

Deliberate recovery: Exploring the relationship between sleep and expertise in athletes

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Abstract

The balance between training stress and recovery is essential in the pursuit of athletic performance; however, characteristics of recovery use among experts have been understudied. This thesis explored deliberate recovery in athletes by examining the relationship between expertise and sleep, a biologically necessary form of recovery. Over a 14-day period, 43 athletes recorded their sleep quantity, quality, and training load. A follow-up questionnaire assessed sleep chronotype and categorized athletes into three skill groups. Elite and pre-elite athletes reported sleeping significantly longer than non-elite athletes, starting significantly earlier in the night. In contrast, elite athletes reported significantly worse sleep quality than both pre- and non-elite athletes, with several possible explanations proposed for this deficit. Results indicate that sleep plays a greater role with higher-skilled athletes, supporting the idea of a differential use of recovery according to athlete expertise and encouraging further replication and exploration of the concept of deliberate recovery.

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Chapter One: Introduction

The pursuit of expertise is influenced by a variety of factors both outside and within the control of the individual (Davids & Baker, 2007). Among modifiable factors, the value of accumulating a large volume of consistent, purposeful practice has long been recognized, especially for the purpose of skill acquisition (Bryan & Harter, 1897, 1899; Simon & Chase, 1973). Ericsson, Krampe and Tesch-Römer (1993) added to this literature by describing how practice characteristics differed between three groups of violinists categorized according to their current and projected skill level. The authors concluded that individual differences in expertise were attributable to differences in the lifetime total of accumulated hours of the most effective type of practice, what they labelled *deliberate practice*. This concept has gone on to dominate the discussion of skill development and expertise over the intervening years, stimulating much debate over its exact role and importance (Davids & Baker, 2007; Tucker & Collins, 2012). While originally presented as the sole determinant of individual differences in expertise, it is now recognized as being a piece of a larger puzzle, albeit a very important one (Hambrick et al., 2014; Macnamara, Moreau, & Hambrick, 2016).

Deliberate practice is characterized as highly effortful, concentrated practice that is not inherently enjoyable, provides no immediate external rewards, and is designed and performed for the purpose of improving a desired skill (Baker & Young, 2014; Ericsson et al., 1993). The accumulation of hours of deliberate practice requires the management of three constraints collectively known as the Deliberate Practice Framework (Baker & Young, 2014; Ericsson et al., 1993): 1) The *resource constraint*, which recognizes the necessity of proper coaching, training facilities and equipment for optimal practice, and the money required to obtain each of them; 2) the *motivational constraint*, which highlights the motivational challenges required to consistently

perform difficult practice over a continuous period of many years, and; 3) the *effort constraint*, which recognizes both the very high level of physical and mental effort required in order for deliberate practice to be effective, and the adequate recovery required to repeat that level of effort at each and every practice in order to achieve optimal adaptation and learning.

In 2014, Baker and Young reviewed Ericsson and colleagues' (1993) original study in the context of the intervening twenty years of sport-related research performed in the area. The authors noted that while the topic had become prominent, research has been focused for the most part on a narrow subset of the conclusions originally made. This was especially noticeable for the effort constraint, where a great deal of research examined the effort involved in deliberate practice, but very little considered the corresponding patterns and characteristics of recovery undertaken to balance this effort (Baker & Young, 2014). Coining the term deliberate recovery to encompass potential findings, the authors called for the investigation of regenerative activities, stating that this may lead the academic community to "better understand the effort constraint, and, perhaps more importantly, account for variance in performance above and beyond deliberate practice alone." (Baker & Young, 2014, p. 150).

This focus on effort over recovery is mirrored in practical settings as evidenced by the consequences of pursuing high volumes of intense training in athletes. For instance, estimates of chronic injuries in adolescent athletes range from 46% to 54%, although these injuries are likely underestimated in literature based on reporting practices, and burnout/overtraining are reported to affect 30-35% of adolescent athletes from a variety of populations (DiFiori et al., 2014). These statistics suggest many athletes suffer negative outcomes and fall short of potential performances not due to a lack of work, but rather a lack of time or capacity to devote to recovery. Considering that expert performance requires several years and thousands of hours of

practice to develop (Baker & Young, 2014), achieving this outcome becomes not only a question of getting enough training of the right type at a high enough intensity, but also of surviving and adapting to the load this imposes on the body.

Deliberate recovery generally addresses the potential patterns and characteristics of activities of recovery employed for the purpose of improving performance. However, at present it remains a vague idea that has not been empirically explored or defined. While extensive knowledge exists regarding the merits of various forms of recovery for training (e.g., Dupuy, Douzi, Theurot, Bosquet & Dugué, 2018), very little is known about how these activities are employed by athletes of varying skill levels, or about how their use impacts the development of expertise in athletes, making deliberate recovery an idea ripe for investigation. The preliminary nature of any investigation in this area encourages a basic, exploratory approach. To this end, sleep represents the most basic form of recovery, necessary on a near-daily basis for all humans. Not limited by any issues of access or resources, the use of sleep is still subject to much variability based on how it is prioritized by the individual (Loft & Cameron, 2014), and this variability has measurable consequences on learning and performance (Fullagar, Skorski, et al., 2015; Simpson, Gibbs, & Matheson, 2017). As such, patterns of sleep timing and duration have been found to differ according to expertise among violinists (Ericsson et al., 1993), which suggests the possibility that skill-based effects could similarly be found among athletes.

The purpose of this thesis is to begin explorations into the notion of deliberate recovery by examining characteristics of sleep among athletes. A review of the relevant literature is presented to establish the role and importance of recovery in athletic development, provide evidence for the validity of sleep as recovery in athletes, and describe the current state of knowledge regarding sleep in athletes. Building on this review, I investigated how sleep differed

among athletes of different skill levels. More specifically, I explored how the quantity, quality, and timing of sleep are related to an athlete's highest level of competition.

Chapter Two: Literature Review

The term deliberate recovery comes from Baker and Young's (2014) review of the 20 years of research into deliberate practice since Ericsson and colleagues' (1993) formally introduced the concept. While deliberate practice continues to garner popular mainstream support (e.g., Coyle, 2009; Gladwell, 2008) and scientific discourse (e.g., Hambrick et al., 2014; Ericsson, 2014), Baker and Young (2014) noted that relatively little research had examined the importance placed by Ericsson et al. (1993) on experts' use of patterns of sleep, napping and leisure time to maximize the effectiveness and repeatability of their practice. Despite this, athletes consider recovery to be of great importance for their training and performance, and consistently rank sleep as among the most important recovery methods they use (Venter, 2014), supporting the results from Ericsson and colleagues' original study (1993). This literature review will provide a general overview of how recovery is used among athletes and how this is manifested in the patterns and characteristics of sleep in athletes.

Adaptation and Recovery

Our current understanding of rest and recovery originates from research on the General Adaptation Syndrome (GAS; Selye, 1950). According to this model, organisms regulate their biological systems with the goal of preserving a state of equilibrium called homeostasis. When homeostatic levels of a system are disrupted by a stressor, the organism will respond by managing the stressor in order to recover and restore homeostasis. If the organism is unable to cope with the stressor, the model predicts that finite resources will eventually deplete, resulting in the 'exhaustion stage' characterized as death, disease, or injury (Selye, 1950).

The general concepts of the GAS may be applied to sport contexts with athletic training serving as a stressor on the body. If sufficient recovery occurs before a subsequent stressor (i.e.,

the next training bout), then the athlete responds with corresponding growth and adaptation to the specific stimulus (Norris & Smith, 2002). When sufficient adaptation cannot occur the final 'exhaustion stage' of the GAS is represented by the concept of burnout, a psychophysiological condition characterized by emotional and physical exhaustion, preceded by staleness and overtraining on a continuum representing an imbalance between stress and recovery (Gustafsson, Kenttä, & Hassmén, 2011; Kellmann, 2010). Accordingly, avoiding these negative outcomes "can only be realized when athletes are able to recover and optimally balance training stress and subsequent recovery." (Kellmann, 2010, p.95-96).

Recovery is an essential process for ensuring a continued positive response to training, yet it is a broad term encompassing many different factors. The works of Kellmann and Kallus provide some insight; they define recovery as "an inter-individual and intra-individual multi-level (e.g., psychological, physiological, social) process in time for the re-establishment of performance abilities" (Kellmann & Kallus, 2001, p. 22). Furthermore, they have provided a list of general key features of recovery for sport:

- Recovery is a process in time and is dependent on the type of and duration of stress.
- Recovery depends on a reduction of stress, a change of stress, or a break from stress.
- Recovery is specific to the individual and depends on individual appraisal.
- Recovery can be passive, active, or pro-active.
- Recovery is closely tied to situational conditions.

(Kallus & Kellmann, 2000, as cited in Kellmann, 2010, p. 96)

Given how broadly the features of recovery are defined, they encompass a wide variety of practices currently undertaken by athletes. Active and pro-active interventions used for physiological recovery include sleep (e.g., Bonnar, Bartel, Kakoschke, & Lang, 2018),

nutritional interventions (e.g., Beck, Thomson, Swift, & von Hurst, 2015), cryotherapy/cold-water immersion (e.g., Bongers, Hopman, & Eijssvogels, 2017), active recovery (e.g., Van Hooren & Peake, 2018), compression garments (e.g., Brown et al., 2017), stretching (e.g., Weerapong, Hume, & Kolt, 2004) and massage therapy (e.g., Poppendieck et al., 2016).

Although not as well investigated as physical recovery interventions, athletes also recognize the importance of activities promoting psychological or social recovery such as prayer, socializing with friends, and discussion with coaches/teammates (Venter, 2014).

The concept of recovery in training includes not only specific activities and modalities of recovery, but also how they are organized in relation to training. The widely used practice of *training periodization* involves varying the type and timing of training stressors applied based on knowledge of the approximate time course of recovery from different types of training (Kiely, 2012). Knowledge of these patterns of recovery can be combined with the extensive understanding of individual recovery activities to enhance the effectiveness of recovery practices, either by accelerating the recovery time-course or by increasing the performance recovered within a specific time period (Dupuy et al., 2018). While situation-specific evidence exists for these advancements, there is a lack of knowledge concerning how these principles relate to the development of expertise.

Perhaps the best evidence of the relationship between recovery and expertise remains Ericsson et al.'s (1993) description of deliberate practice in violinists. Separate from the widely referenced retrospective accounts of hours of deliberate practice accumulated over their lifetime, participants were asked to complete a diary of all activities over a week, with several distinct patterns emerging between musician skill levels. Whereas the lowest skill group, comprising those likely to be future music teachers, spread their practice evenly over the course of the day,

the best violinists displayed two distinct clusters of practice, one in the morning and one in the afternoon or evening. These clusters appeared to be dictated by recovery needs, as the start and end times of the day allowed sufficient nighttime sleep, and a mid-day nap separated the two practice clusters (Ericsson et al., 1993). Accordingly, the best violinists slept more on average over the course of the week than the music teachers, and this held true when each of nighttime sleep and naps were considered separately.

To summarize, effortful work is necessary for the development of expertise, but it must be balanced by adequate recovery, a catch-all term representing a large variety of processes during which the actual improvement of the athlete occurs. There is some evidence of the deliberate use of sleep among skilled performers, and this fits with existing knowledge of sleep as a form of recovery.

Role of Sleep

Described as a “behavioural state of reduced movement and sensory responsiveness” (Fullagar, Skorski, et al., 2015, p. 162), sleep affects almost all human physiological processes (Halson, 2014). Sleep holds numerous functions, including decreasing the caloric demand on the body, replenishing energy stores in the body (and the brain specifically), exerting a bi-directional relationship with immune response, serving a glymphatic role through increased convective flow from the brain, restoring wake-induced performance degradation to use-dependent neuronal pathways, and enhancing neural connectivity by allowing specific kinds of neuronal growth and plasticity (Frank, 2006; Krueger, Frank, Wisor, & Roy, 2016). For example, four or more consecutive nights of six hours of sleep or less impairs appetite regulation (Spiegel, Tasali, Penev, & Van Cauter, 2004), glucose metabolism (Spiegel, Leproult, & Van Cauter, 1999), and immune function (Krueger, Majde, & Rector, 2011). From a hormonal perspective, sleep loss

increases cortisol and decreases testosterone and growth hormone (Chennaoui, Arnal, Sauvet, & Léger, 2015; Uchida et al., 2012), each of which play important roles in the physical development of athletes.

Sleep is necessary for adequate physiological health, but it has a potentially greater impact on neural and cognitive development (Frank, 2006). Halson (2014) summarized that sleep quality and quantity have been correlated with decrements in attention, concentration, perceptual function, language, memory, mood, and executive and intellectual function. One night of sleep loss has been found to inhibit executive functioning, particularly flexible thinking and learning, and inhibitory control (Goel, Rao, Durmer, & Dinges, 2009), while a good night of sleep improves speed and accuracy on a finger-tapping task (Walker, Brakefield, Morgan, Hobson, & Stickgold, 2002). A review by Walker and Stickgold (2005) found that the relationship between sleep and memory consolidation was independent of the simple passage of time and became greater with higher task complexity. While some criticize the methodology of these studies (e.g., Pan & Rickard, 2015), the potential benefits of sleep dependent learning could prove particularly relevant to the investigation of relationships between sleep and expertise. Although they encompass a broad range of outcomes, the common thread among these positions is that sleep allows the restoration or growth of bodily systems through the passive passage of time and absence of activity, and through active growth processes facilitated by the sleeping state.

Sleep and Athletic Performance

While the importance of sleep can be somewhat lost in the day-to-day life of the general population, athletic performance measures change in miniscule increments, making factors such as sleep critically important. When athletes are asked what form of recovery they find to be the most important, sleep is the consensus answer across sex, competition level and sport type

(Venter, 2014). With a full night of sleep deprivation, endurance tests (particularly submaximal tests or those measuring time to exhaustion) find large decrements in performance, which have been hypothesized as being due to an increased perception of effort or decreased motivation (Fullagar, Skorski, et al., 2015; Thun, Bjorvatn, Flo, Harris, & Pallesen, 2015). On the other hand, anaerobic performance, as measured through tests of maximum strength, sprint speed, jump height, or a Wingate bike test, is statistically unchanged the morning after a night of sleep deprivation, although performance may suffer if measured later that evening (Thun et al., 2015).

While studies of the effects of sleep deprivation on athletic performance show strong results, athletes are not often deprived of a full night of sleep on a regular basis. A more relevant design involves restricting sleep by only a few hours, a situation which occurs frequently in daily life. Sleep restriction appears to impair sport-specific skill execution, submaximal strength, and anaerobic power, yet have little effect on maximal measures of strength and one-time tests of maximal aerobic power. However, results should be interpreted with caution as studies in this area are contradictory and frequently use small sample sizes (Fullagar, Skorski, et al., 2015). Poorer overall mood states accompanied by decreased vigor and increased sleepiness, depression, and confusion, are also characteristic of sleep restriction, and could possibly affect motivation and perceived exertion during submaximal tasks (Fullagar, Skorski, et al., 2015; Reilly & Edwards, 2007). Impairments are also seen in cognitive features such as reaction time, attention, alertness, and decision making, suggesting acute sleep restriction has significant psychological effects (Fullagar, Skorski, et al., 2015; Reilly & Edwards, 2007). Taken together, these results suggest that the greatest effects of short-term sleep restriction are psychologically related, with greater consequences for performance situations that take a longer amount of time.

A summary example of the effects of sleep restriction can be seen through an intra-study comparison of swimmers with athletes from darts, tennis and handball. Sinnerton and Reilly (1992) found no negative effects of sleep restriction on gross motor outputs such as tests of strength, lung capacity and swimming performance times over 50m and 400m, whereas significant performance decrements were seen for accuracy in dart throwing (Edwards & Waterhouse, 2009), tennis serving (Reyner & Horne, 2013), and handball goalkeepers (Jarraya, Jarraya, Chtourou, & Souissi, 2014). Instead of performance, Sinnerton and Reilly (1992) found that sleep restriction had large effects on the swimmers' mood states, showing increased depression, tension, confusion and anger. This discrepancy between sports could show a higher susceptibility to sleep restriction for sports relying on fine motor skills, where attention, accuracy, alertness and decision making are of great importance, as compared to those relying mostly on gross motor skills (Fullagar, Skorski, et al., 2015).

In contrast to the numerous studies attempting to measure the effects of sleep loss on athletes, very few have considered the effects of extended sleep. In one such study (Mah, Mah, Kezirian, & Dement, 2011), a group of high level college basketball players were instructed to extend nighttime sleep as much as possible, staying in bed for a minimum of 10 hours each night. Objectively measured sleep duration among these athletes increased from an average of 6.7 to 8.5 hours per night, and athletes showed improved reaction time, subjective well-being, daytime sleepiness, mood states, and athletic performance in basketball-specific tests. Mah (2008, as cited in Halson, 2014) has also presented similar results with a group of swimmers, finding improvements in 15-meter sprint time, reaction time, turn time, and mood states after 6-7 weeks of at least 10 hours per night in bed. Similarly, increasing subjectively recorded sleep time from 7.1 to 8.9 hours per night was found to improve serving accuracy in college-level tennis

players after only one week of at least nine hours per night of sleep (Schwartz & Simon, 2015). A limitation to the study of sleep extension is the potential for effects to be derived simply from the alleviation of sleep debt, the accumulation of which is not uncommon in college-aged athletes (Mah et al., 2011). However, this limited sample of research suggests that athletes may benefit not only by limiting sleep loss, but also by extending their sleep beyond normal durations.

