AN ANALYSIS OF SLEEP AND ERGOMETER PERFORMANCE IN COLLEGIATE MALE ROWERS

A Thesis
Submitted to
the Temple University Graduate Board

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

By
Thaddeus C. L. Babiec
August 2020

Thesis Approvals:
Dr. Daniel Rosney, Ph.D., Thesis Advisor, Kinesiology
Dr. Chantelle Hart, Ph.D., Social and Behavioral Sciences
Dr. Richard Lauer, Ph.D., Health and Rehabilitation Sciences
ABSTRACT

Introduction: Research has increasingly looked at the effects of sleep on athletic performance. Although there is currently a plethora of data expressing the detrimental effects of sleep deprivation on athletic performance, fewer studies have assessed the effects of sleep extension. Of those studies that have been done, all have been with field or team sport athletes and all have been conducted with athletes who traditionally have practice times later in the day. Rowing is a sport with traditionally early practice times and represents an under examined population. Heart rate variability (HRV) biofeedback has been an increasingly utilized tool in monitoring athletes through training programs and allowing coaches a better picture of the effects of an athlete’s training regimen. Members of the Temple Men’s Rowing Team participated in an eight-week sleep extension study to observe any performance benefits gained from the increased amount of sleep. Methods: Nineteen members of the Temple University’s men’s rowing team were asked to increase their sleep to nine to ten hours a night for four weeks, following a two-week baseline period. A two-week post-intervention phase followed the sleep extension period. Three sport specific assessments (Open rate 1-minute, Rate-capped 1-minute, and Interval tests) and daily HRV recordings were captured each week. Results: Subjects were unable to obtain the amount of sleep for sleep extension, averaging 392.07 ± 53.69 and 374.11 ± 41.53 minutes of total sleep time during baseline and the intervention respectively (p = .137). Significant variation was found in the Interval test and OR1-Min test in a week to week comparison. Conclusion: Athletes failed to increase their time asleep, limiting our ability to assess the impact of sleep on performance. Performance did
suffer over the course of the study, suggesting participants were below the minimal amount of sleep necessary to maintain performance. Better athlete education by coaches might prove beneficial for athletes to develop the habits necessary for sufficient sleep and improved performance.
ACKNOWLEDGEMENTS

I would like to thank my parents for providing me the support to pursue this opportunity at Temple.

Thank you to Dr. Rosney for providing guidance and working with me through this whole process. I am sure on more than one occasion there was cause to pull some hair out but you stuck with me and I really appreciate it.

Thank you to Dr. Lauer and Dr. Hart for agreeing to serve on my committee and assist with this process, through the changing schedules and COVID-19, you have both been wonderful.

Thank you to Joe Hines, who really saved me on more than one occasion through the admissions process and each semester with classes. You helped me navigate the system of Temple and made sure I didn’t fall through the cracks. Thank you.

And finally, thank you to Temple University, for giving me this opportunity to pursue an advanced degree here.
# TABLE OF CONTENTS

Page

ABSTRACT........................................................................................................ iii

ACKNOWLEDGMENTS................................................................. v

LIST OF TABLES........................................................................ xi

TABLE OF FIGURES........................................................................ x

CHAPTER

1. INTRODUCTION................................................................. 1

2. REVIEW OF LITERATURE......................................................... 4

Sleep...........................................................................................................4

Sleep Physiology...................................................................................5

Caffeine and Naps..................................................................................6

Sleep Around Training and Competition...........................................8

Sports with Poor Sleep........................................................................11

Sleep Extension...................................................................................11

Sleep Recording Technology............................................................12

Heart Rate Variability..........................................................................14

Heart Rate Variability in Athletes.......................................................15

Performance Measurement ..............................................................17

Heart Rate Variability Individualization in Programming..............18
Heart Rate Variability Technology ................................................................. 19

3. AN ANALYSIS OF SLEEP AND ERGOMETER PERFORMANCE IN

   COLLEGIATE MALE ROWERS ................................................................. 22

   Abstract ........................................................................................................ 22
   Background ................................................................................................. 23
   Methods ....................................................................................................... 26
     Study Design .......................................................................................... 27
   Sport Specific Tests .................................................................................... 288
   Sleep Questionnaires .................................................................................. 299
   Objective Assessment of Sleep .................................................................. 29
   Daily HRV Recording .................................................................................. 30
   Statistical Analysis ..................................................................................... 31
   Results .......................................................................................................... 322
   Discussion .................................................................................................... 388
   Limitations ................................................................................................... 4545
   Conclusions .................................................................................................. 488

BIBLIOGRAPHY ............................................................................................. 50

APPENDICES ................................................................................................. 63
A. LIST OF ACRONYMS .................................................................................. 6464
B. CONCEPT 2 ROWING ERGOMETER ...................................................... 6565
C. SLEEPSCORE MAX DEVICE ..................................................................... 6666
D. EPWORTH SLEEPINESS SCALE QUESTIONNAIRE ......................... 6767
E. PITTSBURGH SLEEP QUALITY INDEX QUESTIONNAIRE .....................68
F. STOP-BANG SLEEP APNEA QUESTIONNAIRE..................................72
G. HRV4TRAINING APP AND QUESTIONNAIRE.................................733
H. SLEEPSCORE MAX USER INTERFACE ........................................800
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Participant Data</td>
<td>26</td>
</tr>
<tr>
<td>2. Outcome and Sleep Measures at Study Phases</td>
<td>32</td>
</tr>
<tr>
<td>3. Outcome and Sleep Measures at Weekly Intervals</td>
<td>32</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Study Timeline</td>
<td>27</td>
</tr>
<tr>
<td>2.</td>
<td>OR1-Min during study, Weeks 2 and 3 significance highlighted</td>
<td>33</td>
</tr>
<tr>
<td>3.</td>
<td>OR1-Min during study, Weeks 3 and 5 significance highlighted</td>
<td>33</td>
</tr>
<tr>
<td>4.</td>
<td>Interval Test during study, Weeks 4 and 8 highlighted</td>
<td>34</td>
</tr>
<tr>
<td>5.</td>
<td>Regression Analysis of OR1-Min baseline to intervention</td>
<td>34</td>
</tr>
<tr>
<td>6.</td>
<td>Regression Analysis of OR1-Min intervention to post-intervention phase</td>
<td>35</td>
</tr>
<tr>
<td>7.</td>
<td>Regression Analysis of RC1-Min baseline to intervention</td>
<td>35</td>
</tr>
<tr>
<td>8.</td>
<td>Regression Analysis of RC1-Min intervention to post-intervention phase</td>
<td>36</td>
</tr>
<tr>
<td>9.</td>
<td>Regression Analysis of the Interval test baseline to intervention phase</td>
<td>36</td>
</tr>
<tr>
<td>10.</td>
<td>Regression Analysis of the Interval test at intervention to post-intervention phase</td>
<td>37</td>
</tr>
<tr>
<td>11.</td>
<td>Regression Analysis of HRV at baseline to intervention phase</td>
<td>37</td>
</tr>
<tr>
<td>12.</td>
<td>Regression Analysis of HRV at intervention to post-intervention phase</td>
<td>38</td>
</tr>
<tr>
<td>13.</td>
<td>Controlling Interval Test results by weight of participants</td>
<td>41</td>
</tr>
<tr>
<td>14.</td>
<td>Controlling OR1-Min Test results by weight of participants</td>
<td>41</td>
</tr>
</tbody>
</table>
CHAPTER 1 – INTRODUCTION

In 1966, Baekeland and Lasky first studied the importance of sleep in athletic performance. They observed the effects of exercise at different points of the day on the subsequent night’s sleep (Baekeland & Lasky, 1966). Sleep extension studies followed shortly after with Taub and colleagues, but they concluded sleep extension and sleep deprivation had similar effects on cognitive performance and mood (Taub & Berger, 1969; Taub, Globus, Phoebus, & Drury, 1971). The next generation of sleep extension studies would not come until years later, during which time numerous sleep deprivation studies through researchers such as Anders, Martin, Reilly, Rosa, and others, studied the effects of partial and total sleep deprivation on many different aspects of performance, such as strength, aerobic conditioning, and intensity self-selection (Anders, Carskadon, Dement, & Harvey, 1978; Francesconi, Stokes, Banderet, & Kowal, 1978; Horne & Pettitt, 1984; B. Martin & Haney, 1982; B. J. Martin, 1981; B. J. Martin & Gaddis, 1981; McMurray & Brown, 1984; Reilly & Deykin, 1983; Rosa, Bonnet, & Warm, 1983). More recently, sleep extension studies have found that extending sleep duration provides measurable and significant improvements to performance (Dement, 2005; C. Mah, Mah, & Dement, 2007; C. D. Mah, Mah, & Dement, 2008; Cheri D. Mah, Mah, Kezirian, & Dement, 2011; Schwartz & Simon, 2015; Simon & Schwartz, 2005; Swinbourne, Miller, Smart, Dulson, & Gill, 2018).

In addition to sleep, biofeedback tools have started playing a larger role in the implementation and modification of training programs. Work by Plews et al. has determined that at a minimum, three daily recordings of heart rate variability (HRV) per week are necessary for accurate and useful data for coaches (D. J. Plews, Laursen, Le...
Meur, et al., 2014). Subsequently, HRV has been used by coaches to help guide their training programs in a variety of sports, such as CrossFit, soccer, cross-country skiing, and rowing (Javaloyes, Sarabia, Lamberts, & Moya-Ramon, 2019; Morales et al., 2014; D. J. Plews, Laursen, & Buchheit, 2017; Schmitt, Willis, Fardel, Coulmy, & Millet, 2018; Williams, Booton, Watson, Rowland, & Altini, 2017).

It has been established that sleep extension has significant benefits for athletes in terms of sport specific skills in addition to mood scores and reaction time drills. HRV has been shown to be a reliable predictor of training load and adaptation on the part of the athlete, with decreasing HRV tending to coincide with injury and increasing HRV with adaptations and improvement. There is no study that has yet looked at the relation between HRV, extended sleep, and rowing performance.

We hypothesized that during and following a period of sleep extension, participants will see significant improvements in their weekly scores on a 1-minute Tests and Interval Test on the rowing ergometer (i.e., measure of sport specific performance). Additionally, improvements in daily HRV measurements, used to assess the recovery of the participants, will improve during the period of sleep extension.

Sleep has been shown to be a key component of athletic performance. When deprived of sleep, athletic performance both in practice and in competition suffer. The evidence suggesting that increasing the amount of sleep athletes get on a regular basis could help their performance is promising but still incomplete. To date, only three studies have conducted a comprehensive sleep extension study on athletes, and of those studies, none assessed physical performance. All the tests done were skill-based tests, not
endurance or strength based. As such, this will be the first study looking at the effect of sleep on physical and strength-based tests in sports.

