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Sink or Swim? Sleep Patterns in Highly Trained Adolescent Swimmers during the In-Season Phase of Training

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Abstract

Objectives The aim of this study was to investigate the sleeping patterns of highly-trained adolescent swimmers. Further objectives were to compare subjective and objective measures of sleep and to evaluate the relationship between electronic device use and sleep in this cohort.

Methods Fifteen national-level swimmers (age: 16.4 ± 1.0 years) wore wrist actigraphs while completing sleep diaries over a two-week training period. Types of nights were classified as early morning training (≤7am - EARLY), day training (>7am - DAY), and no training (REST). Information on electronic device use before bed and other sleep behaviors was collected via questionnaires.

Results Total sleep time (TST) was significantly ($p < 0.05$) shorter on nights preceding EARLY (5:53 ± 1:06 hour:min) compared with nights preceding DAY (7:40 ± 1:12 hour:min) and REST (7:59 ± 1:19 hour:min). Participants overestimated subjective TST by ~54 minutes when compared with objectively measured TST ($p < 0.05$).

Discussion Adolescent athletes obtained a greater amount of sleep prior to later training the next day or before rest days, when compared with early morning swim training the next day. Adolescents also overestimated their sleep duration by ~1 hour per night. There were no significant relationships between electronic device use at night and measured sleep indices.

Keywords
- actigraphy
- sports
- athletes
- sleep

Introduction

In addition to the increasing reports on the prevalence of poor sleep in the general adult population,[1] recent research has also revealed that short sleep duration is prevalent in elite athletes.[2–4] Current research in elite athletes has shown that sleep disruption has been found to have a negative effect on athletic performance, including speed,[5] endurance,[6] attention,[7] and aerobic capacity.[8] Sleep is vital to elite athletes' physical and cognitive recovery, including their daily physiological growth and repair, conservation of energy, and reaction time.[9,10]

Adolescent athletes experience high levels of sleep disturbance due to increased academic and training demands, often requiring early wake-up times and late-night training

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sessions to fit in with school schedules.[11–13] Further exacerbating this issue, adolescents experience a delayed circadian rhythm due to many varying factors including biological, psychological, and sociocultural influences.[14] Sleep onset and offset is usually much later in adolescents, primarily due to a change in the biological timing mechanism that causes a delay in sleep onset.[15] The reduced sleep duration and the later onset time (due to phase delay) in adolescents has been referred to as the "Perfect Storm" model that impacts on sleep behavior.[14] Despite this, very little is known about the sleeping patterns of highly trained adolescent athletes in sports where training schedules may limit the sleep opportunity (e.g., swimming).

Increased electronic device usage before bedtime may impact the delayed sleep onset adolescents experience.[16–18] A recent study by Galland et al.[19] showed that more than 84% of this group used at least one electronic media device on 3 or more nights per week. Previous research has also shown that exposure to device usage before bed suppresses melatonin in adolescents.[20] However, while it is known that shortened sleep duration can be associated with increased electronic device usage, it is still unclear what effects device usage has on adolescents' sleep indices.[21] Furthermore, to our knowledge, night time device use in adolescent athlete populations has not been explored yet. It could be postulated that this group has lower levels of device use in an attempt to manage their challenging training schedules.

With the delayed sleep onset experienced by adolescents, the offset must also be later to cater for the delayed sleep/wake cycle, allowing adequate sleep quantity. However, due to growing demands, such as earlier school starts, extracurricular activities, and part-time work, the later offset that adolescents require is not possible.[22,23] Previous research has also shown that sleep deprivation has been related to injury occurrence in adolescent athletes.[22,24,25] A study by Milewski et al.[24] in 112 adolescent athletes found that those who slept less than 8 hours per night were 1.7 times more likely to have had an injury on average, when compared with those who slept more than 8 hours per night, which highlights the need for this group to obtain the recommended 8 to 10 hours.[24–26]

Adolescent athletes that participate in certain sports may be further implicated in the challenges involved in obtaining adequate sleep, such as those where athletes are often required to train both before and after school. These sports typically involve large training volumes, such as swimming. Two previous studies by Steenekamp et al.,[13] and Gudmundsdottir[12] measured the sleep duration of adolescent swimmers using actigraphy, and found that total sleep duration prior to early morning training (6:44 and 5:21 hour:min, respectively) was well below the recommended 8 to 10 hours of sleep for adolescents.[12,13] Furthermore, Steenekamp et al.,[13] suggested that athletes did not compensate for early morning training sessions by going to bed earlier the night before, and rather, their bedtime remained constant regardless of training times the following day. Both Steenekamp et al.[13] and Gudmundsdottir[12] studied well-trained adolescent swimmers, but little is known about the performance level above these cohorts – those that represent their country or are amongst top placings in their age-group. Indeed, the increased training demands of the next tier of competition may further exacerbate any sleep issues.