Naps have been suggested as a practical method for increasing sleep duration among athletes (Simpson et al., 2017). Naps can reduce sleepiness and benefit skilled learning (Postolache et al., 2005). Naps of any length have been suggested as beneficial (Thun et al., 2015), with the only drawback being the potential effects of sleep inertia, a residual grogginess experienced in the sleep-wake transition (Hilditch, Dorrian, & Banks, 2017). Very few studies have been conducted examining the recovery effect of naps on athletic performance. One study in which all participants were woken up at 3:00 AM found that a 30-minute nap improved 2-meter and 20-meter sprint performance in comparison to a no nap condition (Waterhouse, Atkinson, Edwards, & Reilly, 2007). A randomised crossover study of trained runners found that the effect of a 10 to 30-minute nap on a time to exhaustion test was dependent on the amount of nighttime sleep accumulated the night before, with those sleeping the least at night improving the most after a nap (Blanchfield, Lewis-Jones, Wignall, Roberts, & Oliver, 2018). These results fit with findings that elite athletes use naps strategically to recover from days with early morning or multiple training sessions (Forndran, Lastella, Roach, Halson, & Sargent, 2012). Despite the suggested benefits, athletes do not rate daytime naps as important for recovery (Venter, 2014) and several studies of sleep in athletes have reported infrequent use of naps. A study of 98 Dutch elite athletes reported naps on 18% of the days studied (Knufinke, Nieuwenhuys, Geurts,

Coenen, & Kompier, 2018), a study of 10 Australian Olympic swimmers reported naps on 23% of days studied (Forndran et al., 2012), and a separate study of 124 elite Australian athletes noted 184 naps among 1367 nights of data (13%; Lastella, Roach, Halson, & Sargent, 2015).

Measurement of Sleep

Samuels (2008) states that the recuperative outcome of sleep is based on three factors: sleep duration, sleep quality and sleep phase. Sleep duration is defined as the difference between the time the participant falls asleep and the time they wake up, although the exact definition of these markers varies according to the method of measurement (Halsen, 2014). Sleep quality is operationalized several ways in research according to the type of measurement used, including the number and length of sleep disturbances (Samuels, 2008), the delay between attempted and actual sleep times (sleep efficiency; Leeder, Glaister, Pizzoferro, Dawson, & Pedlar, 2012), or a subjective rating of one's personal satisfaction with their sleep (Krystal & Edinger, 2008). The American National Sleep Foundation (NSF) has published an initial report in an attempt to objectively measure sleep quality, finding consensus among a panel of experts regarding the following characteristics of good quality sleep: 1) a sleep latency of less than 30 minutes; 2) a maximum of one awakening during the night of greater than 5 minutes; 3) fewer than 20 total minutes of wake time after sleep onset, and; 4) a sleep efficiency of greater than 85% (Ohayon et al., 2017).

There are three main ways in which sleep quantity and quality are monitored. The 'gold standard' of measurement is polysomnography, a laboratory test which measures brain activity, eye movement, muscle activity and cardiac activity during sleep. Polysomnography is labour intensive and expensive, and generally used for diagnosing sleep disorders, but not often in applied sport research settings (Halsen, 2014). The second widely-used method is actigraphy,

where an accelerometer is worn on the wrist to measure body movement and results are cross-referenced with a sleep diary for confirmation of sleep onset and offset. Actigraphy is useful for studies of multiple nights of sleep as it is less expensive, non-invasive and more mobile than polysomnography, although it sacrifices accuracy and still represents a financial investment (Halson, 2014).

Much of the normative work in this field has been performed using wrist-watch actigraphy (units reported in published form). Leeder et al. (2012) found that athletes in four different individual sports slept an average of $6:55 \pm 0:43$ hours versus $7:11 \pm 0:25$ hours for a control group, with a sleep efficiency of 81% for athletes versus 89% for controls. Statistically significant sex differences were found, with females sleeping less on average ($6:56 \pm 0:44$ hours versus $7:06 \pm 0:28$ hours), but at a higher efficiency (83.9% versus 81.5%) than males. The authors also reported larger individual variation in all sleep variables for athletes as compared to controls, although this may be in part due to the short 4-day study period used. Similar to Leeder and colleagues, averages of 6.8 hours (Lastella et al., 2015) and $6:30 \pm 1:24$ hours of sleep (Sargent, Lastella, Halson, & Roach, 2014) were found for respective groups of Australian elite athletes from a variety of sports, and Mah et al. (2011) found a baseline of $6:41 \pm 1:02$ hours of sleep for members of an American collegiate basketball team. In contrast to these results, other studies also using wrist-watch actigraphy have reported total sleep times from 5.4 hours for elite swimmers (Sargent, Halson, & Roach, 2014) and up to $8:51 \pm 0:06$ hours for professional Australian Rules Football players (Richmond et al., 2007).

The final method of monitoring sleep is the use of questionnaires and sleep diaries without an accompanying objective measure. Several validated sleep questionnaires exist (e.g., Pittsburgh Sleep Quality Index; Buysse, Reynolds III, Monk, Berman, & Kupfer, 1989),

although these rely on general impressions over a long period of time (e.g., bed time over the last month) and as such provide only general information. Many different sleep diaries exist, although Carney et al. (2012) noted that standard metrics include nightly sleep onset latency, wakefulness after initial sleep onset, total sleep time, total time spent in bed, sleep efficiency (i.e., the proportion of time in bed spent asleep), and sleep quality or satisfaction.

The NSF recommends seven to nine hours of self-reported sleep per night for adults, noting that as few as six hours and as many as 11 hours for young adults (18-25 years of age) or 10 hours for adults (26-64) may be appropriate, although the need for sleep does decrease somewhat through late adulthood (Hirshkowitz et al., 2015). It has been suggested that athletes may need more sleep than the general population due to higher levels of activity (Mah et al., 2011), with some proponents advocating for up to 80 hours of total sleep per week, including both nighttime sleep and naps (Samuels, 2008). Athletic populations assessed using self-report methods seem to vary around these guidelines. Knufinke and colleagues (2018) reported a total self-reported sleep time of $8:11 \pm 0:44$ hours among 98 elite athletes from a variety of individual and team sports. Studies of team sport athletes have noted self-reported sleep times of $8:51 \pm 0:59$ hours for Australian football (Van Ryswyk et al., 2017), $7:50 \pm 1:06$ hours for college basketball (Mah et al., 2011) and $7:16 \pm 1:12$ hours for rugby league (Caia et al., 2018).

Questionnaires and diaries are much less expensive and easier to distribute than other measures of sleep; however, they are less accurate and subject to responder bias, even when assessed to be valid and reliable (Halsen, 2014). As such, discrepancies in total sleep time generally exist between subjectively and objectively recorded measures, with polysomnography and actigraphy reporting lower total sleep times than subjective diaries or questionnaires (Mah et al., 2011; Hirshkowitz et al., 2015). Caia and colleagues (2018) found a strong positive

correlation ($r = 0.85; \pm 0.03, p < 0.0001$) between sleep duration measured by wrist-watch actigraphy as compared to self-report diaries, with mean bias showing the subjective diaries to overestimate sleep duration by an average of 19.8 minutes as compared to actigraphy.

Both sleep length and quality are affected by an individual's circadian sleep phase; the preferred relative timing of an individual's sleep schedule within a 24-hour period (Samuels, 2008). A human's individual sleep-wake cycle is determined through the interaction of their endogenous circadian pacemaker with a homeostatic drive dependent on the duration of time spent awake (Wirz-Justice, 2007). An individual's circadian rhythm may be objectively monitored using a number of measures, including electroencephalography (Wirz-Justice, 2007), oral temperature (Horne & Östberg, 1976), or hormone levels (Randler et al., 2012). Based on these various measures, clusters of general preferred sleep-wake patterns have been identified. Known as sleep chronotypes, membership to these clusters may be subjectively assessed using a questionnaire format (e.g., Morningness-Eveningness Questionnaire; Horne & Östberg, 1976). The most common cluster schemes are based on having 'morning types' (sometimes called larks), and 'evening types' (sometimes called owls), with those in between either simply being 'intermediate types' or 'moderate morning' and 'moderate evening types' (Horne & Östberg, 1976; Lastella, Roach, Halson, & Sargent, 2016). A large general population sample from New Zealand found sleep chronotype to be largely independent of ethnicity, gender and socio-economic position (Paine, Gander, & Travier, 2006), although studies have shown a shift towards a greater proportion of morningness as participants age (Taillard, Philip, Chastang, & Bioulac, 2004; Paine et al., 2006).

Sleep chronotype has been found to largely determine time-of-day effects on athlete performance, with morning types performing better in the morning and evening types better in

the evening (Facer-Childs & Brandstaetter, 2015). Lastella and colleagues (2016) examined sleep chronotype in a group of elite athletes and found that in general, athletes tended to pick sports that matched their chronotype. Athletes in sports with typical morning practices were more likely than controls to be either morning or intermediate types, with only one evening type involved in a 'morning sport' and few evening types overall across both individual (cycling and triathlon) and team sports (cricket, field hockey, soccer).

Factors Affecting Sleep in Athletes

A variety of environmental factors affect the accumulation and experience of sleep in athletes, leading to generally poor sleep quality in elite athletes (Samuels, 2008). Some of the inter- and intra-study variation in athlete sleep may be explained in part by differences in sport type, as individual sport athletes have been found to sleep less than those from team sports (6.5h vs. 7.0h; Lastella et al., 2015). The culture and structure of the sport plays a large role in this, as individual sport athletes reported significantly earlier bed times and wake times in order to manage multiple practices within a day, usually starting with one early in the morning (Lastella et al., 2015). Early morning practices have been found to negatively impact sleep quantity and quality, especially if in conflict with the athlete's sleep chronotype (Forndran et al., 2012; Sargent, Halson, & Roach, 2014; Sargent, Lastella et al., 2014). In contrast, team sport athletes generally have late night games which delay sleep onset through later bed times, residual excitement, and exposure to artificial light (Lalor, Halson, Tran, Kemp, & Cormack, 2017).

Many environmental factors inherent in the lives of athletes influence daily sleep duration and quality, and as such studies in this area attempt to control or address some of these factors. For instance, a review of sleep and athletic performance (Fullagar, Skorski, et al., 2015) summarized that sleep duration, quality, and efficiency have all been found to decrease

significantly in the lead-up to competition, and further investigation by the same group of researchers found impaired sleep duration for elite football players after matches (Fullagar et al., 2016). As such, studies are typically performed in non-competitive training periods (e.g., Leeder et al., 2012), although consideration must be taken for sleep-disturbing factors such as excessive training loads, long-haul travel requirements (Gupta, Morgan, & Gilchrist, 2016), and novel hypoxic conditions (e.g, altitude training; Pedlar et al., 2005).

Despite extensive research into how different factors influence sleep in athletes, it is unknown whether the demonstrated effects change according to the skill level of the athlete. Research on sleep and recovery in athletes has tended to either use populations of elite athletes, or trained members of the general population, with no examination of whether patterns and characteristics differ for athletes of different levels of expertise. Descriptions of sleep among violinists suggest that these differences may exist (Ericsson et al., 1993), and the numerous benefits of sleep and recovery mean that further exploration of their optimal use is always warranted.

Rationale for the Current Study

Recovery is the essential counter-point to training-related stress in the pursuit of positive adaptations. Despite a rich understanding of practice, the patterns and characteristics of recovery used by elite athletes are not well understood. The purpose of this thesis is to begin explorations into the notion of deliberate recovery by examining characteristics of sleep among athletes. Sleep is a biological necessity for all humans and serves as the most basic form of recovery for growth and adaptation. Beyond basic functions, small variations in the characteristics of sleep show strong effects on human performance, especially when measured in athletic domain, implying that patterns and characteristics of sleep could play an influential role in the development of

expertise in athletes. While some research exists describing characteristics of sleep among elite athletes, it is unknown whether sleep differs between athletes of different skill levels, or whether features of sleep differ among levels of relative athletic skill. Therefore, it is the specific purpose of this thesis to compare the timing, duration, and quality of sleep between athletes of different skill levels. Based on the available literature, the following hypotheses were investigated: 1) Elite athletes will have a longer sleep duration than non-elite athletes; 2) Elite athletes will have earlier bed times and sleep onset times than non-elite athletes; 3) Elite athletes will have a higher self-rated sleep quality than non-elite athletes.

Chapter 3: Methods

Participants

Participants were included if they self-reported a) turning 18 years of age within the calendar year and b) actively training in an individual, aerobic-based sport as their main sport. The age criterion was used in an attempt to standardize the demands of daily living experienced by the participants and was based on differing sleep recommendations for teenagers compared to adults (Hirshkowitz et al., 2015). Sport type was restricted because athlete sleep duration and quality differ according to sport type (i.e., individual vs. team sport; Lastella et al., 2015) and because the effects of sleep loss differ according to the type of athletic performance measured (i.e., maximal strength versus submaximal aerobic performance; Fullagar, Skorski et al., 2015). Individual aerobic-based sports were selected because these sports have an established culture of keeping training diaries, as evidenced by their use numerous studies (e.g., Baker, Côté, & Deakin, 2005; Bartulovic, Young, & Baker, 2017), which was expected to minimize the novelty of the demands of the investigation. Additionally, these sports tend to display similar daily and weekly practice patterns, which have been found to have a large effect on sleep (Forn dran et al., 2012).

Participants self-selected the time period during which they completed the diary portion of the study (see sub-heading 'Procedures'), but they were guided by the following conditions:

1. The study period must take place in a non-competitive training period, meaning the athlete would not have any organized competitions during, or in the one week following the study period. This is because the physical and psychological stress of competition can alter sleep patterns in some athletes (Fullagar, Skorski, et al., 2015).

2. The study period must represent a relatively stable training load, because excessive or novel training loads can alter sleep patterns in some athletes (Gupta et al., 2016).
3. There must be a period of at least one week between returning from any "high-altitude" training and the beginning of the study period. Some athletes experience disrupted sleep at abnormally high altitudes, and in the period immediately after returning to normal altitude (Pedlar, 2005).
4. There must be a period of at least one week between taking any flights longer than six (6) hours, and the beginning of the study period. Long flights, especially between time zones, can disrupt sleep in many athletes (Gupta et al., 2016)

Adherence to these guidelines was left up to the athletes, although questions were included in the follow-up questionnaire to allow reporting of any transgressions.

Based on the inclusion criteria, 58 participants were recruited for the study. Participants were excluded from analysis if they did not complete any questionnaires during the diary period ($n = 2$), did not complete the follow-up questionnaire ($n = 2$), completed fewer than ten morning questionnaires ($n = 10$, see 'Results' section, sub-heading of 'Data cleaning'), or were an outlier based on sleep information ($n = 1$, see 'Results' section, sub-heading of 'Data cleaning'). As such, analysis for this investigation involved a sample of 43 athletes who provided information on a total of 562 nights of sleep. Male ($n = 19$) and female ($n = 24$) participants, aged 17-59 ($M = 24.23$, $SD = 9.34$) all reported currently living in Canada, with two reporting living the majority of their life in another country (Qatar: $n = 1$; St. Maarten: $n = 1$). The majority of participants had some post-secondary education ($n = 29$), as compared to those who had completed some secondary school ($n = 5$) or some graduate school ($n = 9$). Participants came from six different main sports: cycling ($n = 7$), competitive distance running ($n = 18$), nordic skiing ($n = 4$), rowing

($n = 10$), swimming ($n = 2$), and triathlon ($n = 2$). Athletes were grouped into three skill levels defined according to the Athlete Development Triangle (Gulbin, Oldenziel, Weissensteiner, & Gagné, 2010): elite athletes ($n = 11$), pre-elite athletes ($n = 18$), and non-elite athletes ($n = 14$). Athletes were considered elite if they reported participating in a senior international level of competition; pre-elite athletes were those who had competed at a junior international or senior national level; and the non-elite group contained those at all remaining lower levels of competition.

Research Design

A cross-sectional, between-groups design was used to compare the dependent variables (i.e., sleep duration, quality and chronotype) according to athlete skill level, considered the independent variable for the purpose of analysis. Information on sleep duration and quality was collected using a prospective daily self-report diary presented online. Further information was retrieved using a self-report follow-up questionnaire.

Measures

This study used three self-report online questionnaires: the ‘Sleep and Training Diary – Morning Section’, the ‘Sleep and Training Diary – Evening Section’ and the ‘Sleep and Training Follow-up Questionnaire’. Self-report measures were selected because they can be widely but inexpensively distributed. This was important considering the small absolute number of elite athletes participating in individual, aerobic-based sports in Canada necessitated recruitment across the entire country. Self-report measures are widely used in general sleep research (Carney et al., 2012), and they capture a respondent’s subjective perceptions of their sleep. Considering that athletes generally do not have access to objective measures of sleep on a daily basis, their

decisions surrounding how to organize sleep with their lives are based on these subjective perceptions, which is relevant to the descriptive nature of this study.

Sleep and Training Diary – Morning Section. Sleep duration and quality were measured using an adapted version of the Expanded Consensus Sleep Diary for Evening (CSD-E; Carney et al., 2012). Developed to standardize prospective sleep self-monitoring in studies of insomnia, this tool has been previously used to examine sleep in elite athletes (Knufinke et al., 2018). The CSD-E contains a morning portion to be filled out within an hour of waking, and an evening portion to be completed before bed. The morning portion of the CSD-E made up the entirety of the morning section of the diary and provided the following variables, listed with appropriate descriptions or the question used in the diary:

- Bedtime: “What time did you get into bed last night?”
- Time of attempted sleep: “What time did you try to go to sleep last night?”
- Time of sleep onset: “At approximately what time did you fall asleep last night?”
- Wake time: “What time was your final awakening?”
- Rise time: “What time did you get out of bed for the day?”
- Time in bed (TIB): The difference between rise time and bedtime.
- Total nighttime sleep time (TNST): The difference between wake time and time of sleep onset, less the duration of nighttime awakenings (i.e., $TNST = \text{Time of sleep onset} - \text{wake time} - \text{dWASO}$).
- Subjective sleep quality: “How would you rate the quality of your sleep?” Rated on a 5-point scale from ‘very poor’ to ‘very good’.
- Subjective feelings of refreshment: “How rested or refreshed did you feel when you woke up for the day?” Rated on a 5-point scale from ‘not at all rested’ to ‘very well-rested’.

- Sleep efficiency (SE): Proportion of time in bed spent asleep, expressed as a percentage (i.e., $SE = TNST / TIB$).
- Sleep onset latency (SOL): The difference between time of attempted sleep and the actual time of sleep onset.
- Frequency of nighttime awakenings (fWASO): “How many times did you wake up, not counting your final awakening?” WASO acronym stands for the technical term of ‘wake after sleep onset’.
- Total duration of nighttime awakenings (dWASO): “In total, how long did these awakenings last?”.

