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Impact of one night sleep restriction on autonomic function and heart rate variability in recreational cyclists

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Impact of One Night Sleep Restriction on Autonomic Function and Heart Rate Variability in Recreational Cyclists

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Table of Contents

List of Tables

Abstract

Introduction: Sleep quality has been shown to influence autonomic function. The autonomic nervous system (ANS) responds to stressors by regulating key functions such as heart rate. Autonomic function can be monitored via heart rate variability (HRV). Athletes are prone to poor sleep quality due to psychological and physical stresses of training and competing. Our objective was to investigate the function of the ANS at rest and during exercise following a night of normal sleep (SLP+) and a night of restricted sleep (SLP-).

Methods: Subjects (n=9) completed a familiarization trial and two identical experimental trials under different sleep conditions: SLP- (3-hour sleep) and SLP+ (8-hour sleep). Trials consisted of laying supine for 10 min (breathing at 12 bpm) before a 20-min exercise test (10 min at 50% W_{max}; 10 min at 60% W_{max}) that was followed by a self-paced 3-km time trial. Data were analyzed using paired sample statistics via SPSS software.

Results: Significant differences ($P < 0.05$) between trials were noted through elevated resting HR after the SLP+ condition and elevated low frequency (LF) power (%) variable in the 60% W_{max} portion of the exercise test during the SLP+ trial. There were no significant differences found in any of the other variables between conditions.

Conclusion: The primary findings of this study indicate that one night of sleep restriction has little impact on HRV during subsequent exercise. These data show that one night of sleep restriction has an effect on resting HR and the LF power (%) variable in the 60% W_{max} portion of the exercise test. The results suggest elevated activity of the sympathetic nervous system during the SLP+ trial. No other variables were impacted by one night of sleep restriction.

Keywords: sleep restriction, cycling, autonomic nervous system, heart rate variability

Chapter I: Introduction

The Autonomic Nervous System

The autonomic nervous system (ANS) responds to different levels of physical stress and switches between parasympathetic (PNS) and sympathetic (SNS) functions.[8] The ANS utilizes the PNS and SNS to regulate key functions such as heart rate, digestive function, and hormone secretion.[15,6] The PNS elicits its affect by releasing acetylcholine by means of the vagus nerve whereas the SNS mediates its affect through epinephrine and norepinephrine. Acetylcholine is reabsorbed slowly, which results in a delay in the shift in autonomic function and takeover of the SNS. Therefore, there is a delay in the physiological changes that respond to altered SNS activity.[6] The PNS is primarily active during periods of rest, and the SNS is dominant during periods of high stress.[3] During high sympathetic output, a decrease in the variability of the heart rate response is seen in addition to tachycardia.[24] When heartbeats occur more regularly, with less variation between beats, it is indicative of activity from the SNS, and when timing varies between beats, it can be inferred that there is more vagal tone and less inhibition of the PNS.[13]

Typically, with exercise, heart rate increases due to parasympathetic withdrawal and increased sympathetic activity. The SNS is primarily active during bouts of exercise or periods of stress to maintain bodily function.[15] Following exercise, parasympathetic reactivation occurs to bring HR closer to baseline levels.[15] During low intensity exercise, HR increases are mainly controlled by withdrawal from the PNS; and at high intensities, there is an increase in SNS activity in addition to inhibition of the PNS that results in a decrease in heart rate variability (HRV).[6, 18] The sinoatrial node (SA) of the heart is innervated by both the PNS and SNS.[6]

Heart Rate Variability

Healthy cardiac functioning demonstrates beat-by-beat variability, and these variations can be responses to external and internal stimuli. Healthy variations between heart beats occurs during periods of low stress and activity. Many stressors such as exercise, anxiety, and fear are associated with decreased variations among heartbeats.[6] HRV quantifies the variability between heart beats and is a useful method of monitoring autonomic activity and may aid in assessing autonomic stress reactivity, or how the ANS responds to stressors, because HRV reflects autonomic innervation to the heart.[15, 24] HRV is an inexpensive measure of tracking autonomic function during exercise. HRV is also non-invasive as it can be monitored by the oscillations between consecutive cardiac cycles on an echocardiogram (ECG).[18] Use of the ECG allows researchers to measure the time interval between beats in milliseconds.[6] In an ECG, the R wave represents ventricular depolarization and is indicative of a single cardiac cycle. Therefore, the R wave is commonly used to monitor HR and HRV. The R wave in the QRS complex is the highest voltage wave seen in the ECG recording, and therefore the best way to analyze variations between beats or HRV.[6] Because of this, HRV is normally measured through R-wave-to-R-wave intervals (RRI) on ECG's, and these intervals reflect a linear relationship to activity from the PNS and SNS.[6,13,14] Changes in RRI can be due to normal responses to environmental and physiological stimuli such as stress, changes in metabolism, physical exercise, breathing, and hemodynamic alterations. These alterations in stimuli control inhibition and excitement of the PNS and SNS. High HRV is indicative of productive autonomic mechanisms for healthy people, and low HRV is associated with abnormal adaptations of the ANS that can result in increased likelihood of morbidity and mortality.[6]

One method for assessing HRV is through the frequency domain methods. The Fast Fourier Transform (FTT) and autoregressive models are used to quantify fluctuations in cardiac

cycles with RRI. There are four separate oscillatory components in the FTT method. The high-frequency (HF) component demonstrates a peak in frequencies (between 0.15 and 0.40 Hz). HF is indicative of respiratory sinus arrhythmia which is a result of vagal activity, or activity from the PNS. Low-frequency (LF) components are controlled by both the PNS and SNS and take course over the span of 10 s (between 0.04 and 0.15 Hz). This LF is due to both sympathetic and parasympathetic control. A very low frequency (VLF) component occurs over a longer span of time (20 seconds to 5 minutes) and ranges between 0.0033 and 0.04 Hz. Lastly, the ultra-low frequency (ULF) component is represented by frequencies below 0.003 Hz and occur between 5 minutes and 24 hours. The physiological mechanisms responsible for VLF and ULF are not yet understood, but are speculated to be related to thermoregulation, the renin-angiotensin-aldosterone system, or peripheral vasomotor tone. HRV can be understood by taking the ratio of LF/HF to reflect the relative and absolute changes between parasympathetic and sympathetic components.[6]

HRV is also expressed in the unit of time (ms) and mean, standard deviation, and histograms are utilized to interpret fluctuations in the cardiac cycle. Usually, measurements of HRV utilize the mean of RRI's for normal beats (in ms) and the standard deviation of these normal values (SDNN, in ms). As SDNN indicates overall ANS function, activity from the PNS and SNS both contribute to SDNN, and is also highly correlated with ULF, VLF, and LF.[6, 20] Other indexes for HRV's time domain are standard deviation of the means of RRI's (SDANN, in ms), mean of the 5-minute standard deviations of RRI's (SDNNI, in ms), percentage of adjacent RRI's with a difference of duration over 50 ms (PNN50), and the root-mean square of differences between normal RRI's (RMSSD).[6] SDANN refers to intervals between beats but does not provide information as useful as SDNN. SDNN reflects autonomic function on HRV. PNN50 is indicative of activity from the PNS and is correlated with HF power and RMSSD measurements. RMSSD is

more indicative of PNS function than SDNN and is also correlated with HF power.[20] These values are gathered from recordings over a long period of time. Around 30-40% of the standard deviation of the means of RRI's is due to differences in RRI's between the day time and night time. All of these indexes are used to interpret activity from the ANS but cannot distinguish between changes in HRV because of increased activity from the SNS or withdrawal of vagal tone.[6]