Another area that has not previously been researched in adolescent athletes is their ability to self-predict sleep duration. Previous research has shown that elite adult athletes overestimate their total sleep time by 19.8 minutes compared with actigraphy monitor results.[27] Furthermore, Short et al.[28] reported that adolescent high school students significantly overestimate their perceived sleep duration (8:17 hour:min) compared with their actigraphy-scored sleep (6:52 hour:min). However, to the authors' knowledge, predicted versus measured sleep has not been investigated in youth athletes as of yet.

While there has been an increase in sleep research occurring in the elite adult athlete population over the past decade,[29] there is a paucity of research on high-performance adolescent athletes (15–18-years-old). Given the phase delay compared with that of adults, combined with training loads and extracurricular activities that adolescent athletes can experience, it is vital that we understand their sleeping patterns to allow for adequate recovery for health and performance. Therefore, the present study aims to assess the sleeping patterns in highly trained adolescent aged swimmers across a 2-week training phase, specifically comparing sleep on nights preceding an early morning training, daytime training, and rest days. Our secondary aim was to compare the adolescent athletes' perceived and measured sleep duration. Furthermore, the study's final aim was to determine if there is a correlation between device usage prior to sleep onset and the effect on different sleep measures. In accordance with previous literature, we hypothesize that this study group's sleep will be impaired on the nights preceding early morning training when compared with day training or rest days. Furthermore, they will overestimate their perceived total sleep time compared with their measured results. Finally, we hypothesize that adolescents' electronic device usage will have a negative relationship with their sleep indices.

Materials and Methods

Participants

A total of 15 adolescent swimmers (15–18-years-old) volunteered to participate in the current study (mean ± standard deviation [SD]; age 16.4 ± 1.0 years, 12 females/3 males). Participants were recruited through the local and national swimming organizations in New Zealand. To be included in the current study, all participants had to attend high school and either have represented their country or placed top three at a national event in the year prior to recruitment. Based on the recommendations by Lakens,[30] after most of or the entire target population is measured, there is no need to perform a sample size calculation. Therefore, due to sampling almost the entire population available (∼30 national level adolescent swimmers representing their country), the calculation was deemed unnecessary in this instance. Study approval was obtained through the University of Waikato's Human Research Ethics Committee. All participants provided informed written consent before taking part in this study and, for participants under 16 years, consent was also provided by a parent/caregiver.

Design

In this crossectional study, participants completed four validated sleep questionnaires via an electronic survey link (Survey Monkey, CA, USA). Upon completion of the questionnaires, participants wore a wrist-actigraphy device for a 2-week (14-day) period to monitor sleep. This period was completed during a normal, in-season training phase, where participants had approximately 11 training sessions per week on average, of which 7 were pool sessions and around 4 were gym sessions. All participants took part in the study sometime in the up to 10 weeks leading up to their next major competition, but not in the final 2 weeks prior to competition, when they were tapering. Therefore, no participant competed during the monitoring period. The research was also completed during a regular school term, in the participants' own home environment. Each morning throughout the 2-weeks, participants were asked to fill out a subjective sleep diary, and at the conclusion of each day they were asked to fill out a training diary.

Classifications of Nights

Each night was coded based on the training schedule of the following day. Therefore, nights of sleep were placed into three categories dependent on the schedule for the preceding day; early morning training (EARLY) which consisted of any training commencing prior to 7am, daytime training (DAY) which consisted of training commencing any time after 7am, and no training (REST) which consisted of a full day rest with no training sessions. These classifications have been reported previously.[12,13]

Measures

Sleep Questionnaires

The sleep questionnaire contained personal characteristic questions, as well as four validated and common sleep questionnaires; the Pittsburgh sleep quality index (PSQI), the sleep hygiene index (SHI), the Epworth sleepiness scale (ESS), and the athlete sleep behavior questionnaire (ASBQ).