Additionally, the role of HRV and its exact relationship to sleep and performance is less clearly understood. Understanding the measurable effect sleep has on daily HRV would be highly beneficial. It is already known that HRV can be used as biofeedback for coaches and athletes to assess recovery during periods of training and competition. Understanding the role of sleep in this process, as it relates to HRV will be valuable.

In athletic performance research, rowers are an understudied population and provide a unique athlete profile to study the effects of sleep extension. As athletes that require both strength and stamina to perform, this group would fill the need for a better understanding of sleep extension on these two traits. This group of athletes are also known for early morning training sessions – a practice time known to truncate the amount of sleep obtained. Performing sleep extension research on a group like this could provide insights into the benefits of this intervention in other early morning sports, such as swimming.
Sleep

Approximately 33% of the average human life will be spent asleep. Sleep is when the human body recovers and repairs any damage done, condensing knowledge and information gained during the day (Krueger, Frank, Wisor, & Roy, 2016). Sufficient and quality sleep are critical to our ability to function effectively. Today, two-thirds of adults throughout developed nations fail to obtain the seven to nine hours of nightly sleep as recommended by the World Health Organization and the National Sleep Foundation (N. F. Watson et al., 2015). As sleep quantity and quality have diminished around the world, the likelihood for increased incidence of injuries and illnesses, such as obesity (Cappuccio et al., 2008), high blood pressure, cardiac arrest (Lusardi et al., 1999), Alzheimer’s disease (Lim, Kowgier, Yu, Buchman, & Bennett, 2013), and soft tissue and ligament injuries (Dennis, Dawson, Heasman, Rogalski, & Robey, 2016; Milewski et al., 2014; von Rosen, Frohm, Kottorp, Friden, & Heijne, 2017) has grown.

A study out of the University of Pennsylvania did find that over the past 14-year period, there were some modest successes in the fight against sleep deficiency (Basner & Dinges, 2018). Through surveys conducted between 2003 and 2016, it was found that there has been a reported increase of 1.40 min/yr of sleep on average during weekdays and 0.83 min/yr of sleep on average during weekends and holidays. This increased sleep time seemed to come as a result of less time watching TV or reading a book in bed, as well as more people working from home, which allows them the flexibility to sleep
longer. Although this change is small and based on self-reporting, it could be a sign of a coming shift in trends of time spent in restorative sleep.

**Sleep Physiology**

Sleep can be separated into two distinct types, REM (Rapid Eye Movement) and non-REM. During REM sleep neurological recovery and memory consolidation take place, in addition to increased movement of cerebrospinal fluid around the brain, which has a protective effect against neurological disorders such as Alzheimer’s disease. It is also the stage where dreaming takes place (Krueger et al., 2016). Non-REM sleep can be divided into four stages (Erwin, Somerville, & Radtke, 1984). Firstly, the state of drowsiness, or Stage 1 sleep, the initial feeling of drifting off to sleep, total muscle activation decreases but some muscle twitching can occur. Light or Stage 2 sleep is where most time asleep is spent, it is the transition point between REM and deep sleep; heart rate decreases and breathing rate changes (Douglas, White, Pickett, Weil, & Zwillich, 1982). Stages 3 and 4 collectively are referred to as slow wave sleep or delta sleep; identified by delta waves in the brain. In these stages physical recovery predominantly takes place. A typical sleep cycle lasts 90 minutes and as we sleep through the night, we cycle through all stages of sleep (Shapiro & Flanigan, 1993). Getting sufficient sleep is critical, as chronically reduced sleep can lead to a whole host of issues, from illness and injury to degradation in neurobehavioral performance (McHill, Hull, Wang, Czeisler, & Klerman, 2018).

The amount of sleep needed at different stages of life is not consistent, nor is the natural circadian rhythm of an individual over the course of a lifetime (Eaton et al.,
Infants require greater amounts of sleep compared to adults. Teenagers naturally begin going to bed and waking up later due to changes in their natural circadian rhythm (Giannotti, Cortesi, Sebastiani, & Ottaviano, 2002). According to the National Sleep Foundation, normal human beings require between seven and nine hours of sleep each night. Mandated school and work times, blue light from handheld electronics, and greater noise levels in and around the home in the evenings lead to individuals at all ages not getting the sufficient amount of sleep required for healthy development. Findings by Twenge in 2017 attributed use of electronic devices as the main reason more adolescents were reporting less than seven hours of sleep on most nights, approximately 16-17% increase from 2011-2013 (Twenge, Krizan, & Hisler, 2017).

Caffeine and Naps

As the amount of sleep deprived individuals increase, the use of stimulants and other supplements or means to combat the effects of sleep deprivation (less than seven hours of sleep a night) increases. For example, of 253 surveyed college students who said they consumed caffeine greater than once a month on average, 67% did so due to insufficient sleep and 65% to increase energy (Malinauskas, 2007). Most commonly used is caffeine in the form of caffeinated beverages and energy drinks (Whittier, 2014). Caffeine and energy drink consumption at steadily increasing amounts have been linked to increased levels of stress, junk food consumption, depression, suicide attempts, and lowered school performance (Kim, Sim, & Choi, 2017; A. P. Smith & Richards, 2018; Whittier, 2014). Due to the length of time it takes the body to process caffeine (70% will
be processed in 10 hours) consumption of caffeine later in the day will have a negative effect on the upcoming night’s sleep (Levy, Zylberkatz, & Granit, 1984).

Despite these issues, there is a great deal of evidence that supports the use of caffeine supplementation in sports. In resistance training and power sports such as weightlifting, caffeine has been shown to improve bar speed and time under tension, as well as increase the maximal voluntary weight an athlete chooses to use (Cook, Beaven, Kilduff, & Drawer, 2012; Wilk, Krzysztofik, Maszczyk, Chycki, & Zajac, 2019). Three mg per kg of bodyweight of caffeine was enough to elicit performance improvements in repeated sprint ability in elite swimmers following a normal night sleep (Goods, Landers, & Fulton, 2017). It is important to note that many of these studies use dosages that far exceed what most people or athletes would normally consume on a daily basis. Reyner and Horne found that a more realistic amount of caffeine (80 mg) following a restricted night sleep did not make up for the lost sleep, highlighting the importance of sufficient sleep for performance (Reyner & Horne, 2013).

Another method to help mitigate sleep deprivation that does not involve stimulants, is napping. One study observed the effects of napping on total sleep obtained by elite young soccer players and found that by allowing athletes to make up for restricted time in bed each night with a nap the following day, total time asleep, as well as the various stages of sleep, were not significantly different between groups (Romyn et al., 2018). In athletes, several studies have examined the effects of napping on performance and skill acquisition. In a study on skill acquisition, Morita et al. compared two groups of volunteers learning to juggle, with one group allowed a 70-minute nap post practice while the other group was to remain awake. The nap group showed significant improvement in
skill acquisition tested both immediately after the nap and the following day when compared to the non-nap group (Morita, Ogawa, & Uchida, 2016). In a study of national level karate athletes, a 30-minute nap was shown to help overcome the cognitive and physical deteriorations in performances caused either by sleep loss or by fatigue induced by exhaustive training in the afternoon (Daaloul, Souissi, & Davenne, 2019). Others have found that a 30-minute nap is enough to help overcome short physical bouts and reaction time performance following a night of as few as four hours of sleep (Waterhouse, Atkinson, Edwards, & Reilly, 2007). Studies observing the effects of napping on endurance performances, such as cross country running or biking, following restricted sleep are few and more research is needed to determine the effects of napping on these types of sports. Although no study has directly compared napping to caffeine on athletic performance, studies have found naps to provide longer lasting benefits compared to caffeine across varying conditions and tasks, including memory, concentration, and motor tasks (Bonnet, Gomez, Wirth, & Arand, 1995; Mednick, Cai, Kanady, & Drummond, 2008).

Sleep is one of the key pillars of recovery and performance during training and competition (Koelling, Steinacker, et al., 2016; Koelling, Wiewelhove, et al., 2016). During intense bouts of training, such as training camps and the lead up to competition, sleep quantity and quality tends to suffer (Chennaoui et al., 2016; Erlacher, Ehrlen, Adegbesan, & El-Din, 2011; Jurimae, Maestu, Purge, & Jurimae, 2004; Jurimae, Maestu, Purge, Jurimae, & Soot, 2002; Koelling, Wiewelhove, et al., 2016; Kolling, Duffield, Erlacher, Venter, & Halson, 2019; Lastella et al., 2015; C. Sargent, Halson, & Roach,
2014; Charli Sargent, Lastella, Halson, & Roach, 2014; Charli Sargent & Roach, 2016; 
Thornton et al., 2017). When sleep is reduced or restricted, performance in competition 
has been shown to suffer along with metrics assessing mood states, physiological markers 
of stress, and a marked increased risk of injury (Hugh H. K. Fullagar et al., 2015; H. H. 
K. Fullagar et al., 2015; Jurimae et al., 2002; Milewski et al., 2014).

One of the first studies assessing the effects of exercise on sleep, specifically non- 
REM (Deep) sleep in collegiate athletes was done by Baekeland and Lasky (1966). They 
found that there were higher amounts of non-REM sleep following physical activity than 
when there was no activity; additionally a majority of those minutes in non-REM 
occurred during the first three hours of sleep (Baekeland & Lasky, 1966). More recently, 
studies have assessed periods of increased exercise and sleep. Two studies that have 
assessed the sleep habits of national and professional level athletes during training camps 
have found that sleep tends to suffer during the days of increased training (or days that 
include more than one session) (Koelling, Steinacker, et al., 2016; Thornton et al., 2017). 
Thornton et al. found significantly reduced total sleep time (TST) and time in bed in 
athletes during training camp compared to training at home (Thornton et al., 2017). 
Koelling et al. found that sleep (TST) and stress scores were generally lower or worse 
during weeks of a training camp when there was intense training versus those when 
training was less intense and athletes had fewer sessions overall, suggesting an effective 
way to modulate this training camp effect on sleep (Koelling, Steinacker, et al., 2016).

