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Effects of sports training on sleep characteristics of Asian adolescent athletes

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Abstract

Adolescents are predisposed to poorer quality of sleep and experience shortened sleep durations, with these trends being more pronounced amongst Asians. Even though sleep is crucial for athletic recovery, there is a dearth of literature on the sleep patterns of Asian adolescent athletes. The purpose of this study was to examine the effects of different intensities of sports training on sleep patterns in adolescent athletes, and to describe novel sleep data and daytime sleepiness amongst Asian adolescents who were high-level athletes. Those athletes (age 14.8 ± 0.9 years) in higher-intensity sports showed significantly more deep sleep, less light sleep and wake time after sleep onset. Actigraphically determined bedtimes and waketimes were significantly delayed on weekends, when mean total sleep time was also significantly longer. There was a large effect for an increased daytime sleepiness in high-intensity sport athletes. These findings highlight the phenomenon of social jet lag in Asian adolescent student-athletes.

Keywords: Adolescent, athlete, sleep, daytime sleepiness, exercise intensity

Introduction

Contemporary sleep guidelines dictate that the average adolescent requires between 8.5-9.25 hours of nocturnal sleep (Carskadon et al., 1980; Matricciani et al., 2013) for optimal health, cognitive, physical, psychological and behavioural outcomes (Auvinen et al., 2010; Matthews et al., 2012; Vriend et al., 2013; Wong et al., 2013). However, factors such as a reduced parental influence on bedtime, early wake-times due to schooling commitments, and the use of stimulating technological devices prior to bedtime, are all known to lead to the loss of sleep in adolescents (Crowley et al., 2007; Wood et al., 2013). In addition, research on brain maturation indicates a natural increase in daytime sleepiness during adolescence, due to reductions in slow wave sleep and waking brain activity, that is independent of the amount of sleep obtained (Campbell et al., 2007). These influences cumulatively cause a chronic state of inadequate sleep for adolescents at a global level, but the problem is most pronounced in Asia (Gradisar et al., 2011; Olds et al., 2010).

The sleep behaviour of high-level adult athletes has also recently come under investigation. Evidence from English and Australian athletes has highlighted sleep reduction due to competition (Juliff et al., 2015; Lastella et al., 2015) and training (Lastella et al., 2014; Leeder et al., 2012), including training-/competition-induced stress. Early school hours are known to conflict with the circadian phase delay found in adolescents attending school (Brandalize et al., 2011), increasing the likelihood of daytime sleepiness (Carskadon et al., 1998). There are also sleep-disrupting effects of fixed training schedules. Some of these problems are likely to be more pronounced

amongst Asian student athletes since they face also pressure to perform successfully in the academic field (Jiang et al., 2015; Sum and Ma, 2014). Indeed, a recent analysis reported that sleep quality and duration were inversely associated with the amount of homework performed by urban Chinese adolescents (Jiang et al., 2015).

That is, for Asian adolescents who are athletes, the effects of training stress, fixed school and training schedules, and academic workloads are likely to combine to produce less-than-ideal sleep habits. In non-athletic adolescents, any accumulated sleep debt results in significant differences between weekday and weekend sleep durations, as individuals attempt to recover from this debt (Carskadon et al., 2001; Gradisar et al., 2011). While considerable data are available on the sleep requirements of adolescents, and there exists growing evidence on high-level adult athletes, there is no research on the sleep behaviour of high-level Asian adolescents who are athletes. This lack of information exists despite recovery during sleep being recognised as an integral component of training (Venter, 2012), due to its ability to improve sports performance physiologically and psychologically (Bird, 2013) and its associations with decreasing injury risk amongst adolescent athletes (Milewski et al., 2014).