The PSQI assesses sleep quality and disturbances over a 1-month period to give a global score relating to overall sleep quality.[31] Global scores range from 0 to 21, with higher scores indicating worse sleep quality. It is suggested that a global score of > 5 equates to severe sleep difficulties in at least two areas or moderate sleep difficulties in more than three areas (out of seven component areas) of the questionnaire.

The SHI is a 13-questions-long, self-administered questionnaire that assesses sleep behavior and habits thought to compromise sleep hygiene.[32] Participants are asked to indicate how frequently they engage in specific behaviors on a five-point rating scale ranging from 0 (never) to 4 (always). Item scores are then summed providing a global score (0 to 52) for sleep hygiene, with a higher score representing poorer sleep hygiene status. The SHI has been shown to be both valid and reliable in a healthy population.[32]

The ESS provides a measurement for general daytime sleepiness rated on a scale of 0 to 3 for eight everyday activities.[33] Scoring ranges between 0 and 24, with numbers greater than 16 indicating high levels of daytime sleepiness, those between 10 and 15 indicating abnormal daytime sleepiness, and those from 0 to 10 indicating normal daytime sleepiness. This test is commonly used to differentiate between individuals with and without sleep disorders and has also been shown to correlate with objective measures of sleepiness.[34]

The ASBQ is an 18-item questionnaire about sleep habits and behaviors thought to be of common concern for elite athletes.[35] It asks participants how frequently specific behaviors occur; never, rarely, sometimes, frequently, or always (e.g., *I go to bed with sore muscles; I use stimulants when I train/compete; I think, plan, and worry about my sporting performance when I am in bed*). Each response is weighted from $1 = \text{never}$ to $5 = \text{always}$. A global score is produced at the end of the questionnaire by summing the answers from each of the 18 items. Global scores can range from 18 to 90, and it is suggested that a global score of ≤ 36 would equate to good sleep behaviors, with a score of ≥ 42 equating to poor sleep behaviors.[35] The ASBQ has been reported to have acceptable reliability (intraclass correlation $= 0.87$) when retested and has moderate to large correlations with validated questionnaires such as the sleep hygiene index (SHI), the Epworth sleepiness scale (ESS) and the PSQI. Furthermore, the ASBQ had acceptable levels of internal consistency in the sampled population (Cronbach $\alpha = 0.73$).

Sleep Monitoring

Participants were required to wear a wrist-actigraphy device (Fatigue Science, Readiband, Vancouver, Canada) over a 2-week period to monitor and objectively quantify sleep patterns. The sleep indices obtained from the actigraph were: total sleep time (TST, h:min), total time in bed (TTB, h:min), sleep latency (SL, min), wake episodes per night (WE, number), wake after sleep onset (WASO, min), sleep efficiency (SE, %), sleep onset time (SOT, time of day), and wake time (WT, time of day). The raw activity scores were translated to sleep-wake scores based on computerized scoring algorithms.[36] Participants were instructed to wear the actigraph device on the wrist they felt most comfortable with,[37] continuously for the 2-week monitoring period, with the exception of time spent in pool training sessions and showering. Sleep indices were quantified via the Fatigue Science (Readiband, Vancouver, Canada) software at a sampling rate of 16 Hz. The Readiband devices used in the current study have shown high levels on intra-device reliability,[38] and have been validated against the gold standard PSG with accuracies of approximately 90% for TST.[39]

Sleep and Training Diaries

For the duration of the sleep monitoring period, participants were also required to fill out a daily sleep and training diary. The sleep diary consisted of five subjective questions to estimate how long participants used an electronic light-emitting device in the 2 hours prior to bedtime, how long it took them to fall asleep, how many times they woke during the night, how long they slept for, and to rate their quality of sleep on a scale of 1 to 5 (1 = very poor, 5 = very good). Similarly, the daily training diary asked participants to outline how many training sessions they had per day, as well as the time, type, and duration of each session.

Statistical Analysis

Simple group and descriptive statistics are reported as means ± SDs unless stated otherwise. A linear mixed model (LMM) was conducted to compare types of night (EARLY, DAY, and REST) for changes in all objective sleep measures. EARLY was used as the reference level. The LMM included a fixed effect of night and random intercept for participant.