Leading up to and during competition, when sleep is most critical, athletes tend to 
have worse sleep patterns (Lastella et al., 2015; Charli Sargent & Roach, 2016). A study 
observing the sleep/wake behavior of elite swimmers during a training camp prior to the
2008 Olympic Games found that only 5.4 ± 1.3 hours of sleep was obtained by these athletes during training days and 7.1 ± 1.2 hours the night before a rest day. Results showed that even leading up to the Olympic Games, sleep is still curtailed in athletes who are competing, leading the authors to suggest that the early morning practice times of these swimmers was perhaps hampering progress instead of helping (C. Sargent et al., 2014). In a study by Lastella et al., endurance cyclists had their sleep recorded before and during competition; it was found that athletes slept almost an hour less each night during competition than during the time leading up to competition. A change was also found in the time they went to bed, going to sleep and rising earlier during competition than before (Lastella et al., 2015). A study by Sargent et al. found that the night immediately following competition, time in bed and total sleep time (TST) were reduced in athletes and sleep onset was longer (Charli Sargent & Roach, 2016). These studies collectively suggest that athletes in the period of time leading up to and during competition are suffering from reduced sleep, leading to potential detrimental effects on their performance. Therefore, coaches and athletes should be attentive to allowing for adequate sleep during periods of competition.

Even during normal training periods, athletes tend to sleep less than what would be considered ideal for optimal performance. In a study observing the sleep habits of nationally ranked athletes across seven different sports, Sargent et al. found that during a normal training week, athletes got 6:30 ± 1:24 hours of sleep each night prior to a training day (Charli Sargent et al., 2014). There is currently minimal research on extending sleep or allowing for extended sleep during and leading into competition. A
need for better awareness and sleep practices for athletes is critical to help improve performance and health (A. M. Watson, 2017).

*Sports with Poor Sleep*

Sports that have traditionally early practice times, such as rowing and swimming, are more likely to have athletes that will suffer from reduced sleep during training periods. Studies assessing the sleep habits of both rowers and swimmers have found reduced sleep is not uncommon in both populations (Jurimae et al., 2004; Kennedy, Tamminen, & Holt, 2013; Koelling, Steinacker, et al., 2016; C. Sargent et al., 2014; T. B. Smith, Hopkins, & Lowe, 2011; Taylor, Rogers, & Driver, 1997). Youth swimmers have been found to average about 7.5 hours in bed on nights before an early morning practice, sometime between 5:30 and 6:30 am (Grant & Glen, 2018). Elite swimmers, even with practices later in the morning, averaged 7.67 hours of total sleep time during training and did not obtain eight hours during rest or taper periods of training (7.78 ± .47 hours) (Taylor et al., 1997; Walsh, Sanders, Hamilton, & Walshe, 2019). In rowers, similar bedtimes and time in bed are seen. Koelling et al. in her study with the German Junior National Team found athletes averaged just 6.9 ± .37 hours of sleep each night (Koelling, Steinacker, et al., 2016). Importantly, this is not uninterrupted sleep, but sleep that is broken up by short awakenings throughout the night, disrupting the natural sleep cycle, so fully restorative sleep might require more time than what athletes are currently getting (Walsh et al., 2019).

*Sleep Extension*

Research in the late 1960’s had found similar effects between sleep extension and sleep deprivation, specifically when subjects were performing calculated, vigilant, and
complex motor tasks (Taub & Berger, 1969; Taub et al., 1971). Recent research has shown this to previous assumption to be untrue, with positive effects of sleep extension including benefits in mood, vigilance and reaction times, blood pressure, hormone regulation, and reduced daytime sleepiness (Dement, 2005; Cheri D. Mah et al., 2011; Simon & Schwartz, 2005; Swinbourne et al., 2018). A study by Rupp et al. found sleep extension prior to a night of sleep deprivation seemed to protect against a loss in performance the day following the sleep deprivation (Rupp, Wesensten, Bliese, & Balkin, 2009). In athletic populations, the landmark study was performed by Mah et al. (2011), who found that sleep extension (9-10 hours each night) provides significant benefits to athletes. In collegiate basketball players, it was found that player free throw shooting, three point shooting, sprint times, mood scores, and reaction times all improved significantly, with some improvements seen in as early as four days, and there was no sign of a plateau when the study concluded (Cheri D. Mah et al., 2011). This research was supported by Schwartz et al. (2015) finding that tennis players who extended their sleep saw improvements in serving accuracy, and further supported by Swinbourne et al. (2018), who looked at the effects of sleep extension in rugby players. Players who increased their time in bed by 7.3% a night (6.3% time asleep), or approximately 20 minutes, saw improved reaction times and a reduction in cortisol levels (Swinbourne et al., 2018). Across multiple athletic disciplines, sleep extension has shown to be very beneficial to subsequent performance with no defined plateau in that performance.

Sleep Recording Technology

To take full advantage of the benefits sleep can offer to performance, it is important for athletes and coaches to be able to monitor sleep effectively, accurately, and
cost effectively. The current gold standard in sleep recording is the polysomnography (PSG), or sleep study. This is done in a lab where recording of brainwave activity, blood oxygen levels, heart rate and respiration, as well as eye and leg movements are done. This is all done to monitor the stages of sleep and identify if or when the typical sleep patterns are disrupted and why. Prior to PSG, early sleep research was either self-reported or participants were required to sleep in a sleep lab so ECGs could monitor their sleep cycles (Feinberg, Koresko, & Heller, 1967; B. Martin & Haney, 1982; Sassin et al., 1969; Taub & Berger, 1969; Taub et al., 1971). Technology has since improved, in addition to improved sleep lab measurements, accurate in-home and cost-effective monitoring has become an option as well. There are different types of monitors, the most common being a wrist worn actigraph monitor. Since the 1970’s, wrist actigraphy has been one of the most cost-effective ways of collecting sleep data and assessing for specific sleep disorders, sleep-wake schedule, and sleep quality (Sadeh, Hauri, Kripke, & Lavie, 1995). Recently, the technology around wearable devices have dramatically improved and there are several validated tools. A popular modern wearable actigraph monitor used by many collegiate and professional athletes is the WHOOP. The WHOOP is a validated device that uses photoplethysmography (PPG; a method to measure HRV by detecting changes in blood flow by illuminating the skin and measuring changes in light absorption to measure five metrics - heart rate (HR), heart rate variability, ambient temperature, motion and movement, and skin response – used collectively to measure and analyze a person’s sleep (Fonseca et al., 2017). It has been utilized in several studies assessing the sleep and recovery of athletes, including baseball players and swimmers, as well as one measuring the quality of sleep in orthopedic surgeons (Armwald, 2018; Harms, 2018; Sochacki,
Dong, Peterson, McCulloch, & Harris, 2018). Another new wrist worn device (myCadian) received validation in 2018 by Pigeon et al., finding that although it underestimated wake and overestimated sleep compared to PSG, it was still more favorable compared to an actigraph monitor made by Philips Respironics, one of the most utilized actigraph monitors in research (Pigeon et al., 2018). Headbands utilizing PPG also have received validation by both Shambroom et al. and Tonetti et al. Both found that, although the headbands were reliable, the technology was likely to overestimate the total time asleep and underestimate the number of awakenings each night. Findings were split when it came to total time in deep sleep, with Tonetti finding it underestimated and Shambroom finding overestimations (Shambroom, Fabregas, & Johnstone, 2012; Tonetti, Cellini, et al., 2013; Tonetti, Fabregas, et al., 2013).

In 2011, researchers began to use contactless sleep monitoring devices. Non-contact device operation is based on the reflection of radio waves and the changes in their phase that are caused by movement, similar to Doppler effect (Weinreich et al., 2018). This technology has been validated by Tal et al. finding that in two different scenarios, the technology had an overall accuracy of 92.5% when compared to PSG and a correlation factor of 0.98 (r = 0.87) when measuring total time asleep (Tal, Shinar, Shaki, Codish, & Goldbart, 2017). In short, for athletes measuring and monitoring their sleep, there are a host of accurate and cost-effective options open to them.

Heart Rate Variability

Heart rate variability (HRV) is the measure of the difference in time between successive heartbeats and is usually reported as the root mean square of successive
differences (rMSSD) (Malik, 1990). HRV provides an indirect view of the current physiological state of the body, if it is one of sympathetic or parasympathetic tone (M. Altini, 2017; Hynynen, Uusitalo, Konttinen, & Rusko, 2006; Ortigosa-Marquez, Reigal, Portell, Morales-Sanchez, & Hernandez-Mendo, 2017). When HRV is higher, there is greater parasympathetic activity and when HRV is lower there is greater sympathetic nervous system activity (M. Altini, 2017). As sympathetic nervous system activity is related to the fight-or-flight response and stress, HRV can be used to assess levels of stress in the body (Bosquet, Papelier, Leger, & Legros, 2003; Gisselman, Baxter, Wright, Hegedus, & Tumilty, 2016; Hynynen et al., 2006; Lee & Mendoza, 2012; Morales et al., 2014).

Heart Rate Variability in Athletes

HRV has attracted the attention of athletes and coaches as a measure of day-to-day recovery and preparedness leading up to and during competition, as well as a feedback mechanism for injury. An early study explored the possibility that HRV was an indicator of overreaching (Bosquet et al., 2003). It was found over a four week period that despite increasing workload by 100%, overnight HRV measurements did not significantly change between baseline, intervention, and post intervention periods, and therefore led to the assumption that, within the conditions of that study, HRV was not a valid measure of overtraining (Bosquet et al., 2003).

Recently, longer studies have found Bosquet’s conclusions to be incorrect. A study on youth rugby players (ages 17-20 years) by Edmonds et al. (2013) looked at heart rate (HR) and HRV leading up to, during, and after competition. It confirmed that prior to the games, players exhibited predominant sympathetic modulation that would persist for
days after. It was found that leading up to competition and post-game performance, HR remained significantly elevated and HRV was significantly reduced until two days post-game. HRV measures were still reduced four days post competition, leading to suggestions for day-to-day measuring of player HRV to help monitor workload (Edmonds, Sinclair, & Leicht, 2013).

A study looking at pre-competition HRV in elite female volleyball athletes found non-significant results similar to Edmonds et al., suggesting the level of experience of the athlete may have some effect on their HRV measures pre-competition (D'Ascenzi et al., 2014). In a study by Morales et al., Judo athletes were found to suffer from decreased strength parameters, higher markers of stress, lower perception of recovery, and decreased vagal modulation when subject to higher intensity workloads than more moderate workloads (Morales et al., 2014). In a study with teenage swimmers, researchers found that the sprint group of swimmers had both higher rates of injury and lower rMSSD over the course of a 20 week training program that included general, sport specific, and competition preparation, compared to the endurance group of swimmers (Lima-Borges, Martinez, Vanderlei, Barbosa, & Oliveira, 2018). A study of elite CrossFit athletes by Williams et al. found that monitoring HRV alongside the daily acute workload of athletes could help indicate when an athlete was both overreaching and beginning to suffer from an overuse injury, suggesting the use of HRV in individualized programming for athletes to monitor differing rates of recovery (S. Williams et al., 2017). A controlled study by Le Meur et al. found similar correlations with HRV in endurance athletes. Following overload training, HRV corresponded to functional overreaching in these athletes. Le Meur also recommended that for effective monitoring, multiple HRV
measurements each week would be required to confidently detect functional overreaching (Le Meur et al., 2013; D. J. Plews, Laursen, Le Meur, et al., 2014). Plews et al. confirmed this hypothesis, concluding that a minimum of three randomly selected data points each week would be necessary for accurate HRV monitoring and tracking (D. J. Plews, Laursen, Le Meur, et al., 2014).

