Elderly Health Journal 2025; 11(1): 38-44.
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Journal Website : http://ehj.ssu.ac.ir

Original Article

The Effect of Physical Activity on Motor Memory in Older Adults: A Comparative Study of Active and Inactive Groups

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ABSTRACT

Article history
Received 26 Feb 2025
Accepted 19 May 2025

Citation: Shahabi Kaseb M, Ravanshenas AM, Estiri Z, Mehranian A. The effect of physical activity on motor memory in older adults: a comparative study of active and inactive groups. Elderly Health Journal. 2025; 11(1): 38-44.

Introduction: Cognitive decline is a common consequence of aging, often affecting motor memory, which plays a critical role in performing daily activities. Impaired motor memory may reduce independence and quality of life among older adults. This study aimed to compare motor memory performance in physically active and inactive elderly individuals and to examine the potential role of physical activity in enhancing motor-related cognitive functions.

Methods: This cross-sectional study was carried out in Sabzevar city, Iran, in 2022. A total of 110 elderly individuals aged over 60 years were selected using convenience sampling based on specific inclusion criteria. Participants were divided into two groups—active and inactive—according to their responses to the Sherki Standard Physical Activity Questionnaire. Data collection tools included the Edinburgh Handedness Questionnaire (to assess dominant hand), the Sherki Standard Physical Activity Questionnaire (to determine physical activity levels), the Linear Movement Device (LM-01) (to measure motor performance), and a Motor Memory Test, in which participants were asked to perform linear hand movements over short and long distances. The number of movement errors was recorded as an indicator of motor memory performance.

Results: The analysis revealed statistically significant differences in motor memory performance between the physically active and inactive elderly groups. Specifically, for the short-distance movement task, participants in the active group demonstrated significantly fewer errors than their inactive counterparts ($Z = -6.129$, $p < 0.001$). The long-distance movement task, the active elderly group again outperformed the inactive group, showing fewer errors ($Z = -8.186$, $p < 0.001$).

Conclusion: The results suggest that regular physical activity is associated with improved motor memory performance in older adults. These findings emphasize the importance of integrating physical activity programs into geriatric care to help maintain cognitive and motor function, promote independence, and enhance overall quality of life in aging populations.

Keywords: Aging, Memory, Exercise, Motor Skills

Introduction

The rapid growth of the aging population has emerged as a significant global challenge, accompanied by complex changes in both physical and cognitive functions. Demographic reports highlight a

[DOI: 10.18502/ehj.v11i1.19000]

sharp increase in the proportion of older adults worldwide, a shift that is reshaping social and economic structures and placing considerable strain on healthcare systems (1). Aging is strongly associated with cognitive impairments such as Alzheimer's disease and other forms of dementia, which are often linked to declines in both motor and cognitive abilities (2). Among cognitive faculties, memory—the ability to store, maintain, and retrieve information crucial for daily functioning-is particularly susceptible to the effects of aging (3). Research indicates age-related deterioration across multiple memory domains, including working memory, long-term memory, and spatial memory (4). An essential type of memory is motor memory, which involves the encoding and retrieval of movement-related information acquired through repetition and training (5). Motor memory plays a vital role in performing everyday tasks such as walking, dressing, and tool use. However, with age-related declines in neural plasticity, motor memory can become impaired, threatening functional independence and reducing the overall quality of life for older adults (6). A growing body of evidence suggests that regular physical activity can play a pivotal role in mitigating age-related cognitive decline. Exercise has been shown to enhance hippocampal volume, reinforce neural connectivity in memory-related brain regions, and improve long-term and spatial memory performance (7, 8). A comprehensive meta-analysis by Colcombe and Kramer demonstrated that aerobic exercise improves cerebral blood flow, increases levels of neurotrophic factors, enhances neuroplasticity, and reduces neuroinflammation leading to improvements in working memory and cognitive flexibility in the elderly (9). Rehfeld et al. reported that motor activities combined with cognitive stimulation such as dancing not only increase hippocampal volume but also reinforce synaptic connections and engage multiple brain systems, including the motor cortex, cerebellum, and hippocampus. These findings suggest that dancing may serve as an effective intervention to counteract age-related declines in both physical and cognitive domains (10). Zhang et al. found that both aerobic and resistance training help regulate key hormones such as cortisol and dopamine, reduce systemic inflammation, and support memory enhancement across multiple domains (11).

Research indicates that regular physical activity plays a significant role in preventing age-related cognitive decline. While numerous studies have explored the benefits of exercise on memory and cognitive performance in older adults, a comprehensive understanding of the effects of physical activity on motor memory remains lacking. Moreover, most existing research has primarily focused on working memory and long-term memory, with limited attention given to motor memory—an essential component for performing daily tasks. In particular, comparisons of motor memory performance between physically active and inactive older adults are scarce. These research gaps highlight the necessity of the present study.

Accordingly, the aim of this study is to examine the impact of daily physical activity on motor memory in older adults. This research specifically focuses on evaluating motor memory through regular engagement in physical activity among the elderly. The findings of this study may contribute to the development of effective interventions for maintaining functional independence and enhancing the quality of life in aging populations, particularly in developing communities.

Methods

Statistical population

The target population of this study included individuals aged 60 years and older residing in Sabzevar. The required sample size was calculated using G*Power software, based on a medium effect size (Cohen's d = 0.5), a significance level of $\alpha = 0.05$, and a statistical power of 0.80 ($\beta = 0.20$). According to these parameters, a total of 110 participants was deemed sufficient to detect statistically meaningful differences (12, 13). Participants were selected through convenience sampling by visiting local parks and elderly associations in Sabzevar city. Eligible individuals were invited to participate voluntarily. To reduce the impact of potential confounding factors, clearly defined exclusion criteria were implemented. Participants were excluded if they had a clinical diagnosis of Alzheimer's disease or other neurodegenerative disorders, musculoskeletal impairments in the upper or lower limbs that could compromise motor function, or a history of stroke. Additionally, individuals with uncorrected severe visual or auditory impairments, were not included in the study.