A repeated measures standardised mean difference (SMD) was calculated by dividing the mean difference (in raw units) of interest by the average within-subject SD (i.e., random effects residual error term). Statistical significance for fixed effects was determined using F tests with the degrees of freedom for F statistics computed using the Satterthwaite approximation method. Bonferroni corrections were made for post-hoc analysis between nights to reduce the likelihood of type-1 error. Magnitudes of the standardized effects between EARLY, DAY, and REST for all sleep measures were also analyzed using Cohen's *d* and interpreted using thresholds of 0.2, 0.5, and 0.8 (*small*, *moderate,* and *large*, respectively).[40] An effect size of < 0.2 was considered to be *trivial*, and the effect was deemed *unclear* if its 95% confidence interval overlapped the thresholds for *small* positive and negative effects. Intraclass correlation coefficients (ICC's) were also used to compare conditions for sleep metrics and the Pearson product-moment correlation was run to assess the relationship between device usage and all sleep indices. The magnitude of correlation between device usage and the sleep indices was assessed using the following thresholds: 0.00–.19, *very weak*; 0.20–.39, *weak*; 0.40–.59, *moderate*; 0.60–.79, *strong*; and 0.80–1.0, *very strong*.[41] Analyses were performed using Statistical Package for Social Science (IBM Corp. Armonk, NY, USA) version 22.0, and Jamovi, version 2.3.18.0, with statistical significance set at $p \leq 0.05$.

Results

The characteristics and measurements of the 2-week monitoring period are presented in ►**Table 1**. Participants averaged 7.1 pool training sessions and 3.5 gym sessions per week.

Table 1 Mean ± standard deviation values for the measured sleep questionnaires and training load of the two-week monitoring period.

	Mean ± SD
Sleep questionnaires	
Pittsburgh sleep quality index *(range 0–21)* *> 5 poor (n = 6)* *≤ 5 adequate (n = 9)*	5.2 ± 1.4 (poor)
Epworth sleepiness scale *(range 0–24)* *>16 high (n = 1)* *10–16 abnormal (n = 7)* *0–10 normal (n = 7)*	8.5 ± 4.0 (normal)
Sleep hygiene index *(range 0–52, with higher score indicating poorer sleep hygiene status)*	18.1 ± 6.1
Athlete sleep behavior questionnaire *(range 18–90)* *≤36 good (n = 5)* *≥42 poor (n = 3)*	36.1 ± 5.3
Training load, per week	
Total training time (h:min)	16:35 ± 3:30
Pool training sessions (No.)	7.1 ± 1.5
Gym training sessions (No.)	3.5 ± 1.5

Abbreviations: SD, standard deviation.

Type of Day

The dataset was distributed across the three types of nights as EARLY (*n* = 102 observations), DAY (*n* = 49 observations), and REST (*n* = 26 observations). The values for the comparison of variables between EARLY, DAY, and REST can be observed in ►**Tables 2** and **3**.

The LMM identified a main effect of day (F[2,28] = 22.2, $p < 0.001$), for TST, with substantial reductions observed between EARLY and DAY (-1:47 ± 0:06 hour:min, d = -1.68 ± 0.54, $p < 0.01$) and between EARLY and REST (-2:06 ± 0:13 hour:min, d = -2.02 ± 0.68, $p < 0.01$).

The LMM identified a main effect of day (F(2,28) = 26.8, $p < 0.001$), for TTB, indicating that it was different from baseline values, with post hoc analysis revealing reductions between EARLY and DAY (-2:11 ± 0:11 hour:min, d = -2.61 ± 0.80, $p < 0.01$) and between EARLY and REST (-2:48 ± 0:51 hour:min, d = -2.73 ± 1.17, $p < 0.01$).

The LMM identified a main effect of day (F(2,28) = 7.42, $p = 0.003$) with a significant difference for SOT between EARLY and REST (0:58 ± 0:12 hour:min, d = 1.15 ± 0.73, $p < 0.05$) and DAY and REST (0:47 ± 0:12 hour:min, d = 1.02 ± 0.83, $p < 0.05$).

The LMM also identified a main effect of day (F (2,28) = 11.7, $p < 0.001$) for WE, between EARLY and REST (-2.8 ± 0.2, d = 1.37 ± 0.59, $p < 0.05$) and DAY and REST (1.5 ± 0.5, d = 0.20 ± 0.55).

The LMM also identified a main effect of day (F (2,28) = 5.99, $p = 0.007$) for WASO between EARLY and REST (-36.6 ± 20.6, d = 1.22 ± 0.56, ►**Table 3 & 4**). There were no significant differences observed in SE, SL, or subjective sleep quality for comparison between nights (►**Table 2**).

Table 2 Mean ± standard deviation values for the measured objective sleep variables and device usage on all days, the night preceding an early morning training session, a day training session, and a rest day.