**Performance Measurement**

More recently, HRV has been increasingly utilized as a predictive measure of performance as well as a feedback mechanism for intensity within a training program. Between 2012 and 2014, Plews published several papers on the merit of daily HRV measurements to help monitor training programs. The 2012 case study of two elite triathletes observed that trends in both absolute HRV values and day-to-day variations may be useful measurements indicative of the progression towards mal-adaptation or non-functional overreaching (D. J. Plews, Laursen, Kilding, & Buchheit, 2012). The 2013 study demonstrated how longitudinal HRV tracking is necessary for optimal programming, as all individuals have a unique HRV “fingerprint” and changes in daily HRV can only be accurately assessed in the context of a rolling average (Daniel J. Plews, Laursen, Stanley, Kilding, & Buchheit, 2013). In a 2014 study, Plews et al. demonstrated this need while assessing the effects of polarized training, training spent between high and low intensity, on the HRV of nine elite rowers during the 26-week build up to the 2011 World Championships and 2012 Olympic Games. It was found that with increased time spent at higher intensity, there was greater parasympathetic activity suppression while low-intensity training preserved and increased parasympathetic activity. These results suggested that periodizing (i.e. incorporating into a training program) in low-
intensity training would be beneficial for optimal training programs (D. J. Plews, Laursen, Kilding, & Buchheit, 2014).

**Heart Rate Variability Individualization in Programming**

Greater individualization of programming based on HRV has been studied in female soccer players. Flatt et al. tracked individualized changes in recovery status indicators and training load in collegiate female soccer players during their preseason. It was found that due to the large correlation of lnRMSSD to training load \( r = -0.85 \) and correlations between lnRMSSD and perceived fatigue \( r = 0.56 \), and soreness \( r = 0.54 \), training interventions based on lnRMSSD and subjective measures of wellness would be useful in managing the accumulation of fatigue (Flatt, Esco, Nakamura, & Plews, 2017). Vesterinen et al. (2017) explored whether a submaximal running test (SRT) with post-exercise heart rate recovery (HRR), HRV, and countermovement jump (CMJ) measurements could be used to monitor endurance training adaptation. It was found that the SRT and CMJ did not significantly affect HRR and HRV, suggesting their use as practical tools in evaluation without causing undue stress to the athletes (Vesterinen et al., 2017). This also showed that HRV and HRR did not seem to show a relation to maximal endurance performance.

In slight opposition to Vesterinen’s work, Esco et al. found a benefit of HRV measurement when they found near perfect correlation between VO2max and weekly mean lnRMSSD values \( r = 0.90, p=0.002 \), indicating that changes in weekly lnRMSSD of a conditioning protocol associates with the eventual adaptation of VO2max (Esco, Flatt, & Nakamura, 2016). Finally, in a 2017 study involving elite level rowers, Plews et al. implemented a training program that was dictated by daily HRV measurements. It was
found that improvements in performance measures and in recovery indicators were greater when compared to a traditional training program that did not account for daily HRV (D. J. Plews, Laursen, et al., 2017).

**Heart Rate Variability Technology**

The barrier to entry for individual coaches and athletes to utilize HRV data in their training programs has dramatically dropped. Initial studies, such as those by Bosquet et al. (2008), required the use of a laboratory setting and ECG to be able to accurately record HRV measurements. As Bluetooth and heart rate monitors became more advanced, mobile recording became possible. Two studies in 2008 and 2009 were some of the first in the sport science field to assess the validity of these new heart rate monitors when compared to the 12-lead ECG. Both studies focused on the Polar S810, and found it to have high reliability in all measures of HRV during periods of rest (Gamelin, Baquet, Berthoin, & Bosquet, 2008; Nunan et al., 2009). Later in 2010 and 2012, researchers did comparison studies of different heart rate monitors compared to ECG recordings of HRV. In the first study, there was strong agreement from all three devices (ambulatory five-lead ECG and Polar S810i and Suunto t6 heart rate monitors) in recording and interpolating R-R intervals but when it came to measuring absolute values, there was a great deal of discrepancy, suggesting ECG was still the best option (Weippert et al., 2010). Similar results were found in the 2012 study, comparing the Polar RS800 to a 3-lead ECG. It was found that the RS800 overestimated HRV and uncertainty increased as the HRV values increased (Wallen, Hasson, Theorell, Canlon, & Osika, 2012).

A 2017 study by Williams et al. found that the new Polar RS800CX was a valid method of recording HRV and reliable after being subjected to a two-week test-retest
protocol (D. P. Williams et al., 2017). Plews et al. compared photoplethysmography (PPG), Polar H7 heart rate monitor, and ECG and found that both PPG and the Polar H7 were highly correlated with ECG. The authors suggested the use of smartphone PPG as a practical and easy to use method of measurement for athletes (D. J. Plews, Scott, et al., 2017). PPG has become one of the primary ways coaches and athletes are currently measuring HRV on a day-to-day basis. For example, Plews et al. used the HRV4Training smartphone application in their 2014 study on elite Olympic rowers to track their daily HRV (D. J. Plews, Laursen, Kilding, et al., 2014).

Studies of large-scale user data of the HRV4Training App have compared lnRMSSD to reported training load and cardiorespiratory fitness in runners and have found high correlations in the predictive value of the app to the reported results from the users (Altini, 2016; M. a. V. H. Altini, C., 2017). Finally, a study by Chrsimas et al. in 2019 utilized the ithlete application (HRV Fit Ltd., UK) to track the HRV of professional soccer players and determine their daily “readiness” to train and perform. It was found that the HRV had a significant relationship to total training load of the athletes, showing HRV to be a valuable indicator of recovery and readiness for performance (Chrismas, Taylor, Thornton, Murray, & Stark, 2019). With the multitude of potential tools available for coaches, the use of HRV in training programs will hopefully become more prominent in the near future.

As it's been shown, HRV is a powerful tool for biomonitoring and as an effective means of tracking fatigue in athletes. Because HRV is directly related to vagal nerve tone, anything that can affect the nervous system will have an effect on HRV, with varying degrees depending on the individual. Consistent monitoring is the only clear way
to detect trends in training programs and understand how individual athletes are responding. With accurate tools becoming more accessible, this is a powerful and cost-effective tool for coaches to consider with their athletes.
CHAPTER 3. AN ANALYSIS OF SLEEP AND ERGOMETER PERFORMANCE IN COLLEGIATE MALE ROWERS

Abstract

**Introduction:** Research has increasingly looked at the effects of sleep on athletic performance. Although there is currently a plethora of data expressing the detrimental effects of sleep deprivation on athletic performance, fewer studies have assessed the effects of sleep extension. Of those studies that have been done, all have been with field or team sport athletes and all have been conducted with athletes who traditionally have practice times later in the day. Rowing is a sport with traditionally early practice times and represents an under examined population, particularly one that is at a high risk of sleep deprivation. Heart rate variability (HRV) biofeedback has been an increasingly utilized tool in monitoring the recovery of athletes through training programs. As a proxy measure of parasympathetic nervous system activity, it is useful for coaches to monitor an athlete or team’s preparedness and recovery on a daily and weekly basis. The purpose of the present study was to determine what sport specific performance benefits would be gained from extending the athlete’s sleep. **Methods:** Participants were nineteen members of the Temple University’s men’s rowing team who were asked to increase their sleep to between nine and ten hours a night for four weeks, following a two-week baseline period. A two-week post-intervention phase followed the sleep extension period. Three sport specific assessments (Open rate 1-minute, Rate-capped 1-minute, and Interval tests) and daily HRV recordings were captured each week of the study. **Results:** Subjects were unable to obtain the amount of sleep for sleep extension, averaging 392.07 ± 53.69 and 374.11 ± 41.53 minutes of total sleep time during baseline and the intervention respectively (\( p = .137 \)). Significant variation was found in the week to week comparison
of the Interval test and OR1-Min test. Regression analysis found high predictive of each test on subsequent performance over the course of the study. Conclusion: Athletes failed to increase their time asleep, limiting our ability to assess the impact of sleep on performance. Performance did suffer over the course of the study, suggesting participants were below the minimal amount of sleep necessary to maintain performance. Better athlete education by coaches might prove beneficial for athletes to develop the habits necessary for sufficient sleep and improved performance.

Background

In the past few years there has been increased public interest in sleep health and hygiene. This interest has extended into athletic performance, where a great deal of research has been conducted. Frequently, studies have centered around the question of the effects of sleep deprivation on athletes and athletic performance in varying age groups, sports, and ability levels. Studies have been consistent when reporting findings around the detriment to performance in cardiovascular-capacity demanding events, such as time to exhaustion and time trial events, with athletes across the spectrum of talent when athletes are subjected to mild to severe sleep deprivation (Azboy & Kaygisiz, 2009; B. J. Martin, 1981; Oliver, Costa, Laing, Bilzon, & Walsh, 2009; Racinais, Hue, Blonc, & Le Gallais, 2004; N. Souissi, Sesboue, Gauthier, Larue, & Davenne, 2003). Reports of similar findings in power and strength sports have also been found. These include reduced maximal load for single and multi-joint exercises, decreased sprint times, and decreased performance in judo athletes (Reilly & Piercy, 1994; Skein, Duffield, Edge, Short, & Mundel, 2011; Nizar Souissi et al., 2013). Conversely, when observing the effects of sleep extension and increased total sleep time on athletic performance, the pool
of available studies dwindles. Widely cited research out of Stanford University found significant improvements in sport specific skills, mood, and hand-eye coordination following and during an eight-week sleep extension study with collegiate basketball players (Cheri D. Mah et al., 2011). Since this publication, several other studies assessed sleep extension effects in sports such as rugby, soccer, and tennis and found similar trends and results to those seen in the Stanford study (Schwartz & Simon, 2015; Swinbourne et al., 2018).

Athlete monitoring and biofeedback has provided a new, technology driven method for training high level athletes. Heart rate variability (HRV), a measure of the change in time between consecutive heartbeats, or the R-R interval, has been shown to be an accurate predictor of recovery (Javaloyes et al., 2019). HRV is a reflection of vagal nerve activation, the main influencer of parasympathetic and sympathetic nervous system activation.

