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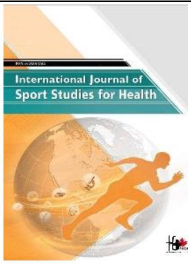

Exploring the Effects of Physical Activity Levels and Sleep Quality on Cognitive Failure in Elderly: A Cross-Sectional Study

Farzaneh. Hatami[1*], Shafagh. Abolghasemi Atani[2], Valerie. Caron[3], Saheb. Yousefi[4]

[1] Department of Motor Behavior, Faculty of Sport Sciences, Shahid Rajaee Teacher Training University, Tehran, Iran
[2] Department of Sports Management, Faculty of Psychology and Educational Sciences, University of Mohaghegh Ardabili, Ardabil, Iran
[3] Department of Special Education, University of Fribourg, Fribourg, Switzerland
[4] Department of Psychology and Exceptional Children Education, Faculty of Psychology and Educational Science, Allameh Tabatabaei University, Tehran, Iran

*** Corresponding author email address**: fhatami2010@gmail.com

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A B S T R A C T

Objective: Aging is a natural stage of life characterized by physiological and cognitive changes that increase the risk of cognitive failure. Among modifiable lifestyle factors, physical activity and sleep quality play a crucial role in maintaining cognitive function in older adults. Therefore, the present study aimed to examine the effects of physical activity levels and sleep quality on cognitive failure in Iranian older adults.

Methods and Materials: To achieve the objectives of the study, a descriptive, cross-sectional study was conducted using a multistage cluster random sampling method. The study population consisted of adults aged 60 and older from five geographical regions of Iran. The data were collected using the Cognitive Failures Questionnaire (CFQ), Pittsburgh Sleep Quality Index (PSQI), and the CHAMPS Physical Activity Questionnaire for Older Adults. Finally, the data were analyzed using a two-way multivariate analysis of variance (MANOVA).

Findings: The results of the two-way multivariate analysis of variance (MANOVA) revealed significant main effects for both physical activity level and sleep quality, as well as a significant interaction effect between physical activity level and sleep quality on the subscales of cognitive failure ($p<.001$). Follow-up tests of the interaction using a simple main effects test indicated that the effect of physical activity level on all subscales of cognitive failure depended on sleep quality. Specifically, in older adults with good sleep quality, the effect of physical activity on cognitive variables was significantly larger and more robust (partial eta squared ranging from .142 to .382). This suggests that under conditions of optimal sleep quality, individuals experience more pronounced benefits from physical activity. Conversely, while the effect of physical activity was also statistically significant in older adults with poor sleep quality (partial eta squared ranging from .060 to .111), the magnitude of this effect was diminished. This implies that even with suboptimal

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sleep, physical activity remains beneficial, although its impact is less pronounced than when sleep quality is also optimal.

Conclusion: The results revealed that the synergistic effect of physical activity and high-quality sleep is crucial for enhancing cognitive performance in the elderly. The beneficial effects of physical activity on cognitive performance were most pronounced when accompanied by optimal sleep quality. Consequently, it is recommended for health specialists and policymakers to prioritize integrated interventions that concurrently promote regular physical activity and offer strategies to improve sleep hygiene. Focusing on a single factor is unlikely to yield optimal results.

Keywords: *Cognitive Failure, Older Adults, Physical Activity, Sleep Quality.*

1. Introduction

Aging is an inevitable stage of human life, and it is naturally accompanied by a set of challenges stemming from extensive physiological, cognitive, and psychological changes. This period not only brings about physical transformations but also introduces numerous individual and social health issues. Furthermore, with increasing life expectancy and advancements in medical care, the global older adult population is rapidly growing, making it even more crucial to investigate factors influencing the health of this age group. Consequently, a significant problem that prominently emerges during old age is the decline in cognitive function and an increased risk of developing conditions such as dementia and Alzheimer's disease. Cognitive function, encompassing abilities like memory, concentration, problem-solving, and decision-making, typically declines with age. Ultimately, this decline can severely impact the quality of life for older adults, limiting their ability to perform daily activities (1).

As a natural phase of the human life cycle, aging is intrinsically linked with physiological, psychological, and social changes that can profoundly affect various aspects of an individual's life. This stage, generally considered to begin around 60 years of age, is accompanied by a gradual reduction in both physical and cognitive functions (2). From a biological perspective, aging refers to a period marked by a progressive decline in the efficacy of various bodily systems, including the nervous system. These changes can lead to reduced cognitive abilities, such as memory, attention, information processing speed, and executive function (3). Moreover, cognitive failures in older adults not only affect their quality of life, but can also lead to increased dependency, diminished autonomy, and a greater care burden for families and society (4). In Iran, for instance, the older adult population is growing rapidly due to increased life expectancy and declining fertility rates. Demographic projections indicate that by 2025, individuals aged 60 and above will constitute over 10% of Iran's total population. Hence, this accelerating demographic shift underscores the critical need to address issues pertaining to the health of older adults, particularly their cognitive well-being (5).

