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Sleep, Recovery, and Performance: The New Frontier in High-Performance Athletics

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The relationship between sleep and post-exercise recovery (PER) and performance in elite athletes has become a topic of great interest because of the growing body of scientific evidence confirming a link between critical sleep factors, cognitive processes, and metabolic function. Although a complete understanding of the function of sleep in humans remains unknown and contested on many fronts, certain indisputable facts remain: sleep restriction (sleep deprivation) is linked causally to cognitive impairment [1]; there is interindividual variability in the response to sleep deprivation with respect to the degree of cognitive impairment [2]; and critical metabolic, immunologic and restorative physiologic processes are negatively affected by sleep restriction, sleep disturbance, and forced desynchrony of the human circadian sleep/wake phase [3].

Sleep has been identified by elite athletes, coaches, and trainers as an important aspect of the PER process, and is thought to be critical for optimal performance [4], even though there is little scientific evidence supporting this observation. The first comprehensive review of sleep and sport [5] concluded that

1) Little is known about the relationship between sleep to PER and performance in elite athletes.
2) Current interventions are based largely on clinical experience and evidence derived from research in other fields, far removed from elite athletics.
3) More sophisticated research methodology is required.

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Previous research in the fields of aviation, transportation, and the military has established that sleep is an active physiologic state, during which critical metabolic, immunologic, and cognitive/memory processes occur [6]. Sleep-deprivation studies have demonstrated a significant effect on glucose metabolism, appetite, and fat deposition [1]. Cognitive performance (psychomotor vigilance) has been shown to be directly affected by sleep deprivation, with a distinct interindividual variability in the response to various doses of sleep deprivation [2]. The impact of sleep disturbance on learning and neural plasticity has also been established. The positive or mitigating effect of recovery sleep (strategic napping) has been established as well in sleep-deprivation studies [3].

Current research performed to explore the relationship between sleep and PER and performance in athletes has been of questionable value because of the multiple variables affecting sleep in athletes, the limitations of the research methodology, and the small sample sizes. To establish an effective research plan, the first step is to identify the key sleep factors of interest (primary outcomes) and to identify valid, reliable measures for subjective capture of these data. With these tools, the relationship of sleep to PER and performance can be explored in a structured fashion. Sleep length (total sleep requirement: hours/night), sleep quality (sleep disturbance or fragmentation), and sleep phase (circadian timing of sleep) are the key factors affecting the overall recuperative outcome of the sleep state [7]. Valid, reliable, subjective and objective measures of these factors can be used to explore the relationship of sleep to PER and performance in athletes. This article describes the theoretic concepts, discusses the results of pilot study data and proposes future research directions.

Theoretical Concepts

Sleep requirement (total sleep time)

There is great interest and debate over the optimum amount of sleep (sleep length) required for humans to recuperate and function normally. Van Dongen and colleagues [2] have shown a dose-response relationship between hours of sleep deprivation and decline in cognitive function using the psychomotor vigilance task. Although a research subject's performance was relatively stable over the course of the experiment, there were significant differences among subjects in their responses to the negative effects of sleep deprivation [2]. In other words, different subjects respond differently to the same amount of sleep deprivation. Walker and Stickgold [3] have summarized the relationship of sleep to consolidation of skill memory and performance enhancement, concluding that sleep restriction poses a risk to sleep-dependent memory consolidation and neural plasticity. Thus a causal relationship exists among sleep, memory, and performance. These results substantiate the importance of adequate sleep (amount and quality) for athletes to ensure optimal performance when cognitive tasks and psychomotor vigilance is required. Human sleep deprivation studies support the assumption that sleep restriction (sleep debt) has a negative effect on neuroendocrine and immune function [8]. Critical metabolic and immune processes are known to occur during specific stages of sleep. Therefore, a critical relationship exists between physiologic recovery during the sleep state and an athlete's ability to train at maximum capacity with optimal results. Overtraining syndrome or chronic training fatigue is a common phenomenon that negatively affects athletes, and is believed to be predominantly the result of immunologic [9], neuroendocrinological [10], and musculoskeltal [11] factors. Therefore, determination of an athlete's total sleep need and ongoing sleep debt is likely a critical factor affecting PER, performance and susceptibility to overtraining syndrome.

