

The Effects of Sleep Extension on the Athletic Performance of Collegiate Basketball Players

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Study Objectives: To investigate the effects of sleep extension over multiple weeks on specific measures of athletic performance as well as reaction time, mood, and daytime sleepiness.

Setting: Stanford Sleep Disorders Clinic and Research Laboratory and Maples Pavilion, Stanford University, Stanford, CA.

Participants: Eleven healthy students on the Stanford University men's varsity basketball team (mean age 19.4 ± 1.4 years).

Interventions: Subjects maintained their habitual sleep-wake schedule for a 2-4 week baseline followed by a 5-7 week sleep extension period. Subjects obtained as much nocturnal sleep as possible during sleep extension with a minimum goal of 10 h in bed each night. Measures of athletic performance specific to basketball were recorded after every practice including a timed sprint and shooting accuracy. Reaction time, levels of daytime sleepiness, and mood were monitored via the Psychomotor Vigilance Task (PVT), Epworth Sleepiness Scale (ESS), and Profile of Mood States (POMS), respectively.

Results: Total objective nightly sleep time increased during sleep extension compared to baseline by 110.9 ± 79.7 min ($P < 0.001$). Subjects demonstrated a faster timed sprint following sleep extension (16.2 ± 0.61 sec at baseline vs. 15.5 ± 0.54 sec at end of sleep extension, $P < 0.001$). Shooting accuracy improved, with free throw percentage increasing by 9% and 3-point field goal percentage increasing by 9.2% ($P < 0.001$). Mean PVT reaction time and Epworth Sleepiness Scale scores decreased following sleep extension ($P < 0.01$). POMS scores improved with increased vigor and decreased fatigue subscales ($P < 0.001$). Subjects also reported improved overall ratings of physical and mental well-being during practices and games.

Conclusions: Improvements in specific measures of basketball performance after sleep extension indicate that optimal sleep is likely beneficial in reaching peak athletic performance.

Keywords: Sleep extension, extra sleep, athletes, athletic performance, sports, basketball, collegiate, reaction time, mood, fatigue

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INTRODUCTION

Sleep deprivation has traditionally been the major approach to illuminating the role of sleep in human functioning. This research has documented the detrimental consequences of sleep restriction and the sleep debt that subsequently accumulates on cognitive function, mood, daytime sleepiness, and traditional performance indices such as reaction time and learning and memory tasks.¹⁻³ Several studies have also demonstrated the negative impact of sleep restriction on physical performance including weight-lifting, cardiorespiratory functioning, and psychomotor tasks that require accuracy and consistent performance.⁴⁻⁶ In general, our understanding of sleep via a sleep deprivation model has been fairly well documented and characterized.

Very few investigations have studied the converse: the impact of extended sleep over multiple nights to weeks; of the few that have, the study designs and results are inconsistent. Many of the limited number of previous sleep extension studies support the idea that obtaining additional sleep is beneficial to human functioning. For example, sleep extended to 10 h/night for 4 days resulted in decreased daytime sleepiness as assessed by

the Multiple Sleep Latency Test (MSLT).⁷ In undergraduate students, extending sleep resulted in faster reaction time, improved mood, and improvements in MSLT scores.⁸ The results from these 2 studies are supported by young adults who experienced improvements in both MSLT and mood testing after extended sleep independent of preexisting sleep debt.⁹ Additionally, obtaining sleep through napping after sleep loss has been shown to improve reaction time, sprinting times, and performance on vigilance tasks.¹⁰⁻¹² However, on the other hand, other previous studies have shown that 2 nights of extended sleep resulted in decrements in vigilance performance tasks¹³ and 4 days of sleep extended to 10 h in bed did not result in significant changes in cognitive performance tests.¹⁴ These variable results underscore that the effects of sleep extension have yet to be thoroughly investigated.

While sleep extension studies have begun to examine the relationship between obtaining extra sleep and cognitive functioning, minimal research has investigated the effects of sleep extension over relatively longer periods of time and on physical performance. Furthermore, little if any research has addressed how sleep extension specifically affects athletic performance, rather than just traditional indices of physical performance measured in the laboratory. To our knowledge, there are no studies to date that document sleep extension and the athletic performance of actively competing athletes.

The aim of the current study was to extend the nocturnal sleep duration of collegiate basketball players for a number of weeks and to examine the effects on specific indices of ath-

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letic performance as well as the traditional measures of reaction time, daytime sleepiness, and mood. With a better understanding of the relationship between total sleep time and athletic performance, athletes may be able to optimize training and competition outcomes by identifying strategies to maximize the benefits of sleep.