The ability of an athlete to recover will directly influence how well they will perform on consecutive days of practice and competition (Hynynen, Vesterinen, Rusko, & Nummela, 2010; Saboul, Balducci, Millet, Pialoux, & Hautier, 2016). Effectively monitoring how long it takes an athlete to recover from a training session or competition can give insights into the training strategies being used and what modifications may be needed (Daniel J. Plews et al., 2013). Evidence for utilizing training programs dictated by daily HRV measures have produced good results, but no direct comparison between traditional and HRV-based training models have been done (D. J. Plews, Laursen, et al., 2017). It is therefore difficult to determine which training method would better serve athletes in practice. Few measures of performance used in sport have been directly
correlated to daily HRV and HRV weekly trends. A better understanding of the relationships between daily HRV and performance is needed for the design of superior training protocols.

Rowing is a sport with unique physical and mental requirements. A true team sport, rowing requires a combination of power and endurance, all while moving in perfect rhythm with as many as seven additional teammates in the boat. According to an NCAA report in October 2018, for the 2017-18 school year there were 2,244 male and 7,277 female collegiate rowers (Irick, 2018). Although a small sport in the US collegiate sports arena, approximately 2% of collegiate athletes, it is steadily growing in popularity in both the collegiate and youth arenas. Despite it being one of the oldest modern sports in the world, and the oldest intercollegiate sport in the country, there is minimal research currently published on it. The physical requirements of the sport make it a unique one for study, since athletes require both high levels of endurance as well as strength. Regarding sleep, rowing is a sport with traditionally early practice and race times, often resulting in athletes not obtaining the recommended seven to nine hours of sleep each night. With sleep deprivation being a known hindrance to performance, observing these athletes in a situation where they are able to obtain eight or more hours of sleep each night will provide continued insight into both the effects of sleep deprivation, as well as the effects of recommended or extended amounts of sleep. Rowers, being an underserved and physiologically unique group of athletes, will provide a good cornerstone for expanded work on the subject of sleep extension.

Thus, the purpose of the present study was to determine whether a period of sleep extension leads improvement on ergometer performance in collegiate male rowing
athletes. We hypothesize that there will be improvement on the rowing ergometer performance as a result of sleep extension. We will observe a protective effect on erg performance and HRV following the intervention phase. And finally, that HRV will increase as sleep increases.

Methods

Nineteen members of the Temple Men’s Crew team elected to participate in this study. Nine of the participants were lightweights (LWT), competing at a maximum body weight of 155lbs, and 10 participants were open weight (HWT). Of the 19 participants that started, five (26%) were dropped out. Three (Two LWT and one HWT) due to an unwillingness or inability to follow the sleep extension protocol. One (LWT) was lost to follow-up, and one (HWT) was dropped in the fourth week of the study due to medication that affected sleep; their data was retained until Week 4. At study completion our n = 14 (LWT = 6, HWT = 8), average age = 19.14 ± .77 yrs, average height = 183.42 ± 5.99 cm, and average weight = 80.21 ± 9.22 kg. Data is presented in Table 1.

<table>
<thead>
<tr>
<th>Table 1. Participant Data</th>
<th>LWT</th>
<th>HWT</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>6</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Age (SD +/-) yrs</td>
<td>19.00 (0.89)</td>
<td>19.25 (0.71)</td>
<td>19.14 (0.77)</td>
</tr>
<tr>
<td>Height (SD +/-) cm</td>
<td>180.76 (4.66)</td>
<td>185.42 (6.37)</td>
<td>183.42 (5.99)</td>
</tr>
<tr>
<td>Weight (SD +/-) kgs</td>
<td>71.31 (1.72)</td>
<td>86.89 (6.07)</td>
<td>80.21 (9.22)</td>
</tr>
<tr>
<td>Years Rowing (SD +/-) yrs</td>
<td>3.67 (2.66)</td>
<td>5.63 (2.07)</td>
<td>4.79 (2.46)</td>
</tr>
</tbody>
</table>

Ethical approval for this study was given by the Temple University Institutional Review Board. Prior to participation, all subjects were given material pertaining to the specific aims and goals of the study and all subjects provided written informed consent. Data collection took place during the 2019 winter training season, January 28th through
March 23rd, capturing the training environment undisrupted by competition. During the sixth week of data collection, the team travelled to Georgia for a spring training trip. Participants were instructed to continue testing and the sleep extension for the duration of the week long camp; the post-intervention phase began when the team returned. Throughout the study, participants followed a training plan implemented by the head coach. The researcher had no influence on the training plan.

Study Design

This was an eight-week, three phase within-subjects study design. Data collection began at the start of the spring semester with a two-week baseline period. At the start of the third week, participants were instructed to increase their sleep to a minimum of nine hours of sleep each night for the next four weeks. If subjects were unable to achieve the requested amount of sleep each night, they were instructed to nap during the day. Following the four-week sleep extension intervention, subjects returned to their baseline amount of sleep for another two-week period to the study conclusion. Each week, sport specific measures of performance, daily HRV, and total sleep were all recorded and given a weekly average for each participant. A graphical representation of this is shown in Figure 1.

Figure 1. Study Timeline
Sport Specific Tests

Measurements of rowing performance were collected weekly through an Open-rate minute test (OR1-Min), a Rate-capped 1-Minute Test (RC1-Min) and an Interval Test (Interval). The two 1-minute tests are variations on peak power testing common in the rowing community. The Interval test is a modified version of a 2000-meter pace indicator workout, 6x500m intervals. The average pace an athlete goes on the 6x500m workout is approximately 20 to 30 watts faster than their projected 2000-meter pace. All three tests were on a Concept 2 Rowing Ergometer (erg) (Concept2, Morrisville, VT) with the drag factor on the erg set to 130. The OR1-Min was a maximal 1-minute effort. No guidance was given to pacing, as long as the output was maximal. Total output was measured in average wattage.

The RC1-Min was a maximal effort one-minute test at a controlled stroke rate or rhythm of 30 strokes per minute (spm). Total output in average wattage was recorded. For the Interval Test, participants were directed to perform three maximal effort 90 second pieces with two minutes rest between each. There was no controlled stroke rate for this test, so participants could perform it at whatever stroke rate was most comfortable to them. The average wattage over the three repetitions was recorded. To minimize confounding factors, testing was prescribed for a specific day of the week; Wednesday for the OR1-Min and RC1-Min and Friday for the Interval test. Participants were allowed to select what time of day they wished to complete the testing to accommodate class schedules.

Baseline testing for OR1-Min, RC1-Min, and Interval tests were performed during Week 2. All data points are represented as the average value of each study week,
with subjects who reported 75% or greater of their data in a given week included in analysis.

Sleep Questionnaires

Prior to beginning testing, all participants were asked to complete three questionnaires, the Epworth Sleepiness Scale (ESS), the Pittsburgh Sleep Quality Index (PSQI), and the STOP-BANG questionnaire. The PSQI and STOP-BANG screen for possible breathing related issues, and the ESS screens for sleep related issues. Due to the fact that breathing related issues can affect sleep, both the PSQI and the STOP-BANG were administered in addition to the ESS. Subject scores that might indicate a sleep disorder were 10 or more on the ESS, 5 or more on the PSQI, and 3 or more on the STOP-BANG (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989; Chung et al., 2012; Johns, 1991).

Objective Assessment of Sleep

Sleep recordings were collected by the subjects on a nightly basis. Each subject was given a SleepScore Max (SleepScore Labs, Carlsbad, CA) to use each night. The SleepScore Max uses ultra-wide band, comparable to ultra-low energy radar, to track the movement and respiration of an individual in bed (Weinreich et al., 2018). This technology has been tested and validated against both actigraphy and polysomnography (Tal et al., 2017). Data was collected during the night and stored in a database through the companion app to the SleepScore Max device. Each recording taken by the SleepScore Max was reviewed, with recorded awakenings, Total Sleep Time (TST), wake after sleep onset, and sleep latency making up the total recorded time for each recording. Of interest to the researchers were the records of Time in Bed (TIB) and TST.
If subjects were unable to obtain 9-10 hours of sleep at night, they were encouraged to nap during the day. Naps have been shown to be an effective intervention at supplementing nightly sleep (Romyn et al., 2018). TST and TIB values for naps were collected and added to the sleep time from the previous night for cumulative minutes. As an example, if a subject went to bed on the evening of the 12th and woke up after eight hours on the morning of the 13th and then slept for another hour midday of the 13th, the total amount of sleep for the time period from the 12th to the 13th would be nine hours.

For assessment purposes, participants who failed to record their sleep 3 or more times in a week were dropped from that week. In order to assess natural changes in sleep, and to avoid any substances that may have an effect on sleep, all participants were to refrain from any caffeine consumption and to avoid the use of diphenhydramine containing sleep aids such as ZzzQuil© or supplements such as melatonin. Any participants who were taking prescribed or over the counter medication that affected sleep were excluded from this study.

**Daily HRV Recording**

HRV data was collected each morning through the HRV4Training smartphone app, validated in several peer reviewed studies, using photoplethysmography (PPG) (Altini, 2016; M. a. V. H. Altini, C., 2017; D. J. Plews, Scott, et al., 2017; Tibana et al., 2019). Following standard procedures, upon waking, the participants were to sit up comfortably in bed and take their morning HRV. Subjects were instructed to cover the camera lens and camera light of their smartphone device with their finger. The HRV4Training app software uses PPG to detect the changes in blood flow by illuminating the skin and measuring changes in light absorption. Once a strong PPG
signal was established, subjects were instructed to sit still, breathing normally, for 60 seconds. Following the collection of the HRV measurement, the app then prompted subjects to complete a short questionnaire of subjective measures of sleep, stress, fatigue, motivation, and lifestyle. Ratings were on a sliding scale, similar to Likert-type scale. If a subject failed to record a minimum of three HRV readings in a given week, their data was not considered statistically viable and was dropped from analysis for that week (D. J. Plews, Laursen, Le Meur, et al., 2014).

Baseline values for HRV, TST and TIB are based on the average of Week 1 and Week 2 for each variable. All data points are represented as the average value of each study week, with subjects who reported 75% or greater of their data in a given week included in analysis.

Statistical Analysis

Power analysis indicated 20 participants would be necessary for this study to have sufficient power. One-way ANOVA for repeated measures with a Bonferroni post hoc analysis was run on the weekly averages of our outcome variables, OR1-Min, RC1-Min, Interval, and HRV to determine week to week variability in outcome measures. Linear regression analysis was used to analyze the influence of Baseline to Intervention phases results and the Intervention phase to Post-Intervention phase results for all outcome variables. Statistical significance was set at $p<0.05$. Analyses and figures were performed and produced using SPSS software (Version 26, IBM Corp, New York, NY, USA) and Microsoft Excel 2017 (Redmond, WA, USA).
Results

The average results for OR1-Min, RC1-Min, HRV, TST, and TIB in each phase of the study are reported in Table 2. The average results for each week of the study for OR1-Min, RC1-Min, HRV, TST, and TIB are reported in Table 3.