Sleep quality (sleep disturbance)

Nonrestorative sleep is the descriptor used to account for the fact that some people get enough sleep (achieve their total sleep need) on a nightly basis, but the quality of the sleep is inadequate. Sleep quality is disturbed by sleep fragmentation as a result of recurrent arousal throughout the sleep period, without full awakening, or light sleep as a result of a hyperaroused state, with recurrent awakening throughout the sleep period [12]. Brief arousal and full awakening during the sleep period are associated with a sympathoadrenal response that negatively impacts sleep quality. Athletes who suffer with nonrestorative sleep may be tired from training as well as from not achieving the full restorative benefit of their sleep. Therefore, determining the athlete's sleep quality is another sleep factor that could be a critical determinant of PER, performance, and prevention of overtraining.

Timing of sleep (circadian phase)

The circadian timing of sleep directly affects sleep length and sleep quality. The circadian phase is both genetically and environmentally determined in humans [13,14]. Each athlete has a preferred sleep schedule that suits his or her circadian phase; however, training, school, and work commitments can have a substantial impact on the athlete's ability to match the circadian phase to the sleep schedule. If the circadian preference and sleep schedule are not matched and are out of phase, this will affect the amount and quality of the sleep. For example, night owls who prefer to go to bed later and sleep in (1 AM–9 AM) and who then have to wake up at 5 AM to train at 6 AM will curtail their sleep by 2 to 4 hours per night, missing critical periods of rapid eye movement (REM) sleep and slow wave sleep.

The clinical significance of sleep, recovery, and performance

Case 1

A 19-year-old male university swimmer presented with a 3-year history of increasing fatigue and inability to tolerate standard training volume and intensity, following a prolonged viral illness. The sleep history was significant for a lifetime of light nonrestorative sleep and intermittent violent myoclonic jerking in sleep. Teammates would not share a room with him because of his habit of banging the wall throughout the night. His mother reported an occasion when the athlete was sleeping in the passenger seat of a car and he struck her while she was driving. The provisional diagnosis was periodic limb movement disorder and nonrestorative sleep. The hypnogram of sleep (Fig. 1) revealed an absolutely normal night of sleep with appropriate sleep staging. The sleep electroencephalograph (EEG) revealed a pattern, referred to as alpha-delta intrusion, consistent with that seen in patients who describe "nonrestorative sleep." The synchronized digital video revealed normal myoclonic jerking in sleep. The key clinical factor in this case is the fact that this athlete is being chronically sleep restricted by 1 to 2 hours per day when morning training begins at 6 AM. The chronic sleep restriction deprives the athlete of a long period of REM sleep in the morning. The combination of chronic sleep restriction and REM sleep deprivation contributes to ongoing fatigue; impaired memory, cognition, and learning; and finally impaired immunologic function. This could account for the prolonged recovery from the viral insult.

Case 2

A 17-year-old female ice hockey goalie presented with initial insomnia and situational anxiety. She was diagnosed with a delayed sleep phase,

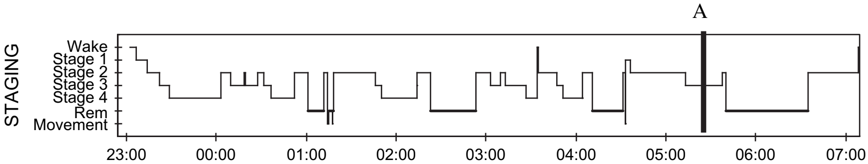

Fig. 1. Hypnogram: Progression of Sleep Staging through the night based on the sleep EEG. Nineteen-year-old national team swimmer sleep hypnogram from nocturnal polysomnography. Sleep staging on the X-axis descends from wake through stages 1 and 2 light non-REM sleep to stages 3 and 4 deep slow wave sleep to REM sleep (indicated by heavy black lines). The Y-axis indicates time 11:00 PM bed time and 7:00 AM wake time. The hypnogram represents a perfectly normal descent into sleep for a 19-year-old with slow wave sleep dominating the first third of the sleep period and a progressive increase in REM density and frequency toward morning intermixed with light stages 1 and 2. The key factor in the hypnogram is to note that rising at 5:30 AM (A) for early morning training clearly eliminates a large REM period on a daily basis and restricts the sleep chronically by 1–2 hours per day.