METHODS

Subject Selection Process

This study was conducted over 2 National Collegiate Athletic Association (NCAA) seasons (2005-2008) at Stanford University, where there are 35 varsity sports, 19 for women, 15 for men, and 1 coed, with approximately 800 total student athletes. During any given quarter of the academic calendar, approximately 11 sports are in-season although various sports' schedules span multiple quarters. Subjects were selected from a pool of undergraduate athletes that were currently participating in a varsity sport at Stanford University. The full roster of men's and women's sports whose main competitive season occurs during the collegiate winter quarter from January to March, when this study was initiated, received a general solicitation email. A sport was examined if ≥ 5 athletes responded in the 2005 season. Inadequate numbers, such as only 1-2 athletes per sport, would not be sufficient to draw generalized conclusions from because each sport investigates specific athletic performance measures not comparable across sports.

Next, a detailed screening questionnaire was administered to athletes who responded to the solicitation email inquiring about their current and past medical health as well as sleeping habits. Subjects were included if they were healthy, did not report current difficulties with their sleep, and were "in season" for their sport, regularly practicing, and competing in games or competitions. Subjects were excluded if they had existing injuries that prevented them from regular practice or games. Subjects were also excluded if they had a history of a sleep or psychiatric disorder, took medications with sleep related side effects, or had illicit drug use or other health concerns. Finally, athletes were excluded if they no longer had interest in participating, or were unwilling to or did not feel that they could comply with the study's protocol after the details were explained to them. The Stanford Panel on Human Subject Research approved the study and written informed consent was obtained from all subjects.

Study Design

Subjects maintained their habitual sleep-wake patterns for a 2-4 week baseline period during the NCAA basketball season and stayed within the limits of 6-9 h of subjective sleep time each night. Subjects then extended their nocturnal sleep duration for 5-7 weeks during which they obtained as much extra sleep as possible with a minimum goal of 10 h in bed per night. The baseline and sleep extension periods occasionally varied in length across subjects because of the academic schedule. Some subjects were allowed to enroll slightly later due to changes in their academic courses and schedule at the beginning of the quarter, which coincided with the study's initiation. During sleep extension, subjects were assigned final exams on different days which prevented some subjects from continuing the sleep extension

protocol. These slight variations in subjects' schedules resulted in the differences in baseline and sleep extension periods.

A regular sleep-wake schedule was strongly encouraged as well as daytime naps. Sleep duration, athletic performance, reaction time, daytime sleepiness, and mood measures were recorded throughout the baseline period and sleep extension. Subjects were required to sleep alone in their regular bedroom, except when traveling, during which subjects shared a hotel room with another teammate but slept in separate beds. Subjects were also required to refrain from alcohol and caffeine consumption throughout the study. The study was terminated when subjects could no longer obtain additional sleep each night or the academic quarter which they were enrolled in the study ended, preventing them from continued participation.

Traveling

Subjects frequently traveled to compete at other universities throughout the study which occurred during the regular NCAA basketball season. Travel duration typically was 3-5 days, occurring once to twice a month. Subjects traveled by bus and plane often within Pacific Standard Time zone, and occasionally crossed into Mountain and Central Standard Time zones. Most trips included travel to play games at 2 universities in different cities within the same state. The team's travel schedule included fluctuating times for flights, bus rides, practices, games, and team meetings. Consequently, subjects had less control over their sleep-wake times when traveling and thus frequently had atypical sleep-wake schedules for these 3-5 day periods. When subjects were not able to obtain 10 h of nocturnal sleep due to travel, they were encouraged to nap during the day.

Sleep-Wake Activity, Daytime Sleepiness, and Mood Measurements

To monitor daily sleep-wake activity, actigraphy was utilized in addition to subject reported daily sleep logs and journals. Actigraphy is an accepted method used to quantify sleep-wake activity based on subject movement.¹⁵ Actigraphy devices were worn on the wrist corresponding to the subject's dominant hand 24 h/day except during practices and games (AW-64, Philips Respironics, Andover, MA). The raw actigraphy data (1-min epoch length) was reviewed to remove periods of device malfunction. The nocturnal sleep and napping periods were manually determined from subject recorded sleep journals. Nocturnal sleep was defined as the period between subject reported bedtime and awakening time. Manually setting the nocturnal sleep periods to account for time zone changes during travel was also performed. Actigraphy sleep data was scored by a validated proprietary algorithm within the commercial software (Actiware software, Philips Respironics, Andover, MA). Subjects reported sleep-wake activity in sleep journals including time in bed, awakening time, minutes awake during the night, and hours napping during the day.

To assess the level of daytime sleepiness and monitor changes in mood states, the Epworth Sleepiness Scale (ESS)¹⁶ was administered during the baseline and at the end of sleep extension, while the Profile of Mood States (POMS)¹⁷ was recorded weekly. The ESS measures sleep propensity on a 0-3 scale in 8 standardized daily situations. Possible scores range from 0 to 24, with higher scores reflecting greater sleepiness. The POMS questionnaire is a psychological assessment commonly used to

monitor and compare distinct mood states. Subjects report on 65 identifiable mood states over the previous 7 days, which are categorized into 6 mood subscales: tension, depression, anger, vigor, fatigue, and confusion. The POMS questionnaire was hand-scored.