<table>
<thead>
<tr>
<th>Table 2.</th>
<th>Outcome and Sleep Measures at Study Phases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base</td>
</tr>
<tr>
<td></td>
<td>Average</td>
</tr>
<tr>
<td>OR1-Min (W)</td>
<td>798.80</td>
</tr>
<tr>
<td>RC1-Min (W)</td>
<td>470.62</td>
</tr>
<tr>
<td>Interval (W)</td>
<td>444.45</td>
</tr>
<tr>
<td>HRV (ms)</td>
<td>128.05</td>
</tr>
<tr>
<td>TST (Min)</td>
<td>392.07</td>
</tr>
<tr>
<td>TIB (Min)</td>
<td>479.09</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3.</th>
<th>Outcome and Sleep Measures at Weekly Intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 1</td>
</tr>
<tr>
<td></td>
<td>Avg</td>
</tr>
<tr>
<td>1 Min Open (W)</td>
<td>798.80</td>
</tr>
<tr>
<td>1 Min Rate-capped (W)</td>
<td>470.62</td>
</tr>
<tr>
<td>Interval Test (W)</td>
<td>444.45</td>
</tr>
<tr>
<td>HRV (ms)</td>
<td>128.05</td>
</tr>
<tr>
<td>TST (Min)</td>
<td>392.07</td>
</tr>
<tr>
<td>TIB (Min)</td>
<td>479.09</td>
</tr>
</tbody>
</table>

There was no significant change between baseline and intervention TIB but there was a non-significant reduction in TST of 18 minutes during intervention (392.07 ± 53.69 vs. 374.11 ± 41.53, p = .137).

Significant differences were found in the weekly OR1-Min results (p < 0.05), with pairwise comparison finding significant differences between Week 2 and Week 3.
(Mean dif = 80.3, std error = 16.06, $p < 0.005$) (Figure 2), and between Week 3 and Week 5 (Mean dif = -63.3, std error = 11.60, $p < 0.005$) (Figure 3). Significant differences were also seen in the weekly Interval results ($p < 0.05$) with pairwise comparison indicating significant differences between Week 4 and Week 8 (Mean dif = -39.77, std error = 9.943, $p < 0.05$) (Figure 4).

Figure 2. OR1-Min during study, Weeks 2 and 3 significances highlighted.

Figure 3. OR1-Min during study, Weeks 3 and 5 significances highlighted.
Figure 4. Interval Test during study, Weeks 4 and 8 highlighted.

Regression analysis was used to determine the predictive value of baseline and intervention phase measures on subsequent measurements for all outcome variables. OR1-Min at baseline was found to significantly predict times during the intervention, $R = .917, p < 0.005$, with a significant proportion of variance predicted by baseline times $R^2 = .841, F(1,6) = 26.486, p < 0.005$ (Figure 5). OR1-Min during the intervention phase significantly predicted times post-intervention, $R = .972, p < 0.005$, with a significant proportion of variance predicted by baseline times $R^2 = .946, F(1,6) = 86.952, p < 0.001$ (Figure 6).

Figure 5. Regression Analysis of OR1-Min baseline to intervention phase.

OR1-Min at baseline was found to significantly predict times during the intervention ($R = .917, p < 0.005$), with a significant proportion of variance predicted by baseline times ($R^2 = .841, F(1,6) = 26.486, p < 0.005$).
Figure 6. Regression Analysis of OR1-Min intervention to post-intervention phase.

OR1-Min during the intervention phase significantly predicted times post-intervention ($R = .972, p < 0.005$). A significant proportion of variance predicted by baseline times ($R^2 = .946, F(1,6) = 86.952, p < 0.001$).

RC1-Min at baseline was found to significantly predict times during the intervention, $R = .841, p < 0.005$, with a significant proportion of variance predicted by baseline times $R^2 = .707, F(1,12) = 26.542, p < 0.001$ (Figure 7). RC1-Min during the intervention phase significantly predicted times post-intervention, $R = .932, p < 0.005$, with a significant proportion of variance predicted by baseline times $R^2 = .868, F(1,11) = 65.893, p < 0.001$ (Figure 8).

Figure 7. Regression Analysis of RC1-Min baseline to intervention phase.

RC1-Min at baseline was found to significantly predict times during the intervention ($R = .841, p < 0.005$), with a significant proportion of variance predicted by baseline times ($R^2 = .707, F(1,12) = 26.542, p < 0.001$).
Figure 8. Regression Analysis of RC1-Min intervention to post-intervention phase.

RC1-Min during the intervention phase significantly predicted times post-intervention ($R = .932, p < 0.005$), with a significant proportion of variance predicted by baseline times ($R^2 = .868, F(1,11) = 65.893, p < 0.001$).

The Interval test at baseline was found to significantly predict times during the intervention, $R = .636, p < 0.05$, with a significant proportion of variance predicted by baseline times $R^2 = .404, F(1,10) = 6.113, p < 0.05$ (Figure 9). Interval test results during the intervention phase significantly predicted times post-intervention, $R = .871, p < 0.005$, with a significant proportion of variance predicted by baseline times $R^2 = .759, F(1,11) = 31.539, p < 0.001$ (Figure 10).

Figure 9. Regression Analysis of the Interval test baseline to intervention phase.

The Interval test at baseline was found to significantly predict times during the intervention ($R = .636, p < 0.05$), with a significant proportion of variance predicted by baseline times ($R^2 = .404, F(1,10) = 6.113, p < 0.05$).
Figure 10. Regression Analysis of the Interval test at intervention to post-intervention phase.

Interval test results during the intervention phase significantly predicted times post-intervention (R = .871, p < 0.005), with a significant proportion of variance predicted by baseline times (R^2 = .759, F(1,11) = 31.539, p < 0.001).

The HRV at baseline was found to significantly predict times during the intervention, R = .896, p < 0.005, with a significant proportion of variance predicted by baseline times R^2 = .802, F(1,12) = 44.679, p < 0.001 (Figure 11). HRV during the intervention phase significantly predicted times post-intervention, R = .945, p < 0.005, with a significant proportion of variance predicted by baseline times R^2 = .893, F(1,11) = 83.500, p < 0.001 (Figure 12).

Figure 11. Regression Analysis of HRV at baseline to intervention phase.

The HRV at baseline was found to significantly predict times during the intervention (R = .896, p < 0.005), with a significant proportion of variance predicted by baseline times (R^2 = .802, F(1,12) = 44.679, p < 0.001).
Figure 12. Regression Analysis of HRV at intervention to post-intervention phase.

HRV during the intervention phase significantly predicted times post-intervention ($R = .945, p < 0.005$), with a significant proportion of variance predicted by baseline times ($R^2 = .893, F(1,11) = 83.500, p < 0.001$).

Discussion

There were significant changes in performance during the course of study in the OR1-Min test and in the Interval test results. For the OR1-Min test, a significant decrease in performance was found between Week 2 and Week 3 of testing. Although it is unclear what the reasons for this might be, it possibly had something to do with the beginning of the sleep extension phase of the study. Although research suggests improvements would be seen following and during sleep extension (Kamdar, Kaplan, Kezirian, & Dement, 2004; Cheri D. Mah et al., 2011; Simon & Schwartz, 2005; Swinbourne et al., 2018) it is possible that the transition from baseline to the required time in bed could have caused stress or other factors that negatively influenced the performance on the OR1-Min. Additionally, the beginning of the school spring semester began during this time and could have also played a role, with the new workloads and changing schedules from winter break to spring classes. This seems to be further supported since performance on the OR1-Min improved close to Week 2 levels by Week
5 of testing (798.80 ± 70.05, 781.80 ± 57.30). This suggests that participants had adjusted to their new workload and the extra stress of classes starting again would be negligible.

The only other test to display significant differences was the Interval Test, specifically between Week 4 and Week 8 (402.23 ± 42.42, 442.00 ± 32.62). As with the OR1-Min, it is difficult to determine what caused this difference and the reasoning for the change in the OR1-Min performance does not hold here. With any repeated test of performance, we would hope to see improvements in the OR1-Min, RC1-Min, and Interval test outcome variables during the intervention phase of the study. Having only two outcome measures show any significant differences is disappointing but there are possible explanations.

As this was designed as a sleep extension study, finding that there was no change in TIB between baseline and intervention phases of the study; and a decrease of 18 minutes in TST between these two phases was discouraging (See Table 2). TIB stayed consistent around eight hours for the baseline and intervention phases of the study but dropped by an average of 20 minutes after the intervention phase. This drop does suggest that the baseline measurements taken were not indicative of true baseline, habitual sleep patterns for participants. If it had been, baseline and post-intervention TIB would be similar; in this study they are not. This is perhaps due to baseline collection occurring during the start of the school semester and participants could have been taking advantage of the lighter workload to get increased amounts of sleep compared to what they would normally get during the semester, thus skewing the measurement.

As there were no significant changes made in either the time spent asleep or in the time spent in bed, we would expect performance to improve along the lines of what
would be seen with normal practice. Surprisingly though, there was no improvement during this study. For eight weeks, performance across all measured outcome variables remained constant or got worse. Both the OR1-Min and the Interval tests showed performance had declined overall between baseline and the end of the study (798.80 ± 78.38 vs. 756.22 ± 152.42; 444.45 ± 41.16 vs. 434.83 ± 40.49). As the participants practiced and improved their fitness during the course of winter training, it would be expected that their performance on these tests would have improved as well. They did not. Due to the mix of participants in this study, between lightweight and heavyweight rowers, controlling for weight was critical to assessing the data, as heavier athletes in rowing are able to produce more power and therefore could skew the data. Despite this correction, a large practically significant reduction in performance was still seen from the participants (See Figures 13 & 14). Although it is impossible to say that sleep exhibited a strong influence on test performance, it is intriguing that with total sleep less than the amount recommended by the National Sleep Foundation (7-9 hours a night) there was a decrease in performance overtime, despite continuously training and regularly testing during the eight week period. This could suggest a minimum amount of sleep necessary for improvements to be seen in rowing.
A common observation throughout this study and in previous research is the poor sleep behavior and hygiene of athletes. Both Mah and Swinbourne note that their data “support previous findings that have characterized poor normative sleep behaviour in athletes” (Cheri D. Mah et al., 2011; Swinbourne et al., 2018). Poor sleep behaviors can be the result of several things. Lack of education seems to play a role and programs around education seem to have positive effects on sleep indices in both men and women.
Inconsistent sleep schedules can negatively affect sleep and it is not uncommon to see participants report inconsistent bedtimes during the week, in addition to later nights on the weekend. Other factors to consider when assessing the poor sleep behavior of athletes are individual sleep requirements, length and timing of sleep extension interventions, and training load and intensity (Swinbourne et al., 2018). Since sleep times decreased during the course of the study as intensity increased or remained constant, this is similar to findings in over-reached endurance athletes, suggesting disturbances in sleep quality as hard training increased (Hausswirth et al., 2014).

