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Evening electronic device use: The effects on alertness, sleep and next-day physical performance in athletes

Maddison J. Jones [a,b], Peter Peeling[a,b], Brian Dawson[a], Shona Halson[c], Joanna Miller[c], Ian Dunican[a,d], Michael Clarke[e], Carmel Goodman[b] and Peter Eastwood [d]

[a]Department of Sport Science, Exercise and Health, School of Human Sciences, The University of Western Australia, Crawley, WA, Australia; [b]Department of Physiology, Western Australian Institute of Sport, Mt Claremont, WA, Australia; [c]Department of Physiology, Australian Institute of Sport, Bruce, ACT, Australia; [d]Centre for Sleep Science, School of Human Sciences, The University of Western Australia, Crawley, WA, Australia; [e]Centre for Metabolomics, The University of Western Australia, Crawley, WA, Australia

ABSTRACT

The aim of the present study was to investigate the influence of different types of tasks performed with or without an electronic device (tablet) on pre-sleep alertness, subsequent sleep quality and next-day athletic performance. Eight highly trained netball players attended a sleep laboratory for pre-sleep testing, polysomnographic sleep monitoring and next-day physical performance testing on 5 separate occasions (1 familiarisation and 4 experimental sessions). For 2 h prior to bedtime, athletes completed cognitively stimulating tasks (puzzles) or passive tasks (reading) with or without a tablet. Sleepiness tended to be greater after reading compared to completing puzzles without a tablet ($d = 0.80$), but not with a tablet. Melatonin concentration increased more so after reading compared to completing puzzles on a tablet ($P = 0.02$). There were no significant differences in sleep quality or quantity or next-day athletic performance between any of the conditions. These data suggest that using a tablet for 2 h prior to sleep does not negatively affect subsequent sleep or next-day performance in athletes.

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Introduction

Sleep plays a major role in both physiological and psychological repair and recovery. While sleep is necessary to maintain normal day-to-day functioning, it is also important for athletes who have additional training-related stressors from which to recover (Halson, 2014). Indeed, it has previously been demonstrated that sleep quality is superior in athletes compared with non-athletic individuals (Brand, Beck, Gerber, Hatzinger, & Holsboer-Trachsler, 2010; Brand et al., 2010). The rapid increase in the use of electronic devices (i.e., smartphones, tablets and laptops) may present a substantial challenge to sleep, particularly when used in the evening, as such use may interfere with the normal circadian rhythms controlling sleep and subsequently impair sleep quality (Chang, Aeschbach, Duffy, & Czeisler, 2015).

Questionnaires used in previous studies have revealed positive relationships between electronic device use and impaired sleep (Fossum, Nordnes, Storemark, Bjorvatn, & Pallesen, 2014; King, Delfabbro, Zwaans, & Kaptsis, 2014; Suganuma et al., 2007). One mechanism underlying the negative effect of electronic device use on sleep is thought to be due to the effects of emitted light. Numerous studies have reported circadian rhythms to be delayed following evening light exposure (Duffy, Kronauer, & Czeisler, 1996); evidenced through melatonin suppression (Dijk et al., 2012; Lockley, Brainard, & Czeisler, 2003) and increased alertness (Chellappa et al., 2011; Lockley et al., 2006). Several recent studies have shown that the light emitted from computers may have similar effects on sleep (Bues et al., 2012; Cajochen et al., 2011; Figueiro, Wood, Plitnick, & Rea, 2011; Higuchi, Motohashi, Liu, Ahara, & Kaneko, 2003) to that of room and lamp lights. However, other studies using tablets reported no differences in evening sleepiness or subsequent sleep (Heath et al., 2014; Rångtell et al., 2016; Wood, Rea, Plitnick, & Figueiro, 2013), thus warranting further investigation.

In addition to light emissions, it is also possible that the type of task being performed on an electronic device can affect subsequent sleep. Several studies have shown that engaging in alerting or stressful tasks prior to bedtime can impair subsequent sleep by increasing the time it takes to fall asleep (sleep onset latency; SOL), decreasing total sleep time (TST) and impairing sleep efficiency (De Valck, Cluydts, & Pirrera, 2004; Higuchi, Motohashi, Liu, & Maeda, 2005; King et al., 2013; Wuyts et al., 2012). A variety of tasks may be performed on electronic devices (e.g., social media, texting, phone calls, gaming and internet browsing), and therefore it is possible that the task (as opposed to the device itself) may have a negative impact on subsequent sleep.

Previously, studies have shown that changes in sleep quality or quantity can be detrimental to next-day athletic performance. For example, sleep loss may decrease time to exhaustion (Oliver, Costa, Laing, Bilzon, & Walsh, 2009), anaerobic power (Skein, Duffield, Edge, Short, & Mundel, 2011; Souissi, Sesboue, Gauthier, Larue, & Davenne, 2003), submaximal strength (Reilly & Piercy, 1994) and accuracy (Edwards &

CONTACT Maddison J. Jones maddison.jones@research.uwa.edu.au

Waterhouse, 2009; Reyner & Horne, 2013), as well as increase reaction time (Jarraya, Jarraya, Chtourou, & Souissi, 2013) and perceived effort (Engle-Friedman, 2014). In contrast, other studies have shown no differences in athletic performance (Mejri et al., 2013; Sinnerton & Reilly, 1992), therefore the effects of sleep loss on athletic performance requires further investigation.

