*Note*. This article will be published in a forthcoming issue of the *Pediatric Exercise Science*. The article appears here in its accepted, peer-reviewed form, as it was provided by the submitting author. It has not been copyedited, proofread, or formatted by the publisher.

**Section:** Original Research

**Article Title:** Effects of Sport-specific Training Intensity on Sleep Patterns and Psychomotor Performance in Adolescent Athletes

**Authors:** Haresh T. Suppiah[1], Chee Yong Low[2], and Michael Chia[1]

**Affiliations:** [1]Department of Physical Education and Sports Science, National Institute of Education, Nanyang Technological University, Singapore. [2]National Youth Sport Institute, Singapore.

**Journal:** *Pediatric Exercise Science*

**Acceptance Date:** January 7, 2016



**DOI**: http://dx.doi.org/10.1123/pes.2015-0205

"Effects of Sport-specific Training Intensity on Sleep Patterns and Psychomotor Performance in Adolescent Athletes"
by Suppiah HT, Low CY, Chia M
*Pediatric Exercise Science*



# Abstract

**Purpose**: Adolescent student-athletes face time constraints due to athletic and scholastic commitments, resulting in habitually shortened nocturnal sleep durations. However, there is a dearth of research on the effects of sleep debt on student-athlete performance. The study aimed to (i) examine the habitual sleep patterns (actigraphy) of high-level student-athletes during a week of training and academic activities, (ii) ascertain the effects of habitual sleep durations experienced by high-level student-athletes on psychomotor performance, and (iii) examine the impact of sport training intensities on the sleep patterns of high-level student-athletes that participate in low and high intensity sports. **Methods**: Sleep patterns of 29 high-level student-athletes (14.7 ± 1.3 yrs) were monitored over seven days. A psychomotor vigilance task was administered on weekdays to ascertain the effects of habitual sleep durations. **Results**: Weekend total sleep time was longer than weekdays along with a delay in bedtime, and waketimes. Psychomotor vigilance reaction times on Monday were faster than on Thursday and Friday, with reaction times on Tuesday also faster than on Friday. False starts and lapses were greater on Friday compared to Monday. **Conclusion**: There was a negative impact of sleep debt on student-athletes' psychomotor performance.

(192 words)


**Word count**: 3878 words

**Citation count**: 42

# Introduction

Although the implications of shortened sleep on athletic performance are evident (15), recent research highlights the sleep truncating effects of athlete training demands (23). The impact of chronic sleep loss and sleepiness have implications on athlete career longevity (29) and are postulated to predict game outcomes (41). Research indicates that sleep loss may promote muscle degradation, which could impede recovery from training (9). Poor sleep quality is associated with worse outcomes following a sport-related concussion (34). Conversely, extended sleep is shown to elicit improvements on multiple sport performance outcomes (24). Collectively, these findings highlight the integral nature of sleep for athletic recovery.

Adolescence also is recognised to be a period of significant sleep curtailment. Culminating external and internal factors (27) truncate the requisite seven to 11 hours (17) of sleep for adolescents, resulting in sleep debt. Despite its salience, nocturnal durations of adolescent sleep are declining (21), with Asian adolescents acknowledged to obtain the least amount of nocturnal sleep internationally (28). It is necessary to consider that adolescent student-athletes may be at a higher risk of sleep loss due to the unique time demands of having to balance athletic and scholastic commitments concurrently (20). This is of concern with research showing that student-athletes have to sacrifice sleep due to academic commitments (30, 35). Though moderate sleep loss may be seemingly inconsequential, its effects are more pronounced on young adolescents than on adults (14). Recently, the International Olympic Committee highlighted in its consensus statement on youth athletic development (3), the salience of sleep in the development of adolescent athletes. While we previously reported that student-athletes are habitually obtaining less than the recommended durations of sleep (36), the potential performance impact of sleep debt in student-athletes is unknown. Elucidating the effects of chronic sleep loss on student-athletes' performance may have implications for sporting outcomes, injury risk, and academic performance (25). Also, previous research highlighted the differences in sleep architecture between athletes that participated in low and high-intensity sports (36), and between athletic adolescents and controls (5-7), suggesting that adolescents who participated in higher levels of exercise have a greater homeostatic sleep need (13).

The study aimed to (i) examine the habitual sleep/wake patterns of high-level student-athletes during a week of training and academic schedules, (ii) ascertain the effects of habitual sleep durations experienced by high-level student-athletes on sustained attention, and (iii) examine the effects of different training intensities of sport training on the sleep architecture of high-level student-athletes.

# Methods

## Participants

The study comprised of two parts. The first involved the examination of weekday and weekend sleep patterns of participants based on wrist actigraphy. High-level male student-athletes from a school were recruited. All student-athletes were from high-performance shooting, and track & field academies. 29 participants- 15 shooters and 14 track & field sprinters (age: 14.7 ± 1.3 yrs ; body mass: 56.0 ± 10.3 kg ; height: 165.50 ± 8.16 cm) were included in the study. The second part of the study involved a sub-sample of the participants (n = 14; 6 shooting vs. 8 track & field athletes) where differences in sleep stage characteristics using a wireless dry electroencephalographic sensor were examined.

