International Journal of
EXERCISE SCIENCE

Original Research

The Effect of Timing and Type of Exercise on the Quality of Sleep in Trained Individuals

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ABSTRACT

International Journal of Exercise Science 13(7): 837-858, 2020. Sleep is an extremely important component for overall health and for a well-balanced training program. Recent studies have highlighted the interaction between sleep, recovery, and performance in elite and recreational athletes alike. Exercise has been known to affect the quality of sleep, nevertheless the impact is not well understood in the current research, particularly the effects of exercise timing and intensity on sleep quality. The purpose of this study was to understand if exercise timing and intensity significantly impact sleep quality among recreational exercisers. The participants involved were recreational exercisers who were self-grouped into an AM or PM exercise group. They participated in a seven-day quantitative, quasi-experimental, exploratory study wearing an Actigraph watch. The participant's intensity was also self-grouped into moderate intensity or high intensity based on criteria cut points. Data was analyzed using a factorial ANOVA to examine if there was a significant difference between exercise timing and intensity on sleep quality of the participants. There were no significant differences in sleep quality in either the time group (AM vs PM) or the intensity group (MOD vs VIG) within the four measures of sleep that were looked at throughout this study; total sleep time, sleep onset latency, sleep efficiency % and wake after sleep onset (TST, SOL, SE, and WASO). Results within both, the AM and PM group and the MOD and VIG group, results showed no significant differences. These results conclude that neither exercise intensity or timing had an effect on sleep quality.

KEY WORDS: Actiwatch, accelerometer, sleep efficiency

INTRODUCTION

Sleep is a critical component for overall health and a well-balanced training program. Recent studies have highlighted the interaction between sleep, recovery, and performance in elite and recreational athletes alike. Proper sleep is known for releasing hormones which aid in rehabilitating muscles and improving cognitive functions (19). Even missing just one night of sleep has shown negative effects on performance (40).

There are many factors that lead to sleep deprivation. Some are uncontrollable, such as psychological, hormonal or metabolic reasons, while others are controllable factors such as sleep hygiene, sleep environment, and screen time (4, 17, 49). Additionally, the timing of exercise has also been linked with contributing to sleep deprivation (13). Lack of sleep in the athletic population may interrupt the recovery and have detrimental impacts performance. Athletes often encounter many situations that have the likelihood to disrupt a proper sleep schedule, such as their training schedule, traveling for competitions, and stressors from their sport and other areas of life (24).

Anaerobic and aerobic performance, have both shown to decrease after sleep deprivation (39, 40). Additionally, just as the physical performance of an individual is affected by sleep quality, so is the mental aspect of an individual. The active population has been found sometimes to take longer to fall asleep and have less sleep quality than control groups, often due to thinking about the upcoming competition and nervousness (15, 23, 24). Poor sleep quality has been shown to be linked with mood, fatigue, and game results (38).

Aside from those aspects, many of which are unable to be altered, the timing of activity has also been shown to affect sleep. Research is limited on the timing of exercise and sleep quality; however, it has been shown to play a part in the quality of sleep quality.

Very few studies have looked at the timing of exercise and its effect on sleep quality. Those that have examined the relationship, the results have been mixed. For example, some studies have shown night exercise to decrease the quality of sleep (7, 29). However, other studies have shown an increase in sleep quality after night exercise (5). Further, even fewer studies have looked at the different types of exercise (vigorous vs. moderate intensity) and their effects on sleep quality. Therefore, it is important to investigate whether there is a difference in sleep quality between morning and evening exercise, the intensity of exercise performed.

By understanding the timing of exercise and how it may play a part in sleep quality, the athlete may be able to adjust as their schedule as necessary and in turn, will increase their performance and possibly counterbalance the factors that may be affecting their sleep in the first place.

METHODS

Participants

This study employed a convenience sampling of recreational exercise participants from the southeast Florida region. The individuals involved were 18-45 years old, including both male and female participants. Age was determined based on previous research on the stability of sleep stages, which has been stated to stay stable until the age of 45 (6). Participants were active individuals who perform at least 150 minutes of moderate-intensity activity or 75 minutes of vigorous activity throughout the week, which meets the physical activity guidelines defined by the Office of Disease Prevention and Health Promotion (32).

Protocol
Participants were recruited from local recreational facilities, gyms and sports groups, in which it was anticipated that 34-52 participants were recruited in total. To be eligible for the study, participants must meet the inclusion criteria below.

To be included the participants must be 18-45 years of age and willing to provide consent. They must have been consistently been exercising for the last three months, either aerobic, anaerobic, resistance training or a combo of the three and perform exercise at least three days per week; at least 150 minutes of moderate intensity or 75 minutes of vigorous intensity. They must also have no current sleep conditions that may affect their sleeping habits

Individuals will be excluded if they have current or previous sleep conditions or are taking medications for sleep conditions. Also, those with diagnosed depression or anxiety (41). Further, they will be excluded if they are new to exercising or if they only participate in low-intensity exercise mode such as, such as walking, yoga, Tai Chi and Pilates.

Subjects were self-placed into either group A (AM exercise group) or group B (PM exercise group) depending on their current (preferred) exercise schedule. To be classified as Group A, the participant had to participate in exercise before 11:59 am, and to be classified as Group B, the participant had to exercise between 12 – 11:59 pm. The participants were also classified into intensity groups based on their exercise routines: moderate intensity (at least 150 minutes of moderate intensity) or vigorous intensity (at least 75 minutes of vigorous).

There are several ways to measure exercise intensity. For this study, the data was downloaded and analyzed off of the Actiwatch. For each participant, total time spent in either moderate or vigorous intensity exercise for each day were averaged across the total number of days performed to calculate the mean throughout the week.