Influence of Sleep Restriction on Autonomic Function and Performance

Sleep is necessary to allow for proper physiological function, as it is believed to restore functions of the central nervous system (CNS).[4] It is proposed that adults should acquire 7-9 hours of sleep per night, yet the majority of the population receives less than recommended.[4] Athletes are more likely to lose sleep than the average person due to physical and psychological stresses of training and competition periods, and this sleep loss may be detrimental to athletic performance and peak function.[4] Sleep loss can be categorized into sleep restriction (SR) and sleep deprivation (SD). SD involves complete loss of sleep for a prolonged period, while SR is a loss of some, but not all sleep as a result of stressors, abnormal sleep/wake times, or poor sleep quality. However, sleep restriction can also incur in absence of these factors.[9] It has been shown that a single night of SR can negatively impact physical function, which is logical due to the restorative capacities of sleep.[4] Further, SR is known to effect HR and HRV in some individuals.[10] HRV has become a physiological marker that is a practical measure of examining the levels of fatigue in an athlete, and a predictor of reduced quality or duration of sleep. Athletes in fatigued states experience alterations of their ANS that result in neuromuscular fatigue due to altered acetylcholine diffusion/reuptake at the neuromuscular junction. The implications of this include an altered testosterone to cortisol ratio, muscle soreness, injury rates, illness, and sleep quality or

deprivation.[15] HRV has potential to be predictive of exercise performance during submaximal or maximal exercise.[15]

Sleep deprivation may cause disruptions in autonomic function and exercise tolerance. A study done by Konishi et al indicates that time of day impacts autonomic function after sleep deprivation as tolerance for exercise was decreased in the evening. It is also shown that, in the morning/afternoon, activity from the SNS is increased while activity from the PNS is decreased, but there was no effect of SNS or PNS activity at night. It is speculated that increased activity from the SNS is necessary to access energy stores. Activity from the PNS is a protective mechanism against the increased cardiac demand associated with extended wakefulness.[11]

Responses from the ANS are sensitive to changes in exertion. With the onset of fatigue, the parasympathetic influence on heart rate changes.[8] The awake-state is more associated with activity from the SNS as opposed to PNS than any sleep state. However, during REM sleep, autonomic function mirrors that of the awake-state.[24] Several studies show different findings associated with sleep deprivation and its effects on autonomic function. There is not sufficient research on sleep restriction's effects on HRV or performance since most studies implement full sleep deprivation, which has been found to negatively affect HRV.[24, 26] Sleep restriction is more practical and realistic since athletes are not likely to compete after total sleep deprivation. Stressors before a competition may cause a loss of some, but not all sleep. Therefore, sleep restriction is a more accurate measure of the state of fatigue experienced by athletes pre-competition.

Athletes often experience sleep loss prior to competition, and this can have a significant impact on their athletic performance.[9] Athletes also have practice times, training schedules, travel to competitions, jet lag, and pre-competition anxiety that influence the quantity and quality of their sleep before a competition.[21] Therefore, an athlete's ability to adapt to physiological and

psychological stressors is critical to their performance. Previous research notes negative performance effects following sleep loss. However, conflicting results indicate uncertainty in the extent to which sleep loss impacts exercise performance. In addition, the effects of sleep loss on physiological functions in response to exercise also remains in question. It appears that a reduction in sleep quantity and quality over time produces imbalances in the autonomic nervous system, which results in symptoms of overtraining syndrome.[9] The effects of SR and SD on exercise performance vary with each study done or bout of exercise performed.

While the specifics of the impact of SD on exercise performance remains unclear, it appears SD can have significant effects on some aspects of athletic performance.[9] Sleep loss appears to negatively impact athletic performance in spite of equivalent applied effort and may be a result of reductions in glycogen stores prior to performance. One night of sleep loss has also shown to increase resting oxygen uptake, heart rate, and reduce time to exhaustion. Sleep loss effects cause reduced endurance during athletic performance. However, the same study observed no significant decrements in lifting or anaerobic performance. Mild sleep restriction was found to negatively affect accuracy during athletic performance as well.[21]

Due to the lack of research in SR associated with HRV and performance, the purpose of this study is to examine how SR, as opposed to SD, impacts autonomic function (via HRV) and overall athletic performance in recreational cyclists.

Chapter II: Methods

Subjects

Nine male and female subjects (6 male, 3 female), aged 20 to 22-years-old, volunteered for participation. All testing occurred in the Human Performance Lab at James Madison University (JMU). The subjects were recruited from the JMU campus and surrounding communities and had no sleep disorders as assessed by the Pittsburgh Sleep Quality Index questionnaire. Subjects did not currently smoke at the time of recruitment. In addition, the subjects cycled recreationally (minimum 30 minutes 1-2 days per week over the past three months) at the time of recruitment. All subjects were cleared for moderate-to-vigorous intensity exercise, as defined by the American College of Sports Medicine (ACSM).[1]

Preliminary Testing

After providing written informed consent, height and body mass were obtained, followed by a maximal exercise test which determined peak aerobic capacity (VO_{2max}) and peak power (watts). Height was measured using a stadiometer and recorded to the nearest 0.5 cm. For the maximal aerobic capacity test, subjects underwent a graded exercise test. The test began at a self-selected workload that could be maintained comfortably for a 1-hour ride. Workload increased by 25 W at each stage for every 2 minutes until subject reached volitional fatigue or was unable to maintain a cadence >50 rpms. VO_{2max} was measured via indirect calorimetry (ParvoMedics TrueOne 2400, ParvoMedics Inc., Sandy, UT).[27] Each subject completed a familiarization trial identical to the experimental trials described below to minimize learning error during the accompanying two experimental phases.

Experimental Design

Preliminary testing and experimental phases were separated by 7-14 days. Each experimental phase consisted of an exercise session in the morning. Prior to the exercise test, each subject laid supine on a bed for 10 minutes while HR and HRV will be measured with a Polar HR monitor (Polar RS800CX, Polar Electro Inc., Bethpage, NY)[7]. During the resting measurements, subjects were instructed to breathe in sync with a metronome set at 12 beats per minute to prevent respiration from influencing HRV. Following this, subjects completed a 20-minute exercise test (10 minutes at 50% W_{max}, 10 minutes at 60% W_{max}). At the end of the test, subjects completed a self-paced 3-km time trial where maximum effort was encouraged. HR and HRV were measured continuously throughout the exercise bout.

Sleep Protocol

Subjects were randomly be assigned to two experimental trials, one to a normal night of sleep (SLP+) or a night of sleep restriction (SLP-). Subjects initiated sleep between 10:00 pm and 12:00 am for both SLP+ and SLP-. This was to replicate the same onset time in both experimental phases. SLP+ subjects set their wake-up time for 8 hours following sleep onset and report to the exercise trial after waking. SLP- subjects set their wake-up time for 3 hours after sleep onset and reported immediately for monitoring prior to exercise. Exercise times were kept consistent across the SLP+ and SLP- trials. To measure sleep duration and quality, each subject was instructed to wear an accelerometer (ActiGraph wGT3X-BT, Actigraph Corp., Pensacola, FL)[17] on their non-dominant wrist for the 72 hours prior to the trial.

Dietary/Exercise Controls

Subjects recorded all food and beverage intake for 24 hours prior to the first experimental trial. Subjects were provided with copies of their dietary records and instructed to replicate their

dietary habits prior to the second experimental trial. All subjects reported to testing following at least a 2 hour fast. All subjects abstained from caffeine, alcohol and tobacco consumption 24 hours prior to testing. Subjects recorded all physical activity 72 hours prior to both experimental trials and wore an accelerometer during all exercise bouts to measure physical activity levels in this time period before both trials.