Cognitive failures in older adults are influenced by multiple factors, broadly categorized into two distinct groups: non-modifiable factors and modifiable factors (6). Specifically, increased age and genetic factors, such as the presence of the APOE ε4 allele, exemplify non-modifiable factors that heighten the risk of cognitive failure. These factors induce structural and functional alterations within the brain, including reduced hippocampal volume and decreased neural plasticity (6). Conversely, modifiable factors encompass lifestyle elements such as physical activity and sleep. Indeed, consistent engagement in physical activity contributes to mitigating cognitive decline in older adults through several intricate mechanisms. Physical activity enhances cerebral blood flow and optimizes oxygen delivery to the brain, which in turn fosters neuronal function and inhibits the deterioration of brain tissue (7). Furthermore, physical activity stimulates the secretion of neurotrophic factors, such as Brain-Derived Neurotrophic Factor (BDNF), which plays a pivotal role in neuronal growth, survival, and plasticity, thereby contributing to improvements in memory and learning (8). Additionally, physical activity prevents cellular damage within the brain by reducing inflammation and oxidative stress, consequently lowering the risk of neurodegenerative diseases like Alzheimer's (9). Beyond this, physical activity has been shown to increase the volume of the hippocampus, a brain region integral to memory and learning. This effect is particularly significant in older adults, given that the hippocampus is among the initial cerebral areas affected during the aging process and in neurodegenerative disorders (10). Therefore, regular physical activity not only facilitates improvements in cognitive function but also serves as a robust preventive strategy against age-related cognitive failures and neurodegenerative diseases.

Sufficient and high-quality sleep plays a vital role in preventing cognitive decline in older adults, working through multiple key mechanisms. First, sleep, particularly slow-wave sleep and REM sleep, is crucial for cementing memory and learning, as it moves new information from short-term to long-term memory (11). Second, during sleep, the glymphatic system becomes active, clearing toxic metabolites like beta-amyloid protein from the brain. The buildup of this protein is linked to conditions like Alzheimer's disease (12). Third, adequate sleep helps reduce inflammation and oxidative stress in the brain, both significant contributors to cognitive failures (13). Fourth, sleep is essential for maintaining neural plasticity (neuroplasticity) as it facilitates processes like synaptic potentiation and neuronal regeneration (14). Finally, sleep influences the balance of hormones and neurotransmitters, such as serotonin and dopamine, which are involved in regulating mood, attention, and memory (15). Therefore, sleep disturbances can disrupt these vital mechanisms, increasing the risk of cognitive failures, while improving sleep quality can be an effective strategy for maintaining cognitive health in older adults.

Beyond sleep, several other modifiable factors can worsen cognitive failures. These include unhealthy diets, cardiovascular diseases like high blood pressure and diabetes, psychiatric disorders such as depression and anxiety, and social factors like low educational attainment and social isolation. Identifying and managing these factors, particularly the ones we can change, can help prevent or delay cognitive failures in older adults, further emphasizing the importance of comprehensive interventions in elder health.

As previously mentioned, physical activity and sleep are two lifestyle behaviors that seem to play a fundamental role in mitigating the effects of aging on cognitive health. Regular physical activity can reduce the risk of dementia by up to 28%, while good quality sleep reduces the risk by up to 19%. One study has even shown that physical activity might be able to mitigate the negative effects of sleep deprivation on cognitive health. Additionally, sleep itself could be a mechanism through which physical activity improves cognitive ability (16).

In a study titled "Joint Association of Physical Activity and Sleep Duration with Cognitive Aging in a Large Longitudinal Cohort of English Older Adults," Bloomberg et al. (17) demonstrated that a combination of higher physical activity and desirable sleep duration (neither too little nor too much) is associated with a slower rate of cognitive aging and better preservation of cognitive function over time. Specifically, individuals who maintained both sufficient physical activity and desirable sleep duration experienced the lowest rates of cognitive decline. These findings highlight the importance of simultaneously addressing physical activity and sleep as key factors in preserving cognitive health during aging. Similarly, in a cross-sectional study involving 864 older adults, Kim et al. (18) demonstrated a direct link between physical activity and improved cognitive function. Moreover, sleep was identified as an important mediating factor, suggesting that physical activity can positively influence cognitive function by improving sleep quality. These findings suggest that sleep plays a crucial role in amplifying the beneficial effects of physical activity on cognitive health.

In a similar vein, Kato et al. (19)demonstrated that daily physical activity combined with sufficient sleep duration can positively impact the working memory of healthy young adults. Extending this to older populations, in a cross-sectional study titled "Interaction between Physical Activity and Sleep on Cognitive Function and Brain Beta-Amyloid in Older Adults," Sewell et al. (20) found that physical activity may significantly mediate the relationship between sleep, cognitive function, and brain beta-amyloid levels in older adults.

Further underscoring the benefits of structured activity, Poordelavar et al. conducted research on the impact of cognitive-motor exercises on the physical and cognitive health of older adults. Their findings indicated that such exercise programs effectively improved motor performance, especially balance, and cognitive factors in older women (21). This suggests that cognitive-motor activities represent a promising strategy for preserving motor function and slowing the decline of mental faculties in older adults.

Multiple factors can influence cognitive performance, among which physical activity and sleep quality play particularly important roles (22). Moreover, sleep quality is crucial for memory consolidation and cerebral information processing. Insufficient or poor-quality sleep can increase stress levels, disrupt brain metabolism, and elevate the risk of cognitive disorders. Hence, considering these two variables and examining their combined effects on the cognitive health of older adults is of great importance (23).

Numerous studies have emphasized that the combined impact of regular physical activity and quality sleep not only helps maintain cognitive function but also reduces the risk of dementia (24). Given the current absence of a definitive cure for dementia, recent research has increasingly prioritized identifying effective preventive strategies.

With increasing life expectancy and the growth of the older adult population, the prevalence of cognitive disorders in this group has also risen. Research has shown that older adults who are sedentary and experience sleep problems are at a higher risk of cognitive decline than their more active and well-rested counterparts (25). Physical activity, particularly by increasing cerebral blood flow and stimulating the secretion of neurotrophic factors, can help delay the onset and slow the progression of cognitive disorders (26). Similarly, poor quality sleep can impair information processing and reduce memory performance (27).