These variables were categorized as measures of nighttime sleep timing (bedtime, time of attempted sleep, time of sleep onset, wake time, and rise time), duration (TIB and TNST), and quality (SOL, SE, fWASO, dWASO, subjective sleep quality, and subjective feelings of refreshment). All of these nighttime sleep variables are standard in investigations of self-reported sleep in athletes (e.g., Knufinke et al., 2018). The wording, phrasing and question structure (e.g., open-ended, scale, etc.) of all individual questions were retained in the conversion from the CSD-E’s original paper-and-pencil form to the online platform.

Sleep and Training Diary – Evening Section. The evening questionnaire sent to participants contained items related to naps, training load and how many hours of work and/or school the participant had that day (see Appendix A for work/school results). The number and length of naps each day were reported using questions from the evening portion of the CSD-E, giving the sleep duration variable of total nap time (TNT), which could be combined with TNST to estimate total daily sleep time (TDST). To determine training load, participants were asked for the type (e.g., running, weights, basketball, etc.), general purpose (e.g., technique work,

recovery, aerobic work, etc.), duration and intensity of each training session. Intensity was determined using the Modified Rating of Perceived Exertion Scale (Foster et al., 2001), and was multiplied by the duration of the training session to determine the session rating of perceived exertion (sRPE), a previously validated reliable measure of training load (Foster et al., 2001).

Sleep and Training Follow-up Questionnaire. The follow-up questionnaire contained six sections, some of which were existing tools and others that contained questions developed specifically for the current investigation. Section 1 and 2 of the questionnaire collected demographic information using relevant sections of the Developmental History of Athletes Questionnaire (DHAQ; Hopwood, 2013). The full DHAQ uses structured, retrospective questions to address a range of potential influences on sport expertise development and has been validated with both male and female athletes competing at local up to international levels (Hopwood, 2013), and has been used in multiple investigations of athlete development (Hopwood, Farrow, MacMahon, & Baker, 2015; Hopwood, MacMahon, Farrow, & Baker, 2015). Section 1 of the current questionnaire used the portion of the DHAQ related to athlete characteristics including age, gender, country of residence (both current and that of the majority of their life), and education. Section 2 of the questionnaire used the portion of the DHAQ related to sport competition involvement. Specifically, athletes were asked to indicate their highest current level of competition achieved in their main sport using a provided list, which included junior and senior/open categories for each of recreational, local, provincial, national, and international competition. As mentioned, these ten competition levels were collapsed into the three groups (i.e., non-elite, pre-elite and elite) used as a measure of each athlete's skill level.

Sections 3 to 5 of the follow-up questionnaire included questions developed for this study. In section 3, participants indicated their consumption of sleep medication, alcoholic

drinks, and caffeinated drinks over the diary period (see Appendix B for results regarding alcoholic/caffeinated drinks). They were also asked if they have ever been formally diagnosed with a clinical sleep disorder, and whether this diagnosis was current. This was followed by questions to determine whether they had slept at an unfamiliarly high altitude or travelled more than six hours by plane within the past two weeks, both of which addressed conditions set for selecting the diary period. In order to assess the representativeness of the chosen 14-day time period across a number of different variables, in section 4 participants were asked to indicate, on a five-point Likert scale, how the past two weeks had been in comparison to a “normal” stretch of similar time over the past three months. This was asked for sleep duration, sleep quality, the number and duration of naps, training load, stress level, and mood. Finally, the use of sleep in this study as a representative activity of recovery is partially based on findings that athletes consider it to be their most important form of recovery (Venter, 2014). In order to determine whether this is applicable to the selected sample, section 5 contained questions that asked participants to indicate, on a five-point Likert scale, their subjective view of the importance of sleep: 1) as a form of recovery, 2) for overall athletic performance, 3) for activities of daily living.

Section 6 of the follow-up questionnaire determined an athlete’s sleep chronotype using the Morningness-Eveningness Questionnaire (MEQ). A respondent’s cumulative score on this 19-item tool is used to classify them as a morning-type, intermediate-type, or evening-type (Horne & Östberg, 1976). Originally validated in a sample of 18-32 year olds (Horne & Östberg, 1976), the MEQ is the most widely used subjective measure of sleep chronotype, and has been validated in several different populations ranging in age and ethnicity (e.g., Paine et al., 2006; Taillard et al., 2004). The MEQ is also the most frequently used measure of sleep chronotype

among studies of high level athletes (e.g., Lastella et al., 2016; Van Ryswyk et al., 2017). This tool was placed at the end of the follow-up questionnaire so as to avoid biasing the responses of participants both during the diary period, and throughout earlier sections of the follow-up questionnaire.

Procedure

Recruitment was conducted using a convenience sample of athletes contacted through coaches and sport administrators. Email addresses of coaches/administrators were initially retrieved where available from Canadian national, provincial, university and club team websites for the sports of canoe/kayak, cross-country running, cross-country skiing, cycling, rowing, triathlon, and swimming. Additional email addresses were obtained using snowball sampling (e.g., coaches/administrators referred me to colleagues). Introductory emails were sent to coaches/administrators explaining the study with an attached document that could be forwarded to athletes. The athlete document contained an explanation of the study, as well as a link to an online sign-up page (hosted by SurveyMonkey.com) where athletes confirmed they met inclusion criteria, indicated informed consent, provided an email through which they could be contacted, chose a start date for their participation in the study and indicated their local time zone (used to standardize the timing of emails to the individual). Using this information, participants were sent an email confirming their start date and assigned ID code.

This study involved two parts: a 14-day diary period, and a follow-up questionnaire. The day before the diary period began, participants were sent a reminder email re-iterating the study procedure. During the diary period, each day participants received a link to a morning questionnaire at 4:00 AM local time, to be filled out within an hour of waking, and a link to an evening questionnaire at 7:00 PM local time. The morning questionnaire contained items about

their previous night's sleep, and the evening questionnaire contained items about any naps, work hours, school hours, and training sessions that may have been undertaken during the day.

Morning and evening questionnaires were hosted on a secure survey site (SurveyMonkey.com) and both took participants an average of two minutes to complete.

The morning following the diary period, participants were emailed a link to a follow-up questionnaire containing items related to demographics, their current and predicted level of competition, sleep-related behaviours over the diary period such as consumption of alcohol and caffeine, the relative normalcy of their behaviours over the diary period, their sleep chronotype, and their relative importance they place on sleep in their training. This questionnaire was also hosted on a secure survey site (SurveyMonkey.com) and took participants an average of 11 minutes to complete. As thanks for their involvement, upon completion of the follow-up questionnaire participants received a document containing individual results regarding their sleep chronotype, as well as general information on optimal sleep duration and how to improve sleep quality.

An automatic email delivery system (Boomerang for Gmail) was used to standardize the delivery time for the study reminder, the morning questionnaire link, the evening questionnaire link, and the follow-up questionnaire link. This system malfunctioned one time for a period of two days (March 11th to 12th), and all emails were sent individually for these two days. All emails were sent at approximately their standard time, except for participants following Eastern Standard Time, who received their morning questionnaires at approximately 5:00 AM on these two dates.

Data Analysis

Data cleaning. The purpose of this thesis is to perform a between-groups analysis of sleep characteristics. As such, all nights of sleep were analyzed as independent units as opposed to within the context of the individual athlete (i.e., averaged across the study period for each participant). In order to provide sufficient context for each night of information and to avoid biasing results towards participants who completed more questionnaires, data were only included from participants who provided at least ten nights of information. Additional parallel analyses (one set considering participants who provided 12 or more nights of data, and one set with no limits on response rate) were also performed in all cases (see Appendices D through H), with no notable differences found in overall trends.

The following demographic variables were collapsed due to low expected cell counts. Country variables were derived from open-ended questions and were collapsed to the categories of ‘Canada’ or ‘other’. The athlete’s main sport was derived from an open-ended question and was collapsed to the categories of ‘cycling’ (including participant responses of “mountain biking”, “cycling”, and “cyclocross”), ‘distance running’ (includes responses of “cross-country”, “road racing”, “running”, “track and field”, and combinations thereof), ‘nordic skiing’ (includes responses of “nordic skiing” and “cross-country skiing”), ‘rowing’, ‘swimming’, and ‘triathlon’. Education was originally a nine-level question, collapsed to ‘some secondary school’, ‘some post-secondary school’, and ‘some graduate school’. Highest level of competition was originally a ten-level question, collapsed to ‘elite’, ‘pre-elite’ and ‘non-elite’. The representativeness of the diary period was originally assessed using a five-level question, with 1 being “much shorter/worse/fewer/lower than normal”, 2 being “somewhat shorter/worse/fewer/lower than normal”, 3 being “normal”, 4 being “somewhat longer/better/more/higher than normal”, and 5

being “much longer/better/more/higher than normal. As this question was intended to provide information about the general representativeness of the study period, options 2 to 4 were collapsed during analysis to make a middle category of “somewhat normal”.

Items answered using a time of day (e.g., bedtime) were checked for typos and the proper AM/PM designation. Changes were made based on illogical individual cases (e.g., bedtime of 10:00 AM) or calculated variables (e.g., a negative result for SOL) and confirmed by comparing the time in question to other entries from that day (e.g., bedtime versus time of attempted sleep and time of sleep onset). If the proper designation was not clear (e.g., unsure if the error was for the given bedtime or the given time of attempted sleep), then information for that night of data was deleted.

All variables were checked for outliers on a participant basis. Variables provided on a nightly basis were averaged across the 14-day diary period to provide a participant average, which was then assessed. This method allowed for the variability inherent in an individual’s day-to-day life (e.g., one very late bedtime after a party), while still ensuring meaningful analysis. Outliers were assessed as those values falling above the third quartile plus 1.5 times the interquartile range (75th percentile + 1.5 IQRs), or below the first quartile less 1.5 times the interquartile range (25th percentile – 1.5 IQRs).

Six participants reported an age 1.5 IQRs above the 3rd quartile, making them outliers. These participants were evenly distributed among the demographic variables of skill level, gender, education, sport, and country of residence. As such, they were included in all further analysis, although age was included as a covariate in the analysis of all continuous variables. Parallel analyses excluding these age outliers were also performed in all cases (see Appendices D through H), with no notable differences found in overall trends.

When nights of data were averaged across the study period for each participant, one athlete returned means more than 1.5 IQRs below the 1st quartile for all five sleep timing variables (bedtime, time of attempted sleep, time of sleep onset, rise time, and wake time). They were the only participant with outlying means for any measures of sleep timing, duration, or quality. Removing data for this participant significantly changed the results of all relevant analyses, and thus they were excluded from analysis.

Variables provided on a nightly basis were checked again for individual entries with extremely outsized effects using visual inspection of Q-Q plots. Based on this assessment, one night of data was deleted due to the disproportionate effect of one reported duration of nighttime awakenings, and seven reported frequencies of nighttime awakenings were transformed to a value equal to three standard deviations above the mean (Field, 2009).

‘Daylight saving time’ (DST) is the practice of advancing standard time forward by one hour in the spring and is observed in most regions of Canada (National Research Council Canada, 2017). In 2018, DST occurred on March 11th and coincided with the diary periods of 14 participants, who were instructed to fill out their questionnaires ‘according to the time shown by a correctly adjusted clock’. This meant that values recorded on March 11th for bed time, attempted sleep time, and sleep onset represented standard time, and values for final wake time and bed exit time represented DST. An eight-week examination concluded that the human circadian system, which regulates the timing of sleep and activity, of the included participants did not adjust to the imposition of DST (Kantermann, Juda, Mero, & Roenneberg, 2007), meaning that no simple correction could be made in the current study by removing certain days of data. Participants affected by the time change were evenly distributed across all demographic variables (i.e., skill, gender, sport, education and country of residence), and a full parallel

analysis found no notable differences in results. As a result, no accommodations were made for participants affected by the time change associated with DST.

Statistical analyses. Descriptive statistics were performed on all dependent variables, producing means and standard deviations for continuous variables and counts and the corresponding relative percentages for categorical variables. The assumption of normality was tested in continuous variables using a collective assessment of skewness, kurtosis, and whether the Kolmogorov-Smirnov test achieved a p -value $<.05$ (see Appendix C for results).

All dependent variables were examined for differences according to the independent variable of the participant's highest competition level achieved to date in their main sport. Differences were deemed statistically significant in all cases if $p \leq .05$. Continuous variables were analyzed using one-way between-subjects ANCOVAs, with both participant age and main sport type entered as covariates. Age affects sleep habits (Hirshkowitz et al., 2015) and the demands that work or school place on the participant, which are relevant considering the wide range of ages (17-59) represented in the current study. Further, the practice schedule and culture of a sport has been shown to significantly affect athlete sleep (Forndran et al., 2012), and although the inclusion of only individual endurance sports provides some homogeneity, schedules likely still differ across these sports. Effect sizes for ANCOVAs were estimated by partial eta squared (*partial* η^2) and significant main effects were followed up by pairwise comparisons, with Bonferroni adjustments made for multiple comparisons. Any means related to ANCOVA analysis are presented in their adjusted form. Multicollinearity was assessed by checking for correlations between the predictor variables of athlete skill, age, and main sport type. When the assumption of homogeneity of variance was violated for ANCOVAs, one-way between-subjects ANOVAs were run, with significant main effects followed up by Tukey's

honestly significant difference post-hoc tests and effect size estimated by eta squared (η^2). When the assumption of homogeneity of variance was violated for ANOVAs, Welch's F was calculated and significant main effects were followed up by Games-Howell post-hoc tests. This ANOVA procedure was also used whenever age and sport type are not noted as covariates (e.g., when analysing athlete skill x age). Self-rated sleep quality and refreshment were assessed using a five-point Likert-like scale and as such may be considered ordinal variables, however they were analyzed continuously based on statistical (Sullivan & Artino Jr., 2013) and field-specific (e.g., Knufinke et al., 2018; Caia et al., 2018) precedent.

Skill level differences in categorical independent variables were assessed using Pearson chi-square tests for independence, with effects sizes estimated using Cramer's V for nominal data, Kendall's tau-b (τ_b) for square cross-tabulations of ordinal data, and Kendall's tau-c (τ_c) for rectangular cross-tabulations of ordinal data. Due to low expected cell counts, statistical significance was determined using the Monte Carlo method (Field, 2009). Significant main effects were followed up by examining adjusted standardized residuals for each cell, with statistical significance determined by absolute values greater than or equal to 2 for 3x2 contingency tables. For larger tables, a Bonferroni correction was applied to the cut-off value of 2 in order to prevent Type 1 error. Significant contributing factors were further assessed using odds ratios.

Chapter 4: Results

Participant characteristics

A detailed breakdown of participant characteristics may be found in Table 1. The number of participants in each skill level group was not evenly distributed (Non-elite: $n = 14$; Pre-elite: $n = 18$; Elite: $n = 11$), although there was no significant association between skill level and the demographic variables of participant gender, $\chi^2(2) = 2.23, p = .367, V = .228$; the highest level of education achieved, $\chi^2(4) = 2.19, p = .725, \tau_b = .105$; or the participant's main sport, $\chi^2(10) = 4.42, p = .964, V = .227$. No significant effect of skill level was found on the mean age of participants, $F(2, 40) = 0.21, p = .980, \eta^2 = .001$, but sport type was significantly related to the mean age of participants, Welch's $F(5, 5.52) = 1.15, p = .432, \eta^2 = .411$, Levene's test, $F(5, 37) = 7.75, p = <.001$ (cycling: $M = 37.57; SD = 16.65$; distance running: $M = 22.28; SD = 4.65$; nordic skiing: $M = 20.50; SD = 1.92$; rowing: $M = 21.10; SD = 3.14$; swimming: $M = 20.50; SD = 2.12$; triathlon: $M = 22.00; SD = 4.24$). Three participants (7%) reported normally taking sleep medication, and five participants (12%) reported taking sleep medication over the past two weeks (PE: $n = 2, 11\%$; E, $n = 3, 27\%$). Of those five, three consumed sleep medication on four or fewer instances throughout the study, whereas two did every night. No athletes reported ever being formally diagnosed with a sleep disorder, or sleeping at an unfamiliar altitude (e.g., 1000+ ft. higher than usual) over the study period, meaning all athletes met inclusion criteria. Three athletes (7%) reported taking a flight within the study period, although no flights were longer than two hours, meaning all athletes met inclusion criteria.

Table 1: Participant characteristics organized by participant skill level

	Participant Skill Level				<i>p</i> -value	Effect Size
	Total (<i>n</i> = 43)	Non-Elite (<i>n</i> = 14)	Pre-Elite (<i>n</i> = 18)	Elite (<i>n</i> = 11)		
Participant age (SD)	24.23 (9.34)	24.14 (8.64)	24.00 (11.81)	24.73 (5.61)	.980 ^a	$\eta^2 = .001$
Participant sex (%)					.367 ^b	$V = .228$
Female	24 (55.8)	6 (42.9)	10 (55.6)	8 (72.7)		
Male	19 (44.2)	8 (57.1)	8 (44.4)	3 (27.3)		
Participant country – most of life (%)					.336 ^b	$V = .260$
Canada	41 (95.3)	14 (100.0)	16 (88.9)	11 (100.0)		
Other	2 (4.7)	0 (0.0)	2 (11.1)	0 (0.0)		
Highest level of education (%)					.725 ^b	$\tau_b = .105$
Some secondary	5 (11.6)	2 (14.3)	3 (16.7)	0 (0.0)		
Some post-secondary	29 (67.4)	9 (64.3)	12 (66.7)	8 (72.7)		
Some graduate	9 (20.9)	3 (21.4)	3 (16.7)	3 (27.3)		
Main sport type (%)					.964 ^b	$V = .227$
Cycling	7 (16.3)	1 (7.1)	4 (22.2)	2 (18.2)		
Distance running	18 (41.9)	8 (57.1)	6 (33.3)	4 (36.4)		
Nordic skiing	4 (9.3)	1 (7.1)	2 (11.1)	1 (9.1)		
Rowing	10 (23.3)	3 (21.4)	4 (22.2)	3 (27.3)		
Swimming	2 (4.7)	1 (7.1)	1 (5.6)	0 (0.0)		
Triathlon	2 (5.7)	0 (0.0)	1 (5.6)	1 (9.1)		

^a *p*-value reported is for ANOVA *F*-statistic

^b *p*-value reported is for chi-square test

Sleep Timing

A detailed breakdown of sleep timing results, presented in their unadjusted form, may be found in Table 2.