Examples of moderate and vigorous exertion from the US Physical Activity Guidelines consist of the following:

> Moderate exertion includes; walking briskly, water aerobics, bicycling slower than 10mph, tennis, ballroom dancing, general gardening, and light weightlifting.
>
> Vigorous exertion includes; race walking, jogging, running, swimming laps, aerobic dancing, biking ten mph or faster, jump rope, hiking, Olympic weightlifting, high-intensity interval training (HIIT).

The sample size for this study was calculated using the program G*Power. G*Power is a commonly used statistical power analysis program among many studies (18). Effect size, power, and statistical significance (P value) are the main considerations when estimating sample size. The effect size measures the effect of an intervention, in which the higher the effect size number, the greater effect of the intervention.

In both tests, a small effect size was run to determine the magnitude of the difference between groups (42). In the case of this study, the effect size will emphasize the size of the difference between the quality of sleep based on timing factors (AM or PM) and intensity factors (moderate or vigorous). During this test, a 'small' effect size of 0.25 was used. Cohen (1969) stated that any effect size under five is considered 'small' (42). Repeated measures ANOVA is used for testing if there is any change in sleep quality due to the result of the interaction between time and intensity of exercise.

The alpha level is the probability of making a Type I error, which is when the null hypothesis is rejected when, in fact, the null hypothesis is correct. Conventionally, it is set at a = 0.05, which indicated a 5% change of making a Type I error. For data analysis, the alpha level was set at 0.05. If the results are less than the significance level (0.05), the results are statistically significant (20). The power (1-beta), is the probability of rejecting the null hypothesis when it is false. In both tests, the power is set at 0.80, which signifies that a significant difference was seen 80% of the time (42). After running two separate tests in G*Power, a sample size range was established as 34-52.

An Actigraph watch was used to measure sleep quality and duration, as well as physical activity levels, were measured by using accelerometry data from the Actigraph watch (Philips Actiwatch Spectrum PRO). Actigraph watches are small activity-based data loggers that measure and record gross motor activity, which allows for identification of sleep/wake information and physical activity.

Actigraphy monitoring has been shown to be a valid and reliable procedure (when compared to the gold standard of polysomnography) for evaluating sleep in normal, healthy adult populations (2). The Actiwatch score can detect and record light exposure, sleep schedule variability, sleep quality and quantity. In addition to sleep, physical activity (light, moderate, vigorous, and sedentary times) can also be measured by the Actiwatch.

The Cole-Kripke algorithm was used to perform sleep scoring. This algorithm is considered appropriate for use with adult populations and was found to be a valid method to distinguish sleep from wakefulness based on wrist activity (11). The Cole-Kripke algorithm was developed using 10, 30 and 60-second epochs. A 60-second epoch was used for this study.

The data collected from the Actigraph watch was converted into four measures of sleep – the primary focus was on sleep time, sleep efficiency, wake after onset and sleep latency. Total Sleep Time (TST), is the sum, in minutes, of all sleep epochs between sleep onset and sleep end. Sleep Efficiency (SE%) is the ratio of total sleep time to time in bed x 100. Sleep efficiency scores of ≥ 85% are considered 'good quality,' and those with a score of less than 85% are considered 'poor quality' (34). Wake After Onset (WASO) is sum, in minutes, of all wake epochs between sleep onset and sleep end and the number of wake episodes greater than five minutes. The criteria used to score WASO is any time greater than a total time of 30 minutes of wake after sleep onset, which would be considered poor quality (31). And finally, sleep onset latency (SOL) is the interval in minutes, between lights off and sleep start.

Exercise intensity was measured as the level of intensity above and below the mean as measured throughout the week and is defined by the ODPHP (2018) as; moderate intensity, which includes those participating in at least 150 minutes/week of moderate intensity exercise based on the actigraphy data. And vigorous intensity, which is those participating in at least 75 minutes/week of vigorous intensity of exercise based on the actigraphy data.

Statistical Analysis
Data was downloaded using Actiware software for analysis. Each device was set to collect activity in 60-s epochs. Off-wrist periods were set to 'missing.' Days with 10 hours of wear were included, and a minimum of four valid days was required to be considered a valid measurement. For sleep, at least four nights of sleep was required to be included. The data was divided into wake and sleep periods using the reported times in the activity log. Categorical variables include; time of exercise (AM vs. PM) and levels of exercise (vigorous verse moderate exercise).

To examine the research question, a factorial ANOVA was used to evaluate the effect of the binary independent variables (timing of exercise and intensity of exercise) on the dependent variable (quality of sleep). $P < 0.05$ was considered statistically significant.

A factorial ANOVA is used when two independent categorical variables (factors) are being studied on their effect on the dependent variable. In an ANOVA, an F-ratio is used to compare the means of two groups (25). A factorial ANOVA can be used to compare the means of two or more groups, thus this method was used for this study due to the fact that there are two categorical independent variables (time and intensity of exercise), and both these variables have a small number of categories (AM/PM and Moderate/Vigorous). By using the factorial ANOVA, interactions were also able to be examined among groups and provided an overall comparison on whether the group means differ (12).

RESULTS

The participants included were men and women from the southeast Florida region and were recruited from local recreational facilities. A total of 45 people attended the first meeting. Inclusion criteria required that participants be 18-45 years of age, engages in aerobic, anaerobic and or resistance exercise at least three days per week; at least 150 minutes of moderate intensity or 75 minutes of vigorous intensity, and has consistently been exercising for the last three months and has no current sleep conditions. Nine of the 45 did not meet the inclusion criteria, due to several reasons, such as being new to exercising, taking medications for sleep, or having a sleep disorder. Thus, a total of 36 subjects met the inclusion/exclusion criteria and agreed to participate in this study. Two participants were removed from analysis due to instrumentation error of the Actigraph watch. A total of 34 participants were used for the final analysis. Table 1 shows the frequencies and percentages of individuals by gender, and groups of AM (before 11:59 am) (n = 17) and PM (12-11:59 pm) (n = 17) exercise group and intensity groups of either moderate (MOD) exercise (for 150mins/wk.) (n = 17) or vigorous (VIG) exercise (for 75min/wk.) (n = 17) intensity (Table 1).