In this context, numerous studies have confirmed the positive impact of physical activity on cognitive function in older adults. For example, research indicates that older adults engaging in moderate to vigorous physical activity perform better on cognitive tests compared to their sedentary peers (28). Moreover, consistent exercise for at least six months can lead to increased hippocampal volume and improved spatial memory (29). Conversely, physical inactivity contributes to reduced cerebral blood flow and neuronal atrophy, thereby increasing the risk of cognitive decline (30). Beyond its cardiovascular benefits, physical activity also reduces neuroinflammation and enhances synaptic plasticity, both vital for maintaining brain health. On the other hand, adequate sleep quality improves the function of the hypothalamic–pituitary–adrenal (HPA) axis and helps reduce cortisol levels, which positively influences cognitive processing (31).

The impacts of sleep quality on the cognitive performance of older adults have been investigated in various studies. Specifically, poor sleep is associated with an increased risk of dementia and reduced cognitive function (32). Indeed, older adults reporting less than 6 to 8 hours of sleep per night consistently exhibit poorer performance on cognitive tests (33). Furthermore, poor sleep quality can lead to an increase in stress hormones and a decrease in the efficiency of brain synapses, ultimately resulting in reduced cognitive abilities (34).

A critical consideration in this domain is the interplay between these two factors. Research indicates that physical activity and exercise, through their capacity to elevate core body temperature, can improve sleep quality and prolong deep sleep duration (35). Conversely, better sleep quality is capable of augmenting energy levels and fostering greater motivation for engagement in physical activities, which in turn contributes to improved cognitive function (36). Moreover, recent studies have shown that older adults with better sleep are more motivated to participate in exercise, consequently demonstrating superior cognitive performance (37).

Given the rapid increase in the global and Iranian older adult population, maintaining cognitive health in this age group has become a significant public health priority. Cognitive failures and associated disorders, such as dementia, not only affect the quality of life for older adults but also impose considerable economic and social burdens on families and healthcare systems. In this context, physical activity and sleep quality are recognized as two key, modifiable factors capable of playing a crucial role in mitigating cognitive decline. While the precise causal relationships among physical activity, sleep, and cognition have not yet been exhaustively explored, it is noteworthy that a limited body of research suggests physical activity may mitigate the negative effects of sleep deprivation on cognitive function. Additionally, sleep may be a mechanism for improving cognitive ability through physical activity. Therefore, more research is needed to determine the independent and combined effects of physical activity and sleep on cognitive function in older adults.

Recent, albeit very limited, research indicates that these two factors can have synergistic and interactive effects, concurrently preventing cognitive decline. Consequently, a precise investigation into the impacts of physical activity and sleep quality on the cognitive health of older adults not only enhances understanding of the mechanisms related to cognitive aging but also facilitates the design of effective interventions to improve the quality of life for this age group. Accordingly, the primary objective of the present study is to determine the impact of physical activity levels and sleep quality on cognitive impairment in older adults.

2. Methods and Materials

2.1 Study Design and Participants

This study employed an applied research design, characterized by its descriptive-analytical nature and a causal-comparative (ex-post facto) approach. Data collection was conducted through fieldwork. The statistical population comprised all Iranian older adults aged over 60 years. According to the most recent Iranian national census conducted in 2016, this demographic constituted over 6.1% of the nation's total population (38). Given the extensive nature of the target population and the imperative for the generalizability of findings across the entire country, sample size determination was rigorously predicated upon the principles stipulated by the Morgan table. While the Morgan table suggests a minimum of 384 participants for an indefinite population, in order to secure comprehensive geographical representation, the nation was systematically partitioned into five distinct regions (Central, East, West, North, and South). Consequently, an allocation of 384 participants was designated for each respective region. Furthermore, to mitigate the potential impact of incomplete responses and data attrition, an additional 30% increase was prospectively incorporated into the questionnaire distribution strategy, resulting in the dissemination of 2,496 questionnaires. For illiterate participants, research assistants were enlisted to read the questionnaire items and fill out the survey on their behalf. Following a thorough quality assessment of the collected data, 316 questionnaires were identified as exhibiting flaws and thus systematically excluded, thereby yielding a final analytical sample of 2,180 participants.

A multi-stage random cluster sampling method was employed. Initially, the country was divided into five geographical regions, and one province was randomly selected from each region using cluster sampling. Subsequently, the provincial capital of each selected province was designated as the target community. From there, six parks and public gardens within each provincial capital were selected using a simple random sampling technique. Finally, from each selected park and public garden, 500 older adults were recruited, ensuring equal gender distribution and adherence to the study's inclusion and exclusion criteria. This multi-stage random sampling process significantly enhanced the precision of sample selection and facilitated the generalizability of the study's findings.

The inclusion criteria for this research encompassed individuals aged over 60 years, providing informed consent to participate, absence of severe dementia or progressive neurological disorders, and no continuous use of sedatives or tranquilizers known to affect cognitive function. Conversely, individuals presenting with severe cognitive disorders, individuals consistently using medications that affect cognition, and those who submitted incomplete questionnaires were excluded from the study. For participants who were illiterate, questionnaires were completed through interviews conducted by trained research assistants.