Bedtime. Bedtime was significantly related to the covariates of age, $F(1, 554) = 24.32, p = .<001, partial \eta^2 = .042$, and sport type, $F(1, 554) = 7.60, p = .006, partial \eta^2 = .014$, and there was a significant effect of skill level on bed time after controlling for the effect of age and sport type, $F(2, 554) = 3.93, p = .020, partial \eta^2 = .014$. Pairwise comparisons revealed that pre-elite athletes ($M = 11:03$ PM, $SE = 0:05$) reported going to bed significantly earlier than non-elite athletes ($M = 11:25$ PM, $SE = 0:05, p = .025$), although no significant relationship existed between elite athletes ($M = 11:05$ PM, $SE = 0:07$) and either group.

Time of attempted sleep. Time of attempted sleep was significantly related to age, $F(1, 556) = 26.10, p = .<001, partial \eta^2 = .045$, but not sport type, $F(1, 556) = 3.57, p = .059, partial$

Table 2: Measures of sleep timing presented according to participant skill level

	<i>n</i> =	Total	Participant Skill Level			<i>p</i> -value	<i>Partial</i> η^2
			Non-Elite	Pre-Elite	Elite		
Bedtime	559	23:11 (1:24)	23:26 (1:22)	23:03 (1:30)	23:04 (1:17)	.020	.014
Time of attempted sleep	561	23:29 (1:20)	23:45 (1:22)	23:21 (1:21)	23:21 (1:14)	.007	.018
Time of sleep onset	561	23:48 (1:19)	0:05 (1:16)	23:37 (1:23)	23:45 (1:12)	.002	.023
Wake time	561	7:27 (1:23)	7:24 (1:21)	7:26 (1:32)	7:33 (1:10)	.275	.005
Rise time	561	7:42 (1:24)	7:39 (1:21)	7:40 (1:34)	7:49 (1:11)	.232	.005

Notes: Means are presented in unadjusted form as times of day using the 24-hour clock; *p*-values and *partial* η^2 values reported are from ANCOVA testing where age and sport type were entered as covariates.

$\eta^2 = .006$, and there was a significant effect of skill level on time of attempted sleep after controlling for the effects of age and sport type, $F(2, 556) = 4.96, p = .007, \text{partial } \eta^2 = .018$.

Pairwise comparisons revealed that non-elite athletes ($M = 11:44$ PM, $SE = 0:05$) reported attempting to fall asleep significantly later than both pre-elite ($M = 11:21$ PM, $SE = 0:05, p = .011$) and elite athletes ($M = 11:22$ PM, $SE = 0:05, p = .041$), although no significant differences existed between pre-elite and elite athletes.

Time of sleep onset. Time of sleep onset was also significantly related to age, $F(1, 556) = 31.80, p = .<001, \text{partial } \eta^2 = .054$, but not sport type, $F(1, 556) = 1.71, p = .191, \text{partial } \eta^2 = .003$. There was a significant effect of skill level on time of sleep onset after controlling for covariates, $F(2, 556) = 6.50, p = .002, \text{partial } \eta^2 = .023$. Pairwise comparisons revealed that pre-elite athletes ($M = 11:36$ PM, $SE = 0:05$) reported falling asleep significantly earlier than non-elite athletes ($M = 12:04$ AM, $SE = 0:05, p = .001$), although no significant differences existed between elite athletes ($M = 11:47$ PM, $SE = 0:05$) and either group.

Wake time. Wake time was found to differ by age, $F(1, 556) = 74.25, p = .<001, \text{partial } \eta^2 = .118$, and sport type, $F(1, 556) = 15.97, p = .<001, \text{partial } \eta^2 = .028$, but there was no significant effect of skill level on wake time after controlling for the covariates, $F(2, 556) = 1.29, p = .275, \text{partial } \eta^2 = .005$. It should be noted that Levene's test was significant for this ANCOVA, $F(2, 558) = 6.87, p = .001$, but an ANOVA run without the covariates of age or sport

type found no significant effect of skill level on wake time, Welch's $F(2, 364.79) = 0.638, p = .529, \eta^2 = .002$, Levene's test, $F(2, 558) = 6.11, p = .002$.

Rise time. Rise time was significantly related to age, $F(1, 556) = 68.77, p = <.001$, *partial* $\eta^2 = .110$, and sport type, $F(1, 556) = 9.99, p = .002$, *partial* $\eta^2 = .018$, but no significant relationship was found for skill level after controlling for covariates, $F(2, 556) = 1.47, p = .232$, *partial* $\eta^2 = .005$. Levene's test was significant for this ANCOVA, $F(2, 558) = 7.64, p = .001$, but no significant effect of skill level on rise time was found in an ANOVA without the covariates of age or sport type, Welch's $F(2, 365.33) = 0.86, p = .424, \eta^2 = .003$, Levene's test, $F(2, 558) = 7.20, p = .001$.

Sleep Duration

A detailed breakdown of sleep duration results, presented in their unadjusted form, may be found in Table 3.

Time in bed. Time in bed (TIB) was significantly related to age, $F(1, 553) = 9.16, p = .003$, *partial* $\eta^2 = .016$, but not sport type, $F(1, 553) = 0.05, p = .826$, *partial* $\eta^2 = <.001$, and there was a significant effect of skill level on TIB after controlling for covariates, $F(2, 553) = 6.86, p = .001$, *partial* $\eta^2 = .024$. Non-elite athletes ($M = 8:12, SE = 0:05$) reported spending significantly less time in bed than both pre-elite ($M = 8:35, SE = 0:05, p = .025$) and elite athletes ($M = 8:45, SE = 0:07, p = .001$), with no significant differences between pre-elite and elite athletes. Levene's test was significant for this ANCOVA, $F(2, 558) = 7.64, p = .001$, but an ANOVA run without the covariates again found a significant effect of skill level on TIB, Welch's $F(2, 341.34) = 6.89, p = .001, \eta^2 = .023$, Levene's test, $F(2, 555) = 3.29, p = .038$, with the same significant post hoc relationships.

Table 3: Measures of sleep duration presented according to participant skill level

	<i>n</i> =	Total	Participant Skill Level			<i>p</i> -value	<i>Partial</i> η^2
			Non-Elite	Pre-Elite	Elite		
Time in bed	558	8:30 (1:24)	8:13 (1:14)	8:35 (1:24)	8:45 (1:34)	.001	.024
Total nighttime sleep time	560	7:31 (1:20)	7:15 (1:09)	7:43 (1:22)	7:34 (1:26)	.001	.025
Nights \geq 7:00 ^a		69.3	58.5	74.3	74.8		
Nights \geq 8:00 ^a		38.6	26.2	44.2	45.0		
Nights \geq 9:00 ^a		11.8	6.6	15.5	12.6		
Total nap time	110	0:57 (0:47)	0:35 (0:23)	1:01 (0:46)	1:11 (0:57)	.003	.103
# of naps	545	0.22 (0.46)	0.21 (0.48)	0.20 (0.43)	0.27 (0.49)	.350	.004
Total nap time (all days)	545	0:11 (0:31)	0:06 (0:17)	0:11 (0:30)	0:17 (0:41)	.011	.017
Total daily sleep time	516	7:42 (1:22)	7:21 (1:11)	7:54 (1:26)	7:49 (1:24)	<.001	.034
Nights \geq 7:00 ^a		70.7	61.0	75.1	75.0		
Nights \geq 8:00 ^a		42.4	28.9	49.3	47.2		
Nights \geq 9:00 ^a		17.2	8.8	22.1	19.4		

Notes: Means are presented in unadjusted form; *p*-values and *partial* η^2 values reported are from ANCOVA testing where age and sport type were entered as covariates.

^a Variable is reported as a percentage.

Total nighttime sleep time. Total nighttime sleep time (TNST) was significantly related to age, $F(1, 555) = 15.77, p = <.001, \textit{partial} \eta^2 = .028$, and sport type, $F(1, 555) = 9.72, p = .002, \textit{partial} \eta^2 = .017$, as well as skill level, $F(2, 555) = 7.18, p = .001, \textit{partial} \eta^2 = .025$. Pairwise comparisons revealed non-elite athletes ($M = 7:14, SE = 0:05$) reported sleeping significantly less each night than both pre-elite ($M = 7:43, SE = 0:05, p = .001$) and elite athletes ($M = 7:36, SE = 0:05, p = .030$), with no significant differences between pre-elite and elite athletes.

Number of daily naps. Out of 545 individual days where information was provided on naps, athletes reported taking a total of 120 naps, including nine days with more than one nap (two naps, $n = 8$; three naps, $n = 1$), for an overall average of 0.22 naps per day. Considering all individual days where information was provided on naps, both age, $F(1, 540) = 4.10, p = .043, \textit{partial} \eta^2 = .008$, and sport type, $F(1, 540) = 11.87, p = .001, \textit{partial} \eta^2 = .022$, were significantly related to the mean number of daily naps, but there was no significant effect of skill level, $F(2, 540) = 1.05, p = .350, \textit{partial} \eta^2 = .004$.

Total nap time. Athletes reported napping on 110 of 545 (20.2%) individual days. No significant association was found between skill level and the number of days which included a nap, $\chi^2(2) = 2.35, p = .317, V = .066$. When only those days including naps were considered, total nap time (TNT) was not significantly related to either age, $F(1, 105) = 3.76, p = .055, \text{partial } \eta^2 = .035$, or sport type, $F(1, 105) = .01, p = .941, \text{partial } \eta^2 = <.001$, but there was a significant effect of skill level on TNT after controlling for the covariates, $F(2, 105) = 6.04, p = .003, \text{partial } \eta^2 = .103$. Pairwise comparisons revealed that when they did nap, both pre-elite ($M = 1:01, SE = 0:07, p = .032$) and elite athletes ($M = 1:13, SE = 0:08, p = .004$) did so for significantly longer than non-elite athletes ($M = 0:33, SE = 0:08$), with no significant differences between pre-elite and elite groups.

Considering all days for which information on naps was reported (including if no nap occurred), total nap time (TNTall) was significantly related to sport type, $F(1, 540) = 8.14, p = .005, \text{partial } \eta^2 = .015$, but not age, $F(1, 540) = 3.71, p = .055, \text{partial } \eta^2 = .007$, and there was a significant effect of skill level on TNTall, $F(2, 540) = 4.57, p = .011, \text{partial } \eta^2 = .017$. Elite athletes ($M = 0:17, SE = 0:02$) reported significantly longer nap times than non-elite athletes ($M = 0:07, SE = 0:02, p = .008$), with no significant differences existed between pre-elite athletes ($M = 0:11, SE = 0:01$) and either group. Levene's test was significant for this ANCOVA, $F(2, 542) = 12.69, p = <.001$, but an ANOVA run without the covariates again found a significant effect of skill level on TNTall, Welch's $F(2, 305.00) = 5.01, p = .007, \eta^2 = .016$, Levene's test, $F(2, 542) = 15.96, p = <.001$, with the same significant post hoc trends.

Total daily sleep time. Total daily sleep time (TDST), representing the sum of TNST and the following day's TNT, was calculated only when information on both components was provided, regardless of their duration (i.e., TNT could still equal 0). TDST was significantly

related to age, $F(1, 511) = 18.98, p = <.001, partial \eta^2 = .036$, and sport type, $F(1, 511) = 4.21, p = .041, partial \eta^2 = .008$, and there was a significant effect of skill level, $F(2, 511) = 9.06, p = <.001, partial \eta^2 = .034$. Non-elite athletes ($M = 7:20, SE = 0:05$) reported accumulating fewer minutes of total daily sleep than both pre-elite ($M = 7:53, SE = 0:05, p = <.001$) and elite athletes ($M = 7:50, SE = 0:07, p = .003$), with no significant differences between pre-elite and elite athletes.

Sleep Quality

A detailed breakdown of sleep quality results, presented in their unadjusted form, may be found in Table 4.

Self-rated sleep quality. Self-rated sleep quality was significantly related to both age, $F(1, 554) = 7.57, p = .006, partial \eta^2 = .013$, and sport type, $F(1, 554) = 7.04, p = .008, partial \eta^2 = .013$, and there was a significant effect of skill level, $F(2, 554) = 4.63, p = .010, partial \eta^2 = .016$. Elite athletes ($M = 3.36, SE = 0.07$) rated their sleep as significantly worse than both pre-elite ($M = 3.60, SE = 0.05, p = .016$) and non-elite athletes ($M = 3.60, SE = 0.06, p = .029$), with no significant differences between pre-elite and non-elite athletes.

Subjective feelings of refreshment. Subjective feelings of refreshment were significantly related sport type, $F(1, 556) = 10.17, p = .002, partial \eta^2 = .018$, but not age, $F(1, 556) = .30, p = .583, partial \eta^2 = .001$, and there was a significant effect of skill level, $F(2, 556) = 4.05, p = .018, partial \eta^2 = .014$. Pairwise comparisons revealed that elite athletes ($M = 3.02, SE = 0.07$) reported feeling significantly less refreshed after waking up than non-elite athletes ($M = 3.30, SE = 0.07, p = .014$), with no significant differences between pre-elite athletes ($M = 3.19, SE = 0.06$) and either group.

Table 4: Measures of sleep quality presented according to participant skill level

	<i>n</i> =	Total	Participant Skill Level			<i>p</i> -value	Partial η^2
			Non-Elite	Pre-Elite	Elite		
Subjective sleep quality	559	3.53 (0.82)	3.59 (0.84)	3.60 (0.81)	3.38 (0.79)	.010	.016
Subjective refreshment	561	3.18 (0.90)	3.29 (0.89)	3.19 (0.92)	3.03 (0.89)	.018	.014
Sleep efficiency (%) ^{ab}	558	88.6 (8.4)	88.6 (8.5)	89.8 (7.3)	86.7 (9.3)	.003	.021
Nights \geq 85% ^a		75.3	73.8	79.9	70.2		
Sleep onset latency	561	0:19 (0:22)	0:19 (0:21)	0:15 (0:16)	0:24 (0:29)	.002	.023
Nights \leq 0:30 ^a		85.6	84.7	88.1	82.8		
fWASO	561	1.33 (1.66)	0.81 (0.94)	1.25 (1.71)	2.10 (1.96)	<.001	.089
Nights \leq 1 awakening ^{ab}		65.4	77.6	70.9	42.4		
dWASO	561	0:06 (0:11)	0:03 (0:07)	0:05 (0:10)	0:12 (0:15)	<.001	.089
Nights \leq 0:20 ^a		91.8	97.8	92.5	83.4		

Notes: Means are presented in unadjusted form; *p*-values and *partial* η^2 values reported are from ANCOVA testing where age and sport type were entered as covariates.

^a Variable is reported as a percentage.

^b NSF guidelines for the frequency of nighttime awakenings (fWASO) only include those of five minutes or longer, but the CSD-E asks for all awakenings, making comparisons invalid. This comparison is included only to illustrate between-group differences.

Sleep efficiency. Sleep efficiency (SE) was significantly related to age, $F(1, 553) = 4.24$, $p = .040$, *partial* $\eta^2 = .008$, and sport type, $F(1, 553) = 35.03$, $p = <.001$, *partial* $\eta^2 = .060$, and there was a significant effect of skill level, $F(2, 553) = 5.87$, $p = .003$, *partial* $\eta^2 = .021$. Pairwise comparisons revealed that elite athletes ($M = 86.9\%$, $SE = 0.7\%$) had significantly worse sleep efficiency than pre-elite athletes ($M = 89.8\%$, $SE = 0.5\%$, $p = .002$), although no significant differences existed between non-elite athletes ($M = 88.4\%$, $SE = 0.6\%$) and either group.

Sleep onset latency. Sleep onset latency (SOL) was significantly related to sport type, $F(1, 556) = 4.87$, $p = .028$, *partial* $\eta^2 = .009$, but not age, $F(1, 556) = 1.74$, $p = .188$, *partial* $\eta^2 = .003$, and there was a significant effect of skill level on SOL, $F(2, 556) = 6.52$, $p = .002$, *partial* $\eta^2 = .023$. Elite athletes ($M = 0:24$, $SE = 0:01$) took significantly longer to fall asleep than pre-elite athletes ($M = 0:15$, $SE = 0:01$, $p = .001$), with no significant differences between non-elite athletes ($M = 0:20$, $SE = 0:01$) and either group. Levene's test was significant for this ANCOVA, $F(2, 558) = 6.27$, $p = .002$, but an ANOVA run without the covariates of age or sport type found

a significant effect of skill level on SOL, Welch's $F(2, 307.20) = 6.13, p = .001, \eta^2 = .023$, Levene's test, $F(2, 558) = 7.04, p = .001$, with the same significant post hoc trends.

Frequency of awakenings after sleep onset. The frequency of awakenings after sleep onset (fWASO) was not significantly related to either age, $F(1, 556) = 3.51, p = .062, \text{partial } \eta^2 = .006$, or sport type, $F(1, 556) = 0.37, p = .542, \text{partial } \eta^2 = .001$, but there was a significant effect of skill level, $F(2, 556) = 27.27, p < .001, \text{partial } \eta^2 = .089$ with elite athletes ($M = 2.09, SE = 0.13$) reporting significantly more awakenings during the night than both non-elite ($M = 0.81, SE = 0.12, p < .001$) and pre-elite athletes ($M = 1.26, SE = .11, p < .001$), and pre-elite athletes also reporting significantly more awakenings during the night than non-elite athletes ($p = .017$). Again, Levene's statistic was significant, $F(2, 556) = 16.53, p < .001$, but an ANOVA run without the covariates found a significant effect of skill level on fWASO, Welch's $F(2, 316.64) = 29.16, p < .001, \eta^2 = .092$, Levene's test, $F(2, 558) = 16.05, p < .001$, with the same significant post hoc trends.