Heart Rate Variability Analysis

The data was uploaded via Polar Pro Trainer 5® software (Polar USA, Bethpage, NY), and HRV analysis was executed using Kubios Standard (version 3.1.0.1, Biosignal Analysis and Medical Imaging Group, Kuopio, Finland) software. HRV was analyzed in nonlinear domains, time, and frequency. Nonlinear domain measures consisted of the Poincare plot short-term [SD1 (ms)]. Time domain measures consisted of HR (beats per minute), root mean square of successive differences in NN intervals [RMSSD (ms)], and standard deviation of NN interval time series [SDNN (ms)]. The frequency domain was measured via the fast Fourier Transformation (FFT), where low frequency [LF (ms^2), 0.04-0.15 Hz], high frequency [HF, (ms^2), 0.15-0.4 Hz], LF power (%), HF power (%), and low to high frequency ratio [LF/HF] were analyzed.

Statistical Analysis

Mean power output (Watts) from both 3-km time trials were used as the performance measure. Data from HRV was used to interpret autonomic function. Data from this study was log transformed in order to diminish the effects of non-uniformity. Data analyses were performed using SPSS (IBM SPSS version 25.0, IBM Corporation, Armonk, NY). Paired sample t-tests were used to evaluate differences among variables. A P value of < 0.05 was considered statistically significant.

Chapter III: Manuscript

Impact of One Night Sleep Restriction on Autonomic Function and Heart Rate Variability in Recreational Cyclists

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Abstract

Introduction: Sleep quality has been shown to influence autonomic function. The autonomic nervous system (ANS) responds to stressors by regulating key functions such as heart rate. Autonomic function can be monitored via heart rate variability (HRV). Athletes are prone to poor sleep quality due to psychological and physical stresses of training and competing. Our objective was to investigate the function of the ANS at rest and during exercise following a night of normal sleep (SLP+) and a night of restricted sleep (SLP-).

Methods: Subjects (n=9) completed a familiarization trial and two identical experimental trials under different sleep conditions: SLP- (3-hour sleep) and SLP+ (8-hour sleep). Trials consisted of laying supine for 10 min (breathing at 12 bpm) before a 20-min exercise test (10 min at 50% W_{max}; 10 min at 60% W_{max}) followed by a self-paced 3-km time trial. Data were analyzed using paired sample statistics via SPSS software.

Results: Significant differences ($P < 0.05$) between trials were noted through elevated resting HR after the SLP+ condition and elevated low frequency (LF) power (%) variable in the 60% W_{max} portion of the exercise test during the SLP+ trial. There were no significant differences found in any of the other variables between conditions.

Conclusion: The primary findings of this study indicate that one night of sleep restriction has little impact on HRV during subsequent exercise. These data show that one night of sleep restriction has an effect on resting HR and the LF power (%) variable in the 60% W_{max} portion of the exercise test. The results suggest elevated activity of the sympathetic nervous system during the SLP+ trial. No other variables were impacted by one night of sleep restriction.

Introduction

Healthy cardiac functioning demonstrates beat-by-beat variability in the time lapse between heart beats, and these variations can reflect responses to external and internal stimuli. Healthy variations between heart beats occurs during periods of low stress and activity. Many stressors such as exercise, anxiety, and fear are associated with decreased variations among heartbeats.[6] Heart rate variability (HRV) quantifies the variability between adjacent heart beats. It is a useful method of monitoring autonomic nervous system activity (ANS) and may aid in assessing autonomic stress reactivity (i.e. how the ANS responds to stressors) given that HRV reflects autonomic innervation to the heart.[15, 24]

The ANS responds to different levels of physical stress by adjusting both the parasympathetic nervous system (PNS) and sympathetic nervous system (SNS) activity.[8] The PNS is primarily active during periods of rest, and the SNS is dominant during periods of high stress.[3] The sinoatrial node (SA) of the heart is innervated by both the PNS and SNS.[6] During high SNS output, a decrease in the variability of the heart rate response is seen in addition to tachycardia.[24] When heartbeats occur more regularly, with less variation between beats, it is indicative of activity from the SNS, and when timing varies between beats, it can be inferred that there is more vagal tone and less inhibition of the PNS.[13] Typically, with exercise, heart rate increases due to parasympathetic withdrawal and increased sympathetic activity.[15] The SNS is primarily active during bouts of exercise or periods of stress to maintain bodily function.[15] Following exercise, parasympathetic reactivation occurs to bring HR closer to baseline levels.[12]

Use of the ECG allows researchers to measure the time interval between beats in milliseconds.[6] Changes in R to R intervals (RRI) can be due to normal responses to environmental and physiological stimuli such as stress, changes in metabolism, physical exercise, breathing, and

hemodynamic alterations. These alterations in stimuli control inhibition and excitement of the PNS and SNS.

Sleep helps our body to recover and restore proper physiological function, as it is believed to restore functions of the central nervous system (CNS).[4] The CNS is comprised of the brain and spinal cord, and the brain is responsible for sending signals to the ANS accordingly. It is proposed that adults should acquire 7-9 hours of sleep per night, yet the majority of the population receives less than recommended.[4] Athletes are more likely to lose sleep than the average person due to physical and psychological stresses of training and competition periods, and this sleep loss may be detrimental to athletic performance and peak function.[4] Athletes often experience sleep loss prior to competition, and this can have a significant impact on their athletic performance.[9] Athletes also have practice times, training schedules, travel to competitions, jet lag, and pre-competition anxiety that influence the quantity and quality of their sleep before a competition.[21] Therefore, an athlete's ability to adapt to physiological and psychological stressors is critical to their performance. It has been shown that a single night of sleep restriction (SR) can negatively impact physical function, which is logical due to the restorative capacities of sleep.[4] Further, SR is known to effect heart rate (HR) and HRV in some individuals.[10] HRV has become a physiological marker that is a practical measure of examining the levels of fatigue in an athlete, and a predictor of reduced quality or duration of sleep. Athletes in fatigued states experience alterations of their ANS that result in neuromuscular fatigue due to altered acetylcholine diffusion/reuptake at the neuromuscular junction. The implications of this include an altered testosterone to cortisol ratio, muscle soreness, injury rates, illness, and sleep quality or deprivation.[15] HRV has also been shown to have the potential to predict exercise performance during submaximal or maximal exercise.[12]

While the specifics of the impact of sleep deprivation (SD) on exercise performance remains unclear, it appears SD can have significant effects on some aspects of athletic performance.[9] Sleep loss appears to negatively impact athletic performance in spite of equivalent applied effort and may be a result of reductions in glycogen stores prior to performance. One night of sleep loss has also shown to increase resting oxygen uptake, heart rate, and reduce time to exhaustion. Sleep loss effects cause reduced endurance performance, albeit without decrements in lifting or anaerobic performance.[21] Mild sleep restriction was found to negatively affect accuracy during athletic performance as well.[21] Chase et al. (2017) evaluated the effect of one night of SR after performing a heavy exercise bout. The following morning, there was a significant decrement in performance during a subsequent exercise trial. However, there is speculation as to whether the exercise bout prior to SR, or the SR alone caused the significant changes in performance.[4]

Due to the lack of research in SR associated with HRV and performance, the purpose of this study is to examine how SR, as opposed to SD, impacts autonomic function (via HRV) and overall athletic performance in recreational cyclists.