	ALL	EARLY	DAY	REST	Correlation (*r*)
Sleep index					
Total time in bed (h:min)	8:00 ± 0:30	6:55 ± 0:50#,^	9:06 ± 1:01	9:43 ± 1:41	0.14
Total sleep time (h:min)	6:40 ± 0:46	5:53 ± 1:06#,^	7:40 ± 1:12	7:59 ± 1:19	0.17
Sleep efficiency (%)	84.3 ± 7.1	85.2 ± 7.0	84.2 ± 9.8	82.9 ± 6.9	0.23
Sleep latency (min)	27.3 ± 13.2	26.5 ± 13.4	28.5 ± 18.4	24.5 ± 12.9	-0.12
Wake episodes per night (No.)	3.8 ± 1.7	3.0 ± 1.8^	4.3 ± 2.5^	5.8 ± 2.0#	-0.32
Wake after sleep onset (min)	36.7 ± 30.5	25.3 ± 22.6^	43.7 ± 42.3	61.9 ± 43.2#	-0.18
Sleep onset time (time of day)	21:54 ± 0:34	21:38 ± 0:49^	21:49 ± 0:49^	22:36 ± 1:01	0.06
Wake time (time of day)	5:40 ± 0:30	4:20 ± 0:27#,^	6:40 ± 0:41^	8:01 ± 1:16#	0.33
Subjective sleep quality (1–5 scale)	3.63 ± 0.28	3.65 ± 0.28	3.70 ± 0.46	3.68 ± 0.66	0.19
Device usage (min)	63.7 ± 27.9	59.7 ± 27.7	65.1 ± 30.1	62.8 ± 40.4	n/a
Training times (time of day)	n/a	5:23 ± 0:46	13:27 ± 3:25	n/a	n/a

Notes: Comparison of electronic device usage to sleep indices on ALL nights using the Pearson moment correlation (r). #Significantly different to DAY ($p < 0.05$). ^Significantly different to REST ($p < 0.05$).

Table 3 Mean ± standard deviation data for differences between nights for objective sleep indices, including raw differences between conditions and effect sizes (*d*) with 95% confidence limits (± 95% CL).

Sleep index	EARLY – DAY (effect size)	EARLY – REST (effect size)	DAY – REST (effect size)
Total time in bed (h:min)	-2:11 ± 0:11# *d* = -2.61 ± 0.80 *Large*	-2:48 ± 0:51# *d* = -2.73 ± 1.17 *Large*	-0:37 ± 0:40 *d* = 0.09 ± 0.73 *Unclear*
Total sleep time (h:min)	-1:47 ± 0:06# *d* = -1.68 ± 0.54 *Large*	-2:06 ± 0:13# *d* = -2.02 ± 0.68 *Large*	-0:19 ± 0:07 *d* = 0.29 ± 0.41 *Unclear*
Sleep efficiency (%)	1.0 ± 2.8 *d* = -0.09 ± 0.46 *Unclear*	2.3 ± 0.1 *d* = -0.16 ± 0.53 *Unclear*	1.3 ± 2.9 *d* = -0.05 ± 0.56 *Unclear*
Sleep latency (min)	-2.0 ± 5.0 *d* = 0.12 ± 0.69 *Unclear*	2.0 ± 0.5 *d* = -0.22 ± 0.44 *Unclear*	4.0 ± 5.5 *d* = -0.25 ± 0.60 *Unclear*
Wake episodes per night (No.)	-1.3 ± 0.7 *d* = 1.06 ± 0.61 *Large*	-2.8 ± 0.2# *d* = 1.37 ± 0.59 *Large*	1.5 ± 0.5# *d* = 0.20 ± 0.55 *Unclear*
Wake after sleep onset (min)	-18.4 ± 19.7 *d* = 1.11 ± 0.74 *Large*	-36.6 ± 20.6# *d* = 1.22 ± 0.56 *Large*	18.2 ± 0.9 *d* = 0.06 ± 0.56 *Unclear*
Sleep onset time (h:min)	0:11 ± 0:00 *d* = 0.13 ± 0.58 *Unclear*	0:58 ± 0:12# *d* = 1.15 ± 0.73 *Large*	0:47 ± 0:12# *d* = 1.02 ± 0.83 *Large*
Wake time (h:min)	2:20 ± 0:14# *d* = 4.43 ± 0.63 *Large*	3:41 ± 0:49# *d* = 7.78 ± 1.57 *Large*	1:21 ± 0:35# *d* = 2.21 ± 1.02 *Large*

Notes: #Significant difference between nights ($p < 0.05$).