2.2 *Measures*

Cognitive Failures Questionnaire (CFQ): The Cognitive Failures Questionnaire (CFQ) (1) was initially developed by Broadbent et al. (1982) and has 25 distinct items, categorized across four principal subscales: distractibility, memory problems, lapses, and the name recall difficulties. The distractibility factor specifically addresses the perceptual aspects of tasks wherein attentional resources have been diverted. The memory factor, in contrast, includes items that measure memory problems and instances of forgetting. The lapses factor refers to mistakes made during tasks due to physical incidents. Finally, the forgetfulness factor incorporates questions directly related to the retrieval of individuals' names. Each item is rated on a five-point Likert scale, ranging from "never" to "always." An individual's total cognitive failures score is the sum of scores obtained from all constituent subscales. For the purposes of the present investigation, a numerical score of 1 was assigned to "very much" (always), whereas a score of 5 was allocated to "very little" (never). The scoring protocol for the questionnaire is structured such that a numerically higher total score intrinsically signifies a lower prevalence of cognitive failures. Macasi and Righetti (2006) reported a Cronbach's alpha coefficient of 0.81 for the overall scale score (39). Furthermore, Wallace (2004), in their comprehensive review, documented a Cronbach's alpha of 0.91, an internal consistency coefficient of 0.94, and a test-retest reliability of 0.82 for this particular questionnaire (40).

Pittsburgh Sleep Quality Index (PSQI): The Pittsburgh Sleep Quality Index (PSQI) (3), developed by Buysse et al. (1989), is an 18-item questionnaire meticulously designed to evaluate sleep quality. It has consistently demonstrated robust validity and reliability across numerous previous investigations, and is recognized for its capacity to effectively differentiate between undesirable and desirable sleep quality. The PSQI consists of seven subscales: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, the use of sleeping medication, and daytime dysfunction. Each of these seven subscales exhibits acceptable levels of internal consistency and reliability, approximating 0.82 and 0.78, respectively. For each subscale, a score of 0 is assigned for "not at all" (indicating no problem), 1 for "less than once a week," 2 for "once or twice a week," and 3 for "three or more times a week" (denoting a very serious problem). Scores ranging from 0 to 3 on each subscale, in ascending order, signify normal status, a mild problem, a moderate problem, and a severe problem. Ultimately, the scores derived from each component are aggregated. Consequently, the total score for the questionnaire spans a range from 0 to 21, where a higher score indicates poorer sleep quality. A cumulative score of 6 or greater is indicative of undesirable sleep quality.

Community Health Activities Model Program for Seniors (CHAMPS) Physical Activity Questionnaire: The Community Health Activities Model Program for Seniors (CHAMPS) Physical Activity Questionnaire (4), developed by Stewart et al. (2001) (5), was employed to measure the level of physical activity among older adults. This 41-item instrument systematically assesses activities performed by older individuals during a one-week period in the month preceding the assessment. It comprehensively evaluates physical activity across four distinct intensity strata: sedentary, low-intensity, moderate-intensity, and high-intensity physical activity. The intensity of physical activity is quantitatively determined based on Metabolic Equivalents (METs) (6), which serve as a standardized unit for estimating metabolic expenditure during physical exertion. Sedentary activity is defined as 1 MET. Low-intensity physical activity corresponds to MET values between 1 and 3 (exclusive of 3), while moderate activity is indicated by MET values ≥ 3 and < 6. High-intensity activity is characterized by MET values exceeding 6. The validity and reliability of the CHAMPS questionnaire for older adults in Tehran have been rigorously established by Sahhaf et al. (2014) (41).

2.3 Data Analysis

Data analysis commenced with the examination of demographic characteristics through descriptive statistics, including means, standard deviations, and frequency distributions, stratified by gender, physical activity level, and age. For inferential analysis, Levene's test was conducted to assess the homogeneity of variances, and measures of skewness and kurtosis were evaluated to confirm the normality of the data distribution. To precisely determine the influence of physical activity level and sleep quality on the various subscales of cognitive failures (i.e., distractibility, memory problems, lapses, and name recall difficulties) among older adults, a two-way multivariate analysis of variance (MANOVA) was employed. All statistical analyses were performed using SPSS software, version 26, with a predetermined significance level of 0.05 for all tests.

3. Results

Table 1 presents the frequency distribution of participants by gender, physical activity level, and age. This table also includes the mean and standard deviation for sleep quality scores among older adults, categorized by both their physical activity levels and whether their sleep quality was desirable or undesirable. Furthermore, Table 1 details the cognitive failure scores for older adults, broken down by both their physical activity levels and their sleep quality classifications.

Table 1. Frequency Distribution, Mean, and Standard Deviation of Participants

Variable	Classification	Number	Percent
Gender	Male	1126	51.7
	Female	1054	48.3
	Total	2180	100
Physical Activity Level	Sedentary	830	38.1
	Low	454	20.8
	Moderate	513	23.5
	High	383	17.6
	Total	2180	100
Age	55-60	623	28.6
	60-65	533	24.4
	65-70	456	20.9
	70-75	568	26.1
	Total	2180	100

Mean and Standard Deviation of Sleep Quality Score in Older Adults with Different Physical Activity Levels

Physical Activity Level	Number	Mean Sleep Quality	Standard Deviation
Sedentary	834	10.85	3.12
Low	457	8.74	2.56
Moderate	515	8.96	3.24
High	374	6.86	2.51
Total	2180	9.27	3.27

Mean and Standard Deviation of Sleep Quality Score in Older Adults with Desirable and Undesirable Sleep Quality

Sleep Quality	Number	Mean Sleep Quality	Standard Deviation
Desirable	432	4.84	0.98
Undesirable	1748	10.37	2.65
Total	2180	9.27	3.27

Mean and Standard Deviation of Cognitive Failure Scores in Older Adults with Different Physical Activity Levels

Physical Activity Level	Distractibility		Memory Problems		Lapses		Name recall difficulties	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Sedentary	2.71	0.38	2.88	0.39	3.01	0.41	2.5	0.94
Low	3.30	0.46	2.99	0.65	3.24	0.72	3.06	0.98
Moderate	3.44	0.42	3.26	0.47	3.39	0.54	3.09	0.86
High	3.80	0.61	3.66	0.65	3.89	0.65	3.7	0.72

Mean and Standard Deviation of Cognitive Failure Scores in Older Adults with Different Sleep Quality Levels

Sleep Quality	Measure	Distractibility	Memory Problems	Lapses	Name recall difficulties
Undesirable	Mean	3.1289	3.1077	3.2743	2.9321
	SD	0.59264	0.59929	0.60518	1.01726
Desirable	Mean	3.4666	3.2311	3.4156	3.1235
	SD	0.64140	0.58493	0.77393	0.88465

To assess the normal distribution of the variables, skewness and kurtosis values were examined. As indicated in Table 2, the distribution of the univariate data in this study is normal, given that the skewness and kurtosis indices for all research variables fall within the ±2 range.

