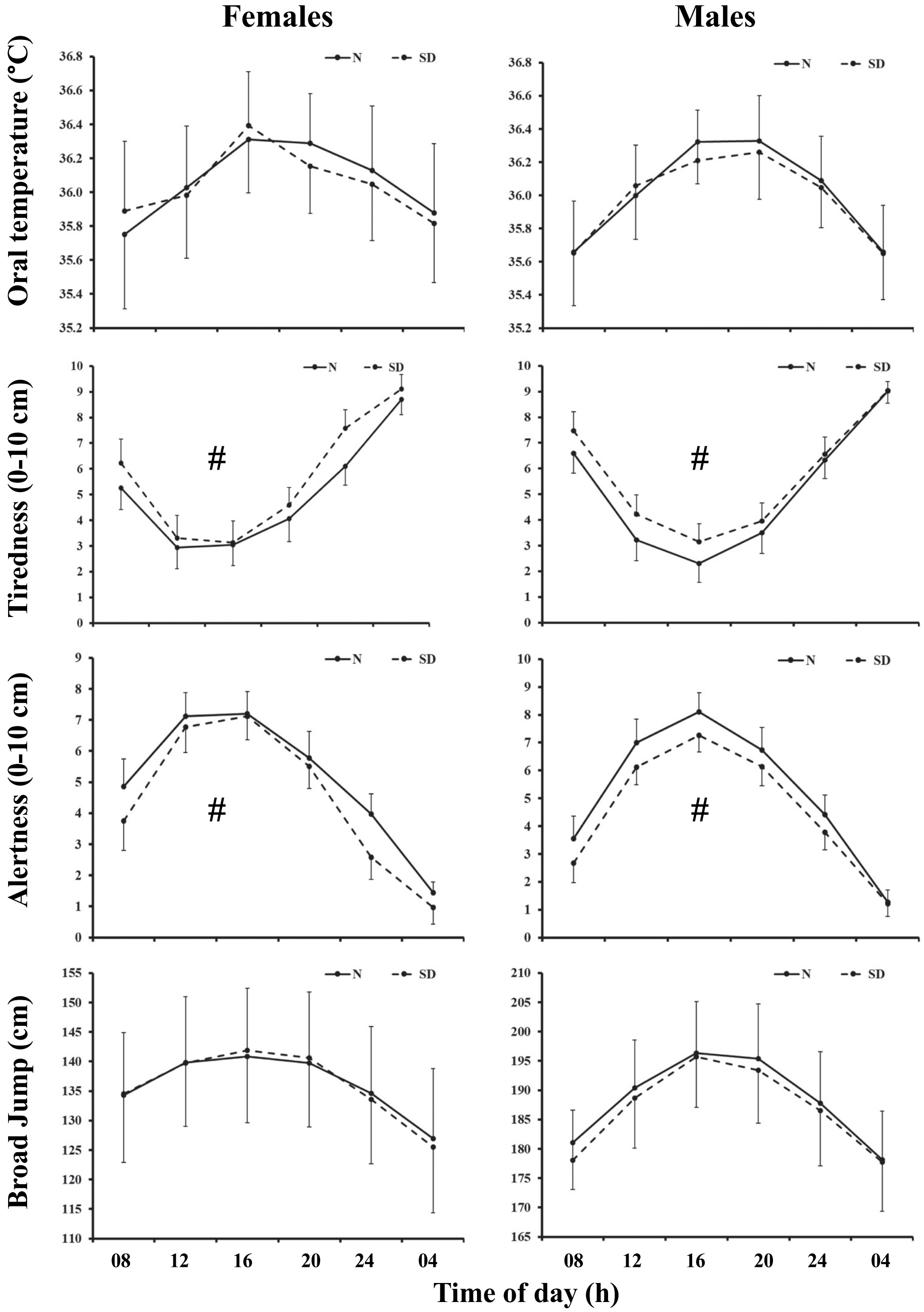


Figure 4. Mean (95%CI) values for oral temperature, tiredness, alertness, and broad jump for the interaction of sex (females and males) sleep condition (SD vs N) for six times-of-day. Significant interactions SD*time-of-day*sex are denoted by #.