Athletic Performance Measures and Testing

Indices of athletic performance specific to basketball were measured after every practice to assess changes in performance. Practices were typically in the afternoon and athletic measures were correspondingly recorded typically between 12:00-15:00. The indices measured, including a timed sprint and shooting accuracy, were chosen because of their routine use during most practices and strong reflection of individual performance in basketball games. The first athletic performance measure was a timed 282 feet sprint (baseline to half-court and back to baseline, then to full-court and back to baseline) and was timed after each practice by the same person. The second and third performance indices were free throw and 3-point shooting accuracy. Specifically, shooting accuracy was assessed by a subject's successful attempts of 10 free throws (15 feet) and 15 three-point field goals (5 in the right corner of the court, then 5 directly facing the basket, and finally 5 in the left corner of the court). It is important to note that the official men's NCAA 3-point field goal line was extended from 19 feet 9 inches (6 subjects) to 20 feet 9 inches (5 subjects) from the basket starting in the 2008-2009 NCAA season. In addition, subjects' subjective mental and physical well-being were assessed after every practice and game by soliciting how they felt during the practice or game on a 10-point rating scale.

Psychomotor Vigilance Task

Subjects performed the Psychomotor Vigilance Task (PVT, Walter Reed Army Institute of Research, Silver Spring, MD) on a personal digital assistant (PDA) (Palm Pilot, Palm USA, Sunnyvale, CA) twice daily throughout the study. The PVT is a standard measure of reaction time and is commonly used to monitor changes in performance.^{18,19} Each 10-min trial consisted of stimuli occurring at intervals ranging from 2 to 12 sec. Subjects responded to the stimuli by pressing a button on the PDA using their dominant thumb. Due to differences in each subject's daily schedule (including academic classes, practices, and team meetings), subjects aimed to complete the 2 PVT trials during the same 1-h periods each day (e.g., 10:00-11:00 and 18:00-19:00 daily) to minimize the effects of circadian rhythms. On days that subjects were traveling, PVT trials continued to be conducted during the same 1-h time intervals based on the time zone in which subjects were located. Subjects also completed an additional PVT trial during their weekly meeting with study investigators. The PVT primary outcome of interest was mean reaction time; secondary outcomes were minimum, maximum, and median reaction times, and number of lapses > 500 millisecond.

Data Analysis

Subjective and objective sleep times were examined during the baseline and sleep extension periods. Total sleep time included nocturnal sleep as well as daytime naps. The initial 2-4 week period established baseline measures of sleep-wake activity, athletic performance, reaction time, daytime sleepiness, and

mood. Sleep times during sleep extension were compared to the mean sleep time for each subject to determine the change in sleep time.

Fixed-effects linear regression models examined the association between the day of the study and outcome measures including total sleep time, athletic performance measures, mean PVT reaction time, ESS, and POMS global and subscale scores. These models were necessary to compare outcome measures during baseline and sleep extension due to the repeated measures testing of individual subjects. All baseline data (considered as day 0) for outcome measures were incorporated into the regression analysis. Descriptive statistics for baseline and sleep extension periods are reported for all outcomes, with P-values determined using the regression models. P-values < 0.05 were considered statistically significant. There was no adjustment for multiple comparisons.

RESULTS

Study Population

Men's basketball was the only sport that satisfied the subject selection criterion of ≥ 5 athletes responding to the solicitation email during the 2005 season, and therefore was the sport examined in the present study. In total, 13 men's basketball players responded with interest, and ultimately 11 healthy undergraduate students (aged 18-22 y) on the Stanford men's varsity basketball team (mean age 19.4 ± 1.4 y) were enrolled in the study. Two were excluded because they were unwilling to or did not feel that they could comply with the protocol. Table 1 lists subjects' demographics and demonstrates no statistically significant difference between basketball players who enrolled in the

Table 1—Subject and non-participant demographics

	Subjects (N = 11)	Non-participants (N = 15)	P
Race			
Caucasian n (%)	2.0 (18.2)	N/A	
African American n (%)	9.0 (81.8)	N/A	
Sex			
Male n (%)	11.0 (100)	15.0 (100)	
Height (m)	1.93 ± 0.1	2.00 ± 0.1	0.06
Range	1.82 - 2.08	1.83 - 2.13	
Weight (kg)	88.3 ± 7.7	95.6 ± 8.9	0.04
Range	79.4 - 108.0	83.9 - 111.1	
BMI (kg/m ²)	23.7 ± 1.2	23.8 ± 1.1	0.80
Range	21.4 - 25.3	21.4 - 25.4	
Year in school	1.9 ± 1.0	2.2 ± 1.4	0.57
Range	1 - 4	1 - 4	
Position on team			
Guard n (%)	8.0 (72.7)	6.0 (40.0)	
Forward n (%)	2.0 (18.2)	6.0 (40.0)	
Center n (%)	1.0 (9.1)	3.0 (20.0)	

Data presented as mean ± standard deviation unless otherwise indicated; BMI (body mass index). Year in School – Freshman = 1; Sophomore = 2; Junior = 3; Senior = 4.

study and those who did not participate, with the exception of weight. Body mass index, which accounts for both height and weight, was not significantly different between the 2 groups.