## Design

Data collection for both parts of the study were conducted within the same week, with electroencephalographic data collected on a single night following sport-specific training in the afternoon (1500-1830 hours). Based upon sport classifications (26), shooting was classified as a lower-intensity sport while track and field was categorised as a higher-intensity sport. Both groups underwent two training sessions per day on weekdays, with approximately 16 hours of supervised training per week, and no weekend training commitments. Weekday training was scheduled daily at 0630 – 0745 hrs and 1600 – 1800 hrs. Between training, participants attended academic lessons between 0900 – 1430 hrs. Participants and parents were duly informed about the nature of the study and risks verbally and in information sheets. As participants were all under the age of 18, written informed assent and parental/guardian consent were obtained from all participants. Ethical approval for the study was obtained from the university's Institutional Review Board (IRB-2014-01-003). Participants resided in a boarding school on weekday nights (Sunday-Thursday) and returned home on weekend nights

(Friday-Sunday). As sleep is influenced by wake-length prior to sleep, light-exposure, time and type of food ingestion, sleep environment, regularity of sleep-wake schedules and exercise, a boarding arrangement was selected because these variables could be standardised. This study was conducted over a week, outside competition periods. Napping was discouraged during the investigation as was caffeine consumption. Participants adhered to their bedtime as implemented by the school: (2215– 0600 hours). Familiarisation to the study procedures and performance tests were conducted one week before the commencement of the study.

## Measures

*Training Session Intensity and Duration.* Participants undertook a baseline Yo-Yo Intermittent Recovery Test (YYIRT) 1 at the start of the study to ascertain their maximal heart rates ($HR_{max}$) and aerobic fitness. Heart rate monitors (Polar Team 2, Polar Electro Oy, Kempele, Finland) were worn during each training session to obtain an objective measure of training intensity from the beginning to the end of every training session, on the days prior to night-time electroencephalographic sleep recording.

The lower-intensity sport training sessions involved a warm-up (~15 min) consisting of arm, hip and wrist rotations, and upper and lower body dynamic stretches. Each stretch was held for five counts of 4. This was immediately followed by shooting-specific skill training for the remainder of the session (~90 min) that was supervised by the coaches. The higher-intensity sport training session involved a warm-up (~15 min) consisting of an 800-metre jog, running drills, high knee lifts, straight knee shuffles, and striding over 100 metres. Apart from the 800-m jog, all other drills were repeated twice. The remainder of the session (~90 min) focused on sprint and technique development unique to the event undertaken by the athlete. The session concluded with a 10-min cooldown. Sport-specific training was conducted entirely under the supervision of the respective coaches without interference by the researchers.

*Sleep measures.* Objective sleep recordings were performed using GT3X activity monitors (Actigraph, FL, USA), for the duration of the study (7 days and nights). Sleep diaries were used to help identify sleep onset and offset times.

The GT3X data were scored and analysed using ActiLife 6.9.2 using the Sadeh algorithm that was validated in an adolescent population and has a high accuracy to that of polysomnography (33). Wrist actigraphs are validated, non-invasive devices that are widely used to record general sleep patterns in an applied setting (37). Participants wore the actigraphs on the non-dominant wrists except when swimming or showering. The actigraph collected the following sleep variables: (1) Bedtime, (2) Waketime, (3) Time in bed, (4) wake time after sleep onset (WASO), (5) total sleep time (TST), (6) number of awakenings, and (7) sleep efficiency.

As a requirement for the second part of the study, an ambulatory sleep electroencephalographic headband (Zeo, MA, USA) was worn on three weekday nights (two non-specific weekday familiarisation nights followed by one weekday night following only sport-specific training). The headband uses a proprietary dry silver-coated fabric sensor headband with three frontal dry electrodes that record electrophysiological signals from the forehead with a single bi-polar channel. The signals recorded from the headband include electroencephalography, eye movements and the frontalis muscle tone, and was worn at approximately Fp1-Fp2. The signals were transmitted wirelessly to a base station in real-time and scored using an automated proprietary algorithm. This system has been validated against an in-laboratory polysomnography (32). Participants wore the headband 5 min prior to their sleep times and removed it upon awakening in the morning.

*Psychomotor performance measures.* A daytime sleepiness measure using the Karolinska Sleepiness Scale (19), was administered from Monday to Friday to coincide with the psychomotor vigilance task at 1500 - 1600 hrs. The validated 10-minute Psychomotor Vigilance Task (PVT) was used to objectively measure sustained attention (12). A bright red circle was depicted at the middle of the screen at random interstimulus intervals of 2-10 seconds. Participants were required to press the spacebar button as fast as possible when the red circle appeared. False starts (during an inter-stimulus interval or making a response faster than 100 msec), lapses (> 500 msec), quickest valid reaction time, slowest valid reaction time were measured in this test. A repeated measures design was adopted, and the PVT was administered daily from Monday to Friday during the investigation. Due to scheduling problems on the Wednesday, not all the participants (n=5; higher-intensity sport) were able to complete the PVT on that day. To allow analysis of all 29 remaining participants, the data collected on Wednesday was not included in the analysis. The time of the test was maintained between 1500 and 1600 hours to minimise any circadian impact. The test was conducted on a computer (32-bit; Intel Core i5 processor; Windows 7 SP1; 4GB RAM) using a 21-inch monitor.