Table 1. Demographics of participants.

Characteristics	n	%
Sex		
Male	11	32.3
Female	23	67.7
Timing Group		
AM	17	50.0
PM	17	50.0
Intensity Group		
Moderate	17	50.0
Vigorous	17	50.0

Note. n represents the number of participants. The percentage is displayed as a percentage among those total participants.

To ensure accuracy among intensities, the individuals reported their activity 'type' based on the US Physical Activity Guidelines, which group 'moderate' and 'vigorous' intensities depending on specific exercise type (ODPHP, 2018). Based on their type of exercise performed, their log was then matched up to their Actiwatch data to ensure the proper amount of time was spent in each category of intensity (150 mins/wk. for moderate exercise; 75 mins/wk. for vigorous exercise; Figure 1).

The frequencies of sleep quality measured by time and intensity of exercise and sleep quality measurements are shown below in Table 2. Throughout this table, the mean (average) number of hours or minutes of sleep measures are highlighted. The standard deviation (SD) is also reported on this table. The SD is a measure of how spread out numbers are from the mean (Table 2).

Table 2. Frequencies of Sleep Quality Measures by Time and Intensity of Exercise and Sleep Quality Measures.

Group	TST (hours) Mean ± SD	SOL (mins) Mean ± SD	SE% Mean ± SD	WASO (mins) Mean ± SD
AM	6.66 ± 0.86	14.95 ± 9.23	84.20 ± 4.61	44.09 ± 13.34
PM	6.68 ± 0.86	14.37 ± 11.63	84.74 ± 4.22	43.23 ± 12.44
Moderate	6.82 ± 0.86	14.85 ± 9.23	84.99 ± 4.61	42.41 ± 13.34
Vigorous	6.64 ± 0.86	14.47 ± 11.63	83.95 ± 4.22	44.92 ± 12.44

Note. n = 17, Mean ± SD. Total Sleep Time (TST), sleep onset latency (SOL), sleep efficiency (SE%) and wake upon sleep onset (WASO).

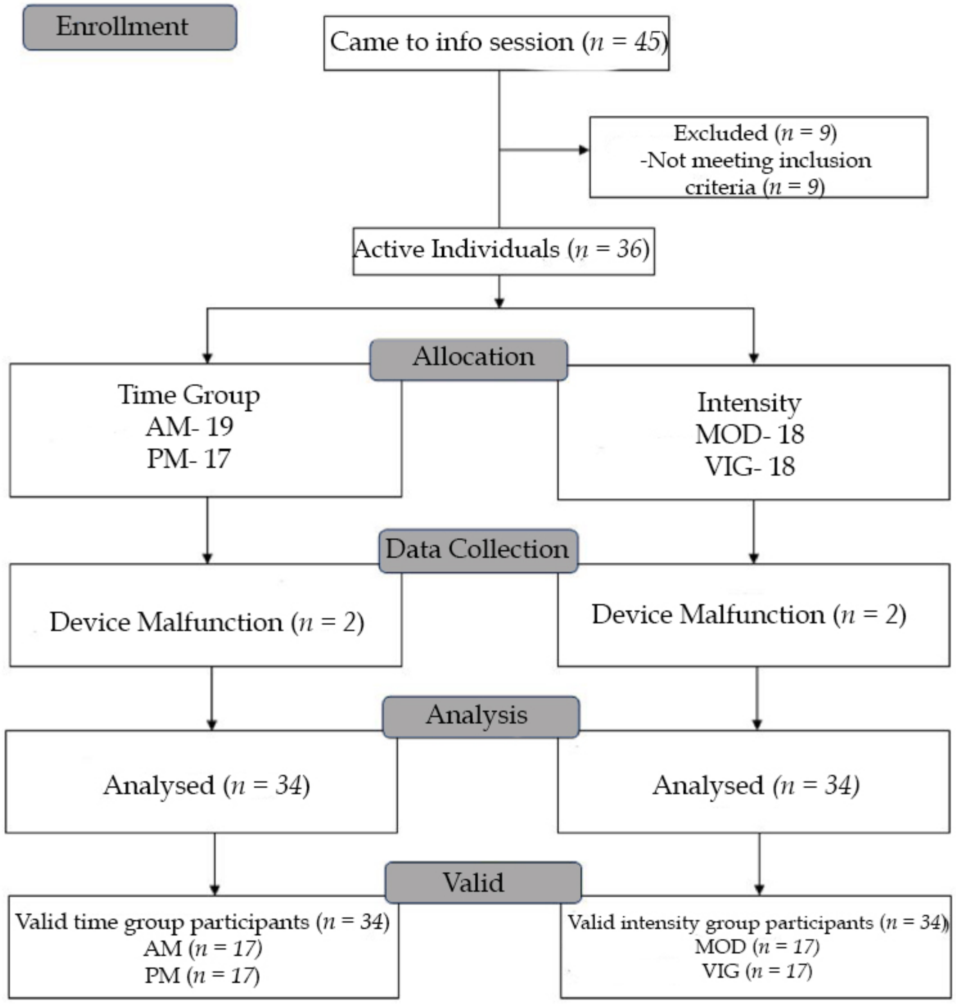

Figure 1. Consort Diagram. This figure illustrates the participation throughout the entire study.