Subjective versus Objective Measures

There were significant differences observed for all three sleep indices (SL, WE, and TST) when comparing participants' objective and subjective sleep diary data from the 2-week monitoring period (►**Table 4**). Participants significantly underestimated their subjective SL compared with actigraphic SL (17.5 ± 5.6 minutes and 27.3 ± 13.2 minutes, respectively, $d = 0.97 \pm 0.55$, $p < 0.05$) and WE (0.8 ± 0.6 and 3.7 ± 1.8, respectively, $d = 1.75 \pm 0.63$, $p < 0.05$). As hypothesized, participants significantly overestimated their subjective TST compared with objective results ($7{:}42 \pm 0{:}42$ hour:min and $6{:}40 \pm 0{:}42$ hour:min, respectively, $d = -1.00 \pm 0.68$, $p < 0.05$, ►**Table 5**).

Device Usage

Electronic light-emitting devices were used on average for 63.7 ± 27.9 minutes in the 2 hours prior to bedtime (►**Tables 1** and **2**). There was no significant difference between EARLY, DAY, and REST conditions for device use, with average use being 59.7, 65.1, and 62.8 minutes in the 2 hours preceding bedtime, respectively. The Pearson product-moment correlation was run to assess the relationship between device usage and sleep indices (TTB, TST, SE, SL, WE, WASO, SOT, and WT). There were no statistically significant correlations observed between device usage and sleep indices ($p > 0.05$), and all relationships were considered *weak – very weak*.

Discussion

The primary aim of this study was to investigate the sleeping patterns of highly trained adolescent swimmers over a 2-week period. In this study, participants averaged 6:40 hour:min of total sleep duration over the monitoring period, which falls below the recommended sleep duration of 8 to 10 hours sleep for adolescents.[26] Furthermore, differences in sleep indices were observed between the three types of nights (EARLY, DAY, and REST), with TST significantly reduced on nights preceding EARLY training compared with both DAY training and REST by 1:47 and 2:06 hour:min, respectively.

When comparing to objective measures, adolescent swimmers in this study objectively overestimated their TST by approximately 1-hour per night, while also substantially underestimating SL and WE when compared with their objective sleep measures determined by actigraphy. The final aim of this study was to determine if there was a correlation between device usage prior to sleep onset and the effect on different sleep measures. No correlation was observed for any of the sleep indices in adolescent swimmers.

As reported by Steenekamp et al.,[13] sleep duration was significantly reduced on nights preceding early morning training (6:44 hour:min) compared with nights with no early morning training session (8:45 hour:min) in 32 adolescent swimming and rowing athletes.[13] A further study by Gudmundsdottir[12] reported sleep duration was significantly shorter on nights preceding early morning training (5:21 hour:min) compared with later morning training (6:37 hour:min) and no morning training (6:53 hour:min) in 108 Icelandic adolescent swimmers.[12] The results of the current study are consistent with previous findings,[12,13]

Table 4 Linear mixed model (LMM) fixed and random effect parameters for the model examining the mean difference in objective sleep indices between nights, with *p*-values, standardized mean differences (SMD), and intraclass correlation coefficients (ICC).

	TTB (h:min)			TST (h:min)			SE (%)			SL (mins)			WE (No.)			WASO (mins)		
Fixed effects	Estimates	*p* value	SMD	Estimates	*p* value	SMD	Estimates	*p* value	SMD	Estimates	*p* value	SMD	Estimates	*p* value	SMD	Estimates	*p* value	SMD
Intercept (EARLY)	6:55	< 0.001		5:53	< 0.001		85.2	< 0.001		26.5	< 0.001		3.0	< 0.001		25.3	< 0.001	
DAY [a]	2:11	< 0.001	1.98	1:47	< 0.001	1.92	-1.0	0.60	-0.19	2.0	0.65	0.17	1.3	0.04	0.80	18.4	0.09	0.63
REST [a]	2:48	< 0.001	2.54	2:06	< 0.001	2.25	-2.3	0.24	-0.44	-2.0	0.66	-0.16	2.3	< 0.001	1.77	36.6	0.00	1.26
Random effects																		
Between subjects SD	0:35			0:44			6.1			9.2			1.4			23.4		
Within subjects SD	1.06			0:56			5.3			12.0			1.6			29.0		
ICC	0.21			0.38			0.57			0.37			0.44			0.40		

Abbreviations: TTB, total time in bed; TST, total sleep time; SE, sleep efficiency; SL, sleep latency; WE, wake episodes; WASO, wake after sleep onset. **Notes:** [a] reference – EARLY (pre 7am).