Total Sleep Time

Total daily sleep time increased from baseline to sleep extension according to both objective actigraphy and subjective sleep journals (Table 2). Objective sleep time increased during the sleep extension period compared to baseline by 110.9 ± 79.7 min ($P < 0.001$). Subjective reports of total sleep time were significantly higher than actigraphy sleep time during both baseline and sleep extension.

Psychomotor Vigilance Task

During sleep extension compared to baseline, subjects demonstrated improved PVT performance during daily and weekly testing (Table 3). Mean reaction time for all daily and weekly

PVT periods significantly decreased ($P < 0.05$). Nearly all other PVT performance measures showed a significant improvement following sleep extension, notably a decreased number of lapses and daily minimum reaction time. Figure 1 presents the change in evening PVT mean reaction time during the sleep extension period compared to baseline.

Athletic Performance

Improvement was observed in all indices assessing basketball athletic performance (Table 4). Sprint time significantly decreased from baseline to the end of sleep extension (16.2 sec vs. 15.5 sec, $P < 0.001$), as illustrated in Figure 2. Subjects experienced a significant improvement in shooting accuracy, with an increase in both successful free throws out of 10 shots (7.9 vs. 8.8, $P < 0.001$) and successful 3-point field goals out of 15 shots (10.2 vs. 11.6, $P < 0.001$). Individual athletic performance measures are reported on a case-by-case basis for all subjects in Table 5. Subjects reported improved practice and game ratings after sleep extension ($P < 0.001$). The subjective ratings at baseline revealed a difference in mental and physical well-being between practices and games (6.9 and 7.8), however following sleep extension, subjects reported similar ratings during both practices and games (8.8).

Daytime Sleepiness and Mood

Both daytime sleepiness and mood improved as measured by ESS scores and POMS from baseline to the end of sleep extension (Table 6). These changes in the ESS scores indicate a substantial reduction in levels of daytime sleepiness. Although all POMS subscale scores demonstrated improvement, the marked changes in POMS vigor, fatigue, and total mood disturbance are particularly impressive.

DISCUSSION

In this study, subjects from the Stanford men's varsity basketball team experienced significant improvements in specific indices of athletic performance, reaction time, daytime sleepiness, and mood after sleep extension over 5-7 weeks. While many variables such as nutrition, conditioning, and coaching certainly contribute to athletic performance outcomes, sleep duration has not been directly studied as an important factor. To our knowledge, this is the first such study. Further understanding of the effects of sleep on athletic performance could benefit athletes at all levels.

Indirect evidence has shown previously that sleep may affect athletic performance, based on observational or retrospective examinations of circadian rhythms and circadian disruptions. These studies have demonstrated effects of circadian rhythms and suggest a negative effect of traveling between multiple time zones on athletic performance.²⁰ According to Kline et al., circadian rhythms affect collegiate swimmers, who demonstrated differences in maximal swim effort during trials at various times of the day.²¹ Other investigations on aerobic and anaerobic responses during high-intensity exercise have further verified these time of day differences

Table 2—Total sleep time per night during baseline and sleep extension

	Baseline	Sleep Extension	P
Subject sleep journals (min)	470.0 ± 65.9	624.2 ± 68.4	< 0.001
Mean days of data	18.2 ± 5.6	41.5 ± 3.3	
Actigraphy (min)	400.7 ± 61.8	507.6 ± 78.6	< 0.001
Mean days of data	17.7 ± 4.8	41.2 ± 3.3	

Data presented as mean ± standard deviation.

Table 3—Psychomotor Vigilance Task performance

	Baseline	End Sleep Extension	P
Weekly PVT			
Mean reaction time (ms)	310.84 ± 77.13	274.51 ± 42.01	0.004
Minimum reaction time (ms)	204.84 ± 52.86	198.10 ± 24.00	0.339
Maximum reaction time (ms)	963.13 ± 719.95	612.38 ± 381.02	0.011
Median reaction time (ms)	287.60 ± 65.91	261.43 ± 35.82	0.012
No. of times RT > 500 ms lapses	4.83 ± 4.34	1.29 ± 2.97	< 0.001
Mean days of data	2.64 ± 0.67	1.91 ± 0.30	
Daily Morning PVT (09:00-13:00)			
Mean reaction time (ms)	329.64 ± 45.44	285.86 ± 34.26	< 0.001
Minimum reaction time (ms)	215.61 ± 34.34	208.49 ± 30.72	< 0.001
Maximum reaction time (ms)	1030.7 ± 516.03	664.15 ± 390.09	< 0.001
Median reaction time (ms)	300.36 ± 38.11	268.77 ± 30.51	< 0.001
No. of times RT > 500 ms lapses	6.70 ± 5.89	1.53 ± 1.90	< 0.001
Mean days of data	10.89 ± 5.16	6.63 ± 5.06	
Daily Evening PVT (18:00-24:00)			
Mean reaction time (ms)	336.03 ± 50.10	285.91 ± 34.17	< 0.001
Minimum reaction time (ms)	215.35 ± 36.04	204.57 ± 27.84	< 0.001
Maximum reaction time (ms)	985.66 ± 439.63	602.22 ± 260.61	< 0.001
Median reaction time (ms)	307.93 ± 43.49	272.22 ± 27.23	< 0.001
No. of times RT > 500 ms lapses	7.07 ± 6.45	1.68 ± 2.34	< 0.001
Mean days of data	11.0 ± 5.52	10.13 ± 6.52	