As shown in Table 2, total sleep time (TST) hours were very similar throughout the AM and PM group (AM 6.66 ± 0.86; PM 6.68 ± 0.86); however in the intensity group, the moderate intensity exercise seemed to have a slightly longer sleep time than the vigorous intensity exercise group (Moderate 6.82 ± 0.86; Vigorous 6.64 ± 0.86). Sleep onset latency (SOL) minutes are the number of minutes it took the individual to fall asleep. Both the AM and PM group averaged similar minutes to fall asleep (SOL) (AM 14.95 ± 9.23; PM 14.37 ± 11.63), and the moderate vs. vigorous group also yielded similar minutes to fall asleep (MOD 14.85 ± 9.23; VIG 14.47 ± 11.63). Sleep efficiency percentage (SE%) yielded similar results within the AM and PM group (AM 84.20 ± 4.61; PM 84.74 ± 4.22). However, the moderate intensity exercise group had a slightly higher percentage in sleep efficiency over the vigorous group (MOD 84.99 ± 4.61; VIG 83.95 ± 4.22). Last, wake after sleep onset (WASO) found that the AM group spent an average of almost a minute more awake after they fell asleep than the PM exercise group (AM 44.09 ± 13.34; PM 43.23 ± 12.44), and the moderate intensity group spent almost two minutes less time awake after sleep onset than the vigorous intensity group (MOD 42.41 ± 13.34; VIG 44.92 ± 12.44).

The following figures (2-9) show individual points on a scatter plot among each measure of sleep within both the time group (AM vs. PM) and intensity group (MOD vs. VIG). Scatter plots are used to show a relationship and correlation between variables. In the following figures, you can see that although there are sometimes individuals who range significantly different, the general trend is that the group as a whole remains similar, resulting in non-significance.

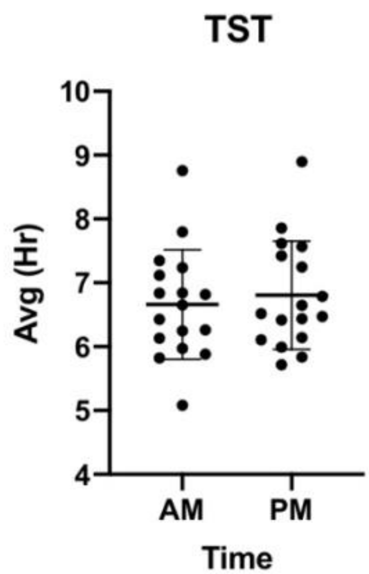

Figure 2. Total Sleep Time within the Time Group.

Scatter plot showing individual points, total sleep time, mean ± SD. AM (6.66 ± 0.9); PM (6.68 ± 0.9), p = 0.70. This figure shows that both AM and PM individual data points are in similar locations, showing non-significant differences among individuals whether they worked out in the AM or PM on the effect of total sleep time (Figure 2).

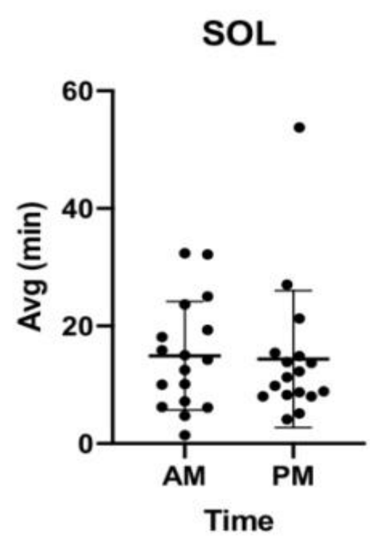

Figure 3. Sleep Onset Latency within the Time Group.

Scatter plot showing individual points, SOL, mean ± SD. AM (14.95 ± 9.2); PM (14.37 ± 11.6), p = 0.86. As shown in this figure, both AM and PM individual data points are in similar locations, showing non-significance between AM and PM exercise times and SOL (Figure 3).

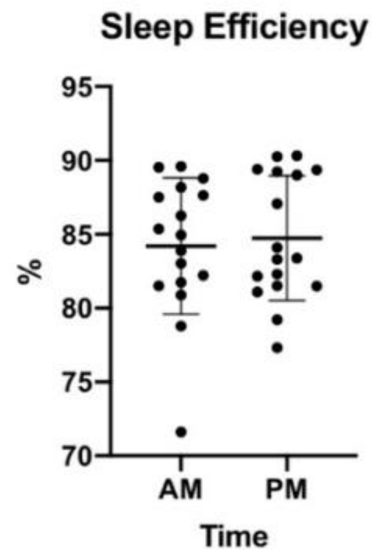

Figure 4. Sleep Efficiency % within the Time Group.

Scatter plot showing individual points, SE%, mean ± SD. AM (84.20 ± 4.6); PM (84.74 ± 4.2), p = 0.82. As shown in this figure, both AM and PM individual data points are in similar locations, showing non-significance in sleep efficiency % between AM and PM times (Figure 4).

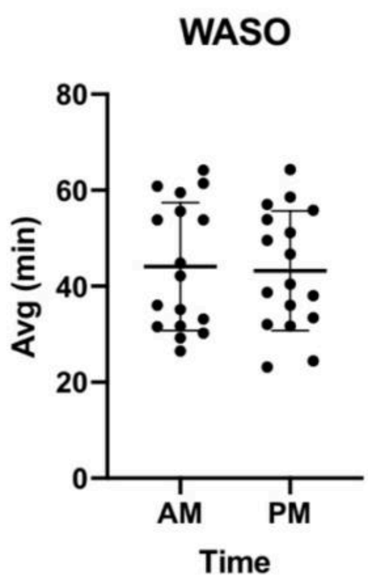

Figure 5. Wake After Sleep Onset within the Time Group.

Scatter plot showing individual data, WASO, mean ± SD. AM (44.09 ± 13.3); PM (43.23 ± 12.4). p = 0.92. As shown in this figure, both AM and PM individual data points are in similar locations, showing non-significance (Figure 5).

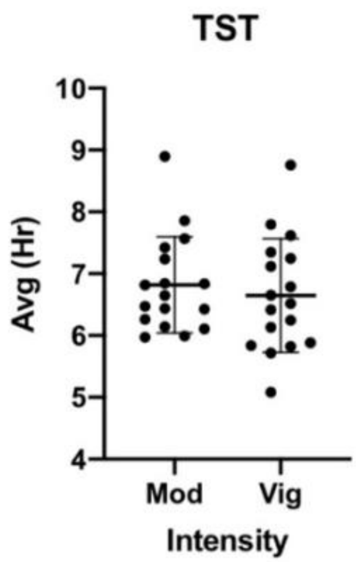

Figure 6. Total Sleep Time within the Intensity Group.