The aim of this study was to investigate the influence of different tasks performed on electronic devices in the evening on pre-sleep alertness, subsequent sleep quality and next-day athletic performance. The study had 3 main hypotheses: firstly, that cognitively stimulating pre-bedtime tasks would have a greater negative impact on pre-sleep alertness and subsequent sleep (particularly SOL), when compared with less-stimulating tasks; secondly, that performing any task on an electronic device would have a negative impact on alertness and sleep when compared with tasks performed without a device; and thirdly, that any observed sleep impairment would be related to poorer next-day athletic performance.

Methods

Participants

Eight highly trained female netball players were recruited from the Western Australian Institute of Sport (WAIS) to participate in the study. Athletes were excluded from participating if they were smokers, not in good physical health, had sleep disorders or complaints, were taking any medications that may affect sleep (e.g., blood pressure medication, beta blockers, sleeping medications) or were unable to complete all 5 testing sessions. No athletes were excluded or dropped out of the study. Participants were aged 18 ± 1 years with 10 ± 2 years of experience in the sport. All athletes were in the off season of their annual training cycle. This study was approved by the University of Western Australia (UWA) Human Research Ethics Committee (RA/4/1/7330) and all participants provided written informed consent prior to their participation.

Procedures

Participants attended 5 testing sessions at the Centre for Sleep Science at UWA, each on the same day of the week and separated by 1 week. Prior to attending their first session, participants completed a range of (online) baseline questionnaires. These included general health and demographic questions (i.e., age, years of experience in the sport), the Morningness-Eveningness Questionnaire (MEQ) (Zavada, Gordijn, Beersma, Daan, & Roenneberg, 2005), Insomnia Severity Index (ISI) (Bastien, 2001), Pittsburgh Sleep Quality Index (PSQI) (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989), Epworth Sleepiness Scale (ESS) (Johns, 1991) and State Trait Anxiety Inventory (STAI) (Spielberger, Gorsuch, Luschene, Vagg, & Jacobs, 1983). Additionally, participants completed a 7-day sleep diary and a 24-h food diary prior to attending the familiarisation session, to be replicated prior to each subsequent session. Participants abstained from caffeine, alcohol, sports drinks, bananas and chocolate for 24 h prior to all testing sessions.

The first session was considered a familiarisation session, where participants completed an overnight sleep study and a battery of physical performance tests the following morning. Participants arrived at the sleep laboratory at 18:00 h on their allocated night and were provided with a standardised evening meal (417 calories, 35 g carbohydrate, 32 g protein, 5 g fat). They were then set up for full polysomnography (PSG), including electroencephalography (EEG), electrooculography (EOG), submental and leg electromyography (EMG), electrocardiography (ECG), respiratory measures (airflow, thermistor, respiratory effort), pulse oximetry and a body position sensor. All sensors were positioned according to the American Academy of Sleep Medicine (AASM) recommendations (Berry et al., 2012), aside from the ECG placements where the AASM alternative placement was used. Continuous overnight video recordings were obtained via an infrared camera. Approximately 30 min prior to bedtime, personal electronic devices were collected and participants were allowed to relax in bed. Just prior to bedtime, participants completed the Brunel Mood Scale (BRUMS) (Terry, Lane, & Fogarty, 2003), the Stanford Sleepiness Scale (SSS) (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973) and 2 visual analogue scales (VAS) asking how alert they felt and how easily they believed they would be able to fall asleep (predicted ease of sleep onset). Simultaneously, tympanic temperature was recorded with a digital infrared thermometer (LCT-200, E-Care). At 22:00 h, the lights were switched off and participants went to sleep. Throughout the sleep period, data were obtained for total time in bed, TST, SOL, wake time after sleep onset, sleep efficiency (sleep duration as a percentage of time in bed), rapid eye movement sleep (REM) latency (amount of time between bedtime and REM sleep onset), number of arousals and the percentage of time spent in each stage of sleep (stages N1, N2, N3 and REM).

The next morning, participants were woken at 06:00 h. They were asked to provide subjective measures of their sleep quality, SOL and how rested they felt on a Likert scale from 1 to 5. The physical testing battery commenced at 06:30 h with a 10-min standardised warm-up prior to undertaking the Star Excursion Balance Test (SEBT) (Kinzey & Armstrong, 1998). Four trials of the SEBT were completed in each direction (antero-medial, anterolateral, postero-medial and posterolateral) before changing to the other leg. The greatest reaching distance for each direction and leg was recorded, and the distances for each leg were summed. Following this, the reactive agility test (RAT) was performed using the "0–1–3 Traffic Light Start" protocol with light gates (Fusion Sport, Australia). The first light gate was positioned 50 cm past the starting line, and the remaining 3 light gates were positioned 4 m from the first gate, either straight ahead (centre) or 45° to the left or right. The protocol randomly selected the direction (right, left or centre) for each trial. Participants completed the test 6 times, and the average times from the starting line to the first gate (R-1) and from the first gate to the next gate (R-2) were recorded. Finally, participants completed the Yo-Yo Intermittent Recovery Test (Yo-Yo IRT) Level 1 (Krustrup et al., 2003), with the commentary removed so that prior knowledge of performance could not affect the level obtained. At the conclusion of the Yo-Yo

IRT, heart rate (Garmin Forerunner 210) and a rating of perceived exertion (Borg, 1982) were recorded.