Data presented as mean ± standard deviation. Daily afternoon (13:00-18:00) PVT data similar to morning and evening data but not shown.

in physical performance.²² In professional sports, Smith et al. found circadian rhythms affected games played by West Coast teams in the National Football League.²³ West Coast teams had a higher tendency to win not only home games, but also away games on the East Coast, likely due to differences in circadian rhythms between the two teams. Although the East Coast games were played at night, West Coast teams had not yet adjusted to the 3-hour time difference, and thus perceived the games to be closer to the late afternoon West Coast time, which has been suggested as a more optimal time of day for peak performance.²⁴⁻²⁶

In the current study, from baseline to the end of 5-7 weeks of sleep extension, there was an increase in mean basketball shooting accuracy as indicated by an increase in the percentage of successful shots for both free throws (9% improvement) and 3-point field goals (9.2% improvement). Following extended sleep, subjects also notably increased their speed resulting in faster sprint times (0.7 sec

Table 4—Athletic performance measures at baseline and end sleep extension

	Baseline	End Sleep Extension	P
282 feet sprint (sec)	16.2 ± 0.61	15.5 ± 0.54	< 0.001
Mean days of data	9.2 ± 3.6	6.9 ± 1.2	
Free throws (out of 10)	7.9 ± 0.99	8.8 ± 0.97	< 0.001
Mean days of data	9.2 ± 3.6	6.9 ± 1.2	
Three-point field goals (out of 15)	10.2 ± 2.14	11.6 ± 1.50	< 0.001
Mean days of data	9.2 ± 3.6	6.9 ± 1.2	
Subject self-rating at practices (1-10)	6.9 ± 1.41	8.8 ± 1.06	< 0.001
Mean days of data	8.9 ± 3.5	6.8 ± 1.3	
Subject self-rating at games (1-10)	7.8 ± 1.07	8.8 ± 1.19	< 0.001
Mean days of data	4.2 ± 1.7	3.7 ± 0.5	

Data presented as mean ± standard deviation.

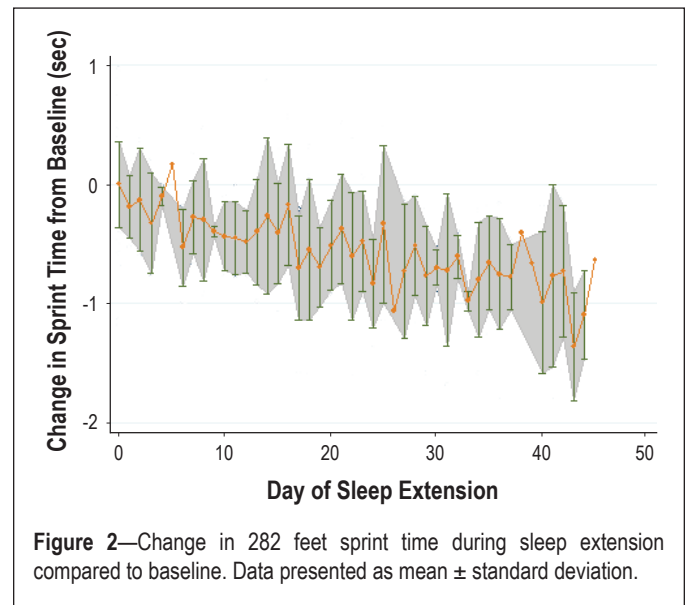
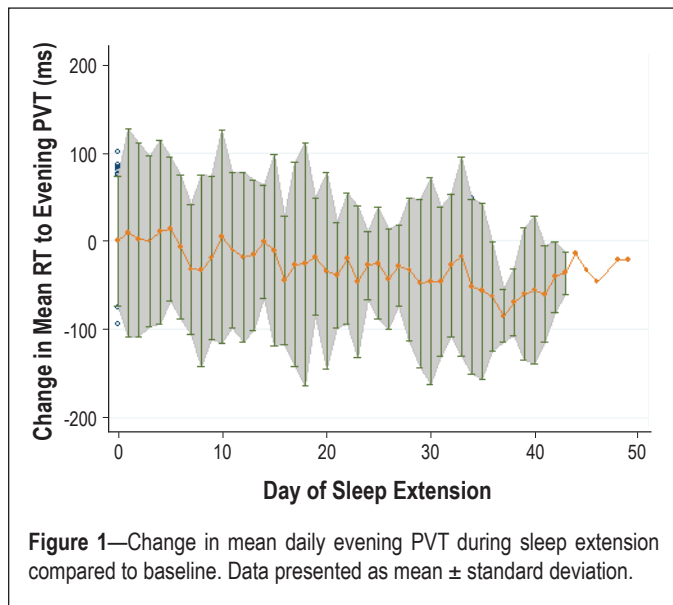