Table 2. Skewness and Kurtosis Values for Assessing Normal Distribution of Variables

Component	Skewness	Kurtosis
Distractibility	0.235	-0.451
Memory Problems	0.472	-0.087
Lapses	0.338	-0.754
Name Recall Difficulties	0.012	-1.019

To determine the impact of physical activity level and sleep quality on the subscales of cognitive failures (Distractibility, memory problems, lapses, name recall difficulties) in older adults, a two-way multivariate analysis of variance (MANOVA) was used.

The results from the multivariate test table indicate the significance of the MANOVA test. Given the violation of the homogeneity of covariances assumption, Pillai's Trace is reported. These findings are presented in Table 3.

Table 3. Results of the Two-Way Multivariate Test for Cognitive Failure Subscales

Effect	Pillai's Trace	df	F-statistic	Significance Level	Partial Eta Squared
Physical Activity Level	0.403	12, 6459	83.479 *	0.001	0.134
Sleep Quality	0.019	4, 2151	10.649 *	0.001	0.019
Physical Activity Level × Sleep Quality	0.076	12, 6459	13.91 *	0.001	0.025

*Significant at $P \leq 0.01$.

Since the significance level is less than 0.01, it is concluded that the main effects of physical activity level and sleep quality, as well as their interaction effect, on the cognitive failure subscales are significant ($P=0.001$). This means there are significant differences in cognitive failure subscales among older adults with desirable and undesirable sleep quality across different physical activity levels.

An analysis of effect sizes, using partial eta squared ($\eta p2$), revealed that physical activity was the most impactful predictor. With an $\eta p2$ of 0.134, it accounted for a large portion of the variance in the dependent variables. In contrast, while the effects of sleep quality ($\eta p2 = 0.019$) and the interaction between sleep and physical activity ($\eta p2 = 0.025$) were statistically significant, their practical effect sizes were small. In summary, these results confirm that physical activity level was the most influential factor impacting the outcomes.

Given that the interaction effect between physical activity level and sleep quality was significant, the interaction effect will be interpreted. This is because interpreting main effects in the presence of a significant interaction effect may lead to incorrect conclusions. Therefore, follow-up analyses of the significant interaction effect were conducted using tests of simple main effects. The test of simple main effects addresses the question of whether cognitive failure subscales differ significantly among older adults with desirable and undesirable sleep quality across various physical activity levels. The results are summarized in Table 4.

Table 4. Skewness and Kurtosis Values for Assessing Normal Distribution of Variables

Cognitive Failure Subscale	Sleep Quality	Sum of Squares (SS)	df	Mean Square (MS)	F-statistic	Significance Level (P)	Partial Eta Squared
Distractibility	Undesirable	278.253	3	92.751	443.631*	0.001	0.110
	Desirable	55.62	3	18.54	88.677*	0.001	0.382
Memory Problems	Undesirable	160.071	3	53.357	200.036*	0.001	0.057
	Desirable	34.881	3	11.627	43.59*	0.001	0.218
Lapses	Undesirable	124.074	3	41.358	131.622*	0.001	0.111
	Desirable	84.211	3	28.07	89.334*	0.001	0.151
Name Recall Difficulties	Undesirable	285.657	3	95.219	118.802*	0.001	0.060
	Desirable	109.718	3	36.573	45.63*	0.001	0.142

*Significant at P≤0.01.

As presented in Table 4, significant differences were observed in the scores of cognitive failure subscales (Distractibility, memory problems, lapses, name recall difficulties) across different physical activity levels (high, moderate, low, and sedentary) for older adults with both desirable and undesirable sleep quality (P=0.001).

A significant interaction effect between physical activity and sleep quality was confirmed, showing that the influence of physical activity on all dependent variables depends on sleep quality. This explains the pattern observed in the preceding multivariate analyses.

Specifically, for all examined dependent variables, under optimal sleep conditions, the effect of physical activity on cognitive and psychological variables was substantially larger, with effect sizes in the "large" to "very large" range (η^2_p = .142 to .382). This indicates that individuals experience more pronounced benefits from physical activity under conditions of better sleep quality.

In contrast, when sleep quality was suboptimal, the effect of physical activity, was more moderate, falling into the "medium" effect size range (η^2_p = .060 to .111). These findings suggest that while physical activity is always beneficial, its positive impact is most pronounced when combined with high-quality sleep.