For the 4 experimental sessions, participants were set up for EEG, EOG, submental EMG and pulse oximetry (respiratory measurements, ECG and leg EMG were not collected as familiarisation studies showed that no participants had a respiratory sleep disorder, cardiac issues or unusual leg movements). Furthermore, they completed a 2-h task immediately prior to the overnight sleep study, which comprised either performing puzzles or reading magazines on a tablet or on paper. The order of implementation of these pre-sleep tasks was counterbalanced and then randomly assigned. Approximately 2 h prior to bedtime, participants completed the pre-sleep questionnaires while tympanic temperature was recorded and a saliva sample was collected in a Sarstedt Salivette® Cortisol tube as per the manufacturer's instructions. Personal electronic devices were collected and participants completed the task that was assigned to them for the next 2 h in bed with the room lights on and the door shut. Recording of PSG activity began just prior to the 2-h task, and continued throughout the night until waking the next morning. Those who were completing the stimulating tasks were provided with a different puzzle (Sudoku, word searches or logic puzzles) every 20 min in an attempt to maintain novelty and interest. Those in the less-stimulating conditions were provided with a selection of magazines that were deemed to be uninteresting to them (i.e., subject matter of cars, boats, finance and medical practices) and were told that if they did not wish to read the material, they could relax but were not to fall asleep during the 2-h period. If participants did fall asleep (assessed via EEG monitoring and video recording), they were immediately woken and advised to sit up in bed. The tablets (Apple iPad mini) had restrictions imposed on them so that other websites and applications were disabled, and the brightness was set to the highest level. A light meter (Gossen Profi-System) was used to measure the lux at the eye level of the tablet (~200 lx) and the magazines (~100 lx). Following the 2-h period, the same pre-task measures were recollected (i.e., SSS, VAS, temperature, saliva and BRUMS), devices were collected and participants were able to do any last-minute activities (e.g., use the bathroom) before the lights were switched off at 22:00 h, indicating the start of the sleep period. The next morning, participants were woken at 06:00 h and completed the subjective sleep measures and physical testing battery in the same manner as for the familiarisation session.

Salivary analysis

Salivary melatonin and cortisol were analysed using liquid chromatography tandem mass spectrometry. Exactly 50 uL of IS (50 ng/mL) was added to 250 µl of saliva or standard and subsequently vortexed in a glass tube. Steroids were extracted into ethyl acetate (1 ml) by vigorous vortexing. The supernatant was transferred into an ultra-high performance liquid chromatography injector vial, and then dried in a centrifugal vacuum evaporator. The analytes were resuspended in 70 µl of mobile phase (70% methanol, 0.1% formic acid, 29.9% water), then 20 µl of sample was injected onto an Agilent 6460 Triple Quadrupole mass spectrometer system coupled to 2 × 1290 UPLC series LC pumps. The LC system was run in 2D mode, consisting of 2 columns; the first was an Agilent Poroshell 120 EC-C18, 2.7um, 2.1 × 50 mm column (Agilent Technologies, Santa Clara, CA, USA), and the second was a Phenomenex Kinetex C18, 2.6 um, 3.0 × 150 mm column (Torrance, CA, USA). The mobile phase flow rate was 0.2 mL/min through both columns and molecules were "heart cut" from column 1 to column 2 between a 1–2-min time window. The instrument was operated in positive ionisation mode. Solvent A was LC-MS grade water (Thermo Optima) + 0.1% Formic acid. Solvent B was LC-MS grade methanol (Burdock and Jackson) + 0.1% formic acid. The transitions monitored for each metabolite were melatonin 233.2 > 174.1, melatonin d-4 237.2 > 178.1, cortisol 363.2 > 121.0 and cortisol d-4 367.2 > 121.0.

Data analysis

A sample size of 8 participants was determined via a power analysis using customised computer software (GPOWER Version 3.1.9.2, Bon, Germany) and effect sizes from related studies (Duvnjak-Zaknich, Dawson, Wallman, & Henry, 2011; Wood et al., 2013) with an expected power of 0.8. All data are expressed as mean and standard deviations of the mean (±SD). Two-way repeated measures ANOVA were used to calculate differences in pre-sleep measurements over time (pre- and post-2-h task) and between conditions. Two-way repeated measures ANOVA were also used to calculate differences between conditions for objective sleep variables, self-reported sleep and physical performance measures. Where a significant main effect was observed, differences were examined using paired-samples *t*-tests. Statistical significance was accepted at an alpha level of $P \leq 0.05$. All analyses were calculated using the software package IBM SPSS Statistics, Version 20.0 (Armonk, NY, USA) for Windows. Cohen's *d* effect sizes were also calculated to locate meaningful trends in the data (Cohen, 1988).