Scatter plot showing individual data, TST for intensity, mean ± SD. MOD (6.82 ± 0.8); VIG (6.64 ± 0.9), $p = 0.61$. As shown in this figure, both MOD and VIG individual data points are in similar locations, showing non-significance (Figure 6).

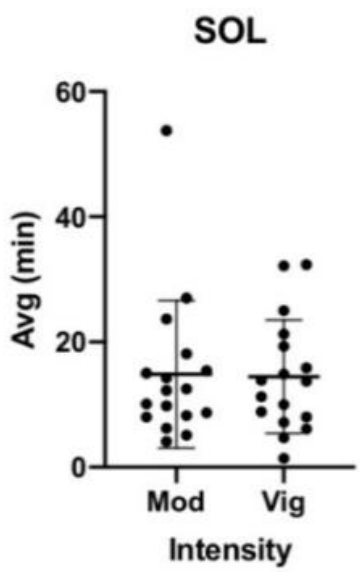

Figure 7. Sleep Onset Latency within the Intensity Group.

Scatter plot showing individual data, SOL for intensity, mean ± SD. MOD (14.85 ± 11.8); VIG (14.47 ± 9.1), $p = 0.89$. As shown in this figure, both MOD and VIG individual data points are in similar locations, showing non-significance (Figure 7).

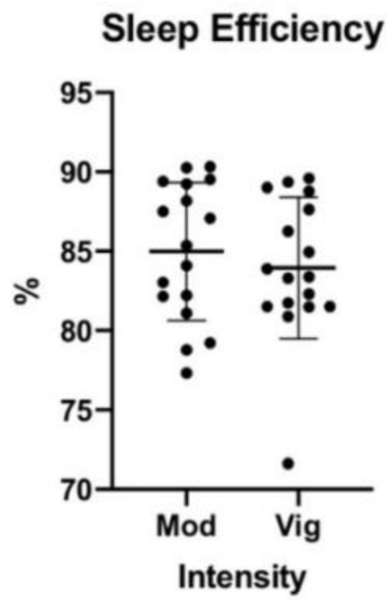

Figure 8. Sleep Efficiency within the Intensity Group.

Scatter plot showing individual data, SE% for intensity, mean ± SD. MOD (84.99 ± 4.3); VIG (83.95 ± 4.5), $p = 0.54$. As shown in this figure, both MOD and VIG individual data points are in similar locations, showing non-significance (Figure 8).

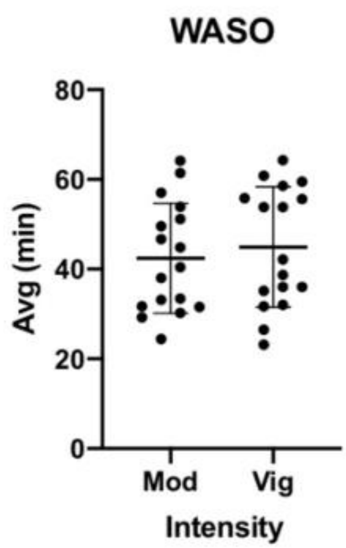

Figure 9. Wake After Sleep Onset within the Intensity Group.

Scatter plot showing individual data, WASO for intensity, mean ± SD. MOD (42.41 ± 12.2); VIG (44.92 ± 13.4), $p = 0.60$. As shown in this figure, both MOD and VIG individual data points are in similar locations, showing non-significance (Figure 9).

For sleep data, a factorial ANOVA comparing the time of exercise and sleep quality compared significant differences among the four measures of sleep quality that were under investigation. The four measures of sleep were analyzed: total sleep time hours (TST), sleep onset latency minutes (SOL), sleep efficiency (SE%) and wake after sleep onset minutes (WASO). An alpha level of .05 was used. Prior to running the factorial ANOVAs for sleep measure variables, the Levene's Test of Equality of Error.

Variances must be analyzed in order to evaluate homogeneity assumption. Homogeneity assumption states that the population variances are equal for all groups (Table 3).

Table 3. Levene's Test of Equality of Error Variances: Based on Mean.

Measure of Sleep	Levene Statistic	df1	df2	Sig.
TST	2.103	3	30	0.121
SOL	2.300	3	30	0.097
SE %	0.646	3	30	0.592
WASO	1.077	3	30	0.374

Table 3 displays the results for the Levene's test in which the variances for sleep measures were equal throughout all measures of sleep ($p > 0.05$), thus, assumption has been met, and factorial ANOVAs are the appropriate data analyses for this study. Post hoc tests were run to confirm where differences occurred between groups; however, because the assumption of homogeneity of variance has been met, there is no need for a post hoc test.

Factorial ANOVAs were employed to determine significant differences between the timing of exercise and intensity of exercise on Total Sleep Time. Table 4, below, displays the results of the factorial ANOVA results of the time of exercise and sleep quality. This test was used to show if there was a difference in sleep quality between the two independent variables (AM and PM) and their interaction on the dependent variables (TST). The sig value is what represents the significance of the relationship between the independent variables and dependent variables. In regards to individuals who worked out in the AM vs. PM or Moderate intensity vs. Vigorous intensity, there was no significant ($p > 0.05$) difference in sleep quality on total sleep in either the time group ($p = 0.701$) or the intensity group ($p = 0.616$). Partial eta squared (partial eta sq.) is the effect size that measures the relationship between the two variables. In the case of total sleep time and the two variables as shown in Table 4, partial eta sq. for the time variable is 0.005 and 0.008 for the intensity variable, both measuring as small effect sizes (Table 4).