with a preferred sleep schedule of 1 AM to 9 AM. Attempts at going to sleep earlier than 11 PM resulted in a 2-hour sleep onset latency, causing anxiety over not being able to fall asleep. This was inadequately treated with a sedative/hypnotic (7.5 mg of zopiclone nightly at bedtime). She was waking early for training at 6 AM and having trouble with her training regimen. Once the delayed sleep phase was treated with a seasonal affective disorder (SAD) light [15], which advances the sleep phase by adjusting melatonin secretion, she was able to adjust her training schedule. She was then able to fall asleep earlier and wake spontaneously at 7 to 8 AM. She began going to the gym later, at 9 AM, and experienced major positive benefits in her training, including weight gain, improved strength, and better performance. The sedative medication was no longer needed once the sleep phase was advanced. Delayed sleep phase syndrome is a circadian rhythm disorder that is best treated with chronotherapy (SAD light and/or melatonin) and not a sedative/hypnotic. This case illustrates the importance of a comprehensive sleep assessment for determination of the cause of initial insomnia. Additionally, adjustment of the sleep phase improved the training regimen and response.

Case 3

A 20-year-old female university swimmer who had a 6-year history of chronic daytime fatigue and recurrent upper respiratory tract infections followed by a bout of mononucleosis was referred for a sleep assessment. The sleep history revealed a preference for a delayed sleep phase, predisposition to initial insomnia, and according to the parents, loud, disruptive snoring. She was referred for ongoing fatigue and possible sleep disorder. The medical workup for fatigue was negative. She was being treated for depression with 20 mg of citalopram every morning, and her mood was stable. Sleep history was unremarkable except for the snoring. A sleep apnea screening study was performed, and she had evidence of high upper airway resistance associated with the snoring [16]. This is a well-described phenomenon that is known to cause recurrent arousals throughout the night, similar to sleep apnea, as a result of partial closure of the airway, increased resistance to airflow, and increased respiratory effort. A therapeutic trial of an autotitrating positive airway pressure (autoPAP) device was done for 2 weeks, followed by 2 weeks off therapy. The patient noted a substantial improvement in her daytime fatigue with therapy. This case points to the importance of careful exploration of the sleep history in order to determine if any primary sleep disorders could be disturbing the quality of the sleep on a chronic basis.

These clinical cases exemplify the importance of determining the athlete's total sleep requirement, the presence of sleep disturbance/fragmentation, and the athlete's preferred circadian sleep phase. Evaluating these sleep factors may explain an athlete's ongoing problems with nonrestorative sleep and chronic training fatigue. More importantly, optimizing these sleep factors for the athlete may have a substantial impact on training, PER, and performance.

A pilot study of sleep quality and circadian sleep phase in competitive athletes

In an effort to determine the prevalence of poor sleep quality, circadian sleep phase preference, and possible sleep disorders in a spectrum of competitive athletes, a pilot survey of two groups of athletes was performed. The preliminary results of this pilot project are discussed below.

National sport school

The National Sport School (NSS) is a special school within the Calgary Board of Education for junior athletes in grades 9 through 12 (Table 1) that accommodates tier travel, training, and competition schedules. Forty-six athletes attended the 2-hour educational program. Each athlete/student anonymously completed the Pittsburgh Sleep Quality Index (PSQI) [17] and Athlete Morningness/Eveningness Scale (AMES) [18]. All athletes were offered a consultation with the sleep physician.