### Statistical analysis

A two-way ANOVA with repeated measures was utilised to assess the effect of time (day) and sport intensity on sleep data obtained from wrist actigraphy, PVT performance and Karolinska Sleepiness Scale scores. Bonferroni's adjustments were conducted to reduce the likelihood of type 1 error for multiple comparisons during post-hoc testing. Independent t-tests were performed to examine the differences in sleep electroencephalography, and heart rate characteristics for training sessions prior to electroencephalographic recording, and YYIRT test results between groups. Effect-size (ES) analyses for ANOVA were calculated using partial eta-squared, η2, (where <0.01 = small; 0.09 = moderate; 0.25 = large), whilst effect–size analyses for t-tests were calculated based upon Cohen's effect sizes (8) (where <0.49 = small; 0.5–0.79 = moderate; ≥0.8 = large). Statistical significance was set at $P < 0.05$. Statistical analyses were done using IBM SPSS 20 for Windows (IBM Corporation, NY).

## Results

Significant differences in predicted $\dot{V}O_2max$ were noted between the lower (44.2 ± 5.77 ml/kg/min) and higher-intensity sport (51.22 ± 6.95 ml/kg/min) groups; $t(27) = 2.97$, $p < 0.01$. Further, Cohen's effect size value ($d = 1.10$) indicated a large effect. Significant differences existed in proportion of training session times spent in the various heart rate zones. No significant differences in training session durations were found (Table I).

There were no statistically significant interactions between actigraphically obtained weekday and weekend total sleep times $F(1, 27) = 1.71$, $p = 0.20$, partial $\eta 2 = 0.06$. Main effect analysis indicated a significant difference in total sleep time, $F(1, 27) = 39.35$, bedtime, $F(1, 27) = 25.24$, waketime, $F(1, 27) = 114.8$, waketime after sleep onset (WASO), $F(1, 27) = 8.01$, time in bed, $F(1, 27) = 42.52$, and number of awakenings, $F(1, 27) = 17.76$. Post-hoc tests with Bonferroni adjustments indicated that TST on the weekend was significantly longer than the weekdays along with WASO, and there was a significant delay in bedtime, and waketimes on weekends (Table II). No significant differences were found between any recorded sleep electroencephalographic variables (Table I).

A two-way ANOVA analysing the effect of the day of test on Karolinska Sleepiness Scale scores at 1500 hours indicated no significant interaction $F(4, 104) = 2.23$, $p = 0.07$, partial $\eta 2 = .08$ . There was also no statistically significant main effect of day of test on Karolinska Sleepiness Scale scores at 1500 hours $F(4, 104) = 1.54$, $p = .20$, partial $\eta 2 = .05$ (Fig. 1A). There were no statistically significant interactions between Average reaction times and Sport, $F(3, 78) = 1.54$, $p = .21$, partial $\eta 2 = .06$, Slowest reaction times and Sport, $F(3, 78) = 1.30$, $p = .28$, partial $\eta 2 = .05$, Quickest reaction times and Sport, $F(3, 78) = 1.28$, $p = .29$, partial $\eta 2 = .05$, False start responses and Sport, $F(3, 78) = 0.16$, $p = .92$, partial $\eta 2 = .01$, Lapsed responses and Sport, $F(3, 78) = 1.94$, $p = .13$, partial $\eta 2 = .07$, and Correct responses and Sport, $F(3, 78) = .57$, $p = .64$, partial $\eta 2 = .02$. The main effect analysis indicate a statistically significant difference in Average reaction times, $F(3, 78) = 9.329$, $p < 0.001$, partial $\eta 2 = .264$, Slowest reaction times, $F(3, 78) = 3.123$, $p < 0.05$, partial $\eta 2 = .107$, False start responses, $F(3, 78) = 2.732$, $p < 0.05$, partial $\eta 2 = .095$, Lapsed responses, $F(3, 78) = 9.011$, $p < 0.001$, partial $\eta 2 = .257$, and Correct responses, $F(3, 78) = 8.969$, $p < 0.001$, partial $\eta 2 = .256$. Follow up pairwise comparisons indicated that PVT Average reaction times on Monday were significantly faster than on Thursday (M = -70.73 msec, 95% CI [-128.49, -12.98], $p = .01$) and Friday (M = -94.19 msec, 95% CI [-149.49, -38.89], $p < .001$), with reaction times on Tuesday also significantly faster than on Friday (M = -93.34 msec, 95% CI [-153.62, -33.06], $p = .001$). There were significantly more false starts (M = 2.68, 95% CI [-5.3, -.06], $p < .05$) and lapsed reactions (M = 8.93, 95% CI [-15.06, -2.79], $p < .01$) on Friday compared to Monday. The number of correct responses were significantly lower on Friday compared to Monday (M = -14.75, 95% CI [4.15, 25.35], $p < .001$). These details are presented in Fig. 1B-1D.