Duration of awakenings after sleep onset. The durations of awakenings after sleep onset (dWASO) were significantly related to age, $F(1, 556) = 26.70, p < .001, \text{partial } \eta^2 = .046$, and sport type, $F(1, 556) = 6.55, p = .011, \text{partial } \eta^2 = .012$, and there was a significant effect of skill level on dWASO after controlling for the covariates, $F(2, 556) = 27.23, p < .001, \text{partial } \eta^2 = .089$. Pairwise comparisons revealed that elite athletes ($M = 0:12, SE = 0:01$) reported longer awakenings during the night than both non-elite ($M = 0:04, SE = 0:01, p < .001$) and pre-elite athletes ($M = 0:05, SE = 0:01, p < .001$), with no significant differences between non-elite and pre-elite athletes. Once again, Levene's test was significant for this ANCOVA, $F(2, 558) = 28.56, p < .001$, but an ANOVA also showed a significant effect of skill level on

dWASO, Welch's $F(2, 317.78) = 22.03, p = <.001, \eta^2 = .093$, Levene's test, $F(2, 558) = 25.45, p = <.001$, with the same significant post hoc trends.

Sleep Chronotype

A detailed breakdown of results for sleep chronotype score and categories, presented in their unadjusted form, may be found in Table 5. Three participants did not answer one of the 19 questions that make of the MEQ (Horne & Östberg, 1976), and as such could not be assessed for chronotype. Sleep chronotype score was significantly related to age, $F(1, 35) = 8.81, p = .005$, *partial* $\eta^2 = .20$, and sport type, $F(1, 35) = 5.98, p = .020$, *partial* $\eta^2 = .15$, but no significant effect of skill level on chronotype score was found after controlling for covariates, $F(2, 35) = 1.03, p = .367$, *partial* $\eta^2 = .056$. Despite this, a non-significant trend indicated that on average, non-elite athletes ($M = 54.3, SE = 2.6$) reported lower sleep chronotype scores (i.e., more towards the 'evening-type' end of the scale) than pre-elite ($M = 58.2, SE = 1.9$) or elite athletes ($M = 58.3, SE = 2.4$).

Chronotype scores were categorized into morning-type ($n = 17$), intermediate-type ($n = 20$), and evening-type ($n = 3$) groups using the MEQ classification system (Horne & Östberg, 1976). Chi-square analysis revealed no significant association between skill level and sleep chronotype, $\chi^2(4) = 2.65, p = .685, \tau_b = .142$. No adjustments were made because chi-square analysis revealed no significant association between sport type and sleep chronotype, $\chi^2(10) = 12.51, p = .257, V = .395$, and analysis of variance found no significant differences in age between chronotype groups, $F(2, 37) = 2.11, p = .136, \eta^2 = .102$. Levene's test was significant for this ANOVA, $F(2, 37) = 8.64, p = .001$, but Welch's F could not be derived because there was no variance in age within the evening type group (i.e., all three evening types were 19 years of age). On average, morning types ($M = 27.5, SD = 13.2$) were older than intermediate types

Table 5: Mean sleep chronotype scores and sleep chronotype frequency distribution presented according to participant skill level

	Total	Participant Skill Level			<i>p</i> -value	Effect Size
		Non-Elite	Pre-Elite	Elite		
Sleep chronotype score (SD)	57.05 (8.72)	53.75 (11.35)	58.24 (8.40)	58.82 (4.81)	.367 ^a	.056 ^a
Sleep chronotype category					.685 ^b	.142 ^b
Evening-type (%)	3 (7.5)	2 (16.7)	1 (5.9)	0 (0.0)		
Intermediate-type (%)	20 (50.0)	6 (50.0)	8 (47.1)	6 (54.5)		
Morning-type (%)	17 (42.5)	4 (33.3)	8 (47.1)	5 (45.5)		

Notes: Three participants (2 non-elite and 1 pre-elite) removed due to incomplete information; means are presented in unadjusted form.

^a *p*-values and effect size (*partial* η^2) derived from ANCOVA testing where age and sport type were entered as covariates.

^b *p*-values and effect size (Kendall's τ_b) derived from chi-square testing

($M = 21.9$, $SD = 4.8$), although this difference was not statistically significant, $t(19.60) = -1.65$, $p = .115$, Levene's test, $F(35) = 13.23$, $p = .001$.

Training

Table 6 provides a detailed breakdown of results for training-related variables presented in their unadjusted form.

Practice days. Participants reported engaging in practices on 434 of 547 (79%) recorded days. No significant association was found between skill level and practice days, $\chi^2(10) = 12.51$, $p = .257$, $V = .395$, although elite athletes (84%) reported practicing on a slightly greater proportion of days than pre-elite (77%) or non-elite athletes (79%).

Training sessions. The mean number of training sessions was not significantly related to age, $F(1, 542) = 1.34$, $p = .248$, *partial* $\eta^2 = <.01$, or sport type, $F(1, 542) = .15$, $p = .702$, *partial* $\eta^2 = <.001$, but a significant effect of skill level on mean training sessions was found after controlling for covariates, $F(2, 542) = 4.63$, $p = .010$, *partial* $\eta^2 = .017$. Elite athletes ($M = 1.20$, $SE = .06$) averaged significantly more practices per day than non-elite athletes ($M = 0.97$, $SE = .06$, $p = .010$), with no significant differences between pre-elite athletes ($M = 1.03$, $SE = .05$) and either group. Levene's statistic was significant for this ANCOVA, $F(2, 544) = 6.63$, $p = .001$, but

Table 6: Measures of training presented according to participant skill level

	<i>n</i> =	Total	Participant Skill Level			<i>p</i> -value	Effect size
			Non-Elite	Pre-Elite	Elite		
Practice day proportion ^a	547	79.3	78.7	77.1	83.7	.307	.067
Mean daily practices	547	1.05 (0.72)	0.96 (0.65)	1.03 (0.71)	1.20 (0.79)	.010	.017
Mean daily training volume	547	1:17 (1:00)	1:04 (0:51)	1:17 (1:03)	1:30 (1:01)	.001	.027
Mean daily training RPE	434	4.63 (2.04)	4.35 (1.70)	5.21 (2.24)	4.09 (1.86)	<.001	.061
Mean daily training sRPE	547	376 (363)	290 (276)	414 (394)	413 (386)	.001	.024

Notes: Means are presented in unadjusted form; Unless otherwise stated, *p*-values and *partial* η^2 values reported are from ANCOVA testing where age and sport type were entered as covariates.

^a Variable is reported as a percentage; *p*-values and effect size (Cramer's *V*) are from chi-square testing

an ANOVA run without the covariates of age or sport type again found a significant effect of skill level on mean training sessions, Welch's $F(2, 329.69) = 4.31, p = .014, \eta^2 = .017$, Levene's test, $F(2, 544) = 6.29, p = .002$, with the same significant post hoc trends.

Training volume. Mean daily training volume, measured in minutes of training time, was significantly related to age, $F(1, 542) = 4.22, p = .040, \text{partial } \eta^2 = .008$, but not sport type, $F(1, 542) = 0.87, p = .353, \text{partial } \eta^2 = .002$. A significant effect for skill level on mean daily training volume was found after controlling for covariates, $F(2, 542) = 7.57, p = .001, \text{partial } \eta^2 = .027$. Elite athletes ($M = 1:30, SE = 0:05$) trained significantly longer each day than non-elite athletes ($M = 1:04, SE = 0:05, p = <.001$), with no significant differences between pre-elite athletes ($M = 1:17, SE = 0:05$) and either group. Levene's statistic was significant for this ANCOVA, $F(2, 544) = 4.26, p = .001$, but an ANOVA run without the covariates found a significant effect of skill level on mean daily training volume, Welch's $F(2, 338.33) = 8.41, p = <.001, \eta^2 = .027$, Levene's test, $F(2, 544) = 3.39, p = .034$, with the same significant post hoc trends.

Training intensity. Mean daily training intensity, as measured by athlete ratings of perceived exertion (RPE), was significantly related to both age, $F(1, 429) = 8.41, p = .004, \text{partial } \eta^2 = .019$, and sport type, $F(1, 429) = 8.71, p = .003, \text{partial } \eta^2 = .020$, and there was a

significant effect of skill level after controlling for covariates, $F(2, 429) = 13.86, p = <.001$, $partial \eta^2 = .061$. Pre-elite athletes ($M = 5.20, SE = 0.15$) rated their perceived effort during training as significantly harder than both elite ($M = 4.05, SE = 0.18, p = <.001$) and non-elite athletes ($M = 4.40, SE = 0.17, p = .001$), with no significant differences between elite and non-elite athletes. Levene's statistic was significant for this ANCOVA, $F(2, 431) = 9.01, p = <.001$, but an ANOVA run without the covariates found a significant effect of skill level on mean daily RPE, Welch's $F(2, 280.53) = 12.36, p = <.001, \eta^2 = .059$, Levene's test, $F(2, 431) = 8.03, p = <.001$, with the same significant post hoc trends.

Training load. Mean daily training load, as measured by sRPE, was significantly related to age, $F(1, 542) = 7.45, p = .007, partial \eta^2 = .014$, but not sport type, $F(1, 542) = 0.06, p = .805, partial \eta^2 = <.001$. There was a significant effect of skill level on mean daily sRPE after controlling for covariates, $F(2, 542) = 6.74, p = .001, partial \eta^2 = .024$. Non-elite athletes ($M = 292, SE = 27$) accumulated significantly less training load than both pre-elite ($M = 415, SE = 23, p = .002$) and elite athletes ($M = 411, SE = 29, p = .010$), with no significant differences between pre-elite and elite athletes. Levene's statistic was significant for this ANCOVA, $F(2, 544) = 10.82, p = <.001$, but an ANOVA run without the covariates found a significant effect of skill level on mean daily training load, Welch's $F(2, 335.22) = 8.90, p = <.001, \eta^2 = .025$, Levene's test, $F(2, 544) = 8.96, p = <.001$, with the same significant post hoc trends.

Representativeness

Normality of study period. Athletes were asked to indicate rate the representativeness of the two-week diary period across several items. Overall, while 18 participants (42%) reported a value outside of "somewhat normal", only two participants reported this for their sleep duration

Table 7: Participant ratings of the normality of the study period in comparison to the previous three months, organized by participant skill level

	Total <i>n</i> (%)	Participant Skill Level		
		Non-Elite <i>n</i> (%)	Pre-Elite <i>n</i> (%)	Elite <i>n</i> (%)
Sleep Duration				
Much longer than normal	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Somewhat normal	42 (97.7)	13 (92.9)	18 (100.0)	11 (100.0)
Much shorter than normal	1 (2.3)	1 (7.1)	0 (0.0)	0 (0.0)
Sleep Quality ^a				
Much better than normal	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Somewhat normal	41 (97.6)	14 (100.0)	17 (100.0)	10 (90.9)
Much worse than normal	1 (2.4)	0 (0.0)	0 (0.0)	1 (9.1)
Nap Frequency				
Many more than normal	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Somewhat normal	42 (97.7)	14 (100.0)	17 (94.4)	11 (100.0)
Many fewer than normal	1 (2.3)	0 (0.0)	1 (5.6)	0 (0.0)
Nap Duration ^b				
Much longer than normal	1 (2.4)	0 (0.0)	1 (5.6)	0 (0.0)
Somewhat normal	40 (95.2)	13 (100.0)	16 (88.9)	11 (100.0)
Much shorter than normal	1 (2.4)	0 (0.0)	1 (5.6)	0 (0.0)
Training Load				
Much higher than normal	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Somewhat normal	36 (83.7)	11 (78.6)	15 (83.3)	10 (90.9)
Much lower than normal	7 (16.3)	3 (21.4)	3 (16.7)	1 (9.1)
Stress Level				
Much higher than normal	5 (11.6)	2 (14.3)	2 (11.1)	1 (9.1)
Somewhat normal	35 (81.4)	11 (78.6)	14 (77.8)	10 (90.9)
Much lower than normal	3 (7.0)	1 (7.1)	2 (11.1)	0 (0.0)
Mood				
Much better than normal	1 (2.3)	0 (0.0)	1 (5.6)	0 (0.0)
Somewhat normal	39 (90.7)	13 (92.9)	16 (88.9)	10 (90.9)
Much worse than normal	3 (7.0)	1 (7.1)	1 (5.6)	1 (9.1)

^a Missing response from one pre-elite athlete

^b Missing response from one non-elite athlete

or quality during the study period, indicating that the results collected were relatively representative. Detailed results may be found in Table 7.

Importance. Athletes were asked to indicate rate how important they considered sleep to be for recovery, athletic performance, and general daily living. All but one participant rated sleep as being at least moderately important for recovery, with 84% ($n = 36$) believing sleep to be “very” or “extremely important”. Detailed results for all three items may be found in Table 8.

Table 8: Participant subjective ratings of the importance of sleep for various purposes, organized by participant skill level

	Total <i>n</i> (%)	Participant Skill Level		
		Non-Elite <i>n</i> (%)	Pre-Elite <i>n</i> (%)	Elite <i>n</i> (%)
Importance for Recovery from Training				
Extremely important	16 (37.2)	3 (21.4)	5 (27.8)	8 (72.7)
Very important	20 (46.5)	8 (57.1)	11 (61.1)	1 (9.1)
Moderately important	6 (14.0)	3 (21.4)	2 (11.1)	1 (9.1)
Slightly important	1 (2.3)	0 (0.0)	0 (0.0)	1 (9.1)
Not at all important	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Importance for Overall Athletic Performance				
Extremely important	15 (34.9)	4 (28.6)	4 (22.2)	7 (63.6)
Very important	19 (44.2)	6 (42.9)	11 (61.1)	2 (18.2)
Moderately important	7 (16.3)	4 (28.6)	2 (11.1)	1 (9.1)
Slightly important	1 (2.3)	0 (0.0)	1 (5.6)	0 (0.0)
Not at all important	1 (2.3)	0 (0.0)	0 (0.0)	1 (9.1)
Importance for Activities of Daily Living				
Extremely important	13 (30.2)	4 (28.6)	6 (33.3)	3 (27.3)
Very important	20 (46.5)	8 (57.1)	8 (44.4)	4 (36.4)
Moderately important	8 (18.6)	2 (14.3)	4 (22.2)	2 (18.2)
Slightly important	1 (2.3)	0 (0.0)	0 (0.0)	1 (9.1)
Not at all important	1 (2.3)	0 (0.0)	0 (0.0)	1 (9.1)

Chapter 5: Discussion

The purpose of this thesis was to explore the concept of deliberate recovery by describing and comparing characteristics of sleep between athletes of different skill levels. Elite and pre-elite athletes were found to sleep significantly longer and earlier in the night than non-elite athletes, supporting our first hypothesis and partially supporting our second hypothesis. Despite this, and in contrast to our third hypothesis, elite athletes reported significantly worse sleep quality than non-elite athletes, which may be related to the higher training demands of elite athletes. Interestingly, elite athletes also reported significantly worse sleep quality than pre-elite athletes, despite no significant differences in sleep timing, sleep duration, or training. These results demonstrate that athlete skill level is related to the organization of patterns of sleep quantity and quality, suggesting that higher-skilled athletes prioritize sleep to a greater extent than lower-skilled athletes, especially in response to the consistent trend of poor sleep quality among elite athletes.

The elite and pre-elite groups of athletes in this study reported sleeping significantly longer at night and spending significantly more time in bed than the non-elite group, confirming our first hypothesis. These findings follow the same pattern found in the original investigation of deliberate practice (Ericsson et al., 1993), where the two higher-skilled groups slept significantly more than the least skilled group. Although all groups in this study reported average nighttime sleep durations within the NSF recommendation of seven to nine hours (Hirshkowitz et al., 2015), elite athletes slept at least 7:00 hours on 74.8% of all nights and at least 8:00 hours on 45.0% of all nights, more than either other group. Compared to other studies using self-report methods, the total nighttime sleep for the elite group in the current study (7:31 +/- 1:26) was notably shorter than those of Dutch elite athletes from multiple sports (8:11 +/- 0:44; Knufinke et

al., 2018) or Australian football athletes (8:51 +/- 0:59; Van Ryswyk et al., 2017), but comparable to the baseline sleep of an elite college basketball team (7:50 +/- 1:06; Mah et al., 2011), and somewhat longer than professional rugby league athletes (7:16 +/- 1:12; Caia et al., 2018). Differences in comparison to previous research are unsurprising, as most previous work has been conducted on team sport athletes, who have been found to sleep significantly more than individual sport athletes such as those in the current sample (Lastella et al., 2015). By consistently devoting a greater portion of their day to sleep, these results suggest elite athletes prioritize recovery strategies to a greater degree than non-elite athletes, although shorter sleep durations by elite athletes in comparison to previous results allow the possibility that the gap between elite and non-elite athletes may be even larger than what was found.

Sleep chronotype did not appear to be a factor in any skill group differences, with all but three participants categorized as either intermediate- (50%) or morning-types (43%) and no significant differences found between skill level groups. Lastella and colleagues (2016) examined sleep chronotype in a multi-sport sample of elite athletes, finding very few evening chronotypes (6% of the sample), including only one participating in an individual sport, and a similar proportion of morning-types to the current study among both cyclists (38%), and triathletes (48%; Lastella et al., 2016). These authors concluded that athletes picked sports matching their chronotypes, and the current sample indicates that this appears to hold true across skill levels.

Inter-group differences in sleep duration were mostly due to differences in measures related to the beginning of sleep as opposed to the end. No significant differences were found between any groups for wake or rise times, which fits with previous work showing that practice schedules can constrain the wake and rise times of individual-sport athletes, who respond by

altering when they go to bed (Sargent, Halson, & Roach, 2014; Sargent, Lastella, et al., 2014). In contrast, elite and pre-elite groups reported going to bed and attempting to sleep significantly earlier than the non-elite group, with the pre-elite group also actually falling asleep significantly earlier. These results only partially confirm our second hypothesis, as despite significant differences in earlier bedtime actions, the actual time of sleep onset was not significantly different between elite and non-elite athletes, as was hypothesized. Compared to the time of sleep onset, bedtime and the time of attempted sleep are both heavily dependent on decisions made by the athlete. With little difference in wake or rise timing, the significantly longer sleep times of pre-elite and elite athletes appear to be driven by a series of choices, or at least environmental circumstances, which prioritize sleep to a greater extent than non-elite athletes.