Discussion

The results of this investigation found no interactions for partial sleep deprivation by time of day for males and females for temperature or jump distance, as hypothesised (See Figure 4). There was, however, a significant interaction between time-of-day and sex for tiredness and alertness only, where pairwise comparisons showed female values were lower at 08:00 h than the males (1.29 and 1.19 cm, $p < 0.05$), and the profiles were lowest and highest, respectively, from 12:00 to 16:00 h compared to 16:00 h in the males. For tiredness, this resulted in the acrophase (Φ) peaking 1:06 h:min earlier in the females than males ($p = 0.001$). For alertness, cosinor analysis showed mesor and amplitude values to be higher in the males than in females (0.54 cm and 0.74 cm, respectively, Table 3). It has recently been proposed that in female ($n = 40$) and male ($n = 40$) university students, women have a stronger sleep drive (hence, women's better sleep quality in the results of polysomnographic studies) but also the opposing influence, the drive for a wake than men (Dorokhov et al. 2024). The stronger drive to sleep may partially explain the susceptibility to SD, and the stronger wake drive could influence perception of sleep loss as well as tiredness, alertness, and sleepiness in females compared to males.

As expected, males' jump performance was greater than females' (~51 cm, Large ES = 1.92), no other variables were different between sexes with trivial effect sizes. The partial sleep deprivation for one night (a reduction in the opportunity to sleep of 57% of that habitually given) had no effect on oral temperature and broad jump performance. This agrees with others, where the effects of partial sleep deprivation on the core temperature in participants (in thermoneutral conditions) who have acutely (1 to 2 nights) and had a 3 or 4 h restriction (33 to 55%) of total sleep has previously been shown to be small (Brotherton et al. 2019; Gallagher et al. 2023; Meney et al. 1998; Reilly et al. 2007). Unlike total sleep restriction for multiple nights in participants who are challenged thermally by environmental stress (hot or cold; Keramidas and Botonis 2021). Investigations which have demonstrated a reduction in core temperature following sleep loss have been attributed to the masking effect due to the reduction in physical activity resulting from sleep loss (Minors 1999). Souissi et al. (2003) observed in a male population a phase advance of oral temperature following one-night total sleep deprivation. The authors attributed this to two possibilities; a mathematical effect solely due to the significant increase in temperature at 14:00 h or a phase advance to the circadian oscillator which is highly sensitive to light exposure due to the extended exposure to artificial light during sleep deprivation. It is thought sleep loss may alter thermoregulation which in-tern may alter performance, through enhanced metabolic reactions, increasing the extensibility of connecting tissue and increasing the convection of action potentials for contraction in connective tissues (Sheppard 1984). In the current investigation, this is not apparent as there was a trivial effect (ES = 0.02) of SD on broad jump performance (a maximal task). This lack of effect maybe because the time-on-task is small, or the broad jump has a small cognitive component and hence is not substantially influenced by alternations in the nervous system following reduced sleep (Edwards et al. 2023), nor performance deteriorate as time-awake increases (Drust et al. 2005). A deterioration in cognitive tasks after sleep loss has been attributed to a) homeostatic drive from fatigue due to time-awake, mental fatigue (Carrier and Monk, 2000) and b) circulation of catecholamine activity in the blood increasing arousal (Reilly and Edwards 2007).

There was a reduction in self-rated alertness and increased tiredness observed in the SD condition compared to N (0.60 and 0.63 cm, respectively). These alterations have previously been associated with the circadian rhythm of core body temperature and time-awake (Akerstedt and Folkard 1995). In agreement, we found daily variations in tiredness, alertness, temperature and performance. Where tiredness falls and alertness increases, in opposition, increases parallel to the diurnal variation of rectal temperature (Figures 2–4). However, at 20:00 h despite rectal temperature peaking, tiredness values increased and alertness decreased (Figure 2). In the current study a circadian rhythm in jump performance (ES = 0.34) in both the male and female participants (4.7 and 5.1% rhythm from amplitude/mesor), for the N condition where cosinor characteristics were (M: 136.06 vs 188.18 cm a 52.13 cm significant difference; A: 6.42 vs 9.52 cm and acrophases of 16.06 vs 17.38 h a 1.32 h significant difference). Comparison of the current findings with others is limited as most of the literature investigates male participants and predominantly uses diurnal protocols (08:00, 12:00, 16:00, and 20:00 h). In the one study that investigated circadian variations in broad jump performance in adult males using two warm-up jumps before data collection and testing at similar time-of-day (02, 06 10, 14, 18, 22 h; although each session was ≥72 h); found similar acrophase and smaller amplitudes of 17:45 vs 14:30 h:min and 7.6 vs 9.6 cm to the current investigation (Reilly and Down 1986). In agreement with diurnal variation studies where male adult athletes' jump performance has been reported to be 3.6–5.5% greater at 06:00–08:30 vs 18:00–20:00 h (Bougard and Davenne 2012; Reilly et al. 2007). The diurnal variation in standing jump or countermovement jump in male and female participants was 4.3% and 4.0% for 07:30 and 17:30 h, respectively (Chtourou et al. 2013).