Methodology

Subjects

Nine male and female non-smoking subjects (6 male, 3 female), aged 20 to 22-years-old, volunteered for participation. All testing occurred in the Human Performance Lab at James Madison University (JMU). The subjects were recruited from the JMU campus and surrounding communities and had no sleep disorders as assessed by the Pittsburgh Sleep Quality Index questionnaire. All subjects were recreational cyclists (minimum 30 minutes 1-2 days per week over the past three months). All subjects were cleared for moderate-to-vigorous intensity exercise, as defined by the American College of Sports Medicine (ACSM).[1]

Preliminary Testing

After providing written informed consent, height and body mass were obtained, followed by a maximal exercise test which determined peak aerobic capacity (VO_{2max}) and peak power (watts; W_{max})). Height was measured using a stadiometer and recorded to the nearest 0.5 cm. For the maximal aerobic capacity test, subjects underwent a graded exercise test. The test began at a self-selected workload that could be maintained comfortably for a 1-hour ride. Workload increased by 25 W at each stage for every 2 minutes until subject reached volitional fatigue or was unable to maintain a cadence >50 rpms. VO_2 was measured continuously via indirect calorimetry (ParvoMedics TrueOne 2400, ParvoMedics Inc., Sandy, UT) and VO_{2max} was defined as the highest 30-second average achieved during the test. Each subject completed a familiarization trial identical to the experimental trials described below to minimize learning error during the accompanying two experimental phases.

Experimental Design

Preliminary testing and experimental phases were separated by 7-14 days. Each experimental phase consisted of an exercise session in the morning. Prior to the exercise test, each subject laid supine on a bed for 10 minutes while HR and HRV were measured with a Polar HR monitor (Polar RS800CX, Polar Electro Inc., Bethpage, NY)[7]. During the resting measurements, subjects were instructed to breathe in sync with a metronome set at 12 beats per minute to prevent respiration from influencing HRV. Following this, subjects completed a 20-min exercise test (10 min at 50% W_{max}, 10 minutes at 60% W_{max}). At the end of the test, subjects completed a self-paced 3-km time trial where maximum effort was encouraged. HR and HRV were measured continuously throughout the exercise bout.

Sleep Protocol

Subjects were randomly assigned to two experimental trials, one to a normal night of sleep (SLP+) or a night of sleep restriction (SLP-). To replicate the same onset time in both experimental phases, subjects initiated sleep between 10:00 pm and 12:00 am for both SLP+ and SLP-. SLP+ subjects set their wake-up time for 8 hours following sleep onset and reported to the exercise trial after waking. SLP- subjects set their wake-up time for 3 hours after sleep onset and reported immediately for monitoring prior to exercise. Exercise times were kept consistent across the SLP+ and SLP- trials. To measure sleep duration and quality, each subject was instructed to wear an accelerometer (ActiGraph wGT3X-BT, Actigraph Corp., Pensacola, FL)[20] on their non-dominant wrist in the 72 hours prior to the trial.

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Subjects recorded all food and beverage intake for 24 hours prior to the first experimental trial. Subjects were provided with copies of their dietary records and instructed to replicate their dietary habits prior to the second experimental trial. All subjects reported to testing following at least a 2 hour fast. All subjects abstained from caffeine, alcohol and tobacco consumption 24 hours prior to testing. Subjects recorded all physical activity 72 hours prior to both experimental trials and wore an accelerometer during all exercise bouts to measure physical activity levels in this time period before both trials.

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The data was uploaded via Polar Pro Trainer 5® software (Polar USA, Bethpage, NY), and HRV analysis was executed using Kubios (version 3.1.0.1, Biosignal Analysis and Medical Imaging Group, Kuopio, Finland) software. HRV was analyzed in nonlinear domains, time, and frequency. Nonlinear domain measures consisted of the Poincare plot short-term [SD1 (ms)]. Time domain measures consisted of HR (beats per minute), root mean square of successive differences

in NN intervals [RMSSD (ms)], and standard deviation of NN interval time series [SDNN (ms)]. The frequency domain was measured via the fast Fourier Transformation (FFT), where low frequency [LF (ms^2), 0.04-0.15 Hz], high frequency [HF, (ms^2), 0.15-0.4 Hz], LF power (%), HF power (%), and low to high frequency ratio [LF/HF] were analyzed.

Statistical Analysis

Mean power output (Watts) from both 3-km time trials was used as the performance measure. Data from HRV was used to interpret autonomic function. Data from this study were log transformed in order to diminish the effects of non-uniformity. Data analyses were performed using SPSS (IBM SPSS version 25.0, IBM Corporation, Armonk, NY). Paired sample *t*-tests were used to evaluate mean differences among variables. Data for non-normally distributed variables (LF and HF for all conditions) were log transformed for analysis. Significance was set at $p < 0.05$.

Results

Subjects, Physical Activity and Sleep Data

Subject descriptors are displayed in Table 1. Days of physical activity (PA), average steps per day, sedentary minutes, light intensity PA minutes, moderate intensity PA minutes, vigorous intensity PA minutes, and moderate-to-vigorous intensity PA (MVPA) are displayed in Table 2. There was no significant difference in PA in the days prior to each of the sleep trials for both the SLP+ and SLP- conditions. By study design, there was a significant difference between total sleep time across both trials (170.7 $\pm$ 37.6 vs. 442.2 $\pm$ 64.3 minutes for SLP- and SLP+ trials, respectively, $P < 0.001$).

Resting Heart Rate Variability Variables

Resting HR and HRV variables are displayed in Table 3. HR was significantly lower with the SLP- experimental trial compared to the SLP+ experimental trial. There were no differences

in any resting HRV variable between trials when assessing the time domain, frequency domain, or non-linear HRV variables.

Exercise Bout Heart Rate Variability Variables

HR, SDNN, RMSSD, LF/HF, LFnu, HFnu, SD1, LF power, and HF power variables for the 50% W_{max} portion of the exercise bout are displayed in Table 4. There was no significant difference in 50% W_{max} HRV variables between sleep conditions.

HR, SDNN, RMSSD, LF/HF, LFnu, HFnu, SD1, LF power, and HF power variables for the 60% W_{max} portion of the exercise bout are displayed in Table 5. LF Power was significantly greater with the SLP+ trial. There was no significant difference in the remaining 60% W_{max} HRV variables between sleep conditions.

3-km Time Trial Heart Rate Variability Variables

Average HR, peak HR, SDNN, RMSSD, LF HF, LFnu, HFnu, SD1 for the 3-km time trial are displayed in Table 6. There was no significant difference in any of the variables analyzed for the 3-km time trial between sleep conditions.

Discussion

This study was designed to investigate the effect of one night's sleep restriction on autonomic function via HRV and overall athletic performance in recreational cyclists. The primary findings were that one night of sleep restriction had little impact on HRV during subsequent exercise. However, resting HR and LF power (%) during the 60% Watts max exercise for the SLP+ condition, suggesting increased SNS activity.

Dettoni et al. (2012) performed a study in which subjects underwent partial sleep deprivation. Subjects endured 5 nights of sleep of either an 8-hour average duration or a 4.5-hour average duration. This study found that partial sleep deprivation did not significantly change resting HR measurements. However, partial sleep deprivation did cause a significant increase in sympathetic activity as there was an increase in percent low-frequency and an increase in percent high-frequency variables of HRV.[5] The results from this study contradict our findings that resting HR measurements were significantly higher during the SLP+ condition. This study also reported changes in the resting low-frequency and resting high-frequency variables that were not replicated with our protocol. The disparities in results may be due to differences between study protocols such as increased duration of sleep conditions (one night vs. five nights) and differing sleep durations in the sleep restriction trial (3 hours vs. 4.5 hours). It can be speculated that the impact of successive sleep loss was amplified by several days as opposed to just one night.