Naps may be used to supplement nighttime sleep for recovery purposes, and both elite and pre-elite groups took advantage of this. A nap was recorded on 20% of days in the study, which is comparable to previous examinations of Dutch elite athletes (18% of days studied; Knufinke et al., 2018) and Australian Olympic swimmers (23%; Forndran et al., 2012). When only looking at the duration of naps taken, both elite and pre-elite groups reported napping significantly longer than the non-elite group. Nap duration was also considered for all days, as this takes into account the decision of whether to nap in addition to the decision of duration, and again both pre-elite and elite groups reported longer durations than the non-elite group, with a significant difference between elite and non-elite groups. Similar skill differences were seen in Ericsson and colleagues' (1993) study of musicians, where the top two groups of musicians napped significantly more than the low-skill group. The summated effects of the skill level differences in decisions regarding napping and sleep timing can be represented by total daily sleep time (TDST). Elite and pre-elite groups accumulated significantly more sleep over the

course of an average day than the non-elite group, a trend which again matches with that found in Ericsson and colleagues' study of musicians (1993) where the best performers both slept more at night and napped more during the day. It is unclear whether the higher-skilled athletes in this study used to naps to extend their total sleep time, or as a way to compensate for the poorer quality sleep achieved the previous night. Previous studies of elite athletes have generally found naps to be deliberately used to compensate for low total nighttime sleep durations, (e.g., after an early morning practice). However, naps were not perceived as important for recovery by a large sample of elite athletes which rated nighttime sleep as very important (Venter, 2014), thus making it unsurprising that naps are considered underused as a method of increasing sleep volume overall (Forndran et al., 2012). Results of the present investigation suggest that while napping may be underused by elite athletes, they make better use of this strategy than athletes of lower skill levels.

Despite longer sleep durations of all types, the elite group reported poorer measures of sleep quality than the non-elite group, which lies in direct opposition to our third hypothesis. Subjective ratings of sleep quality and subjective feelings of refreshment were both significantly lower among the elite group than the non-elite group. Poor sleep quality has been noted as prevalent among elite athletes (Samuels, 2008). Although the wide variety of subjective scales used in different studies make comparisons difficult, the elite group from the current study did report similar levels of subjective sleep quality (3.4 +/- 0.8) to a sample of professional rugby league players (3.4 +/- 0.9; Caia et al., 2018). Relatedly, the elite group reported a significantly greater frequency and total duration of nighttime awakenings compared to the non-elite group, with both relationships carrying moderate measures of effect size (*partial* $\eta^2 = .089$). Although all group means met the NSF quality sleep guideline of fewer than 20 minutes of wake after

sleep onset (Ohayon et al., 2017), elite athletes reported the smallest proportion of nights meeting those criteria. The elite group reported a total duration of nighttime awakenings similar to a multi-sport sample of elite Dutch athletes evaluated using the CSD-E (0:13 +/- 0:15 versus 0:13 +/- 0:19; Knufinke et al., 2018), but a slightly greater frequency (2.10 +/- 1.96 versus 1.19 +/- 0.90). The NSF defines quality sleep as including no more than one nighttime awakening of longer than five minutes (Ohayon et al., 2017), however the CSD-E asks for the number of nighttime awakenings of any length (Carney et al., 2012), limiting comparison. Although the motivation behind their decisions is unknown, the bedtime decisions made by the elite group provided some compensation for their poor sleep quality by increasing the quantity of sleep they accumulated, allowing the potential to recoup some of the recovery benefits otherwise lost.

It is possible the discrepancy between the reported relationships of sleep quantity and quality in elite and non-elite athletes may be due to training volume. On average, the elite group reported significantly more training sessions and a greater training volume than the non-elite group, leading to a significantly larger average training load. This relationship is unsurprising, as a review found expert groups of athletes accumulated more hours of practice than non-expert groups in 16 of 17 included studies (Baker & Young, 2014). It is also well-established, however, that training load can impact sleep. Both training intensity (Oda & Shirakawa, 2014) and volume (Hauswirth et al., 2014; Taylor, Rogers, & Driver, 1997) negatively influence sleep quantity and quality through physiological means. Additionally, high training volumes can lead to practice schedules which interfere with sleep (e.g., early morning practices; Forndran et al., 2012). These factors may have negatively influenced sleep quality in the elite group, but they also reinforce the prioritization of sleep despite the greater time pressures presented by higher training volumes.

Similar to the non-elite group, the pre-elite group reported significantly better measures of sleep quality than the elite group. On average, pre-elite athletes reported significantly higher ratings of sleep quality than elite athletes, with a corresponding, but non-significant, trend for subjective feelings of refreshment. Sleep efficiency (i.e., the proportion of time in bed spent asleep) was significantly lower in the elite group compared to the pre-elite group, a result that represents the summation of a number of trends. For instance, non-significant differences in time of attempted sleep and actual sleep onset resulted in a significantly longer sleep onset latency for the elite group compared to the pre-elite group. Although all group means met the NSF guideline of fewer than 30 minutes of latency for quality sleep (Ohayon et al., 2017), the elite group did so on the lowest proportion of nights (82.8%). Similar to the non-elite group, the pre-elite group reported significantly a smaller frequency and duration of nighttime awakenings than the elite group, further decreasing their sleep efficiency. Overall, the elite group took longer to fall asleep, woke up in the night more frequently and for a longer period, and subjectively rated their sleep worse upon awakening.

While the sleep quality relationship between elite and pre-elite groups is somewhat similar to that found between elite and non-elite groups, the surrounding relationships make interpretations somewhat more complex. For instance, no significant differences were found for any measures of sleep timing or duration between elite and pre-elite groups, meaning that, unlike in the comparison to the non-elite group, the elite group were not compensating for the lack of sleep quality with additional quantity. One possible explanation is that scheduling demands created a ceiling effect on sleep duration, which can only be extended so much before being restricted by training, school or work. Taking the findings for quantity and quality together, the pre-elite group reported overall better sleep than the elite group. Whereas training load emerged

as a possible contributor to sleep quality deficits in comparison to the non-elite group, the elite group reported only a slightly greater training volume and frequency than the pre-elite group, with no significant differences between groups. Furthermore, the pre-elite group reported a significantly higher average daily RPE, which led to almost identical training loads for the elite and pre-elite groups. These reported values suggest training load did not contribute to the differences in sleep quality between elite and pre-elite groups, although it is possible that the subjectivity of the measures used was an issue. For instance, training intensity was measured using ratings of perceived exertion, which is inherently moderated by the athlete's interpretation of their effort (see Marcora, Staiano, & Manning, 2009). This can be beneficial as it summates the many different psychological, physiological and interactive processes occurring internal to the athlete during training that may not appear in external measures of intensity of effort (Borg, 1982). However, RPE can also be interpreted as allowing the possibility that at the same given objective intensity, two athletes may perceive different levels of exertion, despite the same physiological outcomes. It has been suggested that, through the course of accumulating a large volume of intense training, elite athletes 'adapt' to the pain and discomfort of training, and thus perceive effort and exertion more conservatively (Hutchinson, 2018). In the context of this investigation, the elite group perceived a lower training intensity than the pre-elite group, whereas evidence suggests it could have been physiologically equivalent (or even higher). This perspective, which requires further verification and future study, suggests the elite group could have incurred a higher training load, providing some explanation for their lower sleep quality.

Similarly, subjectively rating sleep quality and recording awakenings during sleep may have introduced inter-group bias. Athlete skill level has been associated with the self-monitoring component of self-regulation, meaning that higher skilled athletes are more aware of their

practice and performance-related actions (Bartulovic et al., 2017). While these findings were related to practice, athletes in the current study were asked to monitor their sleep patterns. In this context, the elite group may have been more sensitive to deficits in sleep quality than lower-skilled athletes less able and experienced at self-monitoring. As in many sleep studies using similar measures, the subjective nature of our measures of training intensity and sleep quality were limitations of the study, and any attempt to interpret how it may have affected results remains speculative. It is thus important that future investigations consider the discrepancy between objective and subjective measures of sleep and effort not as sources of measurement error, but as potentially important characteristics of what makes elite athletes different from their lower skilled counterparts.

Limitations

Several points of interest for further consideration have been raised; however, these conclusions should be considered in the light of some limitations of the investigation. First, the design of this study was entirely questionnaire-based, using all self-report measures. This method has been frequently used for the study of sleep in athletes (e.g., Knufinke et al., 2018), but it introduces the subjective element of athlete interpretation. This may be seen as a strength, considering an athlete's interpretations of their stress and recovery levels (i.e., the psychological component of recovery) are critical to understanding relationships between training stress, recovery and adaptation (Kiely, 2018). However, previous research has shown significant discrepancies between objective and subjective measures of sleep (e.g., Caia et al., 2018; Mah et al., 2011). As such, it is important that future investigations consider examining skill-based differences in sleep using both objective and subjective methods, as both provide crucial information in the context of expertise research.

Second, although this is the first study to look at differences in sleep according to expertise or skill level (defined here using the athlete's level of competition) and our skill classification strategy is theoretically grounded (Gulbin et al., 2010) and previously used (e.g., Hopwood, Farrow et al., 2015; Hopwood, MacMahon et al., 2015), it does carry some limitations. For instance, the relative difficulty of achieving the objective markers of expertise differs across sports. In other words, it may be "easier" to compete at a senior international level in some sports compared to others, based on such factors as specific competition and team entry rules and regulations, and inter-country differences in a particular sport's popularity and average athlete skill level. While this may relate more to in-depth discussions of general issues related to defining the terms "expert" and "elite" covered elsewhere (Swann, Moran & Pigott, 2015), these differences could affect both the homogeneity within the skill levels (i.e., "pre-elite" runners versus cyclists) and the heterogeneity between skill levels in this study. (i.e., "elite" versus "pre-elite" may be less separate for certain sports). As a result, the present sample of elite athletes may not have been as "elite" as other studies defined more strictly (e.g., using Olympic or championship performance). Extending these analyses with larger, more representative and diverse samples would be important in future work.

Another limitation was that the inclusion of elite athletes necessitated the use of a convenience sample, which likely introduced bias in several ways. First, while previous research indicates that high-level athletes view sleep as the most important form of recovery (Venter, 2014), this investigation likely attracted athletes especially interested in the role of sleep in their training (i.e., selection bias). While this bias would likely have been consistent across skill level groups, it limits the generalizability of some findings to a larger population of athletes. Second, the sample included a wide range of ages and an unbalanced distribution of main sports among

participants. Attempts were made to account for this, as no skill level differences were found for either age or sport type, and both variables were entered as covariates in all between-group analyses. Additionally, all data collection took place within a three-month period and athletes were asked to self-select a non-competitive period of basic training. Despite this, some variability very likely remained as while some sports were at the beginning of their off-season (e.g., Nordic skiing), others were approaching their competitive season (e.g., rowing), presenting potential differences in training load as well as in psychological factors such as athlete commitment and motivation. Previous research on sleep in athletes has included team-wide samples (e.g., team sports: Caia et al., 2018; individual sports: Forndran et al., 2012), which would standardize a number of variables (e.g., age, time of season) while likely including a wider range of perspectives and beliefs regarding sleep. This method could be applied to future skill-based investigations by sampling from teams at different skill levels within the same sport, or from different developmental levels within the same organization.

The decision to use questionnaire-based methods and a convenience sample were both based on the objective of accumulating a large sample size to account for the large variability generally found in investigations of sleep (Halson, 2014) and training (Baker & Young, 2014). Despite this, only 58 athletes responded in any way to recruitment, and only 43 were included in final analyses. While the purpose of this study was exploratory and follow-up investigations are clearly warranted, the low sample size limits how the results found here can be applied to further samples. This limitation may be addressed using either of the two future directions already proposed: 1) Improving the current methodology using a more effective and extended recruiting process to increase the sample size; or 2) using a team- or organization-based approach to reduce the variance within the sample.

Implications for Deliberate Recovery

This thesis sought to explore the idea of deliberate recovery by examining whether athletes engaged in recovery activities differently according to their skill level. While it originates conceptually from the deliberate practice framework, deliberate recovery has not been specifically defined. For the purpose of this thesis, deliberate recovery represents the leveraging of recovery activities and opportunities for the purpose of maximizing learning and performance. Recovery practices, as represented by sleep in the current study, were found to differ according to skill level group. The implications of these findings are that deliberate recovery may be an important consideration for athletes, although this is subject to much needed further confirmatory and expansive research.

Sleep is a biologically necessary form of recovery, making it an ideal representation for this study. Unlike other modalities, sleep is free and equally-accessible to all; its use depends only on the prioritization and self-regulation of the individual. In the current study, 84% of all athletes reported sleep as being very or extremely important as a form of recovery from training, which is similar to Venter's (2014) findings that across sex, skill level and sport type, athletes rated sleep as the most important form of recovery. Despite equal opportunity and opinion of sleep, elite and pre-elite groups still achieved longer sleep durations than the non-elite group, mainly because the higher-skilled groups went to bed and tried to sleep earlier. Whether made for the purpose of recovery or not, going to bed and trying to sleep represent decisions made daily by all but the most sleep deprived. The habit of higher-skilled athletes of consistently acting on these decisions earlier in the night relative to lower-skilled athletes represents a greater prioritization of sleep, and by extension recovery.

The results of this study are suggestive of the importance of the deliberate use of recovery among athletes; however, considering the scope and limitations of the project, many further avenues of investigation exist. Foremost among these future considerations would be replication of these results using a more robust sample. If these differences in sleep patterns can be reliably found, the most obvious question becomes why they exist. While prioritization was inferred through the timing of bed and attempted sleep times, the current investigation included no direct accounts of why the groups engaged in the demonstrated patterns of sleep. For example, do elite athletes train and perform at a higher level because they already sleep more, or have they chosen to sleep more in response to their training and performance? Further, while sleep quality is reliably noted as poorer among elite athletes due to environmental factors such as the psychological and physiological demands of competition and training (Fullagar, Duffield, et al., 2015; Samuels, 2008), do elite athletes take deliberate steps to improve their sleep quality (i.e., sleep hygiene) as much as possible? Beyond this, the ideas of deliberate recovery must be examined in contexts other than sleep, such as the organization and use of psychological and social forms of recovery (e.g., hanging out with friends, team dinners, etc.). The results of this study provide a rationale for the further investigation of deliberate recovery, raising a host of questions that must be addressed before the concept is well understood.

Concluding Remarks

This thesis provides an initial exploration of the use of deliberate recovery in athletes through an examination of sleep. Elite and pre-elite groups of individual sport athletes reported sleeping significantly more and earlier than athletes in a non-elite group. However, on average elite athletes also reported significantly worse sleep quality than both non-elite and pre-elite athletes, with training load and self-monitoring ability put forward as possible explanations.

While further investigation is needed, these results suggest that athletes engage in sleep differently according to their skill level, opening the possibility of an influential role for deliberate recovery in the development of expertise.

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Appendix A: Analysis of work and class/studying during the diary period

Table A1: Proportion of participants who reported work or class/studying on at least one day during the diary period, organized by skill level

	Total	Participant Skill Level			<i>p</i> -value	Cramer's <i>V</i>
		Non-Elite	Pre-Elite	Elite		
≥1 day of work (%)	35.3	31.7	33.5	42.1	.125	.088
≥1 day of class/studying (%)	54.6	66.3*	46.7†	53.4	.001	.167

Notes: *p*-values reported for chi-square analysis

* Corresponding count significantly less than expected based on adjusted standard residual ≤ -2 .

† Corresponding count significantly more than expected based on adjusted standard residual ≥ 2 .

Table A2: Average hours of work or class/studying during the diary period, organized by skill level

	Total <i>M</i> (SD)	Participant Skill Level			<i>p</i> -value	η^2
		Non-Elite <i>M</i> (SD)	Pre-Elite <i>M</i> (SD)	Elite <i>M</i> (SD)		
Mean daily work hours	2.07 (3.41)	1.96 (3.56)	2.06 (3.29)	2.21 (3.41)	.811	<.001
Mean daily class/study hours	2.78 (3.25)	3.48 (3.32)	2.44 (3.28)	2.51 (3.02)	.003	.021

Notes: *p*-values reported for ANOVA analysis; post-hoc testing of class/study hours revealed significant differences between non-elite athletes and both the pre-elite and elite groups.

Appendix B: Analysis of alcohol and caffeine consumption during the diary period

Table B1: Proportion of participants who reported alcohol or caffeine consumption during the diary period, organized by skill level

	Total	Participant Skill Level			<i>p</i> -value	Cramer's <i>V</i>
		Non-Elite	Pre-Elite	Elite		
Alcohol consumption of any amount	25 (58.1)	9 (64.3)	10 (55.6)	6 (54.5)	.859	.087
Mean alcohol consumption of ≥1 drink/day	4 (9.3)	2 (14.3)	2 (11.1)	0 (0.0)	.547	.194
Caffeine consumption of any amount	33 (76.7)	11 (78.6)	11 (61.1)	11 (100.0)	.054	.368
Mean caffeine consumption of ≥1 drink/day	18 (41.9)	5 (35.7)	7 (38.9)	6 (54.5)	.628	.153
Mean caffeine consumption of ≥2 drink/day	10 (23.3)	2 (14.3)	4 (22.2)	4 (36.4)	.491	.199

Notes: p-values reported for chi-square analysis

Table B2: Average drinks of alcohol or caffeine consumed per day during the diary period, organized by skill level

	Total <i>M</i> (SD)	Participant Skill Level			<i>p</i> -value	η^2
		Non-Elite <i>M</i> (SD)	Pre-Elite <i>M</i> (SD)	Elite <i>M</i> (SD)		
Mean daily alcoholic drinks	3.84 (5.23)	4.29 (4.81)	4.56 (6.45)	2.09 (3.08)	.444	.040
Mean daily caffeinated drinks	11.88 (11.93)	9.93 (9.83)	10.78 (13.48)	16.18 (11.65)	.385	.047

Notes: p-values reported for ANOVA analysis.