Table 5—Athletic performance measures at baseline and end sleep extension by subject

Subject	282 Feet Sprint (sec)		Free Throws (out of 10)		Three-Point Field Goals (out of 15)		Days of Data	
	Baseline	End Sleep Extension	Baseline	End Sleep Extension	Baseline	End Sleep Extension	Baseline	End Sleep Extension
1	15.62 ± 0.34	14.94 ± 0.28	8.7 ± 1.0	8.8 ± 0.7	12.1 ± 1.9	12.0 ± 1.7	13.0	8.0
2	17.38 ± 0.46	15.71 ± 0.08	7.7 ± 0.5	9.3 ± 0.7	9.2 ± 1.0	11.5 ± 1.1	6.0	8.0
3	15.84 ± 0.81	14.98 ± 0.17	7.6 ± 0.7	9.8 ± 0.5	9.5 ± 2.4	10.0 ± 0.8	8.0	4.0
4	15.74 ± 0.17	14.86 ± 0.13	7.9 ± 0.6	8.8 ± 0.7	7.9 ± 1.1	11.3 ± 0.7	9.0	8.0
5	16.76 ± 0.31	15.73 ± 0.38	7.6 ± 0.5	8.5 ± 0.9	6.8 ± 1.1	10.8 ± 0.7	5.0	8.0
6	16.19 ± 0.75	15.66 ± 0.40	8.0 ± 0.6	8.6 ± 1.4	9.7 ± 1.4	10.0 ± 1.2	7.0	7.0
7	16.76 ± 0.16	16.23 ± 0.11	8.1 ± 1.5	8.7 ± 1.1	8.1 ± 1.5	13.0 ± 1.5	8.0	7.0
8	16.00 ± 0.16	15.69 ± 0.16	8.1 ± 0.6	8.2 ± 1.5	11.7 ± 1.6	11.3 ± 1.0	9.0	6.0
9	16.45 ± 0.14	16.29 ± 0.04	7.3 ± 1.0	8.4 ± 0.5	10.7 ± 1.5	11.4 ± 1.4	9.0	7.0
10	15.91 ± 0.25	11.43 ± 1.40	8.0 ± 1.1	8.9 ± 1.1	11.3 ± 1.4	11.9 ± 1.2	18.0	7.0
11	16.65 ± 0.16	15.83 ± 0.09	7.4 ± 1.1	9.5 ± 0.5	9.6 ± 1.7	13.8 ± 0.8	9.0	6.0

Data presented as mean ± standard deviation.

Table 6—Daytime sleepiness and mood at baseline and end sleep extension

	Baseline	End Sleep Extension	P
Epworth Sleepiness Scale	9.64 ± 3.80	3.36 ± 1.69	< 0.001
Range	4 - 16	1 - 7	
POMS Vigor	11.71 ± 5.31	18.14 ± 5.57	< 0.001
POMS Fatigue	8.24 ± 5.28	1.45 ± 2.46	< 0.001
POMS Tension	5.26 ± 3.24	2.73 ± 2.25	< 0.001
POMS Depression	2.95 ± 3.53	0.59 ± 1.14	0.006
POMS Anger	4.24 ± 5.39	1.05 ± 1.68	0.002
POMS Confusion	4.79 ± 2.28	1.95 ± 1.40	< 0.001
POMS Total Mood Disturbance	13.76 ± 17.17	-10.36 ± 9.62	< 0.001

Data presented as mean ± standard deviation.

faster). The improvement in sprinting after obtaining additional sleep is consistent with the Waterhouse et al. study that found a short nap following partial sleep loss improved sprint time.¹² Similarly, the improvement in PVT reaction time seen in this study parallels an earlier investigation that found faster reaction time when nocturnal sleep was extended to 10 h/night for several days.²⁷ On the other hand, Belenky et al.¹⁸ showed that PVT speed in subjects who obtained 5 and 7 h of sleep demonstrated no evidence of recovery after 3 consecutive 8-h nights of sleep. This is similar to the nonsignificant changes in cognitive performance tests seen after 4 days of extended sleep.¹⁴ However, the sleep recovery and extension periods in both these studies may not have been of sufficient duration to reveal improvements in reaction time. In contrast, the present study involved a much longer period (5-7 weeks of sleep extension) and found a significant increase in PVT reaction time. It is likely that a longer period of sleep extension is crucial to obtaining significant PVT and other performance improvements.