Similarly, Sauvet et. al (2010) conducted a study where HRV variables were measured for subjects laying in the supine position at different time intervals during a 40-hour total sleep deprivation (TSD). They found that after experiencing TSD, supine HR measurements were significantly increased. Also, LFnu was significantly higher and HFnu was significantly lower after TSD.[19] LF is under both sympathetic and parasympathetic control while HF is indicative of

respiratory sinus arrhythmia which is a result of vagal activity, or activity from the PNS.[6] Increased LFnu and decreased HFnu may be indicative of increased activity from the SNS. This is different from our findings as the SLP+ condition elicited a significantly higher resting HR response than the SLP- condition. Also, there were no significant differences in measured resting LFnu and resting HFnu variables found using our protocol. Differences in our results compared to both of these studies may be caused by subject variability (12 males aged 29.1 $\pm$ 3.3 years vs. 3 males/6 females aged 20.6 $\pm$ 1.3 years), research setting (research institute with funding/skilled professionals vs. undergraduate university study conducted by students), and established protocol (3-hour sleep duration vs. 40 hours TSD). There are potential research opportunities regarding physiological variables caused the resting HR values to be significantly higher for the SLP+ condition using our protocol.

Our findings of an elevated LF power (%) variable allows for estimations of sympathetic cardiac activity according to research conducted by Perini and Veicsteinas (2003). They determined that LF power (%) is an expression of sympathetic activity due to its role in mediating fluctuations less than 0.15 Hz. The study observed a lack of change in LF power at low intensity exercise and a decrease to negligible values at higher intensities where enhanced sympathetic activity is noted. However, the powers of the spectral peaks variables are not considered direct measures of autonomic nerve activity. It is indicated that the HR spectral peaks are helpful when quantifying autonomic responsiveness as opposed to autonomic tone.[16] Shaffer and Ginsberg (2017) define the LF power (%) as the "relative power of the low frequency band (0.04-0.15 Hz). The LF power can be produced by the SNS, PNS, and BP regulation via baroreceptors, primarily PNS activity, or only baroreflex activity.[20] There is room for further research regarding the significance of the LF power variable at medium/high exercise intensities following one night's

sleep restriction. There is also room for investigating how much of a shift in autonomic responsiveness is associated with the change in the LF power variable.

Estimations of sympathovagal balance from HRV measurements were significantly higher during sleep restricted conditions in a study designed to analyze the impact of sleep deprivation on metabolic and endocrine function.[23] The power spectrum is commonly used to measure the balance of activity between the SNS and the PNS.[6] Because of the elevated LF power variable, it is logical to conclude that this is a result of elevated sympathetic activity in the SLP+ condition. Heart rate has also been known to be a measurement of sympathovagal balance according to the Rosenblueth-Simeone model.[2] Therefore, an elevated resting HR in the SLP+ condition is a result of elevated sympathetic activity. This brings about the conclusion that some HRV variables were affected by an increased sympathetic activation in the SLP+ trial. Also, the significant decrease in subject resting heart rate in the SLP- trial can be explained by the progressive lowering of heart rate as the body tries to enter the initial phases of sleep.[22] Per protocol, resting measurements were obtained while subjects laid supine for 10 minutes while breathing to a metronome at 12 bpm. Potentially, resting heart rate could drop if the subjects started the process of falling asleep due to their sleep restricted state. This may explain the lower heart rate seen in the current study.

Chase et. al (2017) discovered that an exercise bout prior to each of the SLP+ and SLP- trials resulted in impairment of 3-km time trial performance following a night of restricted sleep. It is thought that the evening session of vigorous exercise may have caused the participants to be more susceptible to the negative effects of sleep loss.[4] Further research potential should investigate whether or not HRV was impacted in a similar fashion to the performance variables with this protocol. This comparison emphasizes the importance of the exercise session prior to initiating sleep for each experimental condition.

This study was unique in that it analyzed the impact of only one night of sleep restriction as opposed to sleep deprivation on HRV during exercise. Our findings bring about new research questions regarding physiological causes for decreases in resting HR values following one night of sleep restriction. It also surfaces questions regarding the LF power (%) variable and its role in autonomic function at higher exercise intensities following one night of sleep restriction. Lastly, there is the potential for future research questions regarding protocol entailing exercise bouts prior to each sleep condition. This allows insight into sleep's essential role in recovery after exercise, and the effect of sleep recovery on HRV.

Table 1. Participant Demographics

	Mean	Std. Deviation
Age (years)	20.6	1.3
Height (cm)	167.8	8.8
Weight (kg)	65.2	10.1
BMI (kg/m^2)	23.0	1.8
VO_{2max} (mL/kg/min)	45.2	9.6
Max METs	12.9	2.7
RER_{max}	1.1	0.1
HR_{max} (bpm)	200.2	9.2
Max Power (watts)	244.4	64.5
50% Power (Watts)	122.3	32.3
60% Power (Watts)	146.7	38.7

Table 2. Participant Physical Activity Paired Samples Statistics

	Mean	Std. Deviation	Sig. (2-tailed)
Steps/Day (SLP-)	3162.6	1054.2	0.3
Steps/Day (SLP+)	3599.9	1200.0	
Sedentary Minutes (SLP-)	102.8	34.2	0.6
Sedentary Minutes (SLP+)	124.0	31.3	
Light Minutes (SLP-)	41.6	13.9	0.4
Light Minutes (SLP+)	41.7	13.9	
Moderate Minutes (SLP-)	25.9	8.6	0.5
Moderate Minutes (SLP+)	31.3	10.4	
Vigorous Minutes (SLP-)	11.1	3.7	0.4
Vigorous Minutes (SLP+)	15.1	5.0	
MVPA (SLP-)	32.1	10.7	0.8
MVPA (SLP+)	42.9	14.3	

Table 3. Resting Heart Rate Variability Paired Samples Statistics

	Mean	Std. Deviation	Sig. (2-tailed)
Resting HR (bpm) [SLP -]	58.1	12.6	0.03**
Resting HR (bpm) [SLP +]	66.3	12.8	
SDNN (ms) [SLP -]	37.8	9.3	0.4
SDNN (ms) [SLP +]	33.6	8.6	
RMSSD (ms) [SLP -]	23.3	4.2	0.9
RMSSD (ms) [SLP +]	23.0	4.8	
LF (ms) [SLP -]	1371.9	1469.1	0.3
LF (ms) [SLP +]	783.0	537.6	
HF (ms) [SLP -]	142.1	87.8	0.3
HF (ms) [SLP +]	204.9	133.9	
LF/HF [SLP -]	13.3	10.8	0.2
LF/HF [SLP +]	6.7	6.1	
LFnu [SLP -]	88.0	7.7	0.2
LFnu [SLP +]	75.0	22.2	
HFnu [SLP -]	12.0	7.7	0.1
HFnu [SLP +]	24.9	22.1	
SD1 (ms) [SLP -]	16.5	3.0	0.9
SD1 (ms) [SLP +]	16.3	3.4	