# Discussion

Despite the known prevalence of short habitual sleep durations amongst athletes and adolescents, the accrued effects of potential sleep debt on student-athletes' psychomotor performance has not been evaluated. The main conclusions of the current study are as follows: (i) Asian student-athletes obtained 5.5 hours of habitual nocturnal sleep, (ii) the habitual sleep durations experienced by Asian student-athletes can cause cumulative declines in psychomotor vigilance performance over 5 days, and (iii) that no differences in electroencephalographic obtained sleep stages were noted between Asian student-athletes that participated in lower and higher intensity sports, following a day of sport specific training.

## Habitual Sleep Durations

In this study, student-athletes obtained 5.5 hours of nocturnal sleep on weekdays, less than the recommendations for this population (17). However, this finding is in agreement with those reported in a separate investigation on student-athletes (36). This inability to meet requisite sleep amounts parallels with sleep habits reported by elite-level athletes (23). This research also showed a significant delay of bedtimes and waketimes and increases in TST on weekends when compared with weekdays. This misalignment between biological and social sleep/wake patterns, or *social jetlag*, is likened to chronically experiencing the effects of jet lag, following transmeridian travel (42) on a daily basis, throughout the second decade of life. With the unique demands of the student-athlete, stakeholders (coaches, parents, teachers and school administrators) need to acknowledge the scheduling pressure brought about by scholastic and sporting commitments and the conflict with the biologically driven sleep/wake patterns. The need for flexible academic pathways to cater to the dual role experienced by student-athletes prompted several universities to adopt a more supportive and flexible higher-education environment (1, 24) as ameliorative measures to mitigate any adverse impact on student-athlete performance. The modification of training and school start-times to harmonise with the developmental changes of adolescent sleep/wake patterns, or to implement an extended academic curriculum that allows for shortened daily schooling hours, could be viable considerations. In the present study, this misalignment in biological sleep requirements and school/training commitments presented in the form of 'catch-up' sleep, and a significantly delayed sleep/wake schedule on weekends. With reports of similar complexities being present in North America (4) and other parts of Asia (35), there is a need to consider alternative educational curriculums that allow for greater flexibility, such as the Massive Open Online Course model (16).

## Performance-Sustained Attention

Present research data show that the habitual sleep durations experienced by student-athletes per night over five nights, resulted in cumulative declines in sustained attention by day 4 of the investigation, with these effects most pronounced by day 5. Specifically, average reaction times were slower by Thursday when compared to Monday, with higher occurrences of false starts and lapsed reactions on Friday when compared to Monday. These findings are consistent with data on adolescents that were given a sleep extension opportunity on a night before the start of the week. When compared to data obtained at the beginning of the week, psychomotor performance outcomes on reaction time and lapsed reaction significantly deteriorated by the end of the school week (39). Similar increases in reaction time and frequencies of lapsed reactions were also reported in Asian workers that were accustomed to habitually short nocturnal sleep durations (22). Following a weekend of extended sleep, workers had significantly faster reaction times and fewer lapses in the PVT on the Monday compared to Thursday. However, this cumulative decline in psychomotor performance was not evident following a weekend in which sleep durations mimicked habitual sleep durations (<6 hours). Taken together, these findings highlight that providing an extended sleep opportunity in the weekend prior to shortened weekday sleep durations results in superior performances at the start of the following week. While it is unclear to what degree of impairment sleep debt has on sport-specific performance, the criticality of sleep in the offline consolidation from learning new skills (40) may highlight a need for novel skills to be taught at the start of the week, when accrued sleep debt is at its minimum. It is noteworthy that no concomitant increases in sleepiness levels were reported by the participants at the time of the daily PVT during the week. This may be attributed to the resultant effect of the loss of introspection into one's perception of sleepiness when experiencing chronic partial sleep restriction, inasmuch as a minimum of 4 hours of nocturnal sleep may provide a sense that the effects of sleep loss are merely benign (38). These cumulative declines in performance are unlikely to be due to boredom as participation in the psychomotor vigilance task was designed to elicit a high signal load to avoid excessive levels of task-related fatigue (11). While these findings indicate a cumulative negative impact of sleep debt on performance in sustained attention, addressing these effects by way of nocturnal sleep extension or a brief daytime nap is still a matter of debate (18, 31). In their work, Horne and colleagues (18) reported that a single night of sleep extension (~74 mins) had no significant effect on PVT outcomes when compared to a night of habitual sleep. However, objective daytime testing via the multiple sleep latency test indicated that a brief afternoon nap was able to ameliorate afternoon sleepiness better than a night of extended sleep or caffeine. Contrary to these findings, Rupp and colleagues (31) report that "banking extra sleep", in that sleep was extended for seven nights, prior to sleep restriction resulted in fewer PVT lapses and quicker reaction times when compared to a condition that sleep restriction was preceded by habitual sleep durations for seven nights. Further investigations into potential countermeasures to address the sleep loss experienced by student-athletes are warranted.