It is well documented that athletes tend to also have worse sleep than non-athletic populations, with athletes subject to more awakenings during the night and lower sleep efficiency (time asleep ÷ time in bed) despite similar TIB to non-athletes (M. W. Driller et al., 2019; Knufinke, 2018; Kolling et al., 2019). Prior research has found variations in sleep efficiency that range from approximately 80% to 90% in different athlete populations (Belenky et al., 2003; Lastella et al., 2015; Swinbourne et al., 2018). For our study, our data was on the low end of this range, at 79.6%, which was most consistent with data from Swinbourne et al. (2018) in their study on competitive rugby athletes. In their study, similar issues were found with athletes being unable to obtain the requested 10 hours of sleep each night during the study intervention, though participants did increase their sleep time from baseline by approximately 20 minutes.

One possibility for the decreased sleep efficiency with our population was the use of naps. With sleep onset latency averaging approximately 20 minutes (Ablen, 2014; Koelling, Steinacker, et al., 2016; Leeder, Glaister, Pizzoferro, Dawson, & Pedlar, 2012),
naps will affect the total sleep efficiency for a subject on a given day. Most sleep extension studies have utilized naps to assist participants in obtaining the ten hours in bed required for the study. In the 2011 basketball study by Mah, researchers utilized wrist actigraphy monitors to track sleep (Cheri D. Mah et al., 2011). This allowed for continuous data collection, which would have accounted for microsleeps and naps during the day when the participant was not in their bed but in a lounge between classes, for example.

In addition to naps affecting sleep efficiency, another possible option could be that excess systemic stress from the physical demands of being an athlete is affecting the sleep habits of the participants, which is in agreement with Hausswirth et al. (Hausswirth et al., 2014). Since it has been established that athletes sleep worse than non-athletes, this could be a possible relationship to explore. Sleep efficiency could further be reduced by electronic use before and while in bed. Evidence suggests that exposure to blue light common in most electronic devices and light bulbs has a negative impact on sleep and sleep efficiency, reducing use of electronic devices 30 minutes before bed seems to improve sleep (M. Driller & Uiga, 2019; Jones et al., 2018).

The test that had the strongest predictive value from regression analysis was the OR1-Min test, with 84.1% and 94.6% of test results being explained by the results from the previous phase for the intervention phase and the post intervention phase. The Interval test had the lowest predictive values in its models, with 40.4% of baseline tests explaining the results during the intervention phase, and 75.9% of intervention phase testing explaining post intervention results. On all outcome measurements, the predictive value of the intervention phase on the post-intervention phase was higher than the
baseline phase on the intervention phase. This is in part due to the short baseline phase, being only one week in length. As more testing was done, the predictive value of the regression model improved. For future research, a longer baseline of two to four weeks might be advisable for predictive values of 80% or higher. The results here though should be viewed with caution. Most of the analyses were done with only 11 data points, which is not sufficient to have strong power with an analysis like this. Additionally, some of these tests could demonstrate more variability than something shorter in length.

There are many factors in addition to sleep that could have affected these tests, explaining both the lack of improvement during the intervention phase and the changes not explained by the regression models. Primary among them being that we did not control what the rest of the participants practice schedule consisted of. Although everyone was on the same training plan from the coaches, it is possible that athletes were doing additional workouts on their own or they would do assigned “on-your-own” workouts in conjunction with the testing. Although the testing environment could be controlled, participants might not be coming into testing rested. This would have an effect on their performance week to week. It is important to note that, although conditions were not well controlled, this study was performed in a collegiate sports team setting, which speaks to its ecological validity.

Another factor that could have contributed to the results we saw was nutrition. We did not control for nutrition, and diet can have a very large impact on performance (Burke, 2017; Thomas, 2017). We also did not control for lifestyle stress or school stress. Due to the time frame of the study, there would have been several exams for classes. Studying for these would have likely resulted in later nights and higher levels of stress for
the participants. We could indirectly monitor stress through the weekly HRV recordings for each athlete, although these cannot give specific causes or sources of stress, merely systemic stress and how well the participants were adapting to it.

Finally, it is important to note that this study was done with a group of athletes that traditionally have early practice times. Other studies looking at the effect of sleep extension on athletic performance have worked with athletes from sports with practice times that are typically held in either the later morning or in the early afternoon (Cheri D. Mah et al., 2011; Schwartz & Simon, 2015; Swinbourne et al., 2018). This schedule would allow those athletes a greater opportunity for extended sleep during the night as they do not have the restrictions on when they need to wake up in the morning. For the participants in our study, bedtime needed to be approximately 8 pm for them to have a recorded TIB of nine hours or more. That is simply not a feasible lifestyle for a college student-athlete.

Limitations

There were several limitations to this study. First, the athletes had difficulty getting the necessary time in bed and time asleep. Even with napping they did not achieve the prescribed increase in sleep. Better adherence might be possible if a study was to look at the effects of smaller increases in sleep, eight and a half to nine hours instead of nine to ten hours. We looked at sleep time as our primary independent variable. Had we prioritized time in bed, or framed the objectives of the study as time in bed attempting to sleep, there may have been better adherence from the subjects, particularly those who may not be “good” sleepers.
Because we focused on time asleep, we utilized naps to help increase total sleep time. Even though naps have been shown to be effective at supplementing lost sleep, the possibility that naps could have impacted adherence to strict bedtimes at night must be considered. Additionally, because we used a sleep tracker that’s designed for bed use, we may have missed accounting for episodes of sleep that occurred during the day, such as dozing in class or episodes of microsleep which can occur during the day. A sensitive wrist actigraph would be able to account for and track instances such as these.

Second, because these are student athletes with varying class schedules, the participants were able to self-select the time they completed performance tests, which made it challenging to rule out time of day and the potential effect of circadian rhythm on the performance of the athletes in these tests. There has been research to suggest that later practice times will lead to improved performance whether due to the result of circadian rhythm or subjective feelings of more restful sleep (Deschodt & Arsac, 2004; Grant & Glen, 2018; Heishman et al., 2017).

Third, for all participants there was a great deal of inconsistency with the testing and daily measurements, where participants would miss a test one week or neglect to take their morning HRV consistently, resulting in sections of missing data. Feedback from the coaches and participants suggested that creating an environment where it was easy to access the equipment for testing alongside regularly scheduled sessions in the weight room would lead to better adherence from all participants.

As this was a small participant group and we did not have a control group, it is difficult to make any determinations or conclusions based on the data we collected. A controlled study that involved the entire team (approximately 60 or more athletes) would
provide a sufficient level of power to draw conclusions. Finally, having a longer baseline measurement period could have been helpful. From the data in Tables 2 and 3 it can be seen that most measurements, specifically TIB and TST, lowered after baseline. It is unclear as to why this was and why the participants did not manage to achieve the requested nine to ten hours. It is quite possible that the requested time was simply not possible for this particular group of participants from a sport like rowing. With practice usually around 6:00 am each morning, it is likely the participants simply could not go to bed early enough or get enough naps during the day to meet the requirements of the study.

Finally, the performance tests used, the OR1-Min, RC1-Min, and Interval tests were all created and implemented following best practice guidelines within the sport of rowing. There is no research backed testing that would have been practical to use with this population for weekly analysis. Perhaps a better method would have been to track a specific workout that the head coach already had as part of their weekly practice schedule instead of implementing something additional to the training program.

Future research should include tracking of training load and volume during the course of the study, to control for and identify the influence of outside stressors. Non-fatiguing performance tests, such as peak power testing or vertical jump testing will be better for measuring short, explosive power. In addition to the non-fatiguing tests, tracking a consistently prescribed weekly workout that is longer in duration would address no having a longer duration test as part of the testing protocol. Finally, using an activity monitor would allow for greater flexibility with napping locations and it would
record microsleeps, in addition to providing a better gauge of total physical activity on a day to day basis for subjects.

Conclusions

In this study, athletes did not change their sleep during the intervention period so we were unable to evaluate how sleep impacts performance. Additionally, the average sleep time for participants was less than what is recommended by the National Sleep Foundation. Performance measures showed day-to-day variability but were generally highly correlated over time. Despite the amount of training that was done, participants did not improve on any of the performance measures used. It is the author’s opinion that, in sleeping less than the recommended seven to nine hours hurt the participants recovery and by extension, their subsequent and continue performance over the course of the eight weeks. The sleep needs of athletes are apparent and athletes themselves recognize the need for increased time asleep, though few achieve the recommended amount. Despite previously published evidence to suggest improvement, we found athletes will still choose to pass up time sleeping for other activities. This choice is something that requires further exploration. If performance is the main outcome that an athlete judges their success by, a path towards performance improvement should take priority. As it does not, coaches should include sleep education and reminders as part of their daily interactions with their athletes, emphasizing the importance of a good night’s sleep.
BIBLIOGRAPHY


Armwald, B. C. (2018). The influence of sleep and heart rate variability on the occurrence of injuries, illnesses, and missed participation days in ncaa collegiate swimmers. (Masters of Kinesiology), Pennsylvania State University.


Weippert, M., Kumar, M., Kreuzfeld, S., Arndt, D., Rieger, A., & Stoll, R. (2010). Comparison of three mobile devices for measuring r-r intervals and heart rate variability: Polar s810i,


APPENDIX A

LIST OF ACRONYMS

DEEP – Deep or stages 3 and 4 of sleep
ESS - Epworth Sleepiness Scale
HR - Heart Rate
HRV – Heart rate Variability
LIGHT – Light or stages 1 and 2 of sleep
OSA - Obstructive Sleep Apnea
PSQI - Pittsburgh Sleep Quality Index
REM – Rapid Eye Movement Sleep
SBD - Sleep Disordered Breathing
SST – Subjective Sleep Time
SSQ – Subjective Sleep Quality
TST – Total Time Asleep
APPENDIX B

CONCEPT 2 ROWING ERGOMETER
APPENDIX C

SLEEPSCORE MAX UNIT
APPENDIX D

EPWORTH SLEEPINESS SCALE QUESTIONNAIRE

Epworth Sleepiness Scale

Name: ________________________________ Today’s date: __________________

Your age (Yrs): ___________ Your sex (Male = M, Female = F): ______

How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired?

This refers to your usual way of life in recent times.