Table 5. Results of Post-Hoc Test for Cognitive Failure Subscales

Subscale	Sleep Quality	Comparison Between Physical Activity Levels	Mean Difference	Significance Level (P)
Distractibility	Undesirable	High - Sedentary	1.085	0.001
		Moderate - Sedentary	0.727	0.001
		Low - Sedentary	0.635	0.001
	Desirable	High - Sedentary	1.052	0.001
		Moderate - Sedentary	0.733	0.001
		Low - Sedentary	0.385	0.001
Memory Problems	Undesirable	High - Sedentary	0.957	0.001
		Moderate - Sedentary	0.425	0.001
		Low - Sedentary	0.195	0.001
	Desirable	High - Sedentary	0.307	0.001
		Moderate - Sedentary	0.004	0.001
		Low - Sedentary	-0.474	0.001
Lapses	Undesirable	High - Sedentary	0.812	0.001
		Moderate - Sedentary	0.435	0.001
		Low - Sedentary	0.247	0.001

	Desirable	High - Sedentary	1.133	0.001
		Moderate - Sedentary	0.328	0.001
		Low - Sedentary	0.303	0.001
Name recall difficulties	Undesirable	High - Sedentary	1.237	0.001
		Moderate - Sedentary	0.575	0.001
		Low - Sedentary	0.576	0.001
	Desirable	High - Sedentary	1.538	0.001
		Moderate - Sedentary	0.891	0.001
		Low - Sedentary	0.737	0.001

The results of the pairwise comparisons for cognitive failure subscales, including Distractibility, memory problems, lapses, and name recall difficulties, are presented based on sleep quality and physical activity level. In all instances, significant differences were observed between various physical activity groups, indicating that physical activity level influences the reduction of cognitive failures in older adults.

On the distractibility subscale, a statistically significant reduction in distractibility was observed among older adults exhibiting high physical activity levels when compared to their sedentary counterparts. This effect was consistent across both groups characterized by desirable and undesirable sleep quality. Specifically, within the undesirable sleep quality cohort, the mean difference between highly physically active and sedentary older adults was 1.085, reaching statistical significance at $p<0.001$. Similarly, in the desirable sleep quality group, the mean difference between these two physical activity strata was 1.052, thereby indicating a positive influence of physical activity on the reduction of distractibility. Furthermore, older adults engaging in moderate and low physical activity also demonstrated reduced distractibility relative to sedentary individuals, though this reduction was less pronounced compared to those with high physical activity. Concerning the memory problems subscale, older adults with high physical activity levels reported fewer memory-related difficulties when contrasted with sedentary older adults. This finding was consistent across both groups defined by desirable and undesirable sleep quality. In the undesirable sleep quality group, the mean difference between highly physically active and sedentary older adults was 0.957, whereas in the desirable sleep quality group, this value was 0.307. These results collectively suggest that physical activity may positively contribute to the mitigation of memory problems. Additionally, a statistically significant difference ($p<0.001$) was observed between older adults with moderate physical activity levels and sedentary individuals **.**Regarding the lapse's subscale, findings indicate that older adults with high physical activity levels experienced significantly fewer lapses, irrespective of their sleep quality (both desirable and undesirable groups). Specifically, among older adults with undesirable sleep quality, the mean difference between those with high physical activity and sedentary individuals was 0.812. For the desirable sleep quality group, this value was 1.133. Furthermore, individuals with moderate and low physical activity levels also demonstrated fewer lapses compared to their sedentary counterparts, though this difference was less pronounced than that observed in the high physical activity group. Similar findings were observed on the name recall difficulties subscale, where older adults with high physical activity levels demonstrated a superior ability to recall names compared to their sedentary counterparts. In the undesirable sleep quality group, the mean difference between highly physically active and sedentary older adults was 1.237. This value increased to 1.538 in the desirable sleep quality group. Furthermore, older adults with moderate and low physical activity levels also exhibited better performance on this subscale compared to sedentary individuals, though the effect of moderate and low physical activity was less pronounced than that of high physical activity. Collectively, these findings demonstrate that the level of physical activity significantly impacts the reduction of cognitive impairment in older adults. This effect is notably more pronounced in older adults who report desirable sleep quality. As physical activity levels increase, there is a corresponding decrease in distractibility, memory problems, lapses, and difficulties with name recall. These findings highlight the critical importance of physical activity in preserving cognitive function among older adults.

4. Discussion and Conclusion

The primary objective of the present study was to examine cognitive performance in Iranian older adults, with a specific focus on the interplay between sleep quality and physical activity. To this end, a two-way MANOVA was conducted to assess the impact of physical activity levels and sleep quality on various subscales of cognitive insufficiency in older adults. The results, as anticipated, revealed a significant interaction effect between desirable/undesirable sleep quality and different levels of physical activity on the cognitive insufficiency subscales. Following up on this significant interaction, simple main effects analyses were performed. These analyses demonstrated that, within both the desirable and undesirable sleep quality groups, statistically significant differences ($p<0.001$) were observed in scores across all cognitive insufficiency subscales (distractibility, memory problems, lapses, and name recall difficulties) when comparing various physical activity levels (high, moderate, low, and sedentary). Importantly, the findings consistently followed a similar pattern across all four subscales: older adults in both desirable and undesirable sleep quality groups who engaged in high physical activity exhibited significantly fewer cognitive difficulties (i.e., distractibility, memory problems, lapses, and name recall difficulties) compared to those with moderate, low, or sedentary activity levels. Therefore, across both groups of older adults with desirable and undesirable sleep quality, it can be concluded that increased physical activity levels are associated with reduced cognitive problems.

These findings largely align with previous research in the field. For instance, a notable study by Bloomberg et al. (17), titled "The Joint Association of Physical Activity and Sleep Duration with Cognitive Aging," conducted on 8958 healthy individuals aged 50 to 95 years in England, demonstrated that physical activity can indeed mitigate the negative effects of poor sleep on cognitive function. Conversely, insufficient sleep was shown to diminish the cognitive benefits derived from physical activity. Consequently, these findings highlight the importance of public health recommendations that promote both adequate sleep (7-8 hours per night) and regular physical activity (>150 minutes per week) to maintain cognitive health in older adults.