## Electroencephalographic Sleep Data

No differences in sleep patterns were noted between the lower and higher-intensity sport student-athletes in the present study. These results contrast those previously reported in badminton student-athletes (36). Although speculative, our findings suggest the need to consider the possibility that sport-specific training elicits different changes to sleep architecture. More specifically, findings from the collective comparisons of student-athlete sleep patterns show a marked difference in sleep architecture exclusive to the reactive sport of badminton. Reactive sports are known to be reliant on visuomotor processing ability and has been reported to alter brain structure in badminton athletes (10). With evidence that increases in slow wave activity during sleep is anteceded by visuomotor learning, the increased deep sleep noted exclusively to badminton student-athletes may plausibly be related to the unique cognitive requirements of reactive sports. We propose that sleep-dependent adaptations occur following sport-specific training/learning. With novel neuroscience techniques using non-invasive auditory stimuli (2), it may be possible to selectively enhance slow-wave activity and slow-wave sleep, and in so doing, further optimise sleep-dependent offline learning (40). The potential of augmenting sport-specific skill learning via the enhancement of specific sleep states requires further exploration. Some limitations of the study are noteworthy. Firstly, we only investigated the effects of habitual sleep durations of male student-athletes on psychomotor performance, precluding any gender comparisons. In addition, no sport performance tests were conducted in our investigation. Therefore, the PVT performance declines noted in the current study cannot be generalized to sport performance. Furthermore, due to the applied nature of this study, and its setting within a school for high-performance youth athletes, a comparison of the effects of extended sleep durations was not possible. However, the primary purpose of this study was to ascertain the psychomotor performance effects of habitual sleep durations. We were only able to collect sleep stage data from a single night's analysis. Future clinical studies could use polysomnography on multiple nights to elucidate the effects of sport-specific skill learning on sleep architecture. Finally, it would have been of interest to examine the effects of sleep extension during weekends on subsequent weekday performance on PVT and other sport performance outcomes. Despite these limitations, this is, to our knowledge, the first study to highlight the psychomotor performance impact of sleep debt in high-level student-athletes.

## Conclusions

Our findings are apparently the first to underline the effects of sleep debt over five weekday nights of habitual sleep on psychomotor performance in high-level adolescent student-athletes. There is a need to address the curtailment of optimum sleep durations and recognise the rigidity in scheduling in current student-athlete development systems when compared to their tertiary level counterparts. Reaching the pinnacle of athletic potential requires a near-perfect synchrony of multiple attributes. Incorporating sleep as a form of recovery may yield greater dividends when compared to current practice.

# References

1. AIS. Elite Athlete Friendly University program Australia: Australian Institute of Sport; N.D. [cited 8 June 2015 2015]. Available from: http://www.ausport.gov.au/ais/personal_excellence/university_network/elite_athlete_friendly_university_program.

2. Bellesi M, Riedner BA, Garcia-Molina GN, Cirelli C, Tononi G. Enhancement of sleep slow waves: underlying mechanisms and practical consequences. Frontiers in systems neuroscience. 2014;8:208. PubMed PMID: 25389394. Pubmed Central PMCID: PMC4211398. Epub 2014/11/13. eng.

3. Bergeron MF, Mountjoy M, Armstrong N, Chia M, Côté J, Emery CA, et al. International Olympic Committee consensus statement on youth athletic development. Br J Sports Med. 2015 July 1, 2015;49(13):843-51.

4. Berland PS. Student-athlete time demands April 2015. 2015.

5. Brand S, Beck J, Gerber M, Hatzinger M, Holsboer-Trachsler E. 'Football is good for your sleep': favorable sleep patterns and psychological functioning of adolescent male intense football players compared to controls. Journal of health psychology. 2009 Nov;14(8):1144-55. PubMed PMID: 19858334. Epub 2009/10/28. eng.

6. Brand S, Beck J, Gerber M, Hatzinger M, Holsboer-Trachsler E. Evidence of favorable sleep-EEG patterns in adolescent male vigorous football players compared to controls. The World Journal of Biological Psychiatry 2010;11(2 Pt 2):465-75.

7. Brand S, Gerber M, Beck J, Hatzinger M, Pühse U, Holsboer-Trachsler E. High exercise levels are related to favorable sleep patterns and psychological functioning in adolescents: a comparison of athletes and controls. The Journal of Adolescent Health : Official Publication of the Society for Adolescent Medicine. 2010;46(2):133-41.

8. Cohen J. Statistical power analysis for the behavioural sciences. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates; 1988.

9. Dattilo M, Antunes HK, Medeiros A, Monico Neto M, Souza HS, Tufik S, et al. Sleep and muscle recovery: endocrinological and molecular basis for a new and promising hypothesis. Med Hypotheses. 2011 Aug;77(2):220-2. PubMed PMID: 21550729. Epub 2011/05/10. eng.

10. Di X, Zhu S, Jin H, Wang P, Ye Z, Zhou K, et al. Altered resting brain function and structure in professional badminton players. Brain connectivity. 2012;2(4):225-33. PubMed PMID: 22840241. Pubmed Central PMCID: PMC3621728. Epub 2012/07/31. eng.

11. Dorrian J, Rogers NL, Dinges DF. A neurocognitive assay sensitive to sleep loss. Sleep Deprivation: Clinical Issues, Pharmacology and Sleep Loss Effects. 2005:39-70.

12. Dorrian J, Rogers NL, Dinges DF. Psychomotor vigilance performance: Neurocognitive assay sensitive to sleep loss. 2005.