** Resting HR was significantly different when comparing the SLP- and SLP+ trials.

Table 4. 50% Watts Max Heart Rate Variability Paired Samples Statistics

	Mean	Std. Deviation	Sig. (2-tailed)
HR (bpm) [SLP -]	156.0	17.4	0.2
HR (bpm) [SLP +]	161.7	13.5	
SDNN (ms) [SLP -]	3.1	0.9	0.5
SDNN (ms) [SLP +]	3.0	0.8	
RMSSD (ms) [SLP -]	2.5	0.4	0.9
RMSSD (ms) [SLP +]	2.5	0.3	
LF/HF [SLP -]	8.4	9.2	0.8
LF/HF [SLP +]	7.9	7.9	
LFnu [SLP -]	80.1	14.3	0.8
LFnu [SLP +]	79.4	14.1	
HFnu [SLP -]	19.6	14.2	0.8
HFnu [SLP +]	20.3	13.8	
SD1 (ms) [SLP -]	1.8	0.3	0.9
SD1 (ms) [SLP +]	1.8	0.2	
LF Power (%) [SLP -]	55.8	11.1	0.3
LF Power (%) [SLP +]	60.5	16.8	
HF Power (%) [SLP -]	13.8	10.3	0.7
HF Power (%) [SLP +]	14.7	9.8	

Table 5. 60% Watts Max Heart Rate Variability Paired Samples Statistics

	Mean	Std. Deviation	Sig. (2-tailed)
HR (bpm) [SLP -]	173.8	14.6	0.2
HR (bpm) [SLP +]	178.4	12.5	
SDNN (ms) [SLP -]	2.5	1.2	0.2
SDNN (ms) [SLP +]	2.0	0.3	
RMSSD (ms) [SLP -]	2.8	0.8	0.4
RMSSD (ms) [SLP +]	2.6	0.4	
LF/HF [SLP -]	4.1	4.4	0.8
LF/HF [SLP +]	4.5	3.1	
LFnu [SLP -]	66.6	22.6	0.2
LFnu [SLP +]	77.1	10.2	
HFnu [SLP -]	33.0	22.2	0.2
HFnu [SLP +]	22.8	10.1	
SD1 (ms) [SLP -]	2.2	0.9	0.3
SD1 (ms) [SLP +]	1.8	0.3	
LF Power (%) [SLP -]	45.7	14.8	0.02**
LF Power (%) [SLP +]	61.0	14.8	
HF Power (%) [SLP -]	25.7	19.8	0.3
HF Power (%) [SLP +]	17.9	8.7	

** LF Power HRV variable was significantly different when comparing SLP- and SLP+ trials.

Table 6. 3-km Time Trial Heart Rate Variability Paired Samples Statistics

	Mean	Std. Deviation	Sig. (2-tailed)
Average HR (bpm) [SLP -]	187.3	11.2	0.5
Average HR (bpm) [SLP +]	189.4	14.9	
Peak HR (bpm) [SLP -]	194.9	10.4	0.3
Peak HR (bpm) [SLP +]	198.0	12.4	
SDNN (ms) [SLP -]	2.5	1.2	0.4
SDNN (ms) [SLP +]	2.2	0.6	
RMSSD (ms) [SLP -]	3.1	1.0	0.5
RMSSD (ms) [SLP +]	2.9	0.4	
LF/HF [SLP -]	2.2	1.7	0.3
LF/HF [SLP +]	3.8	4.94	
LFnu [SLP -]	61.5	16.3	0.8
LFnu [SLP +]	63.2	21.4	
HFnu [SLP -]	38.1	16.0	0.8
HFnu [SLP +]	36.3	21.0	
SD1 (ms) [SLP -]	2.2	0.7	0.5
SD1 (ms) [SLP +]	2.0	0.3	

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Appendices

APPENDIX A

James Madison University
Department of Kinesiology
Informed Consent

Purpose

You are being asked to volunteer for a research study conducted by Dr. Trent Hargens from James Madison University entitled, *The Impact of One Night of Sleep Restriction on Autonomic Function During Exercise.*

The goal of this study is to examine the effect that sleep restriction has on subsequent exercise performance and autonomic function, compared to a full night of sleep.

Subject Responsibility

You will be asked to visit the Human Performance Laboratory (HPL) in Godwin Hall 4 times over the course of about 4 weeks. Your total time commitment for participation in this study will be about 7 hours (each visit will range between about 1 – 2 hours).

Preliminary Testing

Upon completion of this informed consent, you will be asked to complete 2 short questionnaires, 1 that asks about your ability to participate in physical activity, and 1 that asks about your current sleep quality. Each of these questionnaires should take about 5 minutes to complete.

You will then have your height and weight measured. Upon completion of this, you will be asked to complete a maximal cycle exercise test to determine your maximum oxygen consumption (VO_{2max}). You will be asked to ride a stationary bike at an initial workload that is 'fairly easy'. The workload will then be increased every two minutes until fatigue is reached, determined by either: 1) your request to stop due to fatigue, or 2) inability to maintain a cadence of $\geq$ 50 revolutions per minute. You will be verbally encouraged to continue to obtain an accurate measurement of VO_{2max}. To access oxygen consumption, you will need to breathe through a mouthpiece/breathing apparatus which collects expired air throughout the test (10-15 minutes). Prior to your arrival to the HPL that day, you will be asked to refrain from eating for 4 hours prior to your arrival, and to avoid caffeine and alcohol for the same time frame. This session should last about 60 minutes.

Familiarization Trial

The familiarization phase will consist of 1 day of exercise trials. Procedures will be the same as the experimental trials detailed below, but with no assigned sleep condition. The time commitment for the familiarization trial will be approximately 120 minutes.

Experimental Trials

For the 2 experimental trials, you will be randomly assigned to either a normal night of sleep or a night of sleep restriction. You will be instructed to initiate sleep between 10:00 pm and 12:00 am for both trials, replicating the same onset time in both experimental phases. For the normal night of sleep, you will be instructed to set your wake-up time for 8 hrs following sleep onset. For the restricted night of sleep, you will set your wake-up time 3 hours following sleep onset. During each night of sleep prior to the 2 experimental trials, you will be asked to wear 2 devices while you sleep. One device will be worn on your non-dominant wrist, in a similar fashion to a wrist watch. The second device will be worn over your head. These two devices will be monitoring the quality of your sleep.

Upon waking, you will be asked to report to the HPL. It is very important that you no consume alcohol, tobacco or caffeine for 24 hours prior to arriving at the HPL. When you arrive at the HPL, we will ask you to lie down and still for 10 minutes, upon which we will measure your heart rate with a heart rate monitor. You will be asked to try to breathe in unison with a metronome during this time. The purpose of this is to control for the potential impact of respiration on heart rate. At the end of this 10 minute period, we will obtain your blood pressure.

You will then be asked perform a 20-min warm-up on a stationary cycle ergometer, at approximately half of your maximal workload determined from preliminary testing. Upon completion of this, you will then be asked perform a 3-km computer-simulated time trial on the cycle ergometer. You will need to give your maximal effort on this time trial. This will last approximately 4-7 minutes. You will be fitted for a heart rate monitor so that we can measure your heart rate throughout the 20-minute warm-up and time trial. Additionally, you will be asked to rate your level of exertion on a scale from 6 to 20 at various points throughout. You will also be fitted with a facemask in which we will collect all of your expired air, and used for measurement of oxygen consumption and other cardiorespiratory function variables.

<u>Dietary and exercise controls:</u>

You will be asked to record all food and beverage intake for 24 hours preceding the first exercise trial. After the initial experimental exercise trial, you will be provided with copies of your dietary records and instructed to replicate their dietary habits for the second experimental exercise trial. You will be asked to report to the HPL for each experimental trial after minimum of 2 hour fast. You will also be asked to wear an accelerometer on your hip 72 hours prior to each experimental trial, to measure physical activity. Between experimental trials, you will be asked to continue to wear the accelerometer until you report for the second experimental trial.

