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The Impact of Low-Intensity Aerobic Exercise on Cognitive Performance in Female Volleyball Players Following Partial Sleep Deprivation

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A B S T R A C T

This study aimed to investigate the impact of low-intensity aerobic exercise on cognitive performance in female volleyball players following partial sleep deprivation. A total of 21 elite female volleyball players (mean age: 23.6 ± 2.9 years; mean BMI: 19.1 ± 1.8) participated in a balanced, randomized design, undergoing two conditions: PSD and exercise in the morning following PSD (PSDE). Prior to the study, participants completed the Pittsburgh Sleep Quality Index (PSQI) to assess sleep quality. Cognitive performance was assessed using computerized neurocognitive tests from the Vienna system, including movement detection time (MDT), visual pursuit test (VPT), and cognitrone test (COG). Data analysis was performed using paired student's t-tests. The findings revealed a notable decline in reaction time (RT) (p=0.004), median cognitive reaction (MCR) (p=0.001), and median motor time (MMT) (p=0.01) in the PSD condition when compared to PSDE. However, there were no significant changes observed in processing speed (number of correct responses and rejections) and selective attention (mean time for correct responses and rejections) in the PSDE condition ($p \geq 0.05$). It is crucial to highlight that PSD had a detrimental impact on the cognitive performance of elite female players. Although partial sleep deprivation negatively affected the cognitive performance of volleyball players, engaging in low-intensity aerobic exercise following partial nocturnal sleep deprivation may attenuate these detrimental effects.

Keywords: *Cognitive Performance, Partial Sleep Deprivation, Reaction Time, Attention.*

1. Introduction

Optimizing the performance of elite athletes in competitions has long been a subject of interest for researchers (1-3). Achieving peak performance at a specific moment is crucial for both coaches and athletes.The relationship between physical exercise and cognitive performance has garnered considerable attention in recent years, as researchers seek to unravel the intricate interplay between bodily activity and mental acuity (4). In the realm of sports, understanding how various forms of exercise may influence cognitive function is of particular interest, as athletes often encounter situations where they need to perform at their cognitive best under demanding physical conditions.

Sleep deprivation has been extensively studied and shown to negatively impact cognitive performance, including reaction time (5), attention (6), and memory (7). While many studies have investigated the effects of sleep deprivation, few focus on university elite athlete students. Sleep deprivation has been found to impair cognitive functioning, such as information processing, reaction time, and attention (8) (9). The relationship between sleep-wakefulness and internal circadian timing is crucial for reinforcing cognitive performance (10, 11).

Sports psychologists have turned their attention to cognitive science to better comprehend the interaction between cognitive functioning, sleep, and athletic performance (12-14). Exercise has been well-documented to positively impact sleep quality (15, 16). Additionally, college students are susceptible to poor sleep due to their lifestyle and campus culture, which can lead to depression, anxiety, stress, risky behaviors, and poor lifestyle choices as well as the stress of sports competitions (17-19). These factors, coupled with the stress of sports competitions, raise the question of how professional athletic students can counteract the negative effects of sleep deprivation to achieve optimal athletic performance. While previous research has extensively examined the effects of sleep deprivation on cognitive performance, few studies have investigated the mediating role of exercise in mitigating the adverse consequences of sleep deprivation in professional athlete students. Cognitive performance is a crucial factor that decisively affects athletic performance. Therefore, this study aims to determine the potential negative impact of sleep deprivation on cognitive performance, with a specific focus on reaction time, attention, and information processing in female student volleyball players. Furthermore, we hypothesize that low-intensity exercise may play a mediating role in attenuating the adverse effects of sleep deprivation in these athletes.

2. Methods and Materials

2.1. Study Design and Participants

Data were collected from a total of 25 professional women college student volleyball players. However, only 21 players met the inclusion criteria for the study. The participants had an average age of 23.6 ± 2.9 years old and a BMI of 19.1 ± 1.8. The study followed a balanced, randomized design, with participants undergoing two conditions: partial sleep deprivation (PSD) and partial sleep deprivation with exercise (PSDE) .All experiments were conducted in the exercise physiology laboratory of Imam Khonmeini International University. The inclusion criteria for the study were as follows: (a) a history of championship in the state and participation in the national volleyball league, (b) no cigarette smoking or alcohol use, (c) insignificant depressive symptoms as assessed by the Beck Depression Inventory (BDI) with a score below 13, (d) no history of cognitive or neurological disorders, (e) not taking any medication that could affect cognitive performance, and (f) a Pittsburgh Sleep Quality Index (PSQI) score of 5 or lower, indicating good sleep quality.