Table 4. Two-Way Analysis of Variance for Total Sleep Time (Hours)(TST) as a Function of Exercise Time and Intensity.

Variable and Source	Df	Mean Square	*F*	Sig.	Partial eta sq.
Time (AM/PM)	1	0.114	0.150	0.701	0.005
Intensity (MOD/VIG)	1	0.194	0.257	0.616	0.008

Factorial ANOVAs were utilized to determine significant differences between the intensity of exercise and intensity of exercise on sleep onset latency (SOL) within both the time group (AM vs. PM) and the intensity group (MOD vs. VIG) (Table 5). In regards to individuals who worked out in the AM vs. PM or Moderate intensity vs. Vigorous intensity, there were no significant difference ($p > 0.05$) in sleep quality based on sleep onset latency in either the time group ($p = 0.861$) or the intensity group ($p = 0.896$). In the case of sleep onset latency, partial eta sq. for both effect sizes result in 0.001 of variability in the data which can be explained by the treatment effect (Table 5).

Table 5. Two-Way Analysis of Variance for Sleep Onset Latency as a Function of Exercise Time and Intensity.

Variable and Source	Df	Mean Square	*F*	Sig.	Partial eta sq.
Time (AM/PM)	1	3.623	0.031	0.861	0.001
Intensity (MOD/VIG)	1	2.020	0.015	0.896	0.001

Factorial ANOVAs were again employed to determine significant differences between the intensity of exercise and intensity of exercise on sleep efficiency (SE%) within both the time group (AM vs. PM) and the intensity group (MOD vs. VIG) (Table 6). In regards to individuals who worked out in the AM vs. PM or Moderate intensity vs. Vigorous intensity, there were no significant difference ($p > 0.05$) in sleep quality based on sleep efficiency % in either the time group ($p = 0.820$) or the intensity group ($p = 0.544$). However, there is a larger difference among significance between the AM/PM group, and MOD/VIG group, which shows that sleep quality might be affected more by intensity levels than the time of exercise when it comes to sleep efficiency %. In the case of sleep efficiency %, partial eta sq. for the time variable is 0.002 and 0.012 for the intensity variable, both measuring as small effect sizes. (Table 6).

Table 6. Two-Way Analysis of Variance for Sleep Efficiency as a Function of Exercise Time and Intensity.

Variable and Source	Df	Mean Square	*F*	Sig.	Partial eta sq.
Time (AM/PM)	1	1.082	0.053	0.820	0.002
Intensity (MOD/VIG)	1	7.742	0.376	0.544	0.012

Note: Sleep efficiency % in minutes and SE %

Factorial ANOVAs were again employed to determine significant differences between the intensity of exercise and intensity of exercise on wake after sleep onset (WASO) within both the time group (AM vs. PM) and the intensity group (MOD vs. VIG) (Table 7). In regards to individuals who worked out in the AM vs. PM or Moderate intensity vs. Vigorous intensity, there were no significant difference ($p > 0.05$) in sleep quality based on wake after sleep onset in either the time group ($p = 0.924$) or the intensity group ($p = 0.601$). However, there is a larger difference among significance between the AM/PM group and the MOD/VIG group, which shows that sleep quality might be affected more by intensity levels than the time of exercise when it comes to minutes spent awake after sleep onset. In the case of wake after sleep onset and the two variables as shown in Table 7, partial eta sq. for the time variable is 0.000 and 0.009 for the intensity variable, both measuring as small effect sizes. Thus, both resulting in small effect sizes (Table 7).

Table 7. Two-Way Analysis of Variance for Wake After Sleep Onset as a Function of Exercise Time and Intensity.

Variable and Source	Df	Mean Square	*F*	Sig.	Partial eta sq.
Time (AM/PM)	1	1.605	0.009	0.924	0.000
Intensity (MOD/VIG)	1	48.972	0.279	0.601	0.009

A total of 34 individual's data were used in the analysis of these results. The two independent variables were exercise time and exercise intensity. Among those two variables, four measures of sleep were analyzed (total sleep time, sleep onset latency, sleep efficiency % and wake after sleep onset). No significant differences were noted throughout any sleep measure within either independent variable. There was a slight difference in total sleep time in the moderate intensity exercise group over the vigorous exercise group with a higher total sleep time for the moderate intensity group, however, not enough to yield significant results. The moderate intensity group also spent almost two minutes less awake than the vigorous group after sleep onset (WASO).

Further, the moderate intensity group also had a slightly higher percentage in sleep efficiency over the vigorous intensity group, although once again not significant. This does show a slight advantage in sleep quality to exercising moderately rather than vigorously. The main difference found among the time group was that the AM group spent an average of almost a minute more awake after they fell asleep (WASO) than the PM exercise group.

These results, although not statistically significant, have provided that it may be beneficial to receive better sleep quality if working out in the evening at a moderate intensity, over the alternative. However, because these slight differences are not statistically significant, the research results prove that regardless of time or intensity of exercise, sleep quality remains similar among both independent variables and the four measures of sleep looked at throughout this study.

DISCUSSION

The purpose of this study was to establish the effect of the time exercise was performed and the intensity exercise was performed on the sleep quality in recreational adult exercisers. The study employed a convenience sampling of recreational exercise men and women ages 18-45. Sleep quality in this study was measured by Actigraph scores of TST, SE% SOL, and WASO. It was found, through this study, that there are no significant differences in sleep quality based on the time of exercise performed or the intensity of exercise performed. This current research is one of the first studies to objectively examine a quantitative, quasi-experimental, exploratory study of the interrelation between the time of exercise and sleep quality and intensity of exercise and sleep quality over a 7-day consecutive period in a free-living environment, for multiple days using the same device among all participants.