13. Dworak M, Wiater A, Alfer D, Stephan E, Hollmann W, Struder HK. Increased slow wave sleep and reduced stage 2 sleep in children depending on exercise intensity. Sleep Med. 2008 Mar;9(3):266-72. PubMed PMID: 17644426. Epub 2007/07/24. eng.

14. Fischer S, Wilhelm I, Born J. Developmental differences in sleep's role for implicit off-line learning: comparing children with adults. J Cogn Neurosci. 2007 Feb;19(2):214-27. PubMed PMID: 17280511. Epub 2007/02/07. eng.

15. Fullagar HH, Skorski S, Duffield R, Hammes D, Coutts AJ, Meyer T. Sleep and athletic performance: the effects of sleep loss on exercise performance, and physiological and cognitive responses to exercise. Sports Med. 2015 Feb;45(2):161-86. PubMed PMID: 25315456. Epub 2014/10/16. eng.

16. Glusac D, Karuovic D, Milanov D, editors. Massive open online courses - pedagogical overview. Carpathian Control Conference (ICCC), 2015 16th International; 2015 27-30 May 2015.

17. Hirshkowitz M, Whiton K, Albert SM, Alessi C, Bruni O, DonCarlos L, et al. National Sleep Foundation's sleep time duration recommendations: methodology and results summary. Sleep Health: Journal of the National Sleep Foundation. 2015.

18. Horne J, Anderson C, Platten C. Sleep extension versus nap or coffee, within the context of 'sleep debt'. J Sleep Res. 2008;17(4):432-6.

19. Kaida K, Takahashi M, Åkerstedt T, Nakata A, Otsuka Y, Haratani T, et al. Validation of the Karolinska sleepiness scale against performance and EEG variables. Clin Neurophysiol. 2006 7//;117(7):1574-81.

20. Kennedy MD, Tamminen KA, Holt NL. Factors that influence fatigue status in Canadian university swimmers. J Sports Sci. 2013;31(5):554-64. PubMed PMID: 23140537. Epub 2012/11/13. eng.

21. Keyes KM, Maslowsky J, Hamilton A, Schulenberg J. The Great Sleep Recession: Changes in Sleep Duration Among US Adolescents, 1991–2012. Pediatrics. 2015 February 16, 2015.

22. Kubo T, Takahashi M, Sato T, Sasaki T, Oka T, Iwasaki K. Weekend sleep intervention for workers with habitually short sleep periods. Scand J Work Environ Health. 2011;37(5):418-26.

23. Lastella M, Roach GD, Halson SL, Sargent C. Sleep/wake behaviours of elite athletes from individual and team sports. European Journal of Sport Science. 2015 Mar;15(2):94-100. PubMed PMID: 24993935. Epub 2014/07/06. eng.

24. Mah C, Mah K, Kezirian E, Dement W. The Effects of Sleep Extension on the Athletic Performance of Collegiate Basketball Players. Sleep. 2011;34(7):943-50.

25. Milewski MD, Skaggs DL, Bishop GA, Pace JL, Ibrahim DA, Wren TA, et al. Chronic lack of sleep is associated with increased sports injuries in adolescent athletes. Journal of Pediatric Orthopaedics. 2014 Mar;34(2):129-33. PubMed PMID: 25028798. Epub 2014/07/17. eng.

26. Mitchell J, Haskell W, Snell P, Van Camp S. Task Force 8: classification of sports. J Am Coll Cardiol. 2005;45(8):1364-7.

27. Moore M, Meltzer LJ. The sleepy adolescent: causes and consequences of sleepiness in teens. Paediatr Respir Rev. 2008 Jun;9(2):114-20; quiz 20-1. PubMed PMID: 18513671. Epub 2008/06/03. eng.

28. Olds T, Blunden S, Petkov J, Forchino F. The relationships between sex, age, geography and time in bed in adolescents: a meta-analysis of data from 23 countries. Sleep Med Rev. 2010;14(6):371-8.

29. Potenziano BJ, Pfeifer PE, Rogers SL, Winter WC. Predicting Major League Baseball (MLB) player career longevity via sleepiness measurements. Sleep. 2013;36(Abstract supplement):A326.

30. Rothschild-Checroune E, Gravelle F, Dawson D, Karlis G. Balancing academic and athletic time management : A qualitative exploration of first year student athletes’ university football experiences. Loisir et Société / Society and Leisure. 2012 2012/09/01;35(2):243-61.

31. Rupp TL, Wesensten NJ, Bliese PD, Balkin TJ. Banking sleep: realization of benefits during subsequent sleep restriction and recovery. Sleep. 2009 Mar;32(3):311-21. PubMed PMID: 19294951. Pubmed Central PMCID: PMC2647785. Epub 2009/03/20. eng.

32. Shambroom JR, Fabregas SE, Johnstone J. Validation of an automated wireless system to monitor sleep in healthy adults. J Sleep Res. 2012;21(2):221-30.

33. Slater JA, Botsis T, Walsh J, King S, Straker LM, Eastwood PR. Assessing sleep using hip and wrist actigraphy. Sleep and Biological Rhythms. 2015;13(2):172-80.