There is evidence suggesting that participation in vigorous exercise and sports training can elicit favourable alterations in adolescent sleep patterns. Studies comparing athletic and sedentary adolescents (Brand et al., 2009, 2010a, 2010b, 2010c) reported that adolescents who participated in more vigorous exercise per week (due to the nature of the sport they undertook) had better sleep profiles than did participants whose sport involved less vigorous exercise. Also, it has been demonstrated that 30 minutes of self-paced morning running over 3 consecutive weeks improved subjective and objective measures

of sleep quality in healthy adolescents (Kalak et al., 2012). In contrast, Youngstedt et al. (2003) reported no association between sleep patterns and daily physical activity levels in young and older adults, a difference that was attributed to a “ceiling effect” for sleep improvement amongst adults. As adolescence is associated with several biological alterations that lead to poor sleep quality, the presence of such a ceiling effect may be less likely with adolescents (Dewald et al., 2010), and this could account for the differences in sleep following exercise that have been observed in studies on adolescents.

However, in spite of this evidence regarding the importance of sleep on sports performance - evidence associating sleepiness with poorer academic performance and health (Fallone et al., 2005; Orzech et al., 2014), as well as athletic career longevity (Potenziano et al., 2013) - there are currently no data on the habitual sleep patterns of Asian adolescent athletes and the effects of these patterns on daytime sleepiness. Additionally, a comparison of sleep quality between adolescent athletes who are exposed to sports of varying intensities has not been conducted, despite the potential differences in sleep architecture that differences in exercise intensity might produce. Identifying such differences could ascertain if particular groups of athletes, such as those with lower oxygen uptake and greater static loading, are more predisposed to poorer sleep patterns, for example. Such information would act as an impetus for coaches to administer appropriate interventions for adolescents, in the form of exercise, in sports that do not traditionally include high-intensity training (Ericsson et al., 1993; Hayman et al., 2011, 2014).

Accordingly, the first aim of the present study was to examine the effects of different intensities of daytime sports training on sleep patterns in adolescent athletes. A

secondary aim was to report new sleep data on high-level Asian adolescent athletes and effects of sleep on daytime sleepiness during a week of training. We hypothesize that Asian adolescent athletes participating in high-intensity sports would have significantly more deep sleep than athletes undertaking lower-intensity sports. We further hypothesize that sleep durations during weekdays and the weekend would be significantly different.

Methods

Participants

11 Singaporean male adolescent athletes (students aged 14.8 ± 0.9 years; body mass, 52 ± 9.3 kg; height, 163.5 ± 9.3 cm) were recruited from a school for this study. All the athletes trained in high-performance sports academies. In more detail, the subjects comprised 6 bowlers and 5 badminton players. The bowlers had average bowling scores of 174.1 (±13.9) at the commencement of the study, while the badminton players were national semi-finalists in 2013 for their age-groups. Based upon the classification of sports by Mitchell and colleagues (Mitchell et al., 2005), bowling was classified as a low-intensity sport (LI) while badminton was categorised as a high-intensity sport (HI). Both groups of participants typically underwent one to two training sessions per day on weekdays, with approximately 16 hours of supervised training per week in their respective sports, under the guidance of an experienced coach. Apart from sport-specific training, the athletes also participated in strength and conditioning sessions once a week as part of general athletic development for sports fitness.

The athletes resided in a boarding school on weekday nights (Sunday-Thursday) and returned home on weekend nights (Friday-Sunday), the weekends being days of rest from training. As sleep patterns are known to be influenced by variables such as wake-

length prior to sleep, light-exposure, time and type of food ingestion, sleep environment, regularity of sleep-wake schedules and exercise (Atkinson et al., 2007; Uchida et al., 2012), the boarding school was selected because these variables could be standardised. This allowed the study to be conducted in an ecologically valid, yet controlled, field setting.

The participants and their parents/guardians were duly informed, both verbally and in information sheets, about the nature of the study and the associated risks. Informed consent was obtained from all participants' parents or guardians while informed assent was obtained from the participants. Exclusion criteria were if an individual had injuries, illness or was on medication during the period of the research. Participants were asked to refrain from caffeine during the period of data collection. Ethical approval for the study was obtained from the Nanyang Technological University Institutional Review Board (IRB-2013-02-030).

Procedures

This study comprised of two main parts, data collection occurring outside the competitive season and periods of academic testing. The first part of the study involved the examination of weekday and weekend sleep patterns based on wrist actigraphy. The second part of the study involved a sub-sample of the participants (4 badminton players and 4 bowlers), where differences in sleep stage characteristics using a wireless, dry electroencephalographic (EEG) sensor were examined. Data collection for both parts of the study were conducted within the same week, with EEG data collected only on nights following sport-specific training in the afternoon (1500-1830 hrs).