In another study, Kim et al. (18) explored the integrated relationship among physical activity, sleep, and cognitive function in healthy older adults. Their cross-sectional study, which included 864 older adults, revealed that physical activity had both a direct effect (effect size = 0.97) and an indirect effect (effect size = 0.36) on cognitive performance. Furthermore, the mediating role of sleep in this process was confirmed, with sleep specifically acting as a mediator between physical activity and cognitive performance. Adding to this body of evidence, Siu et al. (20) indicated that physical activity plays a moderating role in the link between sleep and cognitive function in older adults. Notably, higher physical activity levels were found to lessen the negative impacts of both short sleep duration and poor sleep efficiency on episodic memory. Importantly, physical activity also modulated the relationship between sleep quality/duration and cerebral β-amyloid (Aβ) levels, a key pathological factor in Alzheimer's disease. These findings collectively suggest that physical activity not only directly benefits cognitive performance but can also mitigate adverse effects stemming from insufficient and poor-quality sleep (20). Similarly, a systematic review by Melo et al. (42), titled "How Physical Activity and Sleep Influence Cognitive Performance in Older Adults," concluded that sufficient physical activity is crucial for maintaining or improving cognitive function in later life, whereas prolonged sedentary behavior is linked to poorer cognitive outcomes. Recent comprehensive reviews have further corroborated that increased physical activity (especially moderate to vigorous activities) correlates with better cognitive performance in older adults, while increased sedentary behavior is associated with lower cognitive function. Consequently, the findings of the present study are strongly consistent with the results reported in the aforementioned literature.

While all factors and interactions in the multivariate analysis were statistically significant, focusing on effect sizes (partial eta squared) revealed crucial distinctions. Physical activity level was the most impactful factor, demonstrating a large practical effect on the dependent variables. In contrast, both sleep quality and its interaction with physical activity had only small to medium effect sizes.

This finding represents a key limitation: although sleep quality and its interaction with exercise are statistically significant, their limited effect sizes reduce their practical and explanatory utility. In other words, while these factors play a role, the variance they uniquely explain is small. Consequently, substantial real-world changes in the outcomes are unlikely to result from altering sleep quality alone.

This highlights the complexity of the issue and points to other influential factors not captured in the current model. Future research should therefore aim to identify these additional contributors (e.g., education, depression, medication use, chronic diseases, socioeconomic status). Moreover, studies should explore more intricate mechanisms, such as the potential for sleep quality to act as a prerequisite or moderator for other influences. This comprehensive approach will foster a deeper understanding and facilitate the design of more effective interventions.

A two-way multivariate analysis of variance (MANOVA) was conducted to determine how physical activity level and sleep quality impact the subscales of cognitive insufficiency in older adults. The results revealed significant differences across these subscales, both when comparing older adults with desirable versus undesirable sleep quality and when looking at different physical activity levels. Specifically, our findings indicate that older adults reporting desirable sleep quality consistently performed better across all cognitive insufficiency subscales compared to those with undesirable sleep. Conversely, older adults with lower sleep quality showed significantly higher scores on cognitive insufficiency measures, suggesting more pronounced issues with memory, concentration, and decision-making in this group.

The analysis demonstrates that the effect of physical activity on cognitive function is contingent upon sleep quality, confirming the observed interaction effect. Under optimal sleep conditions, physical activity yields substantially larger cognitive benefits, with effect sizes ranging from large to very large. This indicates a positive synergy between these two factors. Conversely, while physical activity remains beneficial with suboptimal sleep, its impact is diminished to a moderate level. This finding has significant practical implications, suggesting that interventions focused solely on increasing physical activity may yield limited results if sleep quality is not also addressed. To maximize cognitive performance, a dual approach that simultaneously optimizes both physical activity and sleep is essential.

These findings align with previous research. For instance, Zhao et al. (2022) (43) investigated how various exercise types affect sleep quality, as assessed by the Pittsburgh Sleep Quality Index, in older adults. Their study concluded that aerobic exercise is the most effective method for overall sleep quality improvement in older and middle-aged adults, while yoga showed the most significant impact on enhancing sleep efficiency and reducing sleep disturbances. Sleep is a fundamental behavior, occupying roughly one-third of our day; it is not only a physiological process crucial for regulating and maintaining bodily health but also a significant indicator of an individual's overall health status (43).

Further supporting this, a 2022 study by Hu et al. (44) in Europe highlighted that 50% of older adults in Europe experience various degrees of sleep disturbances. Conditions such as insomnia, sleep apnea, and snoring, typically characterized by reduced sleep quality or abnormal sleep duration, have become prevalent health issues among older populations (44). Indeed, epidemiological and laboratory studies have consistently confirmed that sleep disorders are linked not only to increased all-cause mortality and a higher prevalence of psychiatric and cardiovascular diseases in older adults but also contribute to fatigue, frailty, and cognitive decline, ultimately undermining an individual's health-related quality of life.

In another study, Wang et al. (2021) (45) reported that moderate-intensity physical activity positively influences cognitive insufficiency and sleep quality. However, they noted that empirical evidence regarding the specific relationship between activity intensity and sleep quality remains insufficient. Furthermore, the desirable duration of physical activity for sleep improvement is not yet clear, indicating a need for more research in this area. Despite these nuances, the positive impact of physical activity on sleep was observed across all age groups, although the nature of this effect might change with increasing age (45). Consistent with our findings, a study by Crescenzo et al. suggested that any type of physical activity, regardless of its intensity, positively affects both sleep and its quality.