No significant interactions for SD by time-of-day were found; hence, in the current study, the participants report similar levels of reduced alertness and increased tiredness through the 24 h. Others have shown after SD of 3 h that subjective tiredness and alertness were not parallel to the diurnal variation of rectal temperature (Waterhouse et al. 2007). This dissociation from core temperature, reduction in alertness, and increase in tiredness are attributed to the increase in homeostatic pressure in the nervous system during prolonged wakefulness and reduced sleep (Saper et al. 2005). This homeostatic component (sleep drive) increases in the nerve cells during wakefulness and diminishes during sleep-promoting wakefulness (wake drive; Achermann 2003). During extended periods of wakefulness, however, the sleep drive exceeds the pressure of the wake drive increasing sleepiness, tiredness, and reducing alertness retrospectively. A time awake component (S) has been incorporated into many models of alertness (Akerstedt and Folkard 1995), and this finding is not unexpected. Our lack of a significant effect, which was hypothesised could be simply due to the reduction of the opportunity to sleep in the SD condition only being only ~56% (4.5/8 h) of habitual sleep, it has been proposed that a dose-response to sleep restriction may exist and the amount chosen was not enough of a stress/strain to elicit responses (Gallagher et al. 2024).

Women using OCs (characterised by a low endogenous progesterone level but with very potent synthetic progestins) are reported to have a higher fast sleep spindle density and corresponding increases in restorative sleep and general cognitive abilities (Plamberger et al. 2021). However, this did not convey an advantage to the cosinor parameters of tiredness and alertness above male participants. Others who have examined sex differences in the diurnal and circadian variation of sleep and waking have sought to control environmental conditions (using ultra-short sleep-wake cycles), while simultaneously controlling for menstrual cycle phase and hormonal contraceptive use. Thompson et al. (2021) reported that the amplitude of the variation of alertness was significantly increased in women vs. men due to a larger decline in alertness scores at night. Similarly, Bovin et al. (2016) reported a phase advance of the alertness rhythm in women vs. men during both the mid-follicular and mid-luteal phases of the menstrual cycle. In this study, the authors increased amplitude of the diurnal and circadian variation of alertness in the female participants was attributed to a larger decline of alertness scores at night. Thompson et al. (2021) suggested that the advance in the drive for alertness in females may conceivably explain the higher prevalence of difficulty maintaining sleep and early-morning awakenings reported in women vs. men.

We recruited young females who were using the monophasic oral contraceptive pill containing an estrogen component paired with one of eight progestins, during any stage of the pill cycle. We chose this population to compare to males as muscle performance does not change with the oral contraceptive cycle, this seems to be evident for some measures (Counter-movement jumps, bilateral hop jumps, handgrip strength, isometric knee extensor strength and isokinetic knee flexion and extension), and however, isometric knee flexion at 240° s^{-1} was significantly higher in the late hormone phase compared with the early hormone phase (Thompson et al. 2021). It is worth noting that other factors than gender are thought to effect circadian rhythms and in the current study from the circadian-type inventory questionnaire, the male population were slightly more Vigorous (Di Milia et al. 2005, more alert across the day and reported needing less sleep) and more Flexible (less influenced by circadian and wakefulness factors and need less sleep) than the females and would less cope with sleep loss (9.5 and 29%). The link between sporting performance peak and biological sex after SD is worth investigating at other phases and with other birth control methods, resulting in practical guidelines for training, competition and travel.