Sleep EEG analysis and training sessions

EEG sleep data were collected on two weekday nights following sport-specific training, which consisted of similar activities, intensities and durations for both bowlers and badminton players; the data from both recording nights were averaged, to avoid bias from a single measurement (Liu and Wu, 2005), and EEG sleep variables were compared between the two groups of athletes. The temperature (27.2 ± 0.8ºC) and humidity (83.5 ± 3.4%) on EEG recording nights were measured using a Kestrel 4000 Weather Tracker (Lymington, UK).

Training Session Intensity and Duration

To obtain an objective measure of training intensity, participants were required to wear heart rate (HR) monitors during each sport-specific training session or any activities that lasted more than 10 minutes. Polar Team 2 system (Polar Electro Oy, Kempele, Finland) monitors were used. The monitors recorded HR at 1-s intervals during each session. Maximal heart rate (HR_{max}) was determined using the age-predicted maximal heart rate formula (220-age) (American College of Sports Medicine, 2006). The time-course of HR was recorded throughout each training session. A training diary was used to validate the duration of a training session against data obtained from the HR monitor.

Heart rate data from the two training sessions that occurred prior to sleep EEG analysis were compared and, if similar, were averaged.

The LI training sessions on the days prior to EEG recording involved a warm-up (~10 min) consisting of jumping jacks, and upper and lower body dynamic stretches. This was immediately followed by training specific to ten-pin bowling for the remainder of the session (~90 min), supervised by assistant coaches. This specific training included skills such as bowling off the foul line, bowling from a foot behind the foul line, etc. The

session concluded with standard game of bowling (~20 min). The HI training session on the days prior to EEG recording involved a warm-up (~15 min) consisting of skipping, shuttle runs, quick stepping drills, arm swings, as well as upper and lower body dynamic stretches. This was followed by warm-up stroking techniques (~15 min). The remainder of the session focused on the development of skills and techniques specific to badminton, such as smashing, drop shoots, drive plays and net play (~90min). This last portion of the training session was supervised by assistant coaches.

It is stressed that sport-specific training was conducted entirely under the supervision of the respective coaches without interference by the researchers.

Sleep measures

Wrist actigraphs

Actiwatches (Phillips Respironics, OR) were used to evaluate sleep patterns objectively for the whole duration of the study - 7 consecutive days and nights. Wrist actigraphs are validated, non-invasive devices that are widely used to record general sleep patterns in a non-laboratory setting (Van de Water et al., 2011). Participants were requested to follow their usual sleep/wake schedules during the week of recording. Actigraphs were worn on their non-dominant wrist, except when swimming or showering. The actigraph record was used to estimate the following sleep variables: (1) Latency to sleep (SOL); (2) Wake time after sleep onset (WASO); (3) Total sleep time (TST); (4) Number of awakenings; and (5) Sleep efficiency defined as the percentage of time-in-bed actually spent asleep. Sleep diaries were used to help identify sleep onset and offset times. The validity of these methods and devices for pediatric and adolescent sleep assessment has been reported elsewhere (Meltzer et al., 2012; Van de Water et al., 2011; Weiss et al., 2010). Data were

collected in 30-s epochs, and scored using Actiware 5.71.0 on medium wake-sensitivity thresholds.

Wireless, dry EEG sleep monitor

For the second part of the study, an ambulatory sleep EEG headband was worn on the two weekday nights following the days of sport-specific training. The EEG recording was performed in the participants' dormitories. The portable EEG sleep monitoring system has been validated against laboratory-based polysomnography (Shambroom et al., 2012). The headband collected information on the following sleep phases: (1) Wake; (2) Light sleep (Stages 1 and 2); (3) Deep sleep (Stages 3 and 4); (4) Rapid eye movement (REM) sleep; and (5) Total sleep time (TST). Participants put on the headband 5 min prior to attempting sleep, and removed it upon awakening each morning. Surgical tape was used to prevent inadvertent movement or removal of the headband during monitoring.