34. Sufrinko A, Pearce K, Elbin RJ, Covassin T, Johnson E, Collins M, et al. The effect of preinjury sleep difficulties on neurocognitive impairment and symptoms after sport-related concussion. Am J Sports Med. 2015 Apr;43(4):830-8. PubMed PMID: 25649087. Epub 2015/02/05. eng.

35. Sum RKW, Ma MMS. A plea for support for elite student athletes in Hong Kong secondary schools. Asia Pacific Journal of Sport and Social Science. 2014 2014/05/04;3(2):95-107.

36. Suppiah HT, Low CY, Chia M. Effects of sports training on sleep characteristics of Asian adolescent athletes. Biol Rhythm Res. 2015:1-14.

37. Van de Water AT, Holmes A, Hurley DA. Objective measurements of sleep for non-laboratory settings as alternatives to polysomnography – a systematic review. J Sleep Res. 2011;20(1pt2):183-200.

38. Van Dongen H, Maislin G, Mullington J, Dinges D. The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. Sleep. 2003 Mar 15;26(2):117-26. PubMed PMID: 12683469. Epub 2003/04/10. eng.

39. Vedaa Ø, West Saxvig I, Wilhelmsen-Langeland A, Bjorvatn B, Pallesen S. School start time, sleepiness and functioning in Norwegian adolescents. Scandinavian Journal of Educational Research. 2011 2012/02/01;56(1):55-67.

40. Walker M, Stickgold R. It's practice, with sleep, that makes perfect: implications of sleep-dependent learning and plasticity for skill performance. Clin Sports Med. 2005 Apr;24(2):301-17, ix. PubMed PMID: 15892925. Epub 2005/05/17. eng.

41. Winter WC, Hammond WR, Green NH, Zhang Z, Bliwise DL. Measuring circadian advantage in Major League Baseball: a 10-year retrospective study. International journal of sports physiology and performance. 2009 Sep;4(3):394-401. PubMed PMID: 19953826. Epub 2009/12/04. eng.

42. Wittmann M, Dinich J, Merrow M, Roenneberg T. Social jetlag: misalignment of biological and social time. Chronobiol Int. 2006;23(1-2):497-.