2.2. Procedure

In the PSDE condition, participants with partial sleep deprivation engaged in 30 minutes of low-intensity aerobic exercise on a treadmill at 55% of their maximal heart rate, as measured by a Polar S810 HR monitor (Polar Electro, Kempele, Finland). The exercise protocol was supervised by an exercise physiologist. Before and after the exercise intervention, participants filled out the PSQI to assess their sleep quality. Cognitive performance was measured using computerized neurocognitive tests of the Vienna system test, which included the MDT, VPT, and COG tests. These tests have been reported as valid and reliable in various studies studies (20, 21). To ensure consistency, participants were instructed to refrain from consuming any stimulants, such as caffeinated drinks, and to avoid taking naps on the test day in the laboratory. The data was analyzed using a paired student's t-test.

2.3. Measure

Cognitive performance was assessed using the Vienna Test System, a computerized psychological assessment tool developed by Schuhfried GmbH, Austria. The test included three components: COG, VPT, and MDT. In the COG test, participants were presented with a geometric figure and had to compare it with four other geometric figures. They were then required to determine whether the comparison figure was identical to any of the other four figures. Respondents used different keys to indicate their response, pressing one key if the figures were identical and another key if they were not. The VPT test involved a visual orientation task in a complex environment. Participants were presented with simple structures and had to react quickly and accurately to them. After completing the test, reaction time and accuracy rate were measured to assess performance. In the MDT test, participants were exposed to a rapid succession of visual movement stimuli. They were then required to respond promptly to these stimuli. Median cognitive reaction time and median motor responses were recorded as measures of performance. These tests were designed to assess various

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aspects of cognitive function, including processing speed, selective attention, reaction time, and motor responses. The nutritional status of the participants, including both macro and micronutrients, was assessed as an important factor influencing sleep and exercise. This was done using a 24-hour calorie intake questionnaire, which allowed researchers to monitor the participants' daily food consumption. To determine the recommended calorie intake for each participant, their basal metabolic rate (BMR) was calculated. This was done using measurements obtained from a body composition analyzer (In Body, 320, Korea), which also provided information on their total energy expenditure. Table 1 provides an overview of the research design, outlining the various factors and measurements considered in the study.

Table 1

The study design

	The preceding day of experiment							The test day		
Group	07:00 A.M	09:00 A.M	12:00	14:00-19:00 P.M	19-20 P.M	20:00 P.M-4:00 A.M	4-7:00A.M	07:00 A.M	08:30-8:50 A.M	9:00 A.M
	Isocaloric breakfast	pretest	Isocaloric lunch	Habitual activities	Isocaloric dinner	Awakening period	Studying and watching Films	Isocaloric breakfast	exercise	Post test
PSDE						Reading the newspaper –Listening to Music-playing table Tennis				
PSD									-	

Abbrevation: PSDE, partial sleep deprivation followed by exercise; PSD, partial sleep deprivation

2.4. *Pittsburgh Sleep Quality Index*

Before the experiment, socio-demographic information and sleep-wake schedules of the participants were collected. This was done using the Pittsburgh Sleep Quality Index (PSQI), a well-established instrument developed by Buysse, Reynolds, Monk, Berman, and Kupfer in 1989 (22). The PSQI is a subjective measure of sleep quality that assesses seven domains across 19 items. These domains include subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medications, and daytime dysfunction over the past month. Participants rate their experiences on a Likert scale ranging from 0 to 3, where 3 represents the most negative extreme .The scoring of the PSQI is based on the sum of the ratings across the seven components, resulting in a total score ranging from 0 to 21. A global sum of 5 or greater indicates poor sleep quality. The PSQI has demonstrated good internal consistency, with a reliability coefficient (Cronbach's alpha) of 0.83 for its seven components (23).