Limitations

Sleep inertia could have partially influenced subjective alertness and tiredness measured 30-min post-awakening, although this is thought to be minimal. Indeed, sleep inertia is generally believed to be dissipated within that time frame (Edwards et al. 2024). Other limitations of the study were that habitual sleep was not assessed formally by a sleep diary and actigraphy nor sleep scales were administered on the morning of the experiment. And the findings of the current study are limited to intermediate chronotypes as no out-right morning or evening types were recruited. It should be noted that oral temperature is highly susceptible to confounding variables including eating, smoking, and drinking, and although we had inclusion criteria and protocol to reduce, this masking may still be present (Terndrup et al. 1989). The present results can only be assumed for recreationally active" by the "Participant Classification Framework" (McKay et al. 2021) as even though the participants had five familiarisation sessions prior to the onset of the protocol, it could be possible that the technique was not reliable, particularly under SD conditions where alertness is low. Whether the long jump values were true representatives of the participants' maximal effort is unknown, nor did we control or measure the level of % of maximal effort for the warm-up. Further investigation into trained long jumpers who would have high levels of intrinsic and possible extrinsic motivation needs to be administered.

Conclusion

The results of the present study suggest that partial sleep deprivation (opportunity to sleep for 4.5 h for 1 night) vs N caused a reduction in alertness and an increase in tiredness but no effect on oral temperature and broad jump performance – suggesting a small if at all cognitive component for broad jump in untrained participants. Circadian rhythms were found for temperature, tiredness, alertness, and broad jump in males and females after SD vs N. As hypothesised, circadian rhythms in temperature (Φ ~18 h, peak in rhythm) were like that of alertness (Φ ~16 h) and jump performance (Φ ~16 h), with the daily profile of tiredness (Φ ~3.5 h) being the reciprocal to that of alertness. Broad jump, alertness, and tiredness profiles peaked earlier or had modified mesor and amplitude of circadian rhythms in the females than the males, and for subjective tiredness, this was mediated through SD. The results have important implications for athletes, particularly females suffering sleep loss, regarding strategies to cope with early peaks in tiredness and physical training demands.

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ORCID

Ben J. Edwards http://orcid.org/0000-0001-8913-0941

References

Achermann P. 2003. Mathematical models of sleep regulation. Front Biosci. 8:683–693. doi: 10.2741/1064

Akerstedt T, Folkard S. 1995. Validation of the S and C components of the three-process model of alertness regulation. Sleep. 18:1–6. doi: 10.1093/sleep/18.1.1

Baker FC, Lee KA. 2018. Menstrual cycle effects on sleep. Sleep Med Clinics. 13:283–294. doi: 10.1016/j.jsmc.2018.04.002

Banks S, Dinges DF. 2007. Behavioral and physiological consequences of sleep restriction. J Clin Sleep Med. 3:519–528. doi:10.5664/jcsm.26918. PMID: 17803017; PMCID: PMC1978335.

Batterham AM, Hopkins WG. 2006. Making meaningful inferences about magnitudes. Int J Sports Physiol Perform. 1:50–57. doi: 10.1123/ijspp.1.1.50. PMID: 19114737.

Bougard C, Davenne D. 2012. Effects of sleep deprivation and time-of-day on selected physical abilities in off-road motorcycle riders. Eur J Appl Physiol. 112:59–67. doi: 10.1007/s00421-011-1948-6

Bovin D, Shechter A, Nmkn Y-K, Begum EA, Ng Ying-Kin NMK. 2016. Diurnal and circadian variation of sleep and alertness in men vs. naturally cycling women. Proc Natl Acad Sci USA. 113:10980–10985. doi: 10.1073/pnas.1524484113

Brotherton EJ, Moseley SE, Langan-Evans C, Pullinger SA, Robertson CM, Burniston JG, Edwards BJ. 2019. Effects of two nights partial sleep deprivation on an evening submaximal weightlifting performance; are 1 h powernaps useful on the day of competition? Chronobiol Int. 36:407–426. doi: 10.1080/07420528.2018.1552702

Carrier J, Monk TH. 2000. Circadian rhythms of performance: new trends. Chronobiol Int. 17:719–732. doi: 10.1081/cbi-100102108