Table 5 Mean ± SD data for differences between subjective and objective sleep for objective sleep indices, including effect sizes (*d*) for comparison between conditions.

Sleep index	Subjective sleep	Objective sleep	Objective / subjective sleep difference (raw)	Objective sleep - subjective sleep (effect size ± 90% CL)
Sleep latency (min)	17.5 ± 5.6	27.3 ± 13.2	9.8 ± 7.6#	0.97 ± 0.55 *Moderate*
Wake episodes per night (No.)	0.8 ± 0.6	3.8 ± 1.7	3.0 ± 1.1#	1.75 ± 0.63 *Large*
Total sleep time (h:min)	7:42 ± 0:54	6:40 ± 0:46	-0:58 ± -0:08#	-1.00 ± 0.68 *Moderate*

Abbreviations: SD, standard deviation. **Notes:** #Significant difference between subjective and objective measures of sleep ($p < 0.05$).

with TST significantly reduced on the night prior to EARLY training sessions (5:53 hour:min) compared with DAY training sessions (7:40 hour:min) and REST (7:59 hour:min). However, unlike in previous studies, it appears that the participating athletes adjusted their bedtimes to offset the earlier wake times due to the early morning training, as SOT was significantly earlier on nights preceding early morning and day training compared with rest days.

Adolescent athletes in the current study had significantly less WASO on EARLY training days (25.3 minute) compared with REST (61.9 minute), which is a similar finding to the Gudmundsdottir[12] study, where WASO was higher when there was no morning training on the next day. Given TTB and TST are significantly lower on nights preceding EARLY training days, it is not surprising that WASO and WE would also be significantly reduced. Given the importance of sleep on athletes' physical and cognitive recovery,[8] there is clearly a need for further research in this area. Furthermore, the increased risk of injury in this population when less than 8 hours of sleep per night is attained[24] emphasizes the importance of adolescent athletes regularly obtaining the recommended hours of sleep. Therefore, practitioners and coaches working with this population should ensure that scheduling of training sessions allows for adequate sleep, or that athletes compensate for early training times by going to bed earlier.

Mean scores from the PSQI placed adolescent swimmers in the "poor" sleep category. However, with an average score of 5.2 and only 6 athletes scoring >5, classifying this population group as poor sleepers may be somewhat harsh, as it has been suggested that appropriate cut-off scores for poor sleep in adolescents may be >8.[42]

Additionally, results from the ESS suggest that adolescent athletes have normal amounts of daytime sleepiness (mean global score of 8.5). The SHI results suggest that adolescent athletes in the current study displayed better sleep behaviors than a similar aged cohort,[43] with a mean global score of 18.1. These results contrast what Setyowati et al.,[43] found in 101 Indonesian adolescent school students, who scored 32 for the SHI on average. A potential reason for the difference in results observed between the two studies could be the differing school times, with a 7am start and 1pm finish in Indonesia, compared with approximately 8:40am and 3:20pm in New Zealand. Furthermore, as participants in the current study were athletes, it is possible that they had some basic understanding of the importance of sleep (e.g., from athlete education sessions) in comparison to the participants of Setyowati et al.,[43] which had a nonathlete cohort.

Results from the ASBQ also showed that adolescent athletes in the current study may have better sleep behaviors (mean global score = 36.1) than adult individual and team sport elite athletes, as reported previously (44.3 and 42.6, respectively).[27] Adolescent athletes may report having better sleep behaviors than elite ones on the ASBQ due to the relevance of certain questions. For example, questions relating to alcohol, travel, foreign sleeping environments, sleeping pills, and use of stimulants scored extremely low in adolescent athletes, which may offer a reason why this group scored lower than elite athletes on the questionnaire. We suggest that a modified version of the ASBQ, specifically for adolescent athletes might be required.

To our knowledge, the current study is the first to examine the difference between subjective and objective sleep measures in adolescent athletes. In elite adult athletes, the use of subjective self-perceived sleep measures has been shown to be in better agreement with objective actigraphy-derived results, with differences in TST being of approximately 20 minutes.[28] The current study indicates that adolescent swimmers significantly overestimate TST (by ~54 minutes) and underestimate SL and WE, suggesting that there may be a greater deficit between subjective and objective sleep measures in this group.