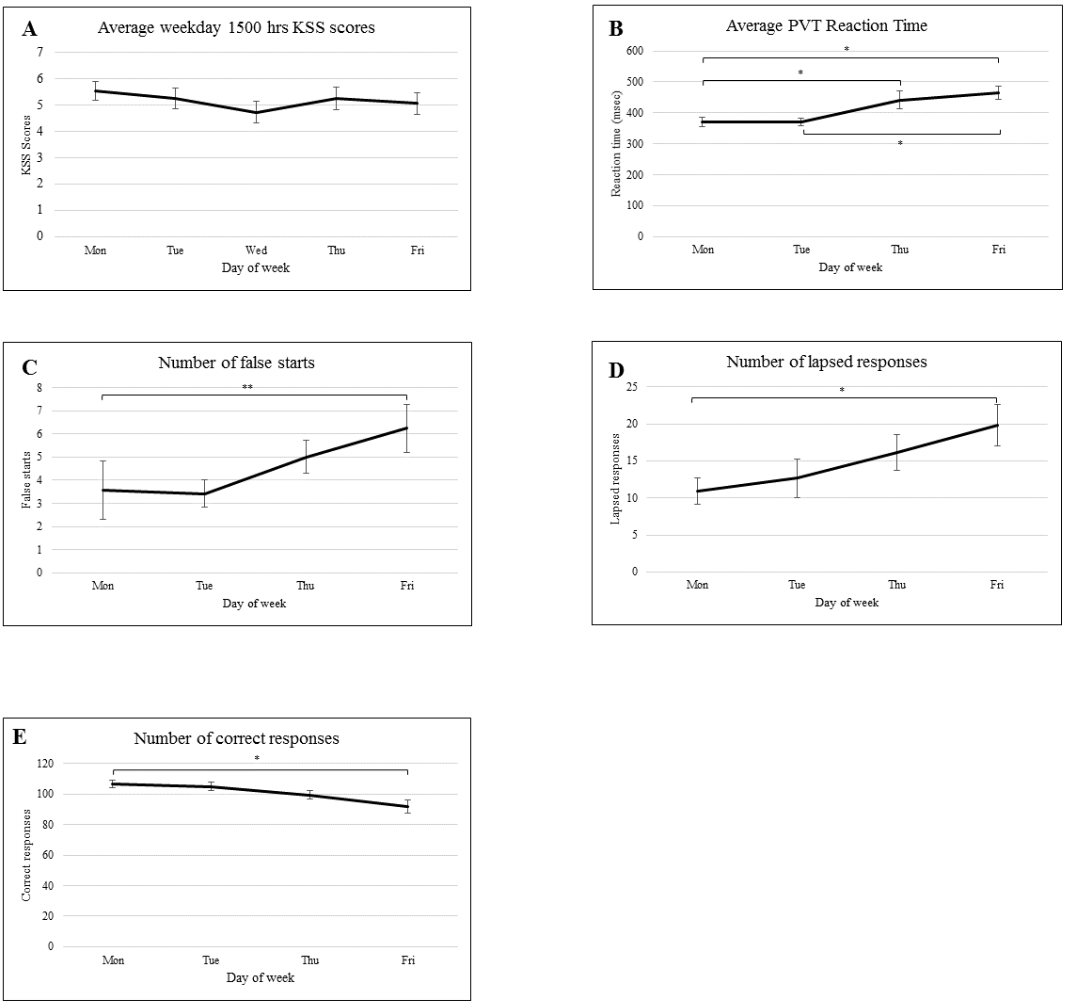


**Figure 1** Performance variables measured during the week. (**A**) Averaged Karolinska Sleepiness Scale scores across the week (Monday - Friday) at 1500 hrs were not significantly different across the week. (**B**) Average reaction times on Monday were significantly faster than on Thursday ($p = .01$) and Friday ($p < .001$), with reaction times on Tuesday also significantly faster than on Friday ($p = .001$). (**C**) There were significantly more false starts ($p < .05$) on Friday compared to Monday. (**D**) There were significantly more lapsed reactions ($p < .01$) on Friday compared to Monday. (**E**) There were significantly less correct responses on Friday compared to Monday * indicates significant differences between days as indicated by brackets at an alpha of level $P < 0.01$. ** indicates significant differences between days as indicated by brackets at an alpha of level $P < 0.05$. Error bars denote SEM.

**Table I**. Group comparative data of training session intensity and electroencephalographic sleep details between lower and higher-intensity sport athletes.

| | LIS | HIS | P | Cohen's d |
|---|---|---|---|---|
| 0-50 % of $HR_{max}$ (min) | 70.05 ± 31.32 | 13.86 ± 14.63* | 0.001 | 2.30 |
| 51-60 % of $HR_{max}$ (min) | 22.32 ± 22.91 | 30.48 ± 12.88 | 0.40 | -0.44 |
| 61-70 % of $HR_{max}$ (min) | 3.87 ± 9.44 | 31.53 ± 13.14* | 0.001 | -2.42 |
| 71-80 % of $HR_{max}$ (min) | 0.05 ± 0.12 | 15.69 ± 4.7* | < 0.001 | -4.70 |
| 81-90 % of $HR_{max}$ (min) | 0 | 6.78 ± 4.71* | 0.004 | -2.04 |
| 91-100 % of $HR_{max}$ (min) | 0 | 1.66 ± 2.36 | 0.11 | -0.99 |
| Session duration (min) | 114.07 ± 36.59 | 116.83 ± 40.32 | 0.90 | -0.07 |
| Light Sleep (min) | 171.00 ± 33.20 | 184.63 ± 32.85 | 0.46 | -0.41 |
| Light Sleep (%) | 43.67 ± 6.77 | 48.13 ± 6.56 | 0.24 | -0.67 |
| Deep Sleep (min) | 104.00 ± 43.16 | 93.75 ± 21.59 | 0.57 | 0.30 |
| Deep Sleep (%) | 29.00 ± 11.45 | 24.13 ± 3.83 | 0.28 | 0.57 |
| REM Sleep (min) | 100.83 ± 38.10 | 102.88 ± 34.64 | 0.92 | -0.06 |
| REM Sleep (%) | 25.33 ± 8.41 | 26.13 ± 7.02 | 0.85 | -0.10 |
| WASO (min) | 2.167 ± 1.72 | 3.00 ± 2.39 | 0.48 | -0.40 |
| TST(min) | 386.83 ± 61.21 | 382.13 ± 61.78 | 0.89 | 0.08 |

*Note*: REM, rapid eye movement sleep; WASO, wake after sleep onset: TST, total sleep time; LIS, lower intensity sport; HIS, higher intensity sport; * indicates significant differences between LIS and HIS at an alpha level of $P < 0.01$; Data are mean ± SD.

**Table II**. Actigraph sleep characteristics, weekdays vs. weekend. n = 29

| | WD | WE | P | $\eta^2$ |
|---|---|---|---|---|
| Bedtime (hh:min) | 23:42 ± 00:35 | 00:37 ± 01:05* | <0.001 | 0.48 |
| Waketime (hh:min) | 06:29 ± 00:33 | 08:57 ± 01:21* | <0.001 | 0.81 |
| Time in bed (min) | 405.44 ± 28.73 | 497.72 ± 76.10* | <0.001 | 0.61 |
| WASO (min) | 74.73 ± 22.64 | 86.69 ± 40.84* | 0.009 | 0.23 |
| Awakenings (#) | 21.58 ± 4.23 | 27.54 ± 9.47* | <0.001 | 0.40 |
| Sleep efficiency (%) | 80.86 ± 8.56 | 80.91 ± 6.86 | 0.93 | 0.00 |
| TST (min) | 327.90 ± 32.79 | 407.74 ± 72.61* | <0.001 | 0.59 |

*Note*: WASO, wake after sleep onset: TST, total sleep time; WD, weekday; WE, weekend; *indicates significant differences between WD and WE variables at an alpha level of $P < 0.01$, Data are mean ± SD. Bedtimes and waketimes are expressed in 24-hour clock format.