Appendix C: Assessment of assumption of normality organized by participant skill level

	Skewness <i>value</i> (SE)	Kurtosis <i>value</i> (SE)	Kolmogorov-Smirnov test		
			Test statistic	<i>df</i>	<i>p</i> -value
Age	2.45 (.36)	5.83 (0.71)	.30	43	<.001
Measures of Sleep Timing					
Bedtime	0.73 (0.10)	0.93 (0.21)	.09	559	<.001
Time of attempted sleep	0.77 (0.10)	0.86 (0.21)	.09	561	<.001
Time of sleep onset	0.67 (0.10)	0.74 (0.21)	.08	561	<.001
Wake time	0.27 (0.10)	0.61 (0.21)	.07	561	<.001
Rise time	0.33 (0.10)	0.35 (0.21)	.04	561	.014
Measures of Sleep Duration					
TIB	-0.03 (0.10)	0.54 (0.21)	.04	558	.018
TNST	-0.53 (0.10)	1.26 (0.21)	.05	560	.003
TNT	2.06 (0.23)	6.21 (0.46)	.20	110	<.001
# of naps	1.47 (0.10)	3.30 (0.21)	.48	545	<.001
TNT (all days)	2.07 (0.11)	4.33 (0.21)	.44	545	<.001
TDST	-0.12 (0.11)	0.47 (0.22)	.03	516	.200 ^a
Measures of Sleep Quality					
Subjective sleep quality	-0.44 (0.10)	0.144 (0.21)	.28	559	<.001
Subjective refreshment	-0.10 (0.10)	-0.07 (0.21)	.23	561	<.001
Sleep efficiency (%)	-2.21 (0.10)	8.86 (0.21)	.12	558	<.001
Sleep onset latency	3.23 (0.10)	15.11 (0.21)	.24	561	<.001
fWASO	1.91 (0.10)	4.29 (0.21)	.23	561	<.001
dWASO	2.82 (0.10)	8.53 (0.21)	.29	561	<.001
Measures of Training					
Mean daily practices	0.36 (0.10)	0.02 (0.21)	.30	547	<.001
Mean daily volume	0.86 (0.10)	1.88 (0.21)	.11	547	<.001
Mean daily RPE	0.65 (0.12)	-0.18 (0.23)	.14	434	<.001
Mean daily sRPE	1.47 (0.10)	3.30 (0.21)	.15	547	<.001

^a Represents lower bound of the true significance

Appendix D: Parallel analysis of participants providing 12+ nights of data

Table D1: Participant characteristics organized by participant skill level for only participants who provided at least 12 nights of data, including age outliers

	Total (<i>n</i> = 39)	Participant Skill Level			<i>p</i> -value	Effect Size
		Non-Elite (<i>n</i> = 13)	Pre-Elite (<i>n</i> = 15)	Elite (<i>n</i> = 11)		
Participant age (SD)	24.41 (9.75)	23.92 (8.95)	24.60 (12.91)	24.73 (5.61)	.977 ^a	$\eta^2 = .001$
Participant sex (%)					.218 ^b	$V = .269$
Female	21 (53.8)	5 (38.5)	8 (53.3)	8 (72.7)		
Male	18 (46.2)	8 (61.5)	7 (46.7)	3 (27.3)		
Participant country – most of life (%)					.320 ^b	$V = .294$
Canada	37 (94.9)	13 (100.0)	13 (86.7)	11 (100.0)		
Other	2 (5.1)	0 (0.0)	2 (13.3)	0 (0.0)		
Highest level of education (%)					.671 ^b	$\tau_b = .158$
Some secondary	5 (12.8)	2 (15.4)	3 (20.0)	0 (0.0)		
Some post-secondary	26 (66.7)	9 (69.2)	9 (60.0)	8 (72.7)		
Some graduate	8 (20.5)	2 (15.4)	3 (20.0)	3 (27.3)		
Main sport type (%)					.925 ^b	$V = .258$
Cycling	7 (16.3)	1 (7.7)	4 (26.7)	2 (18.2)		
Distance running	17 (43.6)	8 (61.5)	5 (33.3)	4 (36.4)		
Nordic skiing	4 (7.7)	1 (7.7)	1 (6.7)	1 (9.1)		
Rowing	8 (20.5)	2 (15.4)	3 (20.0)	3 (27.3)		
Swimming	2 (5.1)	1 (7.7)	1 (6.7)	0 (0.0)		
Triathlon	2 (5.1)	0 (0.0)	1 (6.7)	1 (9.1)		

^a *p*-value reported is for ANOVA *F*-statistic

^b *p*-value reported is for chi-square test

Table D2: Summarized ANCOVA results organized by skill level for only participants who provided at least 12 nights of data, including age outliers

	<i>n</i> =	Participant Skill Level				<i>p</i> -value	Effect size
		Total	Non-Elite	Pre-Elite	Elite		
Sleep Timing Measures							
Bedtime ^a	517	23:12 (1:26)	23:30 (1:23)†	23:04 (1:34)*	23:04 (1:17)	.016	.016
Time of attempted sleep ^a	519	23:31 (1:22)	23:48 (1:23)†^	23:23 (1:25)*	23:21* (1:14)	.010	.018
Time of sleep onset ^a	519	23:50 (1:20)	0:06 (1:17)†	23:39 (1:26)*	23:45 (1:12)	.009	.018
Wake time ^a	519	7:28 (1:25)	7:27 (1:22)	7:26 (1:37)	7:33 (1:10)	.366	.004
Rise time ^a	519	7:44 (1:26)	7:41 (1:22)	7:41 (1:39)	7:49 (1:11)	.335	.004
Sleep Duration Measures							
Time in bed ^a	516	8:30 (1:27)	8:11 (1:15)†^	8:35 (1:28)*	8:45 (1:34)*	.001	.028
TNST ^a	518	7:31 (1:22)	7:17 (1:10)†^	7:40 (1:26)*	7:34 (1:26)*	.005	.020
Total nap time ^a	106	0:58 (0:48)	0:35 (0:23)†^	1:04 (0:48)*	1:11 (0:57)*	.003	.110
# of naps ^a	545	0.23 (0.47)	0.23 (0.49)	0.21 (0.44)	0.27 (0.49)	.522	.003
Total nap time (all days) ^a	505	0:12 (0:32)	0:07 (0:17)^	0:12 (0:32)	0:17 (0:41)*	.029	.014
Total daily sleep time ^a	484	7:42 (1:24)	7:23 (1:11)†^	7:52 (1:30)*	7:49 (1:24)*	.001	.028
Sleep Quality Measures							
Subjective sleep quality ^a	517	3.49 (0.81)	3.55 (0.84)	3.54 (0.81)	3.38 (0.79)	.062	.011
Subjective refreshment ^a	519	3.13 (0.88)	3.25 (0.87)^	3.10 (0.88)	3.03 (0.89)*	.037	.013
Sleep efficiency (%) ^a	516	88.4 (8.3)	89.2 (8.1)	89.3 (7.6)^	86.7 (9.3)†	.023	.015
Sleep onset latency ^a	519	0:18 (0:21)	0:18 (0:18)	0:15 (0:16)^	0:24 (0:29)†	.002	.023
fWASO ^a	519	1.37 (1.69)	0.82 (0.95)†^	1.28 (1.78)*^	2.10 (1.96)*†	<.001	.087
dWASO ^a	519	0:07 (0:12)	0:03 (0:07)^	0:05 (0:11)^	0:12 (0:15)*†	<.001	.085
Sleep Chronotype Measures							
Chronotype score ^a	38	56.74 (8.81)	53.75 (11.35)	57.60 (8.70)	58.82 (4.81)	.454	.047
Chronotype category ^b	38					.780	.148
Evening-type (%)		3 (7.9)	2 (16.7)	1 (6.7)	0 (0.0)		
Intermediate-type (%)		20 (52.6)	6 (50.0)	8 (53.3)	6 (54.5)		
Morning-type (%)		15 (39.5)	4 (33.3)	6 (40.0)	5 (45.5)		
Training Measures							
Practice day proportion ^c	507	79.3	78.0	77.1	83.7	.296	.070
Mean daily practices ^a	507	1.07 (0.73)	0.96 (0.67)^	1.04 (0.72)	1.20 (0.79)*	.013	.017
Mean daily volume ^a	507	1:17 (1:01)	1:04 (0:51)^	1:19 (1:05)	1:30 (1:01)*	.001	.029
Mean daily RPE ^a	402	4.61 (2.05)	4.37 (1.75)†	5.23 (2.26)*^	4.09 (1.86)†	<.001	.060
Mean daily sRPE ^a	507	379 (370)	290 (279)†^	424 (409)*	413 (386)*	.002	.025

Notes: Means are presented in unadjusted form; TNST = Total nighttime sleep time (abbreviated for space).

^a *p*-value and effect size (*partial* η^2) from ANCOVA testing where age and sport type were entered as covariates

^b *p*-value and effect size (Cramer's *V*) from chi-square testing

^c *p*-value and effect size (Kendall's τ_b) from chi-square testing

* Significantly different ($p < .05$) from 'non-elite' group mean

† Significantly different ($p < .05$) from 'pre-elite' group mean

^ Significantly different ($p < .05$) from 'elite' group mean

Appendix E: Parallel analysis regardless of response frequency

Table E1: Participant characteristics organized by skill level for participants, including age outliers, who provided any number of responses

	Total (<i>n</i> = 51)	Participant Skill Level			<i>p</i> -value	Effect Size
		Non-Elite (<i>n</i> = 18)	Pre-Elite (<i>n</i> = 20)	Elite (<i>n</i> = 13)		
Participant age (SD)	24.31 (9.22)	25.00 (9.36)	23.50 (11.28)	24.62 (5.19)	.878 ^a	$\eta^2 = .005$
Participant sex (%) ^b					.482 ^c	$V = .172$
Female	28 (56.0)	8 (47.1)	11 (55.0)	9 (69.2)		
Male	22 (44.0)	9 (52.9)	9 (45.0)	4 (30.8)		
Participant country – most of life (%)					.329 ^c	$V = .252$
Canada	49 (96.1)	18 (100.0)	18 (90.0)	13 (100.0)		
Other	2 (3.9)	0 (0.0)	2 (13.3)	0 (0.0)		
Highest level of education (%)					.509 ^c	$\tau_b = .090$
Some secondary	6 (11.8)	3 (16.7)	3 (15.0)	0 (0.0)		
Some post-secondary	33 (64.7)	10 (55.6)	14 (70.0)	9 (69.2)		
Some graduate	12 (23.5)	5 (27.8)	3 (15.0)	4 (30.8)		
Main sport type (%)					.925 ^c	$V = .258$
Cycling	8 (15.7)	2 (11.1)	4 (20.0)	2 (15.4)		
Distance running	20 (39.2)	9 (50.0)	6 (30.0)	5 (38.5)		
Nordic skiing	4 (7.8)	1 (5.6)	2 (10.0)	1 (7.7)		
Rowing	14 (27.5)	4 (22.2)	6 (30.0)	4 (30.8)		
Swimming	3 (5.9)	2 (11.1)	1 (5.0)	0 (0.0)		
Triathlon	2 (3.9)	0 (0.0)	1 (5.0)	1 (7.7)		

^a *p*-value reported is for ANOVA *F*-statistic

^b Missing information for one participant regarding sex

^c *p*-value reported is for chi-square test

Table E2: Summarized ANCOVA results for participants, including age outliers, regardless of how many nights of data they provided organized by skill level

	<i>n</i> =	Participant Skill Level				<i>p</i> -value	Effect size
		Total	Non-Elite	Pre-Elite	Elite		
Sleep Timing Measures							
Bedtime ^a	621	23:13 (1:24)	23:25 (1:19)†	23:06 (1:31)*	23:06 (1:17)	.027	.012
Time of attempted sleep ^a	623	23:30 (1:20)	23:42 (1:20)†	23:24 (1:23)*	23:25 (1:14)	.033	.011
Time of sleep onset ^a	623	23:49 (1:18)	0:01 (1:14)†	23:41 (1:26)*	23:47 (1:11)	.017	.013
Wake time ^a	623	7:28 (1:26)	7:27 (1:22)	7:27 (1:35)	7:30 (1:16)	.661	.001
Rise time ^a	623	7:43 (1:28)	7:42 (1:23)	7:42 (1:39)	7:46 (1:17)	.654	.001
Sleep Duration Measures							
Time in bed ^a	620	8:29 (1:27)	8:16 (1:18)^	8:34 (1:28)	8:39 (1:36)*	.025	.012
TNST ^a	622	7:30 (1:23)	7:21 (1:13)	7:39 (1:26)	7:29 (1:28)	.082	.008
Total nap time ^a	125	0:55 (0:47)	0:32 (0:23)†^	1:02 (0:47)*	1:10 (0:57)*	<.001	.126
# of naps ^a	610	0.24 (0.52)	0.24 (0.56)	0.23 (0.52)	0.25 (0.48)	.778	.001
Total nap time (all days) ^a	610	0:11 (0:30)	0:06 (0:16)^	0:12 (0:32)	0:16 (0:40)*	.017	.013
Total daily sleep time ^a	555	7:42 (1:24)	7:25 (1:13)†	7:52 (1:29)*	7:45 (1:27)	.004	.020
Sleep Quality Measures							
Subjective sleep quality ^a	621	3.52 (0.83)	3.61 (0.86)^	3.56 (0.82)^	3.37 (0.78)*†	.008	.016
Subjective refreshment ^a	623	3.19 (0.90)	3.31 (0.89)^	3.19 (0.92)	3.05 (0.88)*	.010	.015
Sleep efficiency (%) ^a	620	88.5 (8.6)	89.2 (8.2)^	89.3 (8.4)^	86.6 (9.1)*†	.006	.017
Sleep onset latency ^a	623	0:19 (0:23)	0:18 (0:20)	0:17 (0:22)^	0:22 (0:28)†	.043	.010
fWASO ^a	623	1.31 (1.62)	0.85 (1.00)†^	1.22 (1.68)*^	2.02 (1.90)*†	<.001	.080
dWASO ^a	623	0:07 (0:12)	0:04 (0:07)^	0:06 (0:11)^	0:13 (0:15)*†	<.001	.083
Sleep Chronotype Measures							
Chronotype score ^a	47	57.23 (9.07)	54.20 (12.55)	58.42 (7.97)	59.00 (4.42)	.249	.064
Chronotype category ^b	47					.438	.161
Evening-type (%)		4 (8.5)	3 (20.0)	1 (5.3)	0 (0.0)		
Intermediate-type (%)		21 (44.7)	6 (40.0)	9 (47.4)	6 (46.2)		
Morning-type (%)		22 (46.8)	6 (40.0)	9 (47.4)	7 (53.8)		
Training Measures							
Practice day proportion ^c	612	75.8	69.8^	75.7	83.8*	.008	.125
Mean daily practices ^a	612	1.01 (0.74)	0.85 (0.68)†^	1.02 (0.72)*^	1.20 (0.79)*†	<.001	.035
Mean daily volume ^a	612	1:13 (1:00)	0:58 (0:53)†^	1:16 (1:03)*	1:27 (1:00)*	<.001	.039
Mean daily RPE ^a	464	4.63 (2.04)	4.37 (1.71)†	5.17 (2.21)*^	4.14 (1.95)†	<.001	.052
Mean daily sRPE ^a	612	357 (359)	265 (280)†^	405 (391)*	402 (376)*	<.001	.036

Notes: Means are presented in unadjusted form; TNST = Total nighttime sleep time (abbreviated for space).

^a *p*-value and effect size (*partial* η^2) from ANCOVA testing where age and sport type were entered as covariates

^b *p*-value and effect size (Cramer's *V*) from chi-square testing

^c *p*-value and effect size (Kendall's τ_b) from chi-square testing

* Significantly different ($p < .05$) from 'non-elite' group mean

† Significantly different ($p < .05$) from 'pre-elite' group mean

^ Significantly different ($p < .05$) from 'elite' group mean

Appendix F: Age restricted parallel analysis of participants providing 10+ nights of data

Table F1: Participant characteristics organized by skill level for participants who provided at least 10 nights of data and were not considered age outliers

	Total (<i>n</i> = 38)	Participant Skill Level			<i>p</i> -value	Effect Size
		Non-Elite (<i>n</i> = 12)	Pre-Elite (<i>n</i> = 16)	Elite (<i>n</i> = 10)		
Participant age (SD)	21.26 (3.36)	21.17 (4.00)	20.00 (1.83) [^]	23.40 (3.66) [†]	.038 ^a	$\eta^2 = .171$
Participant sex (%)					.456 ^b	$V = .232$
Female	22 (57.9)	5 (41.7)	10 (62.5)	7 (70.0)		
Male	16 (42.1)	7 (58.3)	6 (37.5)	3 (30.0)		
Participant country – most of life (%)					.331 ^b	$V = .276$
Canada	36 (94.7)	12 (100.0)	14 (87.5)	10 (100.0)		
Other	2 (5.3)	0 (0.0)	2 (12.5)	0 (0.0)		
Highest level of education (%)					.434 ^b	$\tau_b = .176$
Some secondary	5 (13.2)	2 (16.7)	3 (18.8)	0 (0.0)		
Some post-secondary	27 (71.1)	8 (66.7)	12 (75.0)	7 (70.0)		
Some graduate	6 (15.8)	2 (16.7)	1 (6.3)	3 (30.0)		
Main sport type (%)					.976 ^b	$V = .235$
Cycling	3 (7.9)	0 (0.0)	2 (12.5)	1 (10.0)		
Distance running	17 (44.7)	7 (58.3)	6 (37.5)	4 (40.0)		
Nordic skiing	4 (10.5)	1 (8.3)	2 (12.5)	1 (10.0)		
Rowing	10 (26.3)	3 (25.0)	4 (25.0)	3 (30.0)		
Swimming	2 (5.3)	1 (8.3)	1 (6.3)	0 (0.0)		
Triathlon	2 (5.3)	0 (0.0)	1 (6.3)	1 (10.0)		

^a *p*-value reported is for ANOVA *F*-statistic

^b *p*-value reported is for chi-square test

* Significantly different ($p < .05$) from ‘non-elite’ group mean

† Significantly different ($p < .05$) from ‘pre-elite’ group mean

^ Significantly different ($p < .05$) from ‘elite’ group mean

Table F2: Summarized ANCOVA results organized by skill level for participants who provided at least 10 nights of data and were not considered age outliers