Results

Baseline administration of the MEQ revealed that participants were either moderately morning types ($n = 5$) or neither morning nor evening types ($n = 3$). The ISI showed insomnia traits to be absent ($n = 5$) or subthreshold ($n = 3$). The PSQI indicated that, on average, participants reported going to bed at 21:50 h (±30 min), taking 19 (±8) min to fall asleep and waking at 06:30 h (±45 min). Global scores attained in the PSQI were 4 ± 2, indicating that, on average, sleep quality in the cohort was "good" (Buysse et al., 1989). Participants scored 8 ± 2 out of 24 in the ESS, indicating "normal" sleepiness (Johns, 1991), and 38 ± 9 out of 80 on the trait anxiety component of the STAI, which fell into the "normal" range for their age and gender (Knight, Waal-Manning, & Spears, 1983). Four participants briefly fell asleep during the pre-sleep activities (2 during paper-based reading, 1 during paper-based puzzles and 1 during tablet-based puzzles), but were woken up as soon as it was detected by the researcher.

Melatonin concentrations were significantly lower after tablet-based puzzles than tablet-based reading (Table 1). There were no differences in post-task cortisol concentration

Table 1. Salivary melatonin and cortisol concentrations, sleepiness, alertness and tympanic temperature before and after 2-h tablet-based or paper-based tasks performed immediately before bed.

		Tablet-based		Paper-based	
		Puzzles	Reading	Puzzles	Reading
Melatonin (pM)	Pre	0.4 ± 0.6	0.4 ± 0.5	0.5 ± 1.0	0.3 ± 0.5
	Post	4.1 ± 8.6	6.0 ± 8.2[ab]	5.5 ± 11.6	6.8 ± 12.8
Cortisol (pM)	Pre	1.4 ± 0.8	1.1 ± 0.3	1.2 ± 0.7	1.2 ± 0.7
	Post	0.7 ± 0.4[a]	0.6 ± 0.2[a]	0.7 ± 0.4[a]	0.8 ± 0.4
Sleepiness (SSS)	Pre	3 ± 1	3 ± 1	3 ± 1	3 ± 1
	Post	5 ± 2[a]	5 ± 1[a]	5 ± 2	6 ± 1[a]
VAS predicted ease of sleep onset (cm)	Pre	3.9 ± 2.8	5.1 ± 2.8	3.2 ± 2.0	5.1 ± 2.4
	Post	2.6 ± 2.3	2.6 ± 2.2	3.1 ± 1.8	3.5 ± 3.0
VAS alertness (cm)	Pre	5.7 ± 2.3	5.0 ± 2.2	4.9 ± 2.5	6.2 ± 2.9
	Post	3.6 ± 2.6	2.1 ± 1.6[a]	3.8 ± 1.8	2.8 ± 1.7[a]
Tympanic temperature (°C)	Pre	35.05 ± 1.05	35.00 ± 0.79	35.06 ± 0.77	34.95 ± 0.74
	Post	34.56 ± 1.18	35.09 ± 0.45	35.18 ± 0.38	34.58 ± 0.91

All values are mean ± SD. Pre: pre-task; Post: post-task; SSS: Stanford Sleepiness Scale; VAS: visual analogue scale.
[a]Significant effect for time; $P < 0.05$.
[b]Significant effect for task; $P = 0.02$.

between conditions, but there were differences over time for cortisol in both tablet-based conditions and the paper-based reading condition (Table 1). Large effect sizes for the magnitude of change over time in melatonin and cortisol were observed for all tasks (Table 2).

Scores in the SSS increased following tablet-based puzzles, tablet-based reading and paper-based reading, but not paper-based puzzles (Table 1). Large effect sizes for the magnitude of change over time in the SSS were observed for all tasks (Table 2). There was also a tendency for a larger increase in sleepiness after reading than after completing puzzles in the paper-based conditions ($d = 0.80$).

Measures of VAS alertness decreased following both tablet- and paper-based reading, but not after puzzles (Table 1). Moderate and large effect sizes for the magnitude of change in alertness over time were observed for all tasks (Table 2). Additionally, a large effect size between the paper-based reading and puzzle conditions ($d = 0.88$) suggested a trend towards a larger decrease in alertness after reading magazines than after completing puzzles in the paper-based conditions.

Measures from the BRUMS were not significantly different between conditions but there were differences over time for vigour and fatigue, such that vigour decreased after tablet- and paper-based reading and paper-based puzzles, and fatigue increased after tablet- and paper-based reading (Table 3). Moderate and large effect sizes for the magnitude of change over time were observed for vigour and fatigue, while moderate effect sizes were found for depression and annoyance for tablet-based reading (Table 3).

Table 2. Cohen's *d* effect sizes for magnitude of change in salivary melatonin and cortisol, sleepiness and alertness measured before and after 2-h tablet-based or paper-based tasks performed immediately before bed.

	Tablet-based		Paper-based	
	Puzzles	Reading	Puzzles	Reading
Melatonin (pM)	1.74	2.72	1.72	2.04
Cortisol (pM)	3.13	5.00	3.16	2.53
Sleepiness (SSS)	1.00	1.63	0.83	2.04
VAS predicted ease of sleep onset (cm)	0.50	0.98	–	0.57
VAS alertness (cm)	0.85	1.52	0.53	1.59

Only Cohen's *d* effect sizes ≥0.50 are included. SSS: Stanford Sleepiness Scale; VAS: visual analogue scale.