Previous studies have examined the effects of exercise (either timing or intensity) on sleep quality and have produced mixed results. (23, 28). For example, a study by Yamanaka (2015) found that daily moderate intensity exercise over six days had differential effects on circadian rhythm, temperature, sleep stages, and heart rate variability, all which might result in differences in sleep quality. In Yamanaka's study, in particular, it found that exercise earlier in the day might improve the quality of sleep due to the stimulation of the sympathetic nervous system (48). Using a similar methodology could possibly allow for a more accurate grouping of subjects. For example, to observe the individual and their physiological response during exercise, such as heart rate variability, will allow the researcher to see if their physiological response is similar throughout the intensity group. Heart rate variability is just one of the physiological responses to exercises that often change and has been shown to have a direct effect on sleep quality. For example, changes in heart rate variability associated with acute stress (such as exercise), has been found to result in disturbed sleep (22).

Throughout this study, all participants are individuals who already exercise, which, when comparing to results from different studies, could have resulted in the non-significant differences among groups. For example, a previous study measured individuals who were one extreme to another (chronic vs. acute) instead of those with similar exercise habits, such as in this current study (moderate to vigorous intensities). Kredlow (2015) examined the effects of sleep quality on chronic vs. acute exercisers (26). He found that acute exercise had a small effect on TST, slow wave sleep, SOL, and decreased REM. Regular exercise, on the other hand, had a moderate to a strong positive effect on sleep quality, showing an increase in TST and SE%, especially (26). One way to see possibly more of a significant difference between groups would be to measure against possibly a lesser than moderate intensity (i.e., light intensity) vs. a moderate/vigorous intensity.

Further, in a study by Vincent (2017), light, moderate, and vigorous intensity physical activity was measured by accelerometers in primary school aged children. No significant associations were observed between time in bed (TIB), total sleep time (TST) and sleep efficiency (SE) in any of the directions. Although this study had similar results as the current study, it was performed on school-aged children, whereas this present study is performed on adults (ages 18-45). This could play a part in other variables that affect sleep quality in general (such as stressors, etc.) (46).

When looking at the timing of exercise and sleep quality in previous studies, Alley (2015) completed a study on individuals performing resistance exercises at different times of the day and if/how it affects sleep quality compared to days of no exercise. They found no differences in time spent in deep sleep during this study; however, they did find differences in SOL and WASO in the evening following resistance exercise. Morning exercise was found to improve SOL significantly, and evening exercise was found to reduce WASO (1). This is a similar finding in WASO through this current study, where evening exercise also reduced WASO (although not significant). However, when looking at SOL, Alley (2015) found that there was an improved (less minutes to fall asleep) SOL after morning exercise, whereas in this present study, a trend of less minutes to fall asleep SOL (although not significant) was found after evening exercise (1).

It has been found that athletes don't often see the beneficial effects of exercise on sleep if the athlete is already experiencing poor sleep quality, which is common among athletes. This is often due to various reasons such as training schedule, performance anxiety, traveling and time zone changes, and more. (13, 21). Throughout the study, no subjective qualities were observed (such as looking at other stress variables that may affect sleep quality). Therefore, this was not taken into account with the current results. Elite athletes are already at their max capacity in training; therefore, more focus should be given to the timing of exercise, rather than the intensity of exercise when trying to produce a greater quality of sleep in active individuals, as it is harder to differentiate between intensities with individuals who are already working out consistently.

Further, when looking at a periodized plan, which many athletes or active individuals follow, it has been found that an increased intensity periodization resulted in a significantly decreased sleep quality that progressed as the exercise intensified (23). Meaning, as the athletes' program intensity increased, their sleep quality decreased. Of course, increasing intensity over a training period is essential to peak for performance. Therefore, it is important that the athletes focus on other ways that may help improve sleep quality to counteract the imbalance. For example, further research on how macronutrient intake affects sleep quality could be used, as they may be able to alter this variable, easier than altering their training times and intensities to increase sleep quality. For example, Halson (2014) examined several diets and their effects on sleep quality and found that high protein diets can improve sleep quality, and high-fat diets could decrease TST (23).

It has been suggested when objectively measuring for sleep quality, to measure over several days of exercise rather than just a single day of physical activity. (13), which is why this study took place over a week. Although this study was objectively measured, previous studies in the past have found subjective positive correlations between exercise and sleep quality. For example, one study found that combining a twice a week aerobic training program for six weeks, subjective PSQI sleep survey scores produced better sleep quality results. Also, subjectively, a study by Wennman (2014) found that those who engaged in leisure physical activity (over occupational PA or no exercise at all) slept the best. (47).

Several other factors might have contributed to the non-significant results of this present study. For example, time spent outdoors and light exposure have the potential to affect both exercise quality and sleep quality. It was found in a study by Murray (2017), that bright light influences the circadian rhythm, which has been known to affect sleep quality (30). As pointed out in the earlier literature review, the circadian rhythm is controlled by the body's response to light. Exercise has a significant impact on the circadian system, depending on the time of day performed. The circadian rhythm is known for its correlation with body temperature fluctuations and hormone release, which both could possibly also affect sleep quality (30). Therefore, taking into account the location of exercise (indoors vs. outdoors and time of day vs. light exposure) could result in different findings on the significance between exercise and sleep quality throughout the study.

While the relationship between time of exercise and intensity of exercise and sleep quality were not significant, there was a small noticeable difference between AM and PM and moderate and vigorous intensity. In the timing group, the trend appears to show that those who exercise in the PM have an increased sleep quality than those who exercise in the AM. Although not significant, this is different from many previous studies that show an increase in sleep quality after morning exercise, rather than evening exercise (7, 16).

In the intensity group of this present study, it appears those who moderately exercise had better sleep quality than those who exercise vigorously. This finding is opposite than one study by Suppiah (2015), had greater amounts of time spent in deep sleep and decreased WASO than the low-intensity sleep group (43). This could make a difference in results compared to the current study, where the intensities that are measured are 'moderate' and 'vigorous,' which could possibly yield more similar sleep quality results than a 'low' intensity activity.