Subjective sleep measures

Participants were asked to complete the Karolinska sleep diary (Akerstedt et al., 1994) daily for one week. The diary provided a record of bedtime, time of awakening, sleep length, sleep latency, sleep quality and duration of nocturnal awakenings. The information was used to assist in establishing sleep onset and offset times from the actigraphy.

Daytime Sleepiness Measures

Pediatric Daytime Sleepiness Scale

Daytime sleepiness is another characteristic of poor sleep quality (Jenni and Carskadon, 2009). Validated questionnaires provide a convenient option to assess

excessive daytime sleepiness (Lewandowski et al., 2011). The Pediatric Daytime Sleepiness Scale (PDSS) is an 8-item self-report questionnaire that has been validated as a measure of sleepiness in children and adolescents (Drake et al., 2003; Lewandowski et al., 2011). Items include *"How often do you fall asleep or feel drowsy in class?"* and "*Are you usually alert during the day?"*. Total scores range from 0 to 32, with higher scores indicating greater daytime sleepiness. Results from this questionnaire have been associated with academic performance and other school-performance outcomes (Drake et al., 2003).

Karolinska Sleepiness Scale

The 9-point Karolinska Sleepiness Scale (KSS; 1 = *extremely alert* and 9 = *extremely sleepy, can't keep awake*) was administered daily for 7 days at 3-h intervals from 06:00 to 21:00 h to rate levels of subjective sleepiness. This scale reflects physiological signs of sleepiness, with scores of 6 or more indicative of sleepiness (Akerstedt and Gillberg, 1990). Weekday data (3-h time-points) was averaged over the week for between-group comparisons.

Statistical analyses

A two-way repeated measures ANOVA (Time and Sport) was used to examine differences in actigraphically obtained sleep variables. A separate two-way repeated measures ANOVA was conducted to examine differences between weekday KSS scores (Sport and Time of day). Independent t-tests were conducted to examine differences in sleep EEG and PDSS scores between sports. Effect–size (ES) analyses for ANOVA were calculated using partial eta-squared, η^2, (where <0.01 = small; 0.09 = moderate; 0.25 = large), while effect-size analyses for t-tests were calculated based upon Cohen's effect

sizes (Cohen, 1988) (where <0.49 = small; 0.5-0.79 = moderate; ≥ 0.8 = large). In addition, retrospective power analyses were computed for between-group comparisons of EEG recordings of sleep variables (light sleep, deep sleep, REM sleep, wake and TST) and daytime sleepiness (PDSS and KSS scores), to determine the extent to which the sample size correctly rejected the null hypothesis. Statistical significance was set at $P < 0.05$. Statistical analysis was conducted using IBM SPSS 20 for Windows (IBM Corporation, NY).

Results

Training Intensity and Duration

No significant differences ($P > 0.05$) between the training intensity variables recorded on the two days were observed, and so the results were averaged. No significant difference in the duration of training sessions were noted ($P > 0.05$), with LI training sessions lasting 106.7 (SD = 10.3) mins and HI training sessions lasting 124.5 (28.5) mins. However, there were significant differences in the percentages of the training session spent at 0-50, 61-70, 71-80 and 81-90% of maximum HR (HR zones), as indicated in Table I.

Sleep Measures

Wrist actigraphs

There was a significant time effect (weekdays vs. weekend) for TST ($\lambda = 0.37$, $F(1, 9) = 15.39$, $P < 0.01$), bedtimes ($\lambda = 0.18$, $F(1, 9) = 41.02$, $P < 0.01$) and waketimes ($\lambda = 0.08$, $F(1, 9) = 98.10$, $P < 0.01$). Post-hoc tests were conducted to evaluate pairwise differences between the mean values (Bonferroni method). The results indicated that TST at the weekend was significantly longer than on weekdays ($P < 0.01$), and there were

significant delays in bedtime ($P < 0.01$) and waketimes ($P < 0.01$) at the weekend compared with weekdays. Though there was a non-significant Time x Sport interaction for TST ($\lambda = 0.79$, $F(1, 9) = 2.43$, $P = 0.15$, $\eta^2 = .21$), the effect size was moderate-to-large. Combined, the athletes slept and woke up later, and obtained more total sleep, on the weekend compared to weekdays. Table II shows a detailed comparison of the weekdays vs. weekend sleep characteristics for both groups of athletes.