Adequate sleep, typically recommended as 7 to 8 hours per night, plays a crucial role in maintaining both physical and mental health. Conversely, insufficient sleep (less than 5 hours per night) is associated with numerous adverse outcomes, including cardiovascular diseases, cognitive failures, memory decline, and an increased risk of mortality. Furthermore, sleep deprivation can lead to cognitive insufficiency and escalate the reliance on sedative-hypnotics, which themselves carry various side effects.

In this context, exercise emerges as a non-pharmacological intervention capable of improving sleep quality and mitigating cognitive disturbances, thereby contributing to overall physical and mental well-being. This research highlights that both moderate-intensity and vigorous physical activity are beneficial for enhancing sleep. However, it is advisable to avoid strenuous exercise immediately before bedtime, as the associated increase in cortisol levels can suppress melatonin secretion, thereby disrupting the sleep process (29).

Yet, in another study, Al-Hussami et al. (46) found that recreational physical activity can enhance sleep efficiency and reduce cognitive disturbances, whereas increased sedentary time was linked to longer sleep duration. These findings underscore the necessity of systemic changes in how rest and physical activity are promoted. Similarly, a study by Kasmedi et al. (47) investigated the relationship between physical activity intensity, sleep quality, cognitive disturbances, and stress levels in adolescent fitness. Their results indicated that regular physical activity positively impacts adolescent fitness and contributes to improved physical condition. Additionally, adequate sleep quality was significantly associated with reduced cognitive disturbances and fitness levels, suggesting that sufficient and high-quality sleep can be a crucial factor in maintaining and enhancing both cognitive function and physical fitness (47). Therefore, the findings of the present study are consistent with the results of these aforementioned investigations.

Based on our study's findings, older adults who reported both high physical activity levels and desirable sleep quality showed notably superior cognitive performance compared to all other groups. This suggests that physical activity and sleep quality don't just independently influence cognitive status; they also interact synergistically. For instance, even older adults who were highly active but experienced poor sleep still performed better cognitively than those who were deficient in both areas. This indicates that physical activity can, to some degree, compensate for the negative effects of poor sleep quality, but combining these two factors yields a powerful, synergistic improvement in cognitive function.

A closer look revealed that highly physically active individuals performed better across all cognitive insufficiency subscales compared to their less active and sedentary counterparts. Specifically, the reduction in cognitive insufficiency was most pronounced in the name recall difficulties and memory problems subscales for the high physical activity group. This suggests that physical activity, in addition to lowering stress and anxiety, can specifically enhance memory function and the ability to recall information.

Conversely, older adults with desirable sleep quality reported fewer instances of distractibility and attention lapses compared to those with undesirable sleep. This finding indicates that sufficient, high-quality sleep not only improves information processing but also boosts accuracy and concentration. In contrast, individuals experiencing sleep disturbances struggled more with concentration, learning, and processing information.

In summary, this research highlights that physical activity and sleep quality are two critical factors for maintaining cognitive function in older adults. Combining these two elements can play a significant role in reducing the risk of cognitive decline and improving older adults' overall quality of life. Therefore, age-appropriate exercise programs and sleep hygiene education should be considered effective interventions.

Our findings indicate that achieving optimal cognitive function in older adulthood requires a multifaceted approach rather than a focus on a single variable. The analysis underscores that the cognitive benefits of physical activity are significantly contingent upon an individual's sleep quality. In other words, while physical activity is beneficial in itself, its efficacy is most pronounced when older adults also maintain high-quality sleep. Conversely, while physical activity remains advantageous with poorer sleep, its positive effects are considerably diminished compared to when both factors are optimal.

This finding holds significant practical implications for public health and geriatric care. Health professionals and policymakers should design interventions using a comprehensive and integrated approach. These programs must not only promote regular, age-appropriate physical activity but also provide robust strategies and education for improving sleep hygiene. Focusing on either factor in isolation will likely not yield optimal results and could diminish the effectiveness of health initiatives. Therefore, an integrated strategy addressing both physical activity and sleep quality is essential for enhancing cognitive health and quality of life in the older adult population.

This study has several limitations, primarily due to its cross-sectional design, which restricts our ability to establish causal relationships among physical activity, sleep quality, and cognitive insufficiency. Additionally, relying on self-reported measures such as the CHAMPS, PSQI, and CFQ questionnaires may introduce response bias and inaccuracies in participants' reporting. A further limitation of the present study is the lack of control over certain confounding variables, including the educational attainment, depression levels, and socioeconomic conditions of the participants. These factors may have had an impact on the interpretation of the research findings. Furthermore, this study was conducted exclusively on Iranian older adults with a relatively limited sample size; consequently, the generalizability of these findings to other populations or the broader national context may be restricted. Finally, several potential confounding variables, including socioeconomic status, dietary habits, underlying health conditions, and mental health, which could influence cognitive performance, were not comprehensively controlled for.

Our research findings indicate that increasing physical activity levels in older adults leads to a reduction in memory problems. Therefore, we recommend implementing regular exercise programs that incorporate aerobic, balance, and resistance training. These activities are known to improve cognitive function by enhancing cerebral oxygenation and stimulating the hippocampus. Moreover, combining physical exercise with cognitive training—such as puzzle-solving, memory games, and learning new skills—alongside participation in social exercise groups and memory competitions, can further boost older adults' motivation and help prevent cognitive decline.

Additionally, a regular monitoring of older adults' cognitive status, providing counseling and education to their families, and utilizing mobile applications for tracking physical activity and memory can enhance the effectiveness of these interventions. Ultimately, collaborative efforts among medical professionals, physiotherapists, exercise specialists, and cognitive psychologists in developing individualized programs and conducting educational workshops represent an effective strategy for improving cognitive health in older adults.

Authors' Contributions

All authors equally contributed to this study.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

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