Table 3. Brunel Mood Scale (BRUMS) measures before and after 2-h tablet-based or paper-based tasks performed immediately before bed.

		Tablet-based		Paper-based	
		Puzzles	Reading	Puzzles	Reading
Tension	Pre-task	1 ± 2	1 ± 2	1 ± 2	1 ± 3
	Post-task	1 ± 2	1 ± 1	1 ± 1	1 ± 2
	Cohen's *d*	–	–	–	–
Vigour	Pre-task	4 ± 4	4 ± 3	3 ± 2	5 ± 3
	Post-task	2 ± 2	1 ± 1[a]	2 ± 2[a]	1 ± 1[a]
	Cohen's *d*	*0.67*	*1.36*	*0.62*	*1.29*
Confusion	Pre-task	1 ± 2	1 ± 1	1 ± 1	1 ± 1
	Post-task	1 ± 2	1 ± 1	2 ± 2	1 ± 1
	Cohen's *d*	–	–	–	–
Fatigue	Pre-task	6 ± 2	5 ± 3	6 ± 3	4 ± 4
	Post-task	8 ± 4	8 ± 4[a]	8 ± 4	8 ± 3[a]
	Cohen's *d*	*0.50*	*0.72*	–	*2.72*
Depression	Pre-task	1 ± 3	0 ± 1	1 ± 1	2 ± 3
	Post-task	1 ± 3	1 ± 1	1 ± 2	1 ± 1
	Cohen's *d*	–	*0.56*	–	–
Annoyance	Pre-task	1 ± 2	1 ± 1	2 ± 2	2 ± 3
	Post-task	1 ± 2	2 ± 3	2 ± 2	1 ± 2
	Cohen's *d*	–	*0.59*	–	–

All values are mean ± SD. Only Cohen's *d* effect sizes ≥ 0.50 are included.
[a]Significant effect for time; $P < 0.05$.

Tympanic temperature and predicted ease of sleep onset did not differ between conditions or over time (Table 1). Moderate and large effect sizes for the magnitude of change in predicted ease of sleep onset over time were observed for all but the paper-based puzzle condition (Table 2). Only small effect sizes for the magnitude of change in tympanic temperature over time were recorded (Table 2).

Participants had more arousals following paper-based reading than tablet-based reading ($P = 0.05$; Figure 1), but there were no significant differences between conditions for any other sleep variables (Table 4). Moderate effect sizes suggested a tendency for REM latency to be shorter ($d = 0.67$) after paper-based reading than paper-based puzzles, and for REM latency ($d = 0.52$) and percentage of time in REM ($d = 0.72$) to be longer after paper-based puzzles than tablet-based puzzles. A moderate effect size also suggested a tendency for participants to have more arousals following paper-based reading compared with tablet-based reading ($d = 0.73$) Finally, a large effect size was found for percentage of time spent in REM sleep between tablet-based puzzles and

Table 4. Sleep-related measures after 2-h tablet-based or paper-based tasks were performed immediately prior to bed.

	Tablet-based		Paper-based	
	Puzzles	Reading	Puzzles	Reading
Polysomnography Measures				
Time in bed (min)	479 ± 3	478 ± 4	477 ± 4	480 ± 4
TST (min)	433 ± 20	429 ± 39	435 ± 24	443 ± 22
Sleep efficiency (%)	91 ± 5	90 ± 8	91 ± 5	92 ± 5
SOL (min)	31 ± 21	36 ± 42	25 ± 20	25 ± 16
WASO (min)	14 ± 8	12 ± 10	18 ± 16	11 ± 11
Time in N1 (%)	6 ± 2	6 ± 4	7 ± 6	7 ± 3
Time in N2 (%)	38 ± 9	36 ± 7	34 ± 7	34 ± 9
Time in N3 (%)	35 ± 10	35 ± 10	34 ± 7	34 ± 9
Subjective Measures				
SOL (1–5)	4 ± 1	3 ± 1	3 ± 1	3 ± 1
Sleep quality (1–5)	3 ± 1	3 ± 1	3 ± 1	3 ± 1
Restfulness (1–5)	4 ± 1	3 ± 1	3 ± 0	4 ± 0

All values are mean ± SD. TST: total sleep time; SOL: sleep onset latency; WASO: wake after sleep onset; N1: stage 1 sleep; N2: stage 2 sleep; N3: stage 3 sleep; REM: rapid eye movement sleep.

reading (d = 1.04), suggesting a tendency for participants in the tablet-based reading condition to spend a greater percentage of the sleep period in REM sleep. However, the difference in number of arousals and tendencies towards differences in REM latency and time in REM sleep may explained by individual outliers within the data set, as shown in Figures 1, 2 and 3.

There were no significant differences between conditions for subjective SOL, restfulness or sleep quality measures completed upon waking. Moderate effect sizes suggested a tendency for participants to feel less rested after tablet-based puzzles than both tablet-based reading (d = 0.61) and paper-based puzzles (d = 0.52). Additionally, moderate and large effect sizes suggested a tendency for participants to rate sleep quality higher in paper-based conditions compared with tablet-based conditions for puzzles (d = 0.76) and reading (d = 0.90).