Chtourou H, Aloui A, Hammouda O, Chaouachi A, Chamari K, et al. 2013. Effect of static and dynamic stretching on the diurnal variations of jump performance in soccer players. PLOS ONE. 8:e70534. doi: 10.1371/journal.pone.0070534

Craven J, McCartney D, Desbrow B, Sabapathy S, Bellinger P, Roberts L, Irwin C. 2022. Effects of acute sleep loss on physical performance: a systematic and meta-analytical review. Sports Med. 52:2669–2690. doi: 10.1007/s40279-022-01706-y

Di Milia L, Smith ASP, Folkard S. 2005. A validation of the revised circadian type inventory in a working sample. Personality And Individual Differences. 39:1293–1305. doi: 10.1016/j.paid.2005.04.012

Dorokhov VB, Puchkova AN, Shumov DE, Gandina EO, Taranov AO, Ligun NV, Sveshnikov DS, Yakunina EB, Mankaeva OV, Putilov AA. 2024. The yin and yang of two opponent processes of sleep-wake regulation: sex-associated differences in the spectral EEG markers of the drives for sleep and wake. Chronobiol Int. 41:1046–1057. doi: 10.1080/07420528.2024.2378007

Drust B, Waterhouse J, Atkinson G, Edwards B, Reilly T. 2005. Circadian rhythms in sports performance—an update. Chronobiol Int. 22:21–44. doi: 10.1081/cbi-200041039

Duffy JF, Cain SW, Chang AM, Phillips AJK, Münch MY, Gronfier C, Czeisler CA 2011. Sex difference in the near-24-hour intrinsic period of the human circadian timing system. Proceedings of the National Academy of Sciences. 108:15602. 10.1073/pnas.1010666108

Durmer JS, Dinges DF. 2005. Neurocognitive consequences of sleep deprivation. Semin Neurol. 25:117–129. doi: 10.1055/s-2005-867080

Edgar DT, Gill ND, Beaven CM, Zaslona JL, Driller MW. 2021. Sleep duration and physical performance during a 6-week military training course. J Sleep Res. 30:e13393. doi: 10.1111/jsr.13393

Edwards BJ, Gallagher C, Pullinger SA, de Mello TM, Walsh NP. 2023. Athletic performance; effects of sleep loss. In: editor, Kushida CA. The encyclopedia of sleep and circadian rhythms. 2nd ed. Elsevier. pp. 434–443. doi:10.1016/B978-0-12-822963-7.00249-8

Edwards BJ, Harris C, Jackman Z, Linares-Alcolea R, Matta R, Pullinger SA, Doran DP. 2024. Is there a diurnal variation in 4-km cycling time trial performance, where a standardised approach has been employed? Biol Rhythm. 55:184–209. doi: 10.1080/09291016.2024.2316401

Edwards BJ, Waterhouse J. 2009. Effects of one night of partial sleep deprivation upon diurnal rhythms of accuracy and consistency in throwing darts. Chronobiol Int. 26:756–768. doi: 10.1080/07420520902929037

Edwards B, Waterhouse J, Reilly T. 2008. Circadian rhythms and their association with body temperature and time-awake when performing a simple task with the dominant and non-dominant hand. Chronobiol Int. 25:115–132. doi: 10.1080/07420520801921614

Elliott-Sale KJ, Minahan CL, De Jonge XAKJ, Ackerman KE, Sipilä S, Constantini NW, Hackney AC, Hackney AC. 2021. Methodological considerations for studies in sport and exercise science with women as participants: a working Guide for standards of practice for research on women. Sports Med. 51:843–861. doi: 10.1007/s40279-021-01435-8

Everson CA, Crowley WR. 2004. Reductions in circulating anabolic hormones induced by sustained sleep deprivation in rats. Am J Physiol Endocrinol And Metab. 286:E1060–E1070. doi: 10.1152/ajpendo.00553.2003

Faul F, Erdfelder E, Lang AG, Buchner A. 2007. G*power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods. 39:175–191. doi: 10.3758/BF03193146

Folkard S, Monk TH, Lobban MC. 1979. Towards a predictive test of adjustment to shift work. Ergonomics. 22:79–91. doi: 10.1080/00140137908924591