Wireless, dry EEG sleep monitor

There were no significant differences ($P > 0.05$) found between the sleep variables collected on the two nights of EEG recording, and so the results were averaged. Marked differences in sleep patterns were noted between the two groups of athletes with HI athletes obtaining significantly greater amounts of deep sleep and less light sleep than LI athletes. HI athletes also displayed significantly better sleep continuity with less wake time after sleep onset. No significant differences were noted in REM sleep and TST. Table III provides details of these differences in sleep patterns between the groups as well as the power and effect size of each comparison.

Daytime Sleepiness Measures

Pediatric Daytime Sleepiness Scale

Whilst no significant differences were noted between LI and HI PDSS scores (13.2 ± 5.4 vs. 19.0 ± 3.7), a large ES was noted (1.25), with HI athletes reporting greater daytime sleepiness. Power for this analysis was 0.45 as computed post-hoc using G*Power 3.1.7 (Faul et al., 2007).

Karolinska Sleepiness Scale

Results obtained from the two-way ANOVA (Sport and Time of day) indicated no main effect of Time of day ($\lambda = 0.25$, $F(5, 5) = 3.04$, $P = 0.12$, $\eta^2 = .75$). Though there was no significant interaction between Sport x Time of day ($\lambda = 0.67$, $F(5, 5) = 0.05$, $P = 0.77$, $\eta^2 = .33$), the effect size was large.

Discussion

The main purpose of this study was to examine the effects of different intensities of sports training on athletic adolescents' sleep patterns. Our primary findings are that the LI and HI athletes displayed marked differences in EEG sleep patterns following days of sports-specific training. This finding is supported by previous studies highlighting reductions in light sleep and increases in deep sleep following vigorous exercise in adolescents (Brand et al., 2009, 2010a, 2010b, 2010c; Dworak et al., 2008). Increases in deep sleep following exercise was reported to be caused by modifications of brain metabolism that impacted upon the homeostatic regulation of sleep (Dworak et al., 2007), with youths being reported to be more sensitive to these changes following intense exercise (Dworak et al., 2008). Our data provide further elaboration as to the exercise intensity required to elicit changes to adolescent sleep, by establishing that HI athletes spent significantly more time than LI athletes training in the heart rate zone between 61-90% of HR max (Table I).

Deep sleep is suggested to be indicative of the homeostatic pressure to sleep, with deep sleep increasing in proportion to prior time spent awake. The greater amount of deep sleep noted in the HI athletes is supportive of the view of the importance of sleep in replenishing cerebral energy stores following intense exercise (Dworak et al., 2008). An awareness of these variances in sleep patterns amongst athletes who participate in

different sports, or game players positions with differing activity requirements, should be studied in order to obtain better understanding of recovery-sleep requirements. Contrary to our findings, Wong et al. (2012) reported significant increases in light sleep and modest reductions in deep sleep following aerobic exercise of different intensities amongst sedentary adults. This inconsistency highlights possible differences between adolescents and adults in the influence of exercise on sleep patterns. A difference in sleep patterns between individuals who partake regularly in vigorous exercise and sedentary individuals who participate in a single acute bout of exercise is also highlighted. A comprehensive review by Driver and Taylor (2000), on the effects of exercise on sleep, suggests that long-term participation in exercise or increased aerobic fitness both elicit increases in TST and SWS, along with shortened SOL, REM sleep and WASO.