There were no significant differences in any next-day performance measure between the 4 conditions (Table 5). A moderate effect size for SEBT on the right leg (d = 0.50) suggested that reach distance was shorter after tablet-based puzzles than tablet-based reading. There was also a tendency for participants to be faster in R-1 of the RAT in paper-based conditions than tablet-based conditions for puzzles (d = 0.58) and magazines (d = 0.72), but not in R-2. Finally, there was a tendency for participants to attain a lower score in the Yo-Yo IRT in the tablet-based puzzle condition than the tablet-based reading (d = 0.64) and paper-based puzzle conditions (d = 0.58).

Discussion

This study sought to determine the influence of performing different tasks (i.e., puzzles vs. reading) on a tablet on alertness, sleep and next-day performance in athletes. While salivary melatonin concentration was lower after tablet-based puzzles than tablet-based reading, this did not result in significant differences in any objective or subjective measures of sleep, or next-day athletic performance.

We hypothesised that a more stimulating task (puzzles) would increase physiological and/or behavioural arousal levels prior to sleep more so than a less-stimulating task (reading magazines), and result in an increased SOL. Although no

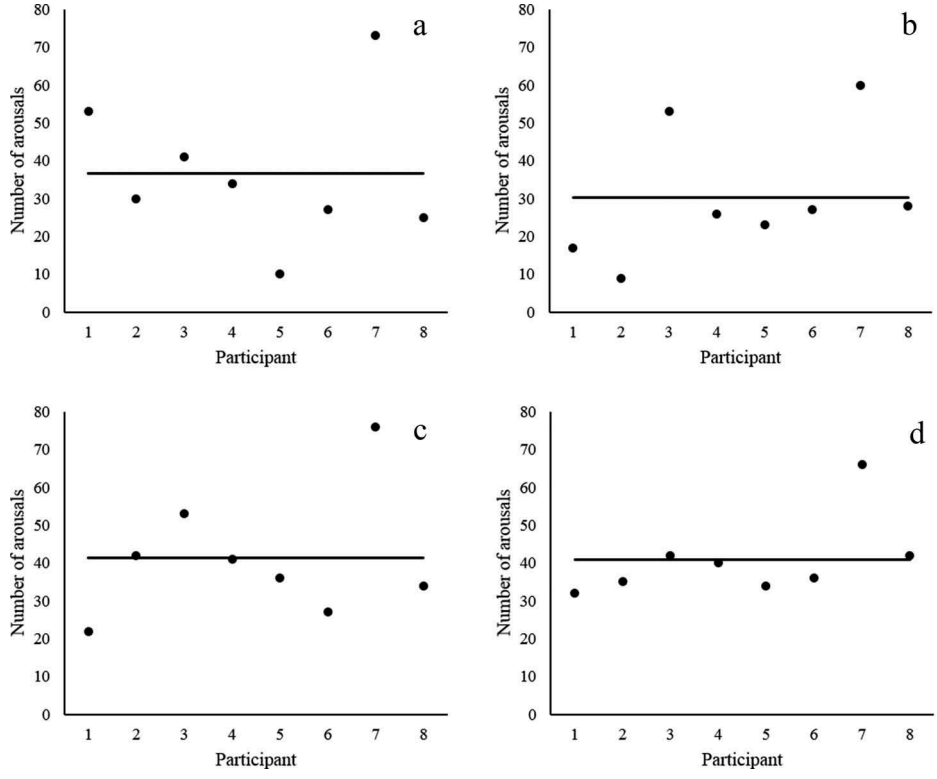

Figure 1. Mean and individual number of arousals in the 4 experimental conditions; (a) tablet-based puzzles, (b) tablet-based reading, (c) paper-based puzzles, (d) paper-based reading. Dots represent individual number of arousals for each condition, and the line represents the mean number of arousals for each condition.