Risks

Cardiovascular Testing:

There is a risk of abnormal changes during the maximal exercise tests. These changes may include abnormal blood pressure, fainting, heart rhythm disorders, stroke, heart attack, and death. The chance of serious heart problems during maximal exercise among adults is very small (less than 1/10,000 maximal exercise tests). Every effort will be made to minimize risks of an abnormal response by reviewing you health history and providing adequate supervision of the exercise test. All staff are certified by the American Heart Association in BLS (Basic Life Support), and all tests will be supervised by individuals certified by the American College of Sports Medicine.
Sleep Restriction: The consequences of a single night of sleep restriction comparable to this investigation have not been well documented, but include impaired insulin sensitivity, increased sleepiness and fatigue, and reduced alertness and constant attentiveness. The latter have the *potential* to impact short-term academic performance, decision-making and tasks such as driving ability but these have not been documented.

Benefits

Participation may include knowledge about your health status. Upon request, you will receive information on your cardiovascular fitness. As a whole, the present study may provide useful information for athletes who are susceptible to sleep restriction.

Confidentiality

All data and results will be kept confidential. You will be assigned an identification number and a pseudonym in place of your real name. At no time will your name be identified with your individual data. The researcher retains the right to use and publish non-identifiable data. All paper data will be kept secured in a locked cabinet in a locked office. All electronic data will be kept on a password-protected computer in encrypted file folders. Final aggregate results will be made available to participants upon request.

Inquiries

If you have any questions or concerns or you would like to receive a copy of the final aggregate results of this study, please contact Dr. Trent Hargens at hargenta@jmu.edu or (540) 568-5844.

Questions about Your Rights as a Research Subject
Dr. David Cockley
Chair, Institutional Review Board
James Madison University
(540) 568-2834
cocklede@jmu.edu

Freedom of Consent

Your participation is entirely voluntary. You are free to choose not to participate. Should you choose to participate, you can withdraw at any time without consequences of any kind.

I have read this consent form and I understand what is being requested of me as a participant in this study. I freely consent to participate. I have been given satisfactory answers to my questions. The investigator provided me with a copy of this form I requested it. I certify that I am at least 18 years of age. By clicking "Yes" to the question below and submitting this confidential online survey, I am consenting to participate in this research.

_____	_____
Name of Subject (Printed)	Name of Researcher (Printed)
_____	_____
Name of Subject (Signed)	Name of Researcher (Signed)
_____	_____
Date	Date

APPENDIX B

Subject Prescreening Information

Age:_____years

Height_____ Weight_____

Typical Exercise Habits over the Past 3-6 Months:

Average number of days of cycling per week_____

Average number of hours of cycling per week_____

Briefly describe your cycling habits over the past 3-6 months:

Average number of days of resistance exercise/weight lifting per week _____

Average number of days of resistance exercise/weight lifting per week _____

Briefly describe your resistance training habits over the past 3-6 months:

Do you have a muscle or joint injury/condition that precludes the completion of the cycling or muscle function protocol? If yes, please explain.

Are you allergic to latex?

APPENDIX C

2018 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1) Has your doctor ever said that you have a heart condition ☐ OR high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** _____	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** _____	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it ***does not limit your current ability*** to be physically active. **PLEASE LIST CONDITION(S) HERE:** _____	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

☑ **If you answered NO to all of the questions above, you are cleared for physical activity.**
Please sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow International Physical Activity Guidelines for your age (www.who.int/dietphysicalactivity/en/).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

PARTICIPANT DECLARATION
If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness centre may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at **www.eparmedx.com** before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

01-11-2017

2018 PAR-Q+

FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?

If the above condition(s) is/are present, answer questions 1a-1c — If **NO** ☐ go to question 2

1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	YES ☐ NO ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	YES ☐ NO ☐

2. Do you currently have Cancer of any kind?

If the above condition(s) is/are present, answer questions 2a-2b — If **NO** ☐ go to question 3

2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck?	YES ☐ NO ☐
2b.	Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)?	YES ☐ NO ☐

3. Do you have a Heart or Cardiovascular Condition? *This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm*

If the above condition(s) is/are present, answer questions 3a-3d — If **NO** ☐ go to question 4

3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	YES ☐ NO ☐
3c.	Do you have chronic heart failure?	YES ☐ NO ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	YES ☐ NO ☐

4. Do you have High Blood Pressure?

If the above condition(s) is/are present, answer questions 4a-4b — If **NO** ☐ go to question 5

4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	YES ☐ NO ☐

5. Do you have any Metabolic Conditions? *This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes*

If the above condition(s) is/are present, answer questions 5a-5e — If **NO** ☐ go to question 6

5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	YES ☐ NO ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	YES ☐ NO ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet?	YES ☐ NO ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	YES ☐ NO ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	YES ☐ NO ☐

2018 PAR-Q+

FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?

If the above condition(s) is/are present, answer questions 1a-1c If **NO** ☐ go to question 2

1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	**YES** ☐ **NO** ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	**YES** ☐ **NO** ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	**YES** ☐ **NO** ☐

2. Do you currently have Cancer of any kind?

If the above condition(s) is/are present, answer questions 2a-2b If **NO** ☐ go to question 3

2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck?	**YES** ☐ **NO** ☐
2b.	Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)?	**YES** ☐ **NO** ☐

3. Do you have a Heart or Cardiovascular Condition? *This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm*

If the above condition(s) is/are present, answer questions 3a-3d If **NO** ☐ go to question 4

3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	**YES** ☐ **NO** ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	**YES** ☐ **NO** ☐
3c.	Do you have chronic heart failure?	**YES** ☐ **NO** ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	**YES** ☐ **NO** ☐

4. Do you have High Blood Pressure?

If the above condition(s) is/are present, answer questions 4a-4b If **NO** ☐ go to question 5

4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	**YES** ☐ **NO** ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	**YES** ☐ **NO** ☐

5. Do you have any Metabolic Conditions? *This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes*

If the above condition(s) is/are present, answer questions 5a-5e If **NO** ☐ go to question 6

5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	**YES** ☐ **NO** ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	**YES** ☐ **NO** ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet?	**YES** ☐ **NO** ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	**YES** ☐ **NO** ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	**YES** ☐ **NO** ☐

2018 PAR-Q+

If you answered NO to all of the FOLLOW-UP questions (pgs. 2-3) about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:

You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

For more information, please contact
www.eparmedx.com
Email: eparmedx@gmail.com

Citation for PAR-Q+
Warburton DER, Jamnik VK, Bredin SSD, and Gledhill N on behalf of the PAR-Q+ Collaboration. The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and Electronic Physical Activity Readiness Medical Examination (ePARmed-X+). Health & Fitness Journal of Canada 4(2):3-23, 2011.

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.

Key References

1. Jamnik VK, Warburton DER, Makarski J, McKenzie DC, Shephard RJ, Stone J, and Gledhill N. Enhancing the effectiveness of clearance for physical activity participation; background and overall process. APNM 36(S1):S3-S13, 2011.
2. Warburton DER, Gledhill N, Jamnik VK, Bredin SSD, McKenzie DC, Stone J, Charlesworth S, and Shephard RJ. Evidence-based risk assessment and recommendations for physical activity clearance; Consensus Document. APNM 36(S1):S266-s298, 2011.
3. Chisholm DM, Collis ML, Kulak LL, Davenport W, and Gruber N. Physical activity readiness. British Columbia Medical Journal. 1975;17:375-378.
4. Thomas S, Reading J, and Shephard RJ. Revision of the Physical Activity Readiness Questionnaire (PAR-Q). Canadian Journal of Sport Science 1992;17:4 338-345.