There is a possibility that the adolescent athlete population in the current study could have inflated their sleep measures in their sleep diaries, for fear of parent/caregivers reviewing their sleep metrics, which should be considered in future research. However, these findings are similar to previous research in adolescents in the general population who also significantly overestimate their perceived TST when compared with objective sleep measures.[44,45] The current study's results suggest that objective sleep measures should be used whenever possible in this cohort of athletes. However, it is important to note that in most adolescent athlete settings, objective sleep measures will not be readily available and could be cost prohibitive.

Research from the current study suggests that adolescent athletes' sleep is disrupted by early morning training, leading to the accumulation of sleep debt throughout the week, and resulting in them trying to 'catch up' on rest days. Although not all rest days occurred during weekends, a majority of them did, which aligns with previous research that highlights the significant change in adolescent's sleeping patterns between weekdays and weekends.[46,47] These patterns lead to disruption in the circadian timekeeping system.[48] Similarly, Steenekamp et al.[13] found that adolescent athletes extended their sleep on weekends without training when compared with weekdays with early morning training.

While it is evident that changes in scheduling of training for adolescent athletes could result in improved sleeping patterns, it is not always practical, and coaches are often unwilling to accommodate. Therefore, the implementation of sleep hygiene education and strategies[49,50] is often the best option for adolescent athletes to understand the importance of sleep, as well as to learn tools to improve it. Furthermore, educating coaches on sleep hygiene may also be beneficial so they have the understanding on why training schedules need to change for adolescent athletes. Based on the results from the current study, a target for sleep education may be electronic device usage at night.

Electronic light-emitting devices were used by adolescent athletes in this study on average for 1h per night in the 2-hours prior to bedtime. It is known that increased device usage can be associated with shortened sleep duration (11–24 minutes).[21,51] Interestingly, no correlations were found for device usage and sleep indices (TTB, TST, SE, SL, WE, WASO, SOT, and WT) in the current study. Perhaps differences would have been found if some of the participants abstained from any device usage in the lead-up to bedtime. However, this was not the case, as all athletes used their devices for at least 30 minutes in the 2-hours prior to bed. Despite the results in the current study, research that has focused specifically on adolescents has found that a 1 and 2-hour exposure to light from self-luminous devices (computers, tablets, and cell phones) suppresses melatonin in adolescents by 23 and 28%, respectively.[20] Much like adolescents, adults who use electronic light-emitting devices before bed had their evening levels of melatonin suppressed by 20%.[52]

As this was a field-based study, there were multiple variables (diet, caffeine intake, environment, and school scheduling) that we were unable to control for, which could have had an impact on the overall results of the study. A further limitation was that female menstruation cycles were not controlled for in this study, nor was any data collected on this variable. We would suggest that this be considered in future research in female adolescent athletes.

Furthermore, we did not collect data on napping habits despite the actigraph used in the current study being able to detect them. Therefore, we cannot rule out the potential that short naps may have taken place (e.g., on the weekend) without being detected. Future studies should address napping habits, as they may be used to supplement night time sleep.

Lastly, although the current study had a relatively small sample size ($n = 15$), the ability to recruit highly trained adolescent swimmers in New Zealand is somewhat limited. Indeed, the overall population to draw from that fits the inclusion criteria is small ($n = \sim 30$). Therefore, we believe that our sample is representative of this cohort. However, given this study took place in only one country (New Zealand), the results may not be representative of elite adolescent swimmers in different countries due to various contextual, cultural, and environmental factors.

Conclusion

In summary, the results of the current study showed that, across a 2-week monitoring period, early morning training resulted in a reduced sleep duration (~5h 53mins) and time in bed in adolescent swimmers. Additionally, adolescent athletes significantly overestimate their sleep duration by 1 hour and underestimate their time to fall asleep by 10 minutes, approximately. Interestingly, there were no links found between electronic device use at night and any of the sleep measures.

The findings of the current study show the importance of coaches, parents, and school administrators being aware of the sleeping habits of adolescent athletes and the subsequent impact that early morning training sessions have on their sleep. Whenever possible, adjusting schedules so they can better balance their schedules around training and school requirements has the potential to benefit their sleep, reduce injury risk, and improve academic performance. Further research is required to investigate interventions that may enhance the sleep/wake behavior of adolescent athletes to better support them.

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Conflict of Interests
The authors have no conflict of interests to declare.

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