	<i>n</i> =	Participant Skill Level				<i>p</i> -value	Effect size
		Total	Non-Elite	Pre-Elite	Elite		
Sleep Timing Measures							
Bedtime ^a	492	23:15 (1:27)	23:30 (1:27)	23:11 (1:31)	23:04 (1:17)	.044	.013
Time of attempted sleep ^a	494	23:33 (1:22)	23:50 (1:24)†	23:29 (1:22)*	23:21 (1:17)	.014	.017
Time of sleep onset ^a	494	23:53 (1:19)	0:09 (1:18)†	23:45 (1:23)*	23:46 (1:15)	.007	.020
Wake time ^a	495	7:35 (1:22)	7:30 (1:25)	7:37 (1:27)	7:37 (1:10)	.139	.008
Rise time ^a	495	7:50 (1:23)	7:45 (1:25)	7:51 (1:30)	7:55 (1:10)	.131	.008
Sleep Duration Measures							
Time in bed ^a	492	8:35 (1:24)	8:15 (1:18)†^	8:39 (1:17)*	8:51 (1:34)*	.001	.028
TNST ^a	494	7:35 (1:19)	7:18 (1:11)†^	7:46 (1:16)*	7:37 (1:28)*	.002	.025
Total nap time ^a	107	0:57 (0:48)	0:36 (0:23)†^	1:02 (0:47)*	1:11 (0:57)*	<.001	.170
# of naps ^a	481	0.24 (0.48)	0.24 (0.50)	0.21 (0.44)^	0.29 (0.50)†	.018	.017
Total nap time (all days) ^a	481	0:12 (0:33)	0:07 (0:18)^	0:12 (0:32)^	0:19 (0:43)*†	<.001	.033
Total daily sleep time ^a	455	7:47 (1:21)	7:26 (1:12)†^	7:58 (1:21)*	7:54 (1:26)*	<.001	.036
Sleep Quality Measures							
Subjective sleep quality ^a	494	3.55 (0.82)	3.62 (0.88)^	3.56 (0.83)*	3.44 (0.74)*†	.001	.030
Subjective refreshment ^a	495	3.22 (0.90)	3.38 (0.90)^	3.17 (0.95)	3.09 (0.80)*	.005	.021
Sleep efficiency (%) ^a	492	88.4 (8.5)	88.8 (8.3)	89.7 (7.6)^	86.2 (9.5)†	.020	.016
Sleep onset latency ^a	494	0:19 (0:22)	0:19 (0:20)^	0:16 (0:17)^	0:25 (0:30)*†	.001	.030
fWASO ^a	495	1.34 (1.67)	0.76 (0.92)†^	1.21 (1.65)*^	2.18 (2.02)*†	<.001	.080
dWASO ^a	495	0:06 (0:11)	0:02 (0:05)†^	0:05 (0:10)*^	0:12 (0:15)*†	<.001	.071
Sleep Chronotype Measures							
Chronotype score ^a	35	56.23 (8.40)	53.70 (12.10)	56.93 (8.00)	57.70 (3.23)	.687	.025
Chronotype category ^b	35					.689	.146
Evening-type (%)		3 (8.6)	2 (20.0)	1 (6.7)	0 (0.0)		
Intermediate-type (%)		19 (54.3)	5 (50.0)	8 (53.3)	6 (60.0)		
Morning-type (%)		13 (37.1)	3 (30.0)	6 (40.0)	4 (40.0)		
Training Measures							
Practice day proportion ^c	481	79.0	79.3	76.4	82.7	.382	.064
Mean daily practices ^a	481	1.04 (0.72)	0.93 (0.60)^	1.00 (0.70)^	1.23 (0.82)*†	.001	.031
Mean daily volume ^a	481	1:14 (0:57)	0:58 (0:41)†^	1:16 (1:02)*	1:29 (1:01)*	<.001	.043
Mean daily RPE ^a	380	4.54 (2.00)	4.23 (1.71)†	5.22 (2.20)*^	3.92 (1.69)†	<.001	.095
Mean daily sRPE ^a	481	354 (341)	250 (222)†^	407 (389)*	387 (348)*	<.001	.040

Notes: Means are presented in unadjusted form; TNST = Total nighttime sleep time (abbreviated for space).

^a *p*-value and effect size (*partial* η^2) from ANCOVA testing where age and sport type were entered as covariates

^b *p*-value and effect size (Cramer's *V*) from chi-square testing

^c *p*-value and effect size (Kendall's τ_b) from chi-square testing

* Significantly different ($p < .05$) from 'non-elite' group mean

† Significantly different ($p < .05$) from 'pre-elite' group mean

^ Significantly different ($p < .05$) from 'elite' group mean

Appendix G: Age restricted parallel analysis of participants providing 12+ nights of data

Table G1: Participant characteristics organized by skill level for participants who provided at least 12 nights of data and were not considered age outliers

	Total (<i>n</i> = 34)	Participant Skill Level			<i>p</i> -value	Effect Size
		Non-Elite (<i>n</i> = 11)	Pre-Elite (<i>n</i> = 13)	Elite (<i>n</i> = 10)		
Participant age (SD)	21.12 (3.38)	20.64 (3.72)	19.77 (1.83) [^]	23.40 (3.66) [†]	.027 ^a	$\eta^2 = .207$
Participant sex (%)					.309 ^b	$V = .281$
Female	19 (57.9)	4 (36.4)	8 (61.5)	7 (70.0)		
Male	15 (42.1)	7 (63.6)	5 (38.5)	3 (30.0)		
Participant country – most of life (%)					.309 ^b	$V = .318$
Canada	32 (94.1)	11 (100.0)	11 (84.6)	10 (100.0)		
Other	2 (5.9)	0 (0.0)	2 (15.4)	0 (0.0)		
Highest level of education (%)					.375 ^b	$\tau_b = .248$
Some secondary	5 (14.7)	2 (18.2)	3 (23.1)	0 (0.0)		
Some post-secondary	24 (70.6)	8 (72.7)	9 (69.2)	7 (70.0)		
Some graduate	5 (14.7)	1 (9.1)	1 (7.7)	3 (30.0)		
Main sport type (%)					.951 ^b	$V = .265$
Cycling	3 (8.8)	0 (0.0)	2 (15.4)	1 (10.0)		
Distance running	16 (47.1)	7 (63.6)	5 (38.5)	4 (40.0)		
Nordic skiing	3 (8.8)	1 (9.1)	1 (7.7)	1 (10.0)		
Rowing	8 (23.5)	2 (18.2)	3 (23.1)	3 (30.0)		
Swimming	2 (5.9)	1 (9.1)	1 (7.7)	0 (0.0)		
Triathlon	2 (5.9)	0 (0.0)	1 (7.7)	1 (10.0)		

^a *p*-value reported is for ANOVA *F*-statistic

^b *p*-value reported is for chi-square test

* Significantly different ($p < .05$) from ‘non-elite’ group mean

† Significantly different ($p < .05$) from ‘pre-elite’ group mean

^ Significantly different ($p < .05$) from ‘elite’ group mean

Table G2: Summarized ANCOVA results organized by skill level for participants who provided at least 12 nights of data and were not considered age outliers

	<i>n</i> =	Participant Skill Level				<i>p</i> -value	Effect size
		Total	Non-Elite	Pre-Elite	Elite		
Sleep Timing Measures							
Bedtime ^a	450	23:17 (1:29)	23:35 (1:27)	23:13 (1:36)	23:03 (1:19)	.036	.015
Time of attempted sleep ^a	452	23:36 (1:24)	23:54 (1:25) [^]	23:32 (1:26)	23:21* (1:17)	.019	.018
Time of sleep onset ^a	452	23:55 (1:21)	0:11 (1:19) [†]	23:49 (1:26)*	23:46 (1:15)	.035	.015
Wake time ^a	453	7:36 (1:24)	7:34 (1:26)	7:38 (1:33)	7:37 (1:10)	.222	.007
Rise time ^a	453	7:52 (1:25)	7:48 (1:26)	7:55 (1:35)	7:55 (1:10)	.218	.007
Sleep Duration Measures							
Time in bed ^a	450	8:35 (1:26)	8:13 (1:19) ^{†^}	8:40 (1:21)*	8:51 (1:34)*	<.001	.036
TNST ^a	452	7:34 (1:21)	7:20 (1:12) ^{†^}	7:44 (1:21)*	7:37 (1:28)*	.010	.020
Total nap time ^a	103	0:578 (0:48)	0:36 (0:23) ^{†^}	1:05 (0:49)*	1:11 (0:57)*	<.001	.169
# of naps ^a	441	0.26 (0.49)	0.26 (0.52)	0.23 (0.46) [^]	0.29 (0.50) [†]	.053	.013
Total nap time (all days) ^a	441	0:13 (0:34)	0:08 (0:18) [^]	0:13 (0:34) [^]	0:19 (0:43)	.002	.029
Total daily sleep time ^a	423	7:47 (1:22)	7:29 (1:12) ^{†^}	7:56 (1:25)*	7:54 (1:26)*	.002	.029
Sleep Quality Measures							
Subjective sleep quality ^a	452	3.50 (0.82)	3.58 (0.87) [^]	3.48 (0.83) [^]	3.44 (0.74)* [†]	.007	.022
Subjective refreshment ^a	453	3.16 (0.88)	3.34 (0.88) ^{†^}	3.05 (0.91)*	3.09 (0.80)*	.004	.025
Sleep efficiency (%) ^a	450	88.3 (8.5)	89.6 (7.7) [^]	89.0 (7.9) [^]	86.2 (9.5)* [†]	.018	.018
Sleep onset latency ^a	452	0:19 (0:22)	0:17 (0:16) [^]	0:17 (0:16) [^]	0:25 (0:30)* [†]	<.001	.052
fWASO ^a	453	1.37 (1.71)	0.77 (0.93) ^{†^}	1.25 (1.72)* [^]	2.18 (2.02)* [†]	<.001	.070
dWASO ^a	453	0:06 (0:11)	0:02 (0:05) ^{†^}	0:05 (0:11)* [^]	0:12 (0:15)* [†]	<.001	.058
Sleep Chronotype Measures							
Chronotype score ^a	33	55.82 (8.45)	53.70 (12.10)	56.00 (8.12)	57.70 (3.23)	.809	.015
Chronotype category ^b	33					.689	.146
Evening-type (%)		3 (9.1)	2 (20.0)	1 (7.7)	0 (0.0)		
Intermediate-type (%)		19 (57.6)	5 (50.0)	8 (61.5)	6 (60.0)		
Morning-type (%)		11 (33.3)	3 (30.0)	4 (30.8)	4 (40.0)		
Training Measures							
Practice day proportion ^c	441	78.9	78.5	76.3	82.7	.381	.065
Mean daily practices ^a	441	1.05 (0.73)	0.93 (0.61) [^]	1.02 (0.72) [^]	1.23 (0.82)* [†]	.001	.032
Mean daily volume ^a	441	1:14 (0:58)	0:57 (0:41) ^{†^}	1:17 (1:04)*	1:29 (1:01)*	<.001	.047
Mean daily RPE ^a	348	4.52 (2.01)	4.24 (1.77) ^{†^}	5.24 (2.22)* [^]	3.92 (1.69)* [†]	<.001	.103
Mean daily sRPE ^a	441	356 (348)	247 (222) ^{†^}	417 (406)*	387 (348)*	<.001	.044

Notes: Means are presented in unadjusted form; TNST = Total nighttime sleep time (abbreviated for space).

^a *p*-value and effect size (*partial* η^2) from ANCOVA testing where age and sport type were entered as covariates

^b *p*-value and effect size (Cramer's *V*) from chi-square testing

^c *p*-value and effect size (Kendall's τ_b) from chi-square testing

* Significantly different ($p < .05$) from 'non-elite' group mean

† Significantly different ($p < .05$) from 'pre-elite' group mean

^ Significantly different ($p < .05$) from 'elite' group mean

Appendix H: Age restricted parallel analysis regardless of response frequency

Table H1: Participant characteristics organized by skill level for participants who were not considered age outliers and provided any number of responses

	Total (<i>n</i> = 45)	Participant Skill Level			<i>p</i> -value	Effect Size
		Non-Elite (<i>n</i> = 15)	Pre-Elite (<i>n</i> = 18)	Elite (<i>n</i> = 12)		
Participant age (SD)	21.36 (3.51)	21.40 (4.37)	19.89 (1.75) [^]	23.50 (3.43) [†]	.018 ^a	$\eta^2 = .173$
Participant sex (%)					.502 ^b	$V = .198$
Female	25 (56.8)	6 (42.9)	11 (61.1)	8 (66.7)		
Male	19 (43.2)	8 (57.1)	7 (38.9)	4 (33.3)		
Participant country – most of life (%)					.323 ^b	$V = .3264$
Canada	43 (94.1)	15 (100.0)	16 (88.9)	12 (100.0)		
Other	2 (5.9)	0 (0.0)	2 (11.1)	0 (0.0)		
Highest level of education (%)					.229 ^b	$\tau_b = .191$
Some secondary	6 (13.3)	3 (20.0)	3 (16.7)	0 (0.0)		
Some post-secondary	31 (68.9)	9 (60.0)	14 (77.8)	8 (66.7)		
Some graduate	8 (17.8)	3 (20.0)	1 (5.6)	4 (33.3)		
Main sport type (%)					.904 ^b	$V = .251$
Cycling	3 (6.7)	0 (0.0)	2 (11.1)	1 (8.3)		
Distance running	19 (42.2)	8 (53.3)	6 (33.3)	5 (41.7)		
Nordic skiing	4 (8.9)	1 (6.7)	2 (11.1)	1 (8.3)		
Rowing	14 (31.1)	4 (26.7)	6 (33.3)	4 (33.3)		
Swimming	3 (6.7)	2 (13.3)	1 (5.6)	0 (0.0)		
Triathlon	2 (4.4)	0 (0.0)	1 (5.6)	1 (8.3)		

^a *p*-value reported is for ANOVA *F*-statistic

^b *p*-value reported is for chi-square test

* Significantly different ($p < .05$) from ‘non-elite’ group mean

† Significantly different ($p < .05$) from ‘pre-elite’ group mean

^ Significantly different ($p < .05$) from ‘elite’ group mean

Table H2: Summarized ANCOVA results organized by skill level for participants who were not considered age outliers and provided any number of responses

	<i>n</i> =	Participant Skill Level				<i>p</i> -value	Effect size
		Total	Non-Elite	Pre-Elite	Elite		
Sleep Timing Measures							
Bedtime ^a	549	23:17 (1:26)	23:30 (1:24)	23:13 (1:32)	23:05 (1:19)	.051	.011
Time of attempted sleep ^a	551	23:35 (1:21)	23:47 (1:22)	23:31 (1:23)	23:25 (1:16)	.048	.011
Time of sleep onset ^a	551	23:55 (1:19)	0:06 (1:16)†	23:49 (1:25)*	23:49 (1:13)	.039	.012
Wake time ^a	552	7:35 (1:25)	7:35 (1:24)	7:37 (1:31)	7:34 (1:17)	.432	.003
Rise time ^a	552	7:51 (1:27)	7:50 (1:25)	7:52 (1:36)	7:50 (1:17)	.457	.003
Sleep Duration Measures							
Time in bed ^a	549	8:34 (1:27)	8:20 (1:22)^	8:38 (1:23)	8:44 (1:37)*	.021	.014
TNST ^a	551	7:33 (1:22)	7:26 (1:15)	7:41 (1:22)	7:31 (1:30)	.227	.005
Total nap time ^a	122	0:55 (0:47)	0:32 (0:23)†^	1:03 (0:48)*	1:10 (0:57)*	<.001	.162
# of naps ^a	532	0.27 (0.55)	0.29 (0.60)	0.25 (0.55)	0.27 (0.49)	.249	.005
Total nap time (all days) ^a	532	0:12 (0:32)	0:07 (0:17)^	0:13 (0:34)	0:17 (0:42)*	.002	.024
Total daily sleep time ^a	489	7:46 (1:23)	7:31 (1:15)^	7:56 (1:24)	7:50 (1:27)*	.014	.018
Sleep Quality Measures							
Subjective sleep quality ^a	551	3.52 (0.83)	3.61 (0.88)^	3.52 (0.84)^	3.42 (0.73)*†	.006	.019
Subjective refreshment ^a	552	3.22 (0.90)	3.39 (0.90)†^	3.16 (0.95)*	3.10 (0.80)*	.004	.020
Sleep efficiency (%) ^a	549	88.4 (8.7)	89.4 (8.0)^	89.1 (8.7)^	86.1 (9.2)*†	.006	.018
Sleep onset latency ^a	551	0:19 (0:24)	0:18 (0:19)^	0:18 (0:23)^	0:23 (0:29)*†	.009	.017
fWASO ^a	552	1.31 (1.63)	0.81 (1.01)†^	1.19 (1.61)*^	2.08 (1.96)*†	<.001	.072
dWASO ^a	552	0:06 (0:12)	0:03 (0:06)†^	0:05 (0:11)*^	0:13 (0:15)*†	<.001	.070
Sleep Chronotype Measures							
Chronotype score ^a	41	56.20 (8.65)	52.75 (12.66)	57.29 (7.58)	58.08 (3.06)	.357	.056
Chronotype category ^b	41					.328	.200
Evening-type (%)		4 (8.5)	3 (25.0)	1 (5.9)	0 (0.0)		
Intermediate-type (%)		20 (48.8)	5 (41.7)	9 (52.9)	6 (50.0)		
Morning-type (%)		17 (41.5)	4 (33.3)	7 (41.2)	6 (50.0)		
Training Measures							
Practice day proportion ^c	532	75.8	70.7^	74.9	82.9*	.040	.011
Mean daily practices ^a	532	1.01 (0.74)	0.83 (0.63)^	1.00 (0.72)^	1.22 (0.82)*†	<.001	.047
Mean daily volume ^a	532	1:11 (0:58)	0:52 (0:43)†^	1:15 (1:02)*	1:26 (1:00)*	<.001	.058
Mean daily RPE ^a	403	4.56 (2.02)	4.29 (1.76)†	5.18 (2.17)*^	4.00 (1.82)†	<.001	.073
Mean daily sRPE ^a	532	339 (340)	230 (236)†^	397 (385)*	377 (339)*	<.001	.047

Notes: Means are presented in unadjusted form; TNST = Total nighttime sleep time (abbreviated for space).

^a *p*-value and effect size (*partial* η^2) from ANCOVA testing where age and sport type were entered as covariates

^b *p*-value and effect size (Kendall's τ_b) from chi-square testing

^c *p*-value and effect size (Cramer's *V*) from chi-square testing

* Significantly different ($p < .05$) from 'non-elite' group mean

† Significantly different ($p < .05$) from 'pre-elite' group mean

^ Significantly different ($p < .05$) from 'elite' group mean