This study had several limitations. First, the population included healthy already active individuals, therefore it might not be able to be generalized to the larger population. Another limitation was self-reporting of the intensity of exercise, as many individuals have different thoughts on their personal exercise intensity, compared to an actual scale. Also, blood pressure has been shown to change during exercise, and also has shown to affect sleep quality. For example, as found in a recent study by Lo (2018). Individuals who sleep poorly had a higher average systolic and diastolic blood pressure. Those with high blood pressure also had significantly worse sleep quality scores than those with normal blood pressure readings (27). Throughout this current study, blood pressure was not monitored, but the previous results on blood pressure and exercise/sleep quality show that this could be another variable that may change individually, that could possibly have an effect on sleep quality.

Throughout previous research in sleep and exercise interactions, including this present one, there have been many variations in the methods performed throughout the study. Thus, making it difficult to compare the findings to understand the true effect of exercise timing and intensity on sleep quality. A recommendation for further research would be more in the form of case studies, and crossover studies, as the groups being looked at would be more specific. For example, examining the relationship between exercise (time and intensity) among a basketball team over a year (season vs. offseason). With doing a study such as that, all participants were on the same or similar training program and time schedule, therefore ensuring consistency throughout the study.

Often those who are not physically active have higher body fat percentage than those who are consistently active. Thus, understanding the level of fitness and sleep quality could be an extension to this previous study. Perhaps comparing those who are not active to those who are consistently active and their sleep quality could provide results that show being active to provide a better quality of sleep, thus an overall healthier lifestyle.

Those individuals who are not active also tend to have a higher body fat percentage. Thus, another recommendation for future research would be looking into the correlation of body composition and sleep quality. Poor sleep quality often disrupts the circadian rhythm, which in turn has been found to increase fat mass (33). This increase in fat mass often leads to obesity which has been found to alter melatonin secretion. This, in turn, can alter the circadian rhythm, leading to poor sleep quality and, as stated above, increased fat mass (9). Thus, future research could show that a decrease in fat mass could possibly lead to increased sleep quality, leading to further prescription of exercise to obese or overweight individuals.

Although negative health problems, such as obesity, heart disease, high blood pressure, etc. have pointed to increased physical activity to overcome health barriers, there is often a fine line between increasing exercise to help increase sleep quality. Some studies have shown exercise (especially as an individual starts to compete at higher levels) to have a negative effect on sleep quality (14, 37). Therefore, understanding how to maintain an optimal level of physical activity and sleep is critical to an active individual and high performing athlete alike.

Monitoring heart rate variability throughout training and how it affects sleep quality could also be a future recommendation to further the depth of the association between exercise and sleep quality. Past research has shown that performance (in watts max) was influenced by the amount of sleep, thus showing the relationship between sleep quality and performance (3). However, exploring if the fitness level of an individual (measured in VO_{2max}), has any correlation with their quality of sleep. If a positive correlation is shown between a higher VO_{2max} and sleep, these results could lead to further implications of fitness to achieve an overall healthier lifestyle. This information could also be helpful when monitoring athletes for any detrimental effects of overtraining. Overtraining occurs when there is an imbalance of training and recovery (23). The restoration theory of sleep as well as current research has found that sleep is a vital factor for recovery (both physical and cognitive) (8). Therefore, if an individual is not sleeping well, they are not recovering properly, ending with a decrease in performance. Understanding if there is a relationship between these factors could determine if overtraining is a result of reduced sleep or if reduced sleep is a result of overtraining. Adjustments could be made to the individuals training schedule if the correlation was found to have profound negative effects, in hopes to increase performance and recovery rates. For example, as training load/time increases, often athletes spend less time in bed therefore, taking that into account when developing the athletes daily schedule could help promote a higher sleep quality overall (36).

Even further, looking into in season training, is taking into account the time, amount and type of light exposure. Light exposure, especially sun light, has been found to increase quality of sleep and sleep patterns (44). However, several barriers often are in place that doesn't allow an individual to receive the benefits of exercising in day light. Perhaps their work schedules only allow them to exercise when it is dark out, or the weather keeps them indoors. While it has been found that exposure to sunlight (whether it be exercising or just exposure without exercising in sunlight), has increased sleep quality compared to less sun light exposure, further research can be explored whether there is a correlation between exercising in sunlight vs exercise indoors (41). This could allow for proper planning with an athlete, team or individual when planning when or where to exercise/train. Further, if an individual is lacking the energy to workout due to decreased sun light exposure, perhaps increasing their sunlight exposure will enhance their energy and in turn lead to a more overall healthy lifestyle (35).

Qualitative studies can also add to understanding the relationship between exercise and sleep, especially during 'in season' times. There have been many instances where athletes have reported to have a harder time to fall asleep or get the proper amount of sleep. Some reasons are related to sleeping in a new environment, stress of competition, jetlag, etc. Future research is needed to determine the qualitative and quantitative relationship over 'on' and 'off' season, taking into account stressors and closely monitoring sleep through qualitative surveys (such as a PSQI) and PSG devices. This will also allow to see changes as load and intensity increases over a season and its effect on sleep. If an athlete is found to decrease sleep quality throughout a season as it intensifies, this could affect their recovery process, which in that point of the season is detrimental in order to maintain (and hopefully increase) performance.

The results of this study show that regardless of the time of day exercise is being performed or the intensity of exercise being performed on the quality of sleep in already active individuals. This information can be helpful to show active individuals that regardless of the time of exercise or intensity of exercise, it does not affect sleep quality either way. Therefore, being active irrespective of the time of day or intensity of activity can be useful to obtain the optimal health and performance benefits and will not directly affect sleep quality based solely on those two variables. Further, if one suffers from a lack of sleep quality, this research provides results that show the lack of sleep may not be due to the time or intensity of exercise. Therefore, examining other areas in the individuals' life to find the root cause of decreased sleep quality is necessary.

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