Pittsburgh sleep quality index

The PSQI is a validated, adult, self-report questionnaire providing a global score of sleep quality. The questionnaire is composed of 19 questions divided into seven component scores: (1) sleep quality, (2) sleep latency, (3) sleep duration, (4) habitual sleep efficiency, (5) sleep disturbance, (6) use of sleep medication, and (7) daytime dysfunction. There is no validated psychometric tool for the assessment of sleep quality in adolescents. The PSQI does provide some indication of sleep quality based on the above parameters, and has face validity for this pilot study. A global score of 5 or higher is considered to indicate poor sleep quality, although a more conservative score of 8 or higher is occasionally used. These cutoffs are based on the assumption that a total sleep time of 7 hours per night is

Table 1
National Sport School Demographics

(N[a] = 46)	n[b]	Percent (%)	Mean	Range
Age (yrs.)	46		15.58	14–18
Gender				
Male	25/44[c]	56.8		
Female	19/44[c]	43.18		

[a] Total Sample Size
[b] Group Sample Size
[c] Two did not indicate gender.

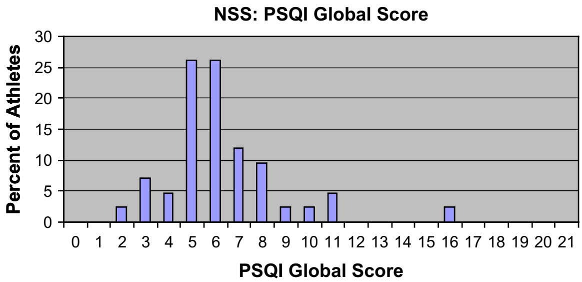

Fig. 2. National Sport School Pittsburgh Sleep Quality Index global score distribution. Approximately 85% of athletes surveyed scored greater than or equal to 5 on the PSQI, indicating a substantial prevalence of poor sleep quality in this pilot population of adolescent athletes.

adequate for an adult. However it is well-known and advocated by the National Sleep Foundation that adolescents require 8 to 10 hours of sleep per day [19]. Therefore, a PSQI global score cutoff of 5 or higher in this adolescent population likely underestimates the prevalence of poor sleep quality based on the parameter of total sleep time alone.

Students achieved global scores ranging from 2 to 16 (Fig. 2). Eighty-five percent of the athletes scored greater than or equal to 5, and 21% of the athletes scored greater than or equal to 8 (Table 2). Clearly there is a wide range of sleep qualities, with a preponderance of poor sleep quality in this population. In fact, most of these athletes were found to be getting less than 8 hours of sleep per night, and this would not be detected as abnormal using the adult scoring system. Therefore it is likely that a higher percentage of the athletes would have been found to be abnormal if the total sleep time was adjusted for age.

The athlete morningness/eveningness scale

The AMES is a four-item, self-report questionnaire designed to classify the respondent's chronotype in terms of preferred sleep/wake phase and preferred competition and training time. The questionnaire has not yet been validated, but is the only chronotype questionnaire specifically designed for athletes. The AMES provides a global score within a numeric

Table 2
National Sport School Pittsburgh Sleep Quality Index: Global Score Distribution

(N[a] = 42/46[b])	n[c]	Percent (%)	Mean	SD[d]	Range
PSQI Global Score			6.28	2.49	2–16
≥ 5	36	85.71			
≥ 8	9	21.43			

[a] Total Sample Size
[b] Four were invalid
[c] Group Sample Size
[d] Standard Deviation

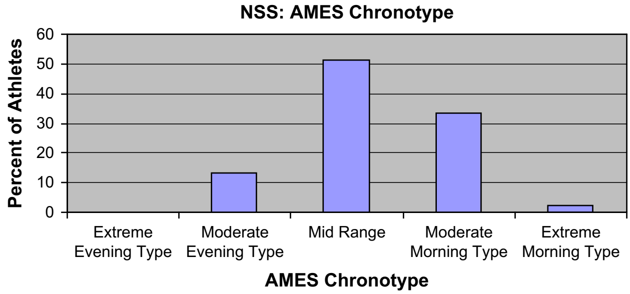

Fig. 3. National Sport School Athlete Morningness/Eveningness chronotype distribution. Only 13% of these adolescent athletes were classified as "Moderate Evening Type". The remainder of the athletes were classified as "Mid Range" or "Morning Type," which is contrary to what would be expected in this population. This finding may reflect the impact of environmental factors such as forced early awakening for training and school.

range of 10 (extreme evening type) to 31 (extreme morning type). Score categories break down in ranges as follows: extreme evening type (10–12), moderate evening type (13–17), mid-range type (18–23), moderate morning type (24–28) and extreme morning type (29–31).