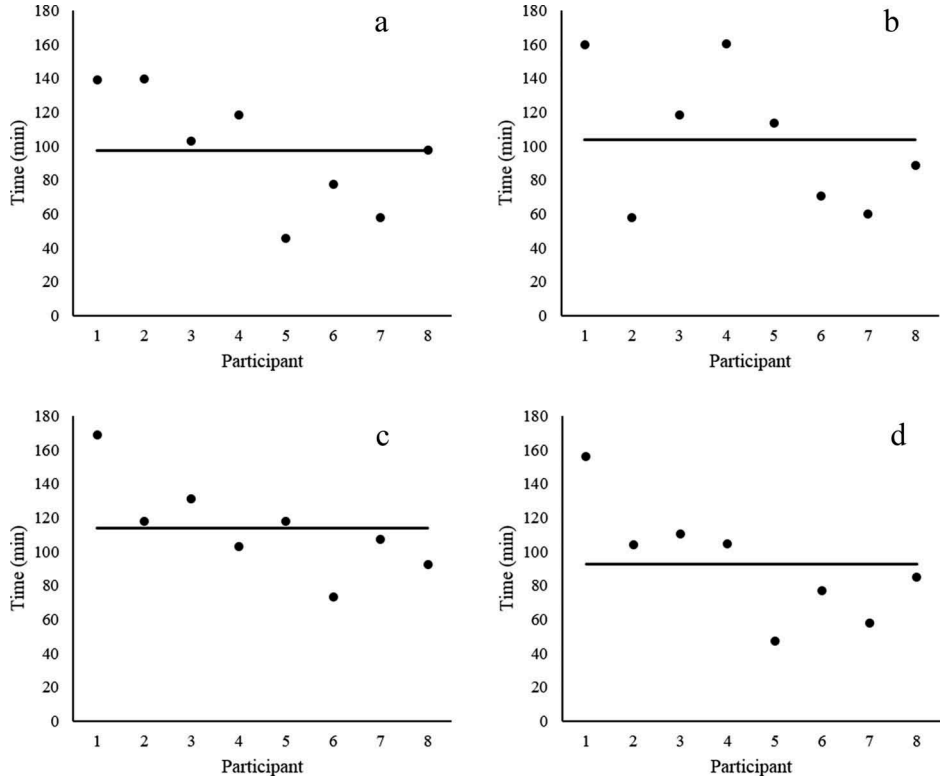

Figure 2. Mean and individual rapid eye movement (REM) sleep latency in the 4 experimental conditions; (a) tablet-based puzzles, (b) tablet-based reading, (c) paper-based puzzles, (d) paper-based reading. Dots represent individual REM latency for each condition, and the line represents the mean REM latency for each condition.

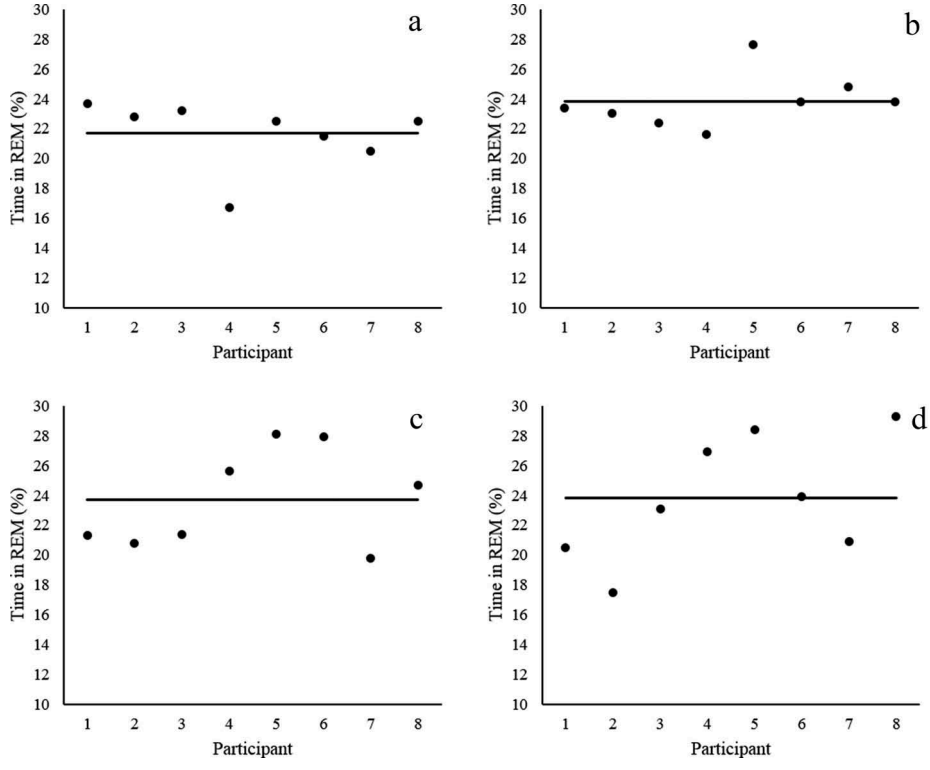

Figure 3. Mean and individual percentage of time spent in REM in the 4 experimental conditions; (a) tablet-based puzzles, (b) tablet-based reading, (c) paper-based puzzles, (d) paper-based reading. Dots represent individual number of arousals for each condition, and the line represents the mean number of arousals for each condition.

Table 5. Next-day performance measures after 2-h tablet-based or paper-based tasks were performed immediately prior to bed.

	Tablet-based		Paper-based	
	Puzzles	Reading	Puzzles	Reading
ΣBalance-R (m)	3.69 ± 0.18	3.78 ± 0.18	3.76 ± 0.17	3.77 ± 0.27
ΣBalance-L (m)	3.83 ± 0.30	3.84 ± 0.18	3.84 ± 0.29	3.83 ± 0.26
R-1 (s)	0.76 ± 0.07	0.74 ± 0.06	0.84 ± 0.18	0.78 ± 0.05
R-2 (s)	1.44 ± 0.08	1.44 ± 0.10	1.47 ± 0.13	1.47 ± 0.10
Yo-Yo Level	14.3 ± 0.7	14.7 ± 0.4	14.8 ± 0.9	14.8 ± 0.8
Yo-Yo HR (bpm)	182 ± 14	180 ± 8	181 ± 15	181 ± 11
Yo-Yo RPE	17 ± 2	17 ± 1	17 ± 1	16 ± 1