A secondary aim was to report new sleep data for Asian high-level adolescent athletes and the effect of sleep on daytime sleepiness during a training week. Our key finding indicates that our subjects normally obtained 6.1 hours of sleep on weekdays. This is important as impairments in neurobehavioral performance have been reported to occur with even as little as 7 hours of sleep (Kamdar et al., 2004). These findings stress that, similar to adolescents' sleep trends in the general population (Gradisar et al., 2011), adolescent, high-level athletes do not meet the experts' recommendations for sleep duration of healthy adolescents of between 7 to 11 hours of sleep (Hirshkowitz et al., 2015). The present study also found that the subjects' bedtimes and waketimes were significantly delayed on weekends, and mean total sleep time was significantly longer. These discrepancies between sleep characteristics on weekdays and the weekend are consistent with worldwide reports on adolescent sleep patterns (Gradisar et al., 2011),

which are known to occur due to progressive delays in bedtimes as a result of neural alterations during adolescence (Feinberg and Campbell, 2010), but with no change in morning waketimes on weekdays due to scholastic or social commitments. This discrepancy, also termed 'social jet lag' (Wittmann et al., 2006), is reported to have consequences for academic performance, daytime sleepiness and mood states amongst adolescents (Touitou, 2013). The decreased sleep in athletes has also been attributed to early morning training (Sargent et al., 2014) and having to maintain the dual role of student/athlete (Sum and Ma, 2014). Whilst it may seem intuitive to address the sleep loss due to early morning training by commencing sleep earlier the night before, adolescents are biologically incapable of doing this as the build-up of sleep pressure during wakefulness in them is slower (Jenni et al., 2005) due to the effects of "synaptic pruning" that occurs in adolescence (Campbell et al., 2011). This effect of delayed sleep has even been observed as a key developmental milestone of adolescence (Roenneberg et al., 2004).

Although HI athletes had more favourable sleep patterns, there was a trend in them to report reduced daytime subjective alertness in comparison to LI athletes, probably due to a greater basal sleep requirement. While the PDSS scores were not significantly different statistically, a large effect size of 1.25 suggests a meaningful difference, with HI athletes reporting greater sleepiness levels. Despite the lack of significant difference in KSS scores between the groups, the HI athletes were more likely to report values of 6 ('*some signs of sleepiness')* or higher at 21:00 h. This finding agrees with those of Robey et al. (2013), where elite youth soccer players showed greater sleepiness close to bedtimes on days with vigorous training. Conversely, Kalak et al.

(2012) reported gradual reductions in daytime sleepiness, and increases in concentration and psychological functioning, over the course of a 3-week daily running intervention in healthy adolescents who had participated in vigorous exercise only modestly prior to the study. Several reviews show an increase in TST following bouts of exercise training (Driver and Taylor, 2000; Uchida et al., 2012; Youngstedt et al., 1997).

It is possible that an optimal exercise intensity or volume is required to elicit improvements in adolescent sleep quality, and that greater durations of sleep may be required for sustained levels of daytime functioning. More importantly, these results further emphasise the different effects of recreational exercise training rather than prolonged high-intensity athletic training on adolescent sleep and consequent daytime functioning. The effects of limited sleep may, therefore, have greater ramifications for adolescent student-athletes, who have to manage sports training as well as a full-time academic workload and so require a sustained level of attention and focus throughout the day. Insufficient sleep may elicit sub-optimal physiological (Skein et al., 2011) and cognitive (Martinez and Coyle, 2007) functioning which may depress an athlete's readiness to perform for training or competition. Premature truncation of sleep due to early morning awakenings is suggested to restrict brain activity required for athletic skill acquisition and learning potential (Walker and Stickgold, 2005). An increase in reaction time and reduction in attention has also been reported in handball goalkeepers following acute partial sleep deprivation of 3-4 hours, when the sleep loss was either at the beginning or end of nocturnal sleep (Jarraya et al., 2012). Additionally, research shows an increased risk of injury when adolescent athletes obtain less than 8 hours of sleep per night (Milewski et al., 2012, 2014). Despite this, there is only limited research on the

impact of chronic partial sleep loss on sport performance amongst adolescents. Future studies could ascertain if various sport-specific performance outcomes are influenced by modest amounts of sleep loss amongst adolescent, high-level athletes. Parents, coaches, school administrators, sport scientists and athletes need to be recognise the unique sleep requirements of adolescent student-athletes, and the potential consequences when the requirements are not met.