Gallagher C, Austin V, Dunlop K, Dally J, Taylor K, Pullinger S, Edwards BJ. 2024. Effects of supplementing zinc magnesium aspartate on sleep quality and submaximal weightlifting performance, following two consecutive nights of partial sleep deprivation. Nutrients. 16:251. doi: 10.3390/nu16020251

Gallagher C, Green CE, Kenny ML, Evans JR, Gdw M, Pullinger SA, Edwards BJ. 2023. Is implementing a post-lunch nap beneficial on evening performance, following two nights partial sleep restriction? Chronobiol Int. 40:1169–1186. doi: 10.1080/07420528.2023.2253908

Keramidas ME, Botonis PG. 2021. Short-term sleep deprivation and human thermoregulatory function during thermal challenges. Exp Physiol. 106:1139–1148. doi: 10.1113/EP089467

Klaus-Karwisch S, Merkle A, Werner S, Ruf L, Woll A, Härtel S, Altmann S. 2023. Sprint and jump performances of female athletes are enhanced in the evening but not associated with individual chronotype. Chronobiol Int. 40:1427–1434. doi: 10.1080/07420528.2023.2267659

Landrum RE. 1992. College students' use of caffeine and its relationship to personality. Coll Stud J. 26:151–155. doi: 10.1089/jcr.2015.0012

McKay AK, Stellingwerff T, Smith ES, Martin DT, Mujika I, Goosey-Tolfrey VL, Sheppard J, Burke LM. 2021. Defining training and performance calibre: a participant classification framework. Int J Sports Physiol And Perform. 17:317–331. doi: 10.1123/ijspp.2021-0451

Melin A, Tornberg AB, Skouby S, Faber J, Ritz C, Sjödin A, Sundgot-Borgen J. 2014. The LEAF questionnaire: a screening tool for the identification of female athletes at risk for the female athlete triad. Br J Sports Med. 48:540–545. doi: 10.1136/bjsports-2013-093240

Meney I, Waterhouse J, Atkinson G, Reilly T, Davenne D. 1998. The effect of one night's sleep deprivation on temperature, mood, and physical performance in subjects with different amounts of habitual physical activity. Chronobiol Int. 15:349–363. doi: 10.3109/07420529808998695

Minors D. 1999. Effects of sleep loss on core temperature when movement is controlled. Ergonomics. 42:647–456. doi: 10.1080/001401399185531

Nelson W, Yong YL, Lee JK, Halberg F. 1979. Methods for cosinor-rhythmometry. Chronobiologia. 6:305–323.

Nevill A, Atkinson G. 1997. Assessing agreement between measurement recorded on a ratio scale in sports medicine and sports science. Br J Sports Med And Sports Sci. 31:314–318. doi: 10.1136/bjsm.31.4.314

Plamberger CP, Van Wijk HE, Kerschbaum H, Pletzer BA, Gruber G, Oberascher K, Dresler M, Hahn MA, Hoedlmoser K. 2021. Impact of menstrual cycle phase and oral contraceptives on sleep and overnight memory consolidation. J Sleep Res. 30:e13239. doi: 10.1111/jsr.13239

Redline S, Kirchner HL, Quan SF, Gottlieb DJ, Kapur V, Newman A. 2004. The effects of age, sex, ethnicity, and sleep-disordered breathing on sleep architecture. Arch Intern Med. 164:406–418. doi: 10.1001/archinte.164.4.406

Reilly T, Atkinson G, Edwards B, Soussi J, Farrelly K, Fairhurst E. 2007. Diurnal variation in temperature, mental and physical performance, and tasks specifically related to football (soccer). Chronobiol Int. 24:507–519. doi: 10.1080/07420520701420709

Reilly T, Down A. 1986. Circadian variation in the standing broad jump. Percept Mot Skills. 62:830. doi: 10.2466/pms.1986.62.3.830

Reilly T, Edwards B. 2007. Altered sleep-wake cycles and physical performance in athletes. Physiol And Behaviour. 90:274–284. doi: 10.1016/j.physbeh.2006.09.017

Roberts SSH, Falkenberg E, Stevens A, Aisbett B, Lastella M, Condo D. 2021. The sleep of elite Australian rules footballers during preseason: a comparison of men and women. Int J Sports Physiol And Perform. 16:641–646. doi: 10.1123/ijspp.2020-0340