2.5. *Exercise protocol*

The exercise protocol for the study involved a single session of light aerobic exercises, specifically based on the Rockport one-mile walking/running test. Participants in the training group completed this exercise protocol before the posttest, while the control group did not engage in any exercise. To ensure appropriate exercise intensity, the participants' heart rates were evaluated and controlled using the Polar Electro system from Kempele, Finland. The exercise program itself consisted of three components: a 10-minute warm-up phase, during which participants maintained a heart rate of 20-30% of their maximum heart rate (MaxHR); a 30-minute period of low-intensity aerobic exercises; and a 10-minute cool-down phase. By incorporating a warm-up, main exercise session, and cool-down, this exercise protocol aimed to provide a balanced and structured approach to physical activity (24).

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2.6. Statistical Analysis

The normality distribution of the variables was assessed using the Kolmogorov-Smirnov test. To compare the cognitive performance of participants in both experimental conditions, a paired student's t-test was conducted. A significance level of $p \leq 0.05$ was set. All values were reported as means ± standard deviation (SD).

3. Findings

As shown in Table 2 and Table 3, there were no statistically significant differences observed in the baseline tests of nutrition status and psychomotor performance ($p \geq .05$). Furthermore, the Sleep Efficiency Score, did not exhibit a significant difference between the experimental and control groups (76.5%±4.8 vs 75.8%±4.3) within the week prior to the test ($p \geq .05$).

Table 2

Comparison of micronutrients and macronutrients in baseline

Groups / Food Analysis	HIIT	Control	*p*-value
Carbohydrate (g)	35.1±234	44.2±238	0.13
Protein (g)	6.9±1.51	2.5±48	0.47
Protein (g)	7.6±62.4	6.3±68.2	0.13
Selenium (micrograms)	7.5±84.3	5.3±94.1	0.51
Vitamin E (mg)	0.9±4.1	1.1±4.4	073
Calcium (mg)	70.1±8.572	58.2±8.478	0.17
Vitamin C (mg)	4.3±51.2	3.2±45.1	0.09
Fiber (g)	3.2±41.2	5.4±13	0.19
Cholesterol (mg)	4.1±76.3	3.7±66	0.29

The values are reported as means ± standard deviation (SD).

As evident from the data presented in Table 3, all psychomotor tests (MDT, VPT, DT, and COG) and their respective subtests showed significant impairment ($p \leq .05$). However, it is noteworthy that the experimental group did not exhibit a further decline in these tests ($p \geq .05$). Our findings indicate that reaction time and response accuracy to the test stimuli were significantly slower during sleep deprivation, and there was also a significant degradation in median cognitive and motor reaction time and speed processing as the duration of wakefulness increased. However, we observed that the combination of sleep deprivation and light aerobic exercise helped to mitigate the detrimental effects of sleep deprivation, leading to improved outcomes.

Table 3

The Effect of Exercise on Cognitive Performance Following Partial Sleep Deprivation (Paired t-test)

Group			Experimental PSDE		t	*p*	Control Sleep deprivation		t	*p*
Tests			Pre test	Post test			Pre test	Post test		
VPT		Reaction Time (S)	1.14±0.1	1.16±0.16	-0.99	0.35	1.20±0.2	1.56±0.3	-4.22	0.004**
VPT		Accuracy Rate (%)	93.25±3.9	93.15±4.12	2.9	0.21	91.99±3.8	87.19±3.9	9.46	0.001***
MDT		Median Cognitive Reaction Time (M sec)	546.37±23.8	525.12±23.8	1.6	0.14	548.5±26.1	576.25±12.0	-5.08	0.001***
MDT		Median Motor Time (M sec)	257.25±8.1	258.75±7.2	-1.14	0.29	248.87±12.2	264.75±15.5	-2.7	0.01**
COG	Processing Speed	Number of Correct Responses	21.83±1.1	21.73±1.1	0.74	0.48	21.80±0.9	19.81±0.44	6.67	0.001***
COG	Processing Speed	Number of Correct Rejection	32.21±2.0	32.24±1.3	0.19	0.85	32.69±1.9	30.34±1.14	4.54	0.003**
COG	Selective	Mean Time	1.87±0.07	1.79±0.07	-1.80	0.12	1.81±0.08	1.87±0.06	-7.39	0.001***