The assumption in this adolescent population of athletes was that there would be a preponderance of moderate and extreme evening types, because of the normal tendency for the sleep phase to delay in adolescence. This would be a significant factor affecting total sleep time and scheduled morning training sessions in athletes whose sleep phase was delayed. The consequences are expressed as difficulty waking for morning training (common in swimmers) and chronically restricting the total sleep time because of difficulty falling asleep at night (initial insomnia). The author speculates that the origin of chronic training fatigue in elite adult athletes is related to inadequate time for recovery during critical adolescent years as a result of long-term chronic sleep restriction.

Interestingly and contrary to hypothesis, the results of the AMES indicate that most athletes (>85%) are mid-range to morning types (Fig. 3;

Table 3
National Sport School Athlete Morningness/Eveningness Chronotype Distribution

(N[a] = 45[b]/46)	n[c]	Percent (%)
AMES Chronotype		
Extreme Evening Type	0	–
Moderate Evening Type	6	13.33
Mid Range	23	51.11
Moderate Morning Type	15	33.33
Extreme Morning Type	1	2.22

[a] Total Sample Size
[b] One was invalid
[c] Group Sample Size

Table 4
Bobsleigh Canada Skeleton Demographics

(N[a] = 24)	n[b]	Percent (%)	Mean	Range
Age (yrs.)			27	21–36
Gender				
Male	10	41.67		
Female	14	58.33		

[a] Total Sample Size
[b] Group Sample Size

Table 3). Only 13% of the athletes are moderate evening types, and there were no extreme evening types (see Fig. 3; Table 3). Although the natural tendency toward a delayed sleep phase in adolescence may not be highly relevant, this tendency still occurs in more than 10% of such athletes, and should be evaluated and addressed in individual cases in order to improve sleep-related training and performance issues.

Bobsleigh Canada Skeleton

Bobsleigh Canada Skelton (BCS) incorporated a sleep education component into its 2007 summer training camp, consisting of four sessions, each 2 to 3 hours long, addressing the basic science of sleep, sleep disorders, and travel fatigue. Athletes who attended the sessions (Table 4) were asked to anonymously fill out the PSQI and AMES. All athletes were offered a consultation with the sleep physician.

Pilot survey results

The results of the PSQI for the BCS athletes were similar to the NSS results. Approximately 78% of the athletes had a global PSQI score of 5 or higher and 26% had a score of 8 or higher (Table 5; Fig. 4). Therefore, even with a conservative cutoff for poor sleep quality of 5, a substantial number of athletes suffer from poor sleep quality and would benefit from further clinical evaluation. More importantly in the BCS group more than 10% of the athletes have global scores above 10 which clearly indicates

Table 5
Bobsleigh Canada Skeleton Pittsburgh Sleep Quality Index: Global Score Distribution

(N[a] = 23[b]/24)	n[c]	Percent (%)	Mean	SD[d]	Range
PSQI Global Score			6.304	0.672	2–13
≥ 5	18	78.26			
≥ 8	6	26.08			

[a] Total Sample Size
[b] One was invalid
[c] Group Sample Size
[d] Standard Deviation

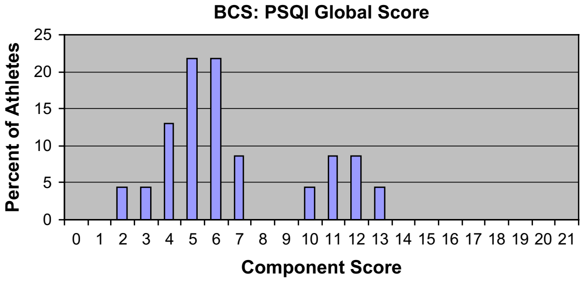

Fig. 4. Bobsleigh Canada Skeleton Pittsburgh Sleep Quality Index global score distribution. Approximately 78% of athletes surveyed scored greater than or equal to 5, indicating a substantial prevalence of poor sleep quality in this pilot population of adult athletes.