We conducted this study under the assumption that the vast majority of collegiate athletes carry a sizable sleep debt due to chronic sleep deprivation. The total nightly baseline sleep time during this study (6.68 h) is consistent with the findings of previous studies examining the prevalence of insufficient sleep in the general public.²⁸⁻³⁰ Daytime sleepiness was confirmed by the baseline ESS scores as well as the substantial decrease in scores following sleep extension. This further supports the findings of Roehrs et al., in which sleep extension over 6 days improved alertness and reduced daytime sleepiness in sleepy subjects.²⁷ Furthermore, Barbato et al. revealed that by extending time in bed to 14 h/day for 4 weeks, subjects demonstrated mood and energy improvements.³¹ The results of the current study suggest similar trends consistent with these earlier investigations.

It is unclear whether this period of sleep extension eliminated all sleep debt. Without utilizing an MSLT, it is very difficult to determine whether objective sleepiness, and thus sleep debt, was completely eliminated. Nonetheless, the length of sleep extension in this study and the findings of decreased ESS scores indicative of reduced levels of daytime sleepiness suggest that subjects substantially reduced their sleep debt. Future studies could possibly utilize longer sleep extension periods. It is possible that at some point athletic indices, reaction time, and mood scores would no longer improve.

As with most sports, an athlete's mental approach is crucial for both training and competition. With an increase in total sleep time, subjects reported an improved self-perception of performance during practices and games. Subject testimonials corroborated these rating scores and suggested a subjective quicker physical recovery, improved weight training and conditioning, and fewer injuries. These findings suggest that obtaining extra sleep likely has beneficial effects on overall well-being and the mental approach to athletics. Further research can examine these findings in more detail.

A common assumption in most sports is that athletes become increasingly tired and fatigued throughout a season. Whether or not this is true, this study, by showing that sleep extension lowers POMS fatigue scores and improves POMS vigor ratings, indicates that these assumed negative mood changes can be avoided. Sleep extension may also contribute to athletic performance by minimizing the assumed cumulative effects of a lengthy season and limiting an athlete's perception of tiredness and fatigue. Additional sleep time improved mood even over the course of a competitive season. These results are consistent with the Kamdar et al. study⁸ that also noted mood improvements in the POMS fatigue and vigor subscales in undergraduate students following sleep extension for several weeks.

In summary, the traditional focus of both off-season and in-season training has been on daily training, conditioning, weight lifting, nutrition, and coaching. This was likewise the case for this study's subjects who attested they were already at their peak performance prior to starting the study, since they had just completed their pre-season training and were beginning regular season competition. However, after experiencing improvements in physical performance and mood following sleep extension, subjects acknowledged that they had previously misperceived the amount of sleep required to perform at their peak both physically and mentally. Thus, athletes should be better able to obtain their full athletic potential if optimal sleep is integrated into their daily training regimen.

While this investigation focused specifically on assessing basketball athletic performance, future studies will need to examine additional sports and improve the measurements of athletic ability. In particular, the number of performance tests as well as their ability to accurately reflect competitive performance should be further addressed. The more valuable measures of athletic performance will be those tailored to the particular sport of interest and those that directly assess performance during actual competition rather than practice.

More globally, accounting for differences between team versus individual sports is a critical consideration when examining other sports. For example, due to the heavy dependence on teamwork with others in sports such as basketball and football, it is difficult to clearly identify individual performance and a single player's effect on a game's outcome. Naturally, there are some sports where individual outcomes are fairly independent of teammates' actions and are already recorded by traditional statistics, such as batting average and pitching in baseball and serving percentage in tennis. These sports more readily lend themselves to comparing performance in actual competition. Furthermore, sports that are solely dependent on the individual, such as swimming and track and field, more easily compare individual competition outcomes.

This study was designed with the goal of examining sleep extension and athletic performance in a controlled setting. To this end, only standardized measures performed in practice that are readily repeatable were used to ensure that results were individually based and minimally reliant on a myriad of in-game variables, such as teamwork mentioned above. Other variables that also influence game performance include the opposing team, the subject's specific opponent, playing time, league standings, game situation, and the shot clock. Furthermore, additional factors that complicate interpreting game data include the varying distance of field goal attempts, the small number of shots a subject takes, and the limited number of games compared to practices. Importantly, subjective ratings from games were included, as they are not affected by the aforementioned factors.

Another important feature of this study is that it was conducted during the NCAA season and included an athlete's occasionally variable daily schedule of practices, games, and travel. By monitoring collegiate athletes during an actual competitive season, this study accurately reflects the potential improvements that sleep extension can have on athletic performance despite the inconsistent schedule of collegiate and professional sports. Furthermore, athletes were able to fulfill their typical personal, work, and training activities and obligations while also extending their total sleep time. In so doing, this study shows that extended sleep is realistically obtainable during training and competition.