All values are mean ± SD. Balance scores are from the Star Excursion Balance Test: R, right; L, left; R-1, first stage of the reactive agility test; R-2, second stage of the reactive agility test; Yo-Yo, Yo-Yo Intermittent Recovery Test; HR, heart rate; RPE, rating of perceived exertion.

significant differences were observed, participants who read magazines tended to feel less alert and sleepier than those who completed puzzles on paper, which was also reflected in differences for vigour and fatigue in the BRUMS. These between-task differences were not observed when using the tablet. Regardless, sleepiness increased in the tablet-based conditions from pre- to post-task, therefore tablet use did not prevent changes in sleepiness or alertness over time. These findings are consistent with Wuyts et al. (2012) and Higuchi et al. (2003) who found that sleepiness increased over time, regardless of whether or not a cognitively stimulating pre-sleep task was performed. Further research is required to determine why there were no differences in perceived sleepiness between puzzle and reading conditions on a tablet.

It is often recommended that individuals avoid using electronic devices prior to sleep, as the screenlight may suppress melatonin secretion, delay the onset of sleep, shorten TST and reduce sleep efficiency (Chang et al., 2015; Fossum et al., 2014; King et al., 2014; Suganuma et al., 2007). In contrast, in the current study there was a tendency for salivary melatonin concentration to increase post-task for all 4 conditions, suggesting that using a tablet prior to sleep did not significantly inhibit melatonin release. While these findings are consistent with Rångtell et al. (2016) and Figueiro et al. (2011), other studies have shown reductions in melatonin concentration following the use of an electronic device in the evening (Bues et al., 2012; Cajochen et al., 2011; Chang et al., 2015). The discrepancy in results may be due to the duration of exposure to the electronic device, as melatonin has been significantly inhibited when electronic devices were used for 4–5 h (Bues et al., 2012; Cajochen et al., 2011; Chang et al., 2015), but not for 2 h (Figueiro et al., 2011; Rångtell et al., 2016), the latter being the case in the present study. As such, it is possible that the use of electronic devices for less than 2 h prior to bedtime may not have a negative impact on subsequent sleep.

The only sleep variable that differed between conditions in the present investigation was the number of arousals. Several previous studies have found that SOL is prolonged when video games (Higuchi et al., 2005; King et al., 2013), stressful situations (Bakotic & Radosevic-Vidacek, 2013) or other cognitively stimulating tasks (Wuyts et al., 2012) are engaged in prior to sleep; this is attributed to the heightened arousal levels experienced by participants following the activity. While the puzzles used in the current study were deemed to be cognitively demanding, it is possible that they were not sufficiently stimulating for the participants to cause any change in SOL. Previous studies by Takahashi and Arito (1994) and De Bruin, Beersma and Daan (2002) also found no significant differences in SOL following language transcription tasks and computer-based cognitive performance tasks, respectively; however, the extended duration of the tasks (7.5–8 h) may have reduced their stimulating effects. Additionally, Grønli et al. (2016) and Rångtell et al. (2016) found no significant differences in objective sleep measures after reading a book on a tablet or paper for 30 min or 2 h (respectively) prior to sleep. As such, future studies could investigate the influence of other activities on pre-sleep arousal and sleep variables, particularly those applicable to electronic device use (e.g., messaging and social media).

Given that there were no differences found in most of the sleep variables measured here, it is not surprising that next-day athletic performance was similar for all conditions. While some studies have shown that athletic performance is affected by sleep loss (Edwards & Waterhouse, 2009; Oliver et al., 2009; Reilly & Piercy, 1994; Reyner & Horne, 2013; Skein et al., 2011); others have reported no such changes (Mejri et al., 2013; Sinnerton & Reilly, 1992). Importantly, most previous studies that have reported sleep-related negative effects on performance have employed sleep deprivation protocols (i.e., no sleep for ~24–72 h) (Skein et al., 2011; Souissi et al., 2003) as opposed to sleep restriction protocols (i.e., sleep is fragmented or shortened for 1 or more days) that tend to not show impaired performance (Abedelmalek et al., 2013; Souissi et al., 2008). Such findings support the notion that any (small) effects of evening electronic devices on sleep will have negligible effects on next-day performance.

The present study has several limitations. Firstly, sleep following each condition was only monitored for 1 evening; it is possible that multiple nights of altered melatonin levels and feelings of sleepiness at bedtime are required before any negative effects on sleep patterns are observed. Secondly, it is possible that individuals may respond differently to the same tasks; thus future research could investigate the effects of self-selected stimulating and unstimulating tasks on pre-sleep and sleep variables. Furthermore, future studies should investigate whether these effects are similar when other types of electronic devices are used (e.g., smartphones, laptops) and in different populations (e.g., non-athletes, adults, males).

Conclusion

In conclusion, the results of the present study suggest that tablet use for 2 h prior to sleep does not result in increased sleepiness, or negatively affect subsequent sleep or next-day performance in athletes.

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ORCID

Maddison J. Jones http://orcid.org/0000-0002-4235-6190
Peter Eastwood http://orcid.org/0000-0002-4490-4138

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