Saper BC, Cano G, Scammell E. 2005. Homeostatic, circadian and emotional regulation of sleep. The J Comp Neurol. 493:92–98. doi: 10.1002/cne.20770

Schaal K, Tafflet M, Nassif H, Thibault V, Pichard C, Alcotte M, Toussaint JF, El Helou N, Berthelot G, Simon S, et al. 2011. Psychological balance in high level athletes: gender-based differences and sport-specific patterns. PLOS ONE. 6:e19007. doi: 10.1371/journal.pone.0019007

Sheppard RJ. 1984. Sleep, biorhythms and human performance, sports medicine. Sports Med. 1:11–37. doi: 10.2165/00007256-198401010-00003

Silva A, Narciso FV, Rosa JP, Rodrigues DF, Aâds C, Tufik S, Viana F, Bichara JJ, Pereira SRD, da Silva SC, et al. 2019. Gender differences in sleep patterns and sleep complaints of elite athletes. Sleep Sci. 12:242–248. doi: 10.5935/1984-0063.20190084

Smith C, Reilly C, Midcaff K. 1989. Evaluation of three circadian rhythm questionnaires with suggestions for an improved measure of morningness. J Appl Phychol. 74:728–738. doi: 10.1037/0021-9010.74.5.728

Souissi N, Sesboüé B, Gauthier A, Larue J, Davenne D. 2003. Effects of one night's sleep deprivation on anaerobic performance the following day. Eur J Appl Physiol. 89:359–366. doi: 10.1007/s00421-003-0793-7

Stolarski M, Gorgol J, Matthews G. 2021. The search for causality of personality-chronotype associations: insights from a one-year longitudinal study of adolescents. Chronobiol Int. 38:489–500. doi: 10.1080/07420528.2020.1867157

Teece AR, Argus CK, Gill N, Beaven M, Dunican IC, Driller MW. 2021. Sleep and performance during a preseason in elite rugby union athletes. Int J Environ Res And Public Health. 18:4612. doi: 10.3390/ijerph18094612

Terndrup ET, Allegra RJ, Kealy AJ. 1989. A comparison of oral, rectal and tympanic membrane-derived temperature changes after ingestion of liquids and smoking. The Am J Emerg Med. 7:150–154. doi: 10.1016/0735-6757(89)90127-7

Thompson BM, Sculley Dv HH, Barba-Moreno L, de Jonge Xak J, Janse de Jonge XAK. 2021. The acute effect of the menstrual cycle and oral contraceptive cycle on measures of body composition. Eur J Appl Physiol. 121:3051–3059. doi: 10.1007/s00421-021-04771-9

Thun E, Bjorvatn B, Flo E, Harris A, Pallesen S. 2015. Sleep, circadian rhythms, and athletic performance, sleep medicine reviews. 23:1–9. doi: 10.1016/j.smrv.2014.11.003

Walsh NP. 2019. Nutrition and athlete immune health: new perspectives on an Old paradigm. Sports medicineVol. 49. (Auckland, N.Z.). pp. 153–168. doi:10.1007/s40279-019-01160-3

Walsh NP, Halson SL, Sargent C, Roach GD, Nédélec M, Gupta L, Leeder J, Fullagar HH, Coutts AJ, Edwards BJ, et al. 2020. Sleep and the athlete: narrative review and 2021 expert consensus recommendations. Br J Sports Med. 55:356–368. doi: 10.1136/bjsports-2020-102025

Waterhouse J, Atkinson G, Edwards B, Reilly T. 2007. The role of a short post lunch nap in improving cognitive, motor and sprint performance in participants with partial deprivation. J Sports Sci. 25:1557–1566. doi: 10.1080/02640410701244983

Watson NF, Badr MS, Belenky G, Bliwise DL, Buxton OM, Buysse D, Dinges DF, Gangwisch J, Grandner MA, Kushida C, et al. 2015. Recommended amount of sleep for a healthy adult: a joint consensus statement of the american academy of sleep medicine and sleep research society. Sleep. 38:843–844. doi: 10.5665/sleep.4716

Zhang B, Wing YK. 2006. Sex differences in insomnia: a meta-analysis. Sleep. 29:85–93. doi: 10.1093/sleep/29.1.85. PMID: 16453985.