The results of this study strongly suggest that the less frequently considered approach of extending total sleep time may perhaps be the one with the most potential for positive impact on athletic performance. For an athlete to reach optimal performance, an accurate knowledge of one's nightly sleep requirement and obtaining this amount should be considered integral factors in an athlete's daily training regimen. An additional factor to be considered beyond the nightly sleep requirement is how one's quality of sleep affects athletic performance, as it has been reported that a substantial number of elite athletes experienced poor sleep quality.³² It is clear that increasing the application of sleep knowledge within individual athletes and athletic programs can be a valuable and likely performance enhancing strategy in all sports at all levels.

Limitations

A typical collegiate basketball team includes 15 or fewer players who participate for at least 4 years, which naturally limited the number of potential subjects that could be enrolled simultaneously and resulted in a small sample size of 11 subjects. Future studies would benefit from enrolling a larger study population. Even so, this study was able to include a substantial percentage and representative sample of the basketball team over 2 seasons to investigate sleep extension. Furthermore, comparisons of subjects' baseline to sleep extension measurements rather than controls were employed due to the limited overall number of available and interested athletes on the team. Also, a traditional control arm in a study with actively competing athletes on the same team is very difficult, due to small team size and logistics, while using comparisons of subjects' baseline to sleep extension measurements allowed the investigators to elucidate relevant in-season performance in relation to sleep extension. Future studies would benefit from a traditional control arm if feasible.

Due to the travel schedule, subjects frequently had difficulty maintaining a rigid sleep-wake schedule because they did not have complete control over their sleep-wake times. When subjects were unable to reach the nightly sleep goal of 10 h, they were encouraged to nap during the day. Occasionally, actigraphy measurements were limited due to abnormal napping situations where movement was a result of the transportation by bus or plane rather than the subject. On a few rare occasions, such as immediately after a practice, subjects took daytime naps but were not wearing their actigraphy device. This resulted in lower actigraphy sleep time for a limited number of napping periods, and therefore, lower total objective sleep time overall.

This study was conducted in-season on the assumption that subjects were entering the study at a high performance level after training year-round and experiencing many of their typical physical performance gains during the off-season. Typically, an athlete's goal is to maintain their performance throughout the long season and ward off the effects of fatigue and wear on their bodies. Additionally, the athletic performance measures were not novel to the subject, as they had previously performed the drills during training on a regular basis for many years. For these reasons, this design aimed to minimize practice effects in athletic training. To help address the possible practice and attention effects that may have influenced outcomes, the number of days of data used for data analysis are included on Tables 2-5. We believe that all of the above supports the hypothesis that the observed effects are due to sleep extension. Furthermore, this study included 5 athletic performance outcomes, 2 assessments (ESS and POMS), and various PVT outcomes. Adjustment for multiple comparisons was not performed; however, the consistent pattern of changes across these measures may suggest that the changes are meaningful in spite of this lack of adjustment.

In regard to study design, this investigation aimed at beginning to elucidate the impact of sleep extension on athletic performance by examining repeatable measures in practice. This study design was employed because the controlled practice setting allowed for standardized and readily repeatable measures of performance with outcomes that are less attributable to the myriad of in-game variables. Although the goal of the present study was to begin to understand the role of sleep extension and the impact on specific athletic performance measures, there is clear value in investigating in-game performance, which could be examined in a larger future study.

Finally, alternative study designs, such as a Latin Square and controlled designs, could be considered for future studies and are likely feasible with traditional sleep study subjects obtained from a heterogeneous population who exercise recreationally. However, elite, collegiate athletes are highly unlikely to participate in these types of study design if the perceived or potential negatives outweigh the benefits as exemplified by the 2 athletes who declined to enroll after expressing initial interest. In our post-study conversations with athletes, they are unlikely to participate in a study if they obtain positive results because of a specific protocol, but then are precluded from adhering to this protocol because of the study design, such as in a Latin Square. Similarly, an athlete is unlikely to participate in any study with a perceived or potential negative effect on their performance or without possible benefit, such as in a control arm. This study had the special opportunity of using a study population of actively competing varsity athletes,

and recognizes that not having a control group or a crossover arm has its limitations. This population has its own unique challenges, but is a valuable population for examining whether sleep extension might have a role in athletic performance.

CONCLUSIONS

Extended sleep beyond one's habitual nightly sleep likely contributes to improved athletic performance, reaction time, daytime sleepiness, and mood. Improvements in shooting percentage, sprint times, reaction time, mood, fatigue, and vigor were all observed with increased total sleep time. These improvements following sleep extension suggest that peak performance can only occur when an athlete's overall sleep and sleep habits are optimal. Furthermore, this study reveals an athlete's inability to accurately assess how much sleep one actually obtains each night, thus leading to a misperception regarding the duration of sleep that constitutes adequate nightly sleep time. As additional knowledge further illuminates the relationship between sleep and athletic performance, it is likely that optimal sleep habits and obtaining adequate sleep will play an important role in peak performance in all levels of sports.

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