01-11-2017

APPENDIX D

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, when have you usually gone to bed at night?

   USUAL BED TIME _____

2. During the past month, how long (in minutes) has it usually take you to fall asleep each night?

   NUMBER OF MINUTES _____

3. During the past month, when have you usually gotten up in the morning?

   USUAL GETTING UP TIME _____

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 spend in bed.)

   HOURS OF SLEEP PER NIGHT _____

INSTRUCTIONS: For each of the remaining questions, check the one best response. Please answer all questions.

5. During the past month, how often have you had trouble sleeping because you...

	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
(a) ...cannot get to sleep within 30 minutes	☐	☐	☐	☐
(b) ...wake up in the middle of the night or early morning	☐	☐	☐	☐
(c) ...have to get up to use the bathroom	☐	☐	☐	☐
(d ...cannot breathe comfortably	☐	☐	☐	☐
(e) ...cough or snore loudly	☐	☐	☐	☐
(f) ...feel too cold	☐	☐	☐	☐
(g) ...feel too hot	☐	☐	☐	☐
(h) ...had bad dreams	☐	☐	☐	☐
(i) ...have pain	☐	☐	☐	☐
(j) Other reason(s), please describe _____ _____				
How often during the past month have you had trouble sleeping because of this?	☐	☐	☐	☐

PSQI Page 1

	Very good	Fairly good	Fairly bad	very bad
6. During the past month, how would you rate your sleep quality overall?	☐	☐	☐	☐

	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
7. During the past month, how often have you taken medicine (prescribed or "over the counter") to help you sleep?	☐	☐	☐	☐
8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?	☐	☐	☐	☐

	No problem at all	Only a very slight problem	Somewhat of a problem	A very big problem
9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?	☐	☐	☐	☐

	No bed partner or roommate	Partner/ roommate in other room	Partner in same room, but not same bed	Partner in same bed
10. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?	☐	☐	☐	☐

If you have a roommate or bed partner, ask him/her how often in the past month you have had...

	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
(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 INSTRUCTIONS FOR THE PITTSBURGH SLEEP QUALITY INDEX:

The Pittsburgh Sleep Quality Index (PSQI) contains 19 self-rated questions and 5 questions rated by the bed partner or roommate (if one is available). Only self-rated questions are included in the scoring. The 19 self-rated items are combined to form seven "component" scores, each of which has a range of 0-3 points. In all cases, a score of "0" indicates no difficulty, while a score of "3" indicates severe difficulty. The seven component scores are then added to yield one "global" score, with a range of 0-21 points, "0" indicating no difficulty and "21 " indicating severe difficulties in all areas.

Scoring proceeds as follows:

Component 1: Subjective sleep quality

Examine question #6, and assign scores as follows:

Response	Component 1 score
"Very good"	0
"Fairly good"	1
"Fairly bad"	2
"Very bad"	3

Component 1 score: _____

Component 2: Sleep latency

1. Examine question #2, and assign scores as follows:

Respo\nse	Score
≤15 minutes	0
16-30 minutes	1
31-60 minutes	2
> 60 minutes	3

Question #2 score: _____

2. Examine question #5a, and assign scores as follows:

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

Question #5a score: _____

3. Add #2 score and #5a score

Sum of #2 and #5a: _____

4. Assign component 2 score as follows:

Sum of #2 and #5a	Component 2 score
0	0
1-2	1
3-4	2
5-6	3

Component 2 score: _____

Component 3: Sleep duration

Examine question #4, and assign scores as follows:

Response	Component 3 score
> 7 hours	0
6-7 hours	1
5-6 hours	2
< 5 hours	3

Component 3 score:_____

Component 4: Habitual sleep efficiency

1. Write the number of hours slept (question #4) here:_____
2. Calculate the number of hours spent in bed:

   Getting up time (question #3):_____

   Bedtime (question #1):_____

   _____

   *Number of hours spent in bed:*_____

3. Calculate habitual sleep efficiency as follows:

   (Number of hours slept/Number of hours spent in bed) X 100 = Habitual sleep efficiency (%)

   (_____/_____) X 100 = %

4. Assign component 4 score as follows:

Habitual sleep efficiency %	Component 4 score
> 85%	0
75-84%	1
65-74%	2
< 65%	3

Component 4 score:_____

Component 5: Step disturbances

1. Examine questions #5b-5j, and assign scores for each question as follows:

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

5b score: _____

5c score: _____

5d score: _____

5e score: _____

5f score: _____

5g score: _____

5h score: _____

5i score: _____

5j score: _____

2. Add the scores for questions #5b-5j:

Sum of #5b-5j: _____

3. Assign component 5 score as follows:

Sum of #5b-5j	Component 5 score
0	0
1-9	1
10-18-4	2
19-27	3

Component 5 score: _____

Component 6: Use of sleeping medication

Examine question #7 and assign scores as follows:

Response	Component 6 score
Not during the past month	0
Less than once a week	1
Once or twice a week	2
Three or more times a week	3

Component 6 score: _____

Component 7: Daytime dysfunction

1. Examine question #8, and assign scores as follows:

Response	Score
Never	0
Once or twice	1
Once or twice each week	2
Three or more times each week	3

Question#8 score: _____

2. Examine question #9, and assign scores as follows:

Response	Score
No problem at all	0
Only a very slight problem	1
Somewhat of a problem	2
A very big problem	3

Question #9 score: _____

3. Add the scores for question #8 and #9:

Sum of #8 and #9: _____

4. Assign component 7 score as follows:

Sum of #8 and #9	Component 7 score
0	0
1-2	1
3-4	2
5-6	3

Component 7 score: _____

Global PSQI Score

Add the seven component scores together:

Global PSQI Score: _____

APPENDIX E

24-HOUR DIET RECORD

*Subject number*_____ *Date*_____ *Day of Week*_____

Time	Food and/or Drink	Method of Preparation	Quantity Consumed	Brand Name

Adapted From: Lee RD, Nieman DC. *Nutritional Assessment.* 2nd ed. United States of America: Mosby; 1996

APPENDIX F

Subject Recruitment flyer

JAMES MADISON UNIVERSITY.
HUMAN PERFORMANCE LABORATORY

Research Participants Needed

Participants wanted for a study evaluating the interactive effects of sleep restriction on short-duration cycling performance. We are looking for:

- Males and females between the ages of 18 and 45
- Currently cycle >30 minutes, at least 2 days per week

Subjects will receive information on their cardiovascular fitness, physical activity, and sleep habits.

For more information please contact:
Lindsay Lickers (lickerlj@dukes.jmu.edu)
OR
Amanda Becker (beckeraj@dukes.jmu.edu)

APPENDIX G

Email Recruitment Statement

Subject Line: Do you cycle?

Body: Do you want to know your cardiovascular fitness (VO_{2max})? James Madison University's **Human Performance Lab** is in search of male and female cyclists to be subjects a sleep and cycling performance study. We are in search of people who cycle a minimum of 30 minutes 2 days a week.
You will be asked to participate in preliminary fitness testing, and two exercise tests that include a 3km cycling time trials. Subjects needed throughout this semester.
Please contact Amanda Becker (beckeraj@dukes.jmu.edu) or Lindsay Lickers (lickerlj@dukes.jmu.edu) for more information.