Even if you haven’t done some of these things recently try to work out how they would have affected you.

Use the following scale to choose the most appropriate number for each situation:

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>would never doze</td>
</tr>
<tr>
<td>1</td>
<td>slight chance of dozing</td>
</tr>
<tr>
<td>2</td>
<td>moderate chance of dozing</td>
</tr>
<tr>
<td>3</td>
<td>high chance of dozing</td>
</tr>
</tbody>
</table>

*It is important that you answer each question as best you can.*

<table>
<thead>
<tr>
<th>Situation</th>
<th>Chance of Dozing (0-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting and reading</td>
<td></td>
</tr>
<tr>
<td>Watching TV</td>
<td></td>
</tr>
<tr>
<td>Sitting, inactive in a public place (e.g. a theatre or a meeting)</td>
<td></td>
</tr>
<tr>
<td>As a passenger in a car for an hour without a break</td>
<td></td>
</tr>
<tr>
<td>Lying down to rest in the afternoon when circumstances permit</td>
<td></td>
</tr>
<tr>
<td>Sitting and talking to someone</td>
<td></td>
</tr>
<tr>
<td>Sitting quietly after a lunch without alcohol</td>
<td></td>
</tr>
<tr>
<td>In a car, while stopped for a few minutes in the traffic</td>
<td></td>
</tr>
</tbody>
</table>

THANK YOU FOR YOUR COOPERATION

© M.W. Johns 1990-97
APPENDIX E

PITTSBURGH SLEEP QUALITY INDEX QUESTIONNAIRE

Pittsburgh Sleep Quality Index (PSQI)

Instructions: The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions.

1. During the past month, what time have you usually gone to bed at night? ________________
2. During the past month, how long (in minutes) has it usually taken you to fall asleep each night? __________
3. During the past month, what time have you usually gotten up in the morning? ________________
4. During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spent in bed.) ________________

<table>
<thead>
<tr>
<th>5. During the past month, how often have you had trouble sleeping because you...</th>
<th>Not during the past month</th>
<th>Less than once a week</th>
<th>Once or twice a week</th>
<th>Three or more times a week</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Cannot get to sleep within 30 minutes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Wake up in the middle of the night or early morning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Have to get up to use the bathroom</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. Cannot breathe comfortably</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. Cough or snore loudly</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f. Feel too cold</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g. Feel too hot</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h. Have bad dreams</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>i. Have pain</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>j. Other reason(s), please describe:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. During the past month, how often have you taken medicine to help you sleep (prescribed or "over the counter")? ________________

7. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity? ________________

<table>
<thead>
<tr>
<th>8. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?</th>
<th>No problem at all</th>
<th>Only a very slight problem</th>
<th>Somewhat of a problem</th>
<th>A very big problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good</td>
<td>Fairly good</td>
<td>Fairly bad</td>
<td>Very bad</td>
<td></td>
</tr>
</tbody>
</table>

9. During the past month, how would you rate your sleep quality overall? ________________
<table>
<thead>
<tr>
<th>10. Do you have a bed partner or room mate?</th>
<th>No bed partner or room mate</th>
<th>Partner/room mate in other room</th>
<th>Partner in same room but not same bed</th>
<th>Partner in same bed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not during the past month</td>
<td>Less than once a week</td>
<td>Once or twice a week</td>
<td>Three or more times a week</td>
<td></td>
</tr>
</tbody>
</table>

If you have a room mate or bed partner, ask him/her how often in the past month you have had:

a. Loud snoring
b. Long pauses between breaths while asleep
c. Legs twitching or jerking while you sleep
d. Episodes of disorientation or confusion during sleep
e. Other restlessness while you sleep, please describe:
Scoring the PSQI

The order of the PSQI items has been modified from the original order in order to fit the first 9 items (which are the only items that contribute to the total score) on a single page. Item 10, which is the second page of the scale, does not contribute to the PSQI score.

In scoring the PSQI, seven component scores are derived, each scored 0 (no difficulty) to 3 (severe difficulty). The component scores are summed to produce a global score (range 0 to 21). Higher scores indicate worse sleep quality.

Component 1: Subjective sleep quality—question 9
Response to Q9 Component 1 score
Very good 0
Fairly good 1
Fairly bad 2
Very bad 3
Component 1 score:_____

Component 2: Sleep latency—questions 2 and 5a
Response to Q2 Component 2/Q2 subscore
≤ 15 minutes 0
16-30 minutes 1
31-60 minutes 2
> 60 minutes 3
Response to Q5a Component 2/Q5a subscore
Not during past month 0
Less than once a week 1
Once or twice a week 2
Three or more times a week 3
Sum of Q2 and Q5a subscores Component 2 score
0 0
1-2 1
3-4 2
5-6 3
Component 2 score:_____

Component 3: Sleep duration—question 4
Response to Q4 Component 3 score
> 7 hours 0
6-7 hours 1
5-6 hours 2
< 5 hours 3
Component 3 score:_____

Component 4: Sleep efficiency—questions 1, 3, and 4
Sleep efficiency = (# hours slept/# hours in bed) X 100%
# hours slept—question 4
# hours in bed—calculated from responses to questions 1 and 3
Sleep efficiency Component 4 score
> 85% 0
75-84% 1
65-74% 2
< 65% 3
Component 4 score:_____
Component 5: Sleep disturbance—questions 5b-5j
Questions 5b to 5j should be scored as follows:

| Not during past month | 0 |
| Less than once a week  | 1 |
| Once or twice a week   | 2 |
| Three or more times a week | 3 |

<table>
<thead>
<tr>
<th>Sum of 5b to 5j scores</th>
<th>Component 5 score</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1-9</td>
<td>1</td>
</tr>
<tr>
<td>10-18</td>
<td>2</td>
</tr>
<tr>
<td>19-27</td>
<td>3</td>
</tr>
</tbody>
</table>

Component 5 score:

Component 6: Use of sleep medication—question 6
Response to Q6 | Component 6 score |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Not during past month</td>
<td>0</td>
</tr>
<tr>
<td>Less than once a week</td>
<td>1</td>
</tr>
<tr>
<td>Once or twice a week</td>
<td>2</td>
</tr>
<tr>
<td>Three or more times a week</td>
<td>3</td>
</tr>
</tbody>
</table>

Component 6 score:

Component 7: Daytime dysfunction—questions 7 and 8
Response to Q7 | Component 7/Q7 subscore |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Not during past month</td>
<td>0</td>
</tr>
<tr>
<td>Less than once a week</td>
<td>1</td>
</tr>
<tr>
<td>Once or twice a week</td>
<td>2</td>
</tr>
<tr>
<td>Three or more times a week</td>
<td>3</td>
</tr>
</tbody>
</table>

Response to Q8 | Component 7/Q8 subscore |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No problem at all</td>
<td>0</td>
</tr>
<tr>
<td>Only a very slight problem</td>
<td>1</td>
</tr>
<tr>
<td>Somewhat of a problem</td>
<td>2</td>
</tr>
<tr>
<td>A very big problem</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sum of Q7 and Q8 subscores</th>
<th>Component 7 score</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1-2</td>
<td>1</td>
</tr>
<tr>
<td>3-4</td>
<td>2</td>
</tr>
<tr>
<td>5-6</td>
<td>3</td>
</tr>
</tbody>
</table>

Component 7 score:

Global PSQI Score: Sum of seven component scores:___________

Copyright notice: The Pittsburgh Sleep Quality Index (PSQI) is copyrighted by Daniel J. Buysse, M.D. Permission has been granted to reproduce the scale on this website for clinicians to use in their practice and for researchers to use in non-industry studies. For other uses of the scale, the owner of the copyright should be contacted.

Citation: Buysse, DJ, Reynolds CF, Monk TH, Berman SR, Kupfer DJ: The Pittsburgh Sleep Quality Index (PSQI): A new instrument for psychiatric research and practice. Psychiatry Research 28:193-213, 1989
APPENDIX F

STOP-BANG SLEEP APNEA QUESTIONNAIRE

Name __________________________
Height ________ Weight ________
Age ________ Male / Female ________

STOP-BANG Sleep Apnea Questionnaire
Chung F et al Anesthesiology 2008 and BJA 2012

<table>
<thead>
<tr>
<th>STOP</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you SNORE loudly (louder than talking or loud enough to be heard through closed doors)?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Do you often feel TIRED, fatigued, or sleepy during daytime?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Has anyone OBSERVED you stop breathing during your sleep?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Do you have or are you being treated for high blood PRESSURE?</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BANG</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI more than 35kg/m2?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AGE over 50 years old?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>NECK circumference &gt; 16 inches (40cm)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GENDER: Male?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TOTAL SCORE

High risk of OSA: Yes 5 - 8
Intermediate risk of OSA: Yes 3 - 4
Low risk of OSA: Yes 0 - 2
APPENDIX G

HRV4TRAINING APP AND QUESTIONNAIRE

Today
7.6

Yesterday
9.7

Baseline

*Last 7 days

HRV-based advice will be provided when you have collected a baseline of at least 4 days of measurements, including today.

Measure HRV
Instructions

Cover your phone’s back camera with your finger and keep still. HRV4Training will automatically check signal quality and start the measurement.

PPG  Heart Rate

Timer

60

Try to relax and breathe naturally

Cancel
You can configure what Tags to use from Settings or by tapping the button below

Configure TAGS

SLEEP TAGS

How was your sleep quality last night?

POOR  OK  GOOD

What time did you fall asleep?

23:07

What time did you wake up?

06:20

Sleep time  07:13

TRAINING TAGS

How was your training yesterday?
How is your current physical condition?

VERY BAD  OK  GREAT

NOT IDEAL  GOOD

How is your mental energy this morning?

LESS  AVERAGE  MORE

How is your muscle soreness this morning?

LESS  AVERAGE  MORE

How fatigued are you this morning?

LESS  AVERAGE  MORE

Are you currently injured?

Specify your current injury
How would you describe your current lifestyle?

UNSTABLE (travel, stress, etc.)

Routine (can focus on training)

Were you traveling yesterday?

No

Yes

Any alcohol intake last night?

Nothing

A little

Too much

Are you sick today?

No

Yes

Where are you located today?

Narberth

Altitude: 170 feet, Temperature: 59.0 F
Humidity: 87 %, Wind: 4.61 mph

What kind of supplements are you taking?

Enter supplements
What kind of diet are you following?

Anything else you'd like to annotate?

percieved total time asleep: 6.50

sleep quality: 8.00

how rested did you feel upon waking up?: 6.00

Go back or tap below to save. You can always edit these annotations from the History page or by tapping on the home screen.

Save
APPENDIX H

SLEEPSCORE MAX USER INTERFACE