Limitations

Results from this study need to be interpreted in the light of some limitations. One limitation of this study is its cross-sectional design, preventing any causal inferences between exercise intensity and sleep architecture in adolescents to be drawn. Additionally, the study employed a small number of participants. Studies on larger and more diverse samples should be conducted. It should be noted, however, that the power of the tests was sufficient to detecting group differences for several EEG sleep variables. The study also investigated the effects of exercise on male participants only, and gender differences cannot be ascertained. Future clinical studies could use polysomnography and a psychomotor vigilance task for more accurate readings of nocturnal sleep stages and daytime performance, respectively. Despite these limitations, this is, to our knowledge, the first study that has investigated sleep patterns of Asian adolescent, high-level athletes.

Conclusions

There is a dearth of research on the sleep requirements of adolescent athletes. The findings of this study indicate that Asian adolescent students who are high-level athletes obtain 6.1 hours of sleep on weekday nights, which is below the recommendations for

minimum sleep duration in healthy adolescents. Further research on objective sports performance outcomes is required to ascertain if a linear relationship exists between sleep duration and performance in sports-specific tests. Additionally, participation in high-intensity sport seems to elicit significantly different sleep patterns - in particular, an increase in the amount of deep sleep. These findings suggest that adolescent athletes may have differing sleep requirements based upon the demands on their sport, necessitating future research on the effects of sleep on athletic performance in adolescents. Future research should also focus on interventions that might alleviate the effects of shortened nocturnal sleep, which is known to be more pronounced amongst Asian adolescents.

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Table I. Percentage of training session spent at different HR zones in LI and HI sports. n = 8, results presented as mean (SD).

HR Zones	LI	HI
0-50 % of HR max	48.5 (11.9)	26.0 (8.1)*

51-60 % of HR max	37.3 (10.6)	28.8 (9.2)
61-70 % of HR max	10.2 (7.6)	24.3 (5.6)*
71-80 % of HR max	2.7 (3.3)	15.0 (4.1)*
81-90 % of HR max	1.1 (1.3)	5.6 (1.8)*
91-100 % of HR max	0.1 (0.3)	0.1 (0.1)

* $P < 0.05$; significantly different from LI

Table II. Actigraph sleep characteristics, weekdays vs. weekend. n = 11; mean (SD)

Group	WD/ WE	Bedtime (h:min)	Waketime (h:min)	SOL (mins)	WASO (mins)	TST (mins)
LI (n = 6)	WD	23:31 (00:38)	06:29 (00:12)	6.7 (10.8)	38.7 (18.1)	360.7 (51.2)
	WE	00:41 (00:33)	08:24 (00:40)	0.3 (0.8)	51.0 (32.0)	404.3 (28.7)
HI (n = 5)	WD	23:28 (00:15)	06:25 (00:15)	3.4 (1.2)	36.0 (15.1)	374.0 (20.4)
	WE	00:24 (00:32)	08:40 (00:45)	0.6 (0.9)	30.2 (7.5)	458.4 (70.4)
Combined	WD	23:30 (00:29)	06:28 (00:13)	5.2 (7.8)	37.5 (16.1)	366.7 (39.1)
(n = 11)	WE	00:33 (00:32)*	08:32 (00:41)*	0.5 (0.8)	41.5 (25.5)	428.9 (56.5)*

*, $P < 0.01$, significantly different from WD for within-group comparison; WD = Weekday; WE = Weekend. Bedtimes and waketimes are expressed in 24-hour clock format; mean (SD)

Table III. EEG recordings of sleep and sleep stages in LI and HI sport. n = 8; mean (SD)

Sleep Stages (min)	LI	HI	Effect size	Power
Light Sleep	191.0 (7.4)	157.6 (25.4)*	1.79	0.56
Deep Sleep	93.1 (7.0)	139.3 (19.6)*	-3.13	0.95
REM Sleep	106.4 (16.5)	105.5 (19.5)	0.05	0.50
Wake	4.4 (1.5)	1.0 (0.4)*	3.2	0.96
TST	390.5 (17.8)	402.4 (19.9)	-0.61	0.11

*, $P < 0.05$; significantly different from LI