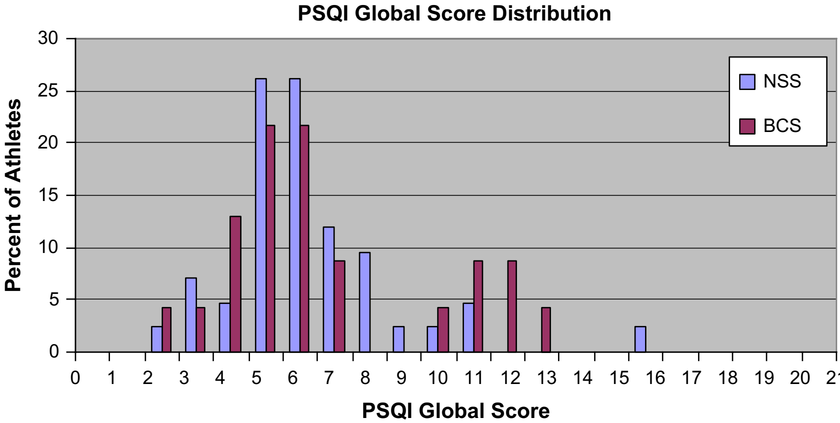

Fig. 5. PSQI Global Score Distribution National Sport School and Bobsleigh Canada Skeleton. The prevalence and distribution of abnormal PSQI global scores are similar in both groups of athletes, which suggests that sleep problems are common and occur throughout the lifecycle of an elite athlete.

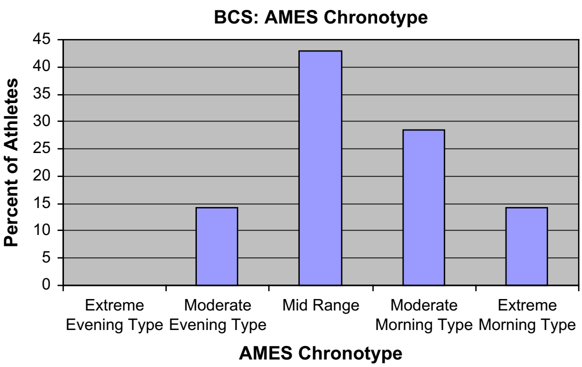

Fig. 6. Bobsleigh Canada Skeleton Athlete Morningness/Eveningess Chronotype Distribution. The distribution of chronotype in the adult athletes is in keeping with what would be expected in this age range.

Table 6
Bobsleigh Canada Skeleton Athlete Morningness/Eveningness Chronotype

(N[a] = 21[b]/24)	n[c]	Percent (%)
AMES Chronotype		
Extreme Evening Type	–	–
Moderate Evening Type	3	14.28
Mid Range	9	42.85
Moderate Morning Type	6	28.57
Extreme Morning Type	3	14.28

[a] Total Sample Size
[b] Three were invalid
[c] Group Sample Size

a significant sleep problem that requires further evaluation. The distribution of the global scores for both the NSS and BCS can be seen in Fig. 5 and reveals a similar distribution with a peak in the moderately abnormal range of 5–7 which displays the magnitude of the problem.

AMES results are more consistent with what would be expected in an adult population. More than 85% of the BCS athletes were in the mid-range to extreme morning type and there were no extreme evening types and only 14% were moderate evening types (see Fig. 6; Table 6).

Summary

A pilot study of sleep quality and circadian sleep phase in two groups of competitive athletes spanning the lifecycle of a typical athlete, from adolescence to adulthood, suggests that the prevalence of poor sleep quality is substantial. The author's hypothesis that a delayed sleep phase (evening type), a common phenomenon in adolescence, would be prevalent in this population was not upheld. Improved sleep screening and case detection is necessary to address the concerns of athletes, parents, coaches, and trainers regarding sleep issues. Future research should focus on the validation of a sleep screening tool, and the determination of prevalence and incidence of sleep problems in athletes. Finally, well-designed and appropriately powered studies investigating the relationship of sleep to training, PER, and performance need to be performed in order to address the fundamental question: do sleep restriction, circadian sleep phase, and sleep quality affect training response, PER, and performance in competitive athletes?

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