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	for Correct Responses								
	Mean Time for Correct Rejections	1.88±0.05	1.89±0.07	-0.81	0.44	1.87±0.06	1.94±0.09	-6.90	0.001***

PSDE: Partial Sleep Deprivation + Exercise PSD: Partial Sleep Deprivation MDT: Movement Detection Time VPT: Visual Pursuit Test DT: Determination Test COG: Cognitrone Test

Note: Paired t-tests were conducted to compare the cognitive performance measures before and after exercise following partial sleep deprivation. The p-values indicate the statistical significance of the differences observed. A p-value less than or equal to 0.05 was considered statistically significant.

4. Discussion

The findings of this study provide valuable insights into the relationship between exercise, sleep deprivation, and cognitive performance in female volleyball players. The significant decline observed in reaction time, median cognitive reaction, and median motor time in the PSD condition suggest that sleep deprivation alone impairs cognitive function. Our findings are consistent with previous studies that have shown a negative impact of sleep deprivation on psychomotor performance (19, 20). However, there are conflicting results in the literature regarding the effects of one night of sleep loss on reaction time and attention (14). These discrepancies may be attributed to factors such as the duration of sleep deprivation, different assessment tools (subjective vs. objective), varied exercise protocols, and diverse age groups of participants. Numerous scientific studies have demonstrated that the prefrontal cortex is highly sensitive to sleep loss (25). Neuroimaging research has revealed decreased metabolism in the prefrontal cortex during sleep deprivation, suggesting that tasks involving executive function are particularly affected (26).Additionally, our findings suggest that a light exercise protocol may have a beneficial effect in mitigating the negative impact of sleep deprivation on psychomotor tasks, which aligns with a study by Monleon (19). According to the Inverted-U model, there is clear evidence of an inverted U-shaped relationship between cognitive performance, such as reaction time, and arousal level (27). These results align with previous research demonstrating the detrimental effects of sleep deprivation on cognitive performance (3). The results of this study support the notion that exercise can attenuate the detrimental effects of sleep deprivation on cognitive performance to some extent. Low-intensity aerobic exercise may have a positive impact on reaction time, cognitive reaction, and motor time, despite the presence of sleep deprivation. These findings suggest that incorporating exercise into the daily routine of female volleyball players, especially following sleep deprivation, could potentially enhance their cognitive performance. However, it is crucial to consider the limitations of this study. The sample size was relatively small, and the study focused solely on elite female volleyball players. Future research should aim to include a larger and more diverse sample to generalize the findings to a broader population. Additionally, the specific mechanisms through which exercise influences cognitive performance following sleep deprivation warrant further investigation.

5. Conclusion

In conclusion, this study highlights the importance of considering the effects of sleep deprivation on cognitive performance in female volleyball players. While sleep deprivation negatively impacted cognitive function, engaging in low-intensity aerobic exercise following partial sleep deprivation showed some potential to mitigate these effects. These findings emphasize the potential benefits of exercise as a non-pharmacological intervention to enhance cognitive performance in athletes, particularly in the context of sleep deprivation.

Authors' contributions

F.V: carried out the experiment and wrote the manuscript.

Y.S; B.Y; helped supervised the project and developed the theoretical formalism, F.HY; B.Y; and M.G: performed calculations and contributed to the final version of the manuscript.

Transparency Statement

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The authors are willing to share their data, analytics methods, and study materials with other researchers. The material will be available upon reasonable request.

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Declaration of Interest

The authors report no conflict of interest.

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Ethics considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants. Additionally, the study protocol was approved by the ethical committee of the Imam Khomeini International University, ensuring that the research was conducted in an ethical manner. (Ref. 17628.1395). Written informed consent was obtained from all participants prior to their participation in the study. They were provided with clear information about the purpose of the research and were given the option to participate or decline. By choosing to take the assessment, participants indicated their voluntary agreement to participate in the study.

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