Data collection tools

Personal and background information form: To collect demographic information and medical history from participants, a standardized form was designed that included items such as age, educational level, marital status, history of illnesses, and the use or non-use of specific medications. The purpose of this form was to ensure sample homogeneity and to reduce potential confounding factors in data analysis.

Edinburgh handedness inventory: The Edinburgh Handedness Inventory was used to assess hand preference. This 10-item questionnaire evaluates hand preference in activities such as writing, drawing, throwing, scissoring, toothbrushing, knife use, spoon use, sweeping, striking a match, and opening a jar lid (14). The scale offers five response options, scored as follows: always right (+2), usually right (+1), usually both (0), usually left (–1), and always left (–2), with scores ranging from –100 (left-handed) to +100 (right-handed) (15). The Edinburgh Inventory demonstrates acceptable validity and reliability. Internal consistency, assessed through correlations between individual items and the total score, ranges from 0.83 to 0.98. The questionnaire's correlation with the Chapman Handedness Inventory was 0.75. Cronbach's alpha was 0.97, and split-half reliability was 0.92 (16).

[DOI: 10.18502/ehj.v11i1.19000]

Linear movement device (Model LM-01): A linear motion device (LM-01) was used to assess motor memory by measuring the linear displacement of upper limb movements. The device consists of a wooden frame with a tube and a movable handle designed to quantify hand movement distance (Figure 1). The participants were instructed to close their eyes and use their dominant hand to pull the handle toward a fixed obstacle positioned at two target distances: 10 cm and 30 cm from the starting point. Each participant performed three trials at each distance, and the average of the two most accurate trials was used for the final analysis. Following the initial attempt, the participants were asked to replicate the same movement again with their eyes closed. A smaller difference between the intended and replicated distances, performed with closed eyes, was interpreted as better motor memory performance. The reliability of the device was confirmed through a test–retest correlation coefficient of 0.90 and a Cronbach’s alpha of 0.93, indicating high internal consistency and measurement accuracy (17).

Sharkey physical activity questionnaire: To classify participants into active and inactive groups, the standardized Sharkey Physical Activity Questionnaire was employed (18). This questionnaire comprises five Likert-scale questions, each scored from 1 (minimum) to 5 (maximum). Participants scoring above 20 are classified as active, while those scoring below 5 are deemed inactive. Additionally, classification is based on physical activity participation: older adults engaging in at least three weekly sessions are considered active, while those with no regular physical activity are classified as inactive. The reliability of the questionnaire for all items was reported as 0.78 using Cronbach's alpha (19, 20).

Clinical dementia rating: The Clinical Dementia Rating (CDR) is one of the most widely used tools for dementia staging and assessment of cognitive impairment (21). It includes 75 items distributed across six domains: memory, orientation (time and place), judgment and problem-solving, community affairs, home and hobbies, and personal care. Each domain is rated on a scale from 0 to 3 (including intermediate score 0.5), with higher scores indicating greater cognitive impairment. The psychometric properties of the Persian version of the CDR have been examined in Iran. Lotfi et al. and Sadeghi et al. reported acceptable levels of validity and reliability, with a Cronbach’s alpha of 0.73 and an overall reliability coefficient of 0.89, confirming its appropriateness for use in Iranian populations (22, 23).

Data collection procedure

Initially, the Sharkey Physical Activity Questionnaire (used to classify participants as active or inactive) and the Clinical Dementia Rating (assessment of cognitive impairment) were administered to accessible elderly men and women. A total of 110 participants (55 physically active and 55 inactive) with moderate cognitive functioning voluntarily agreed to participate in the study. Handedness was subsequently determined for each participant using the Edinburgh Handedness Inventory.

To familiarize participants with the linear movement apparatus, each participant (using their dominant hand and with eyes closed) was initially instructed to move the apparatus handle from the starting position (0 cm) to a target pin positioned at the 20 cm mark. The movement continued until the handle made contact with the pin. Participants were instructed to memorize this distance. Subsequently, the target pin was removed, and participants were asked to reproduce the 20 cm distance three times, still using their dominant hand and with eyes closed. After each attempt, performance feedback was provided: if the handle exceeded the target distance, the error was recorded as a positive value; if it fell short, the error was recorded as a negative value. Following the familiarization phase, participants rested for five minutes before beginning the main testing phase. During this phase, participants used their non-dominant hand and, with eyes closed, were asked to reproduce two distances: a short distance (10 cm) and a long distance (30 cm), in the direction consistent with their non-dominant side. For each distance, a target pin was initially placed at the corresponding location (e.g., at 30 cm), and participants moved the handle until it contacted the pin, then returned the handle to the starting position. The pin was then removed, and participants attempted to reproduce the same distance without visual guidance. The absolute error defined as the absolute difference between the reproduced and actual distances was recorded for each attempt. This procedure was conducted separately for both the short and long distances. All error values in the testing phase were recorded as absolute values for subsequent statistical analysis (17).

Ethical considerations

All experimental procedures were conducted in accordance with ethical guidelines. Informed consent was obtained from all participants prior to their involvement in the study. Participants were informed of their right to withdraw at any time without penalty, and all data were handled confidentially. Ethical approval for this study was granted by the Department of Motor Behavior at Hakim Sabzevari University (Approval No. 5666).

Statistical analysis

Descriptive statistics, including means and standard deviations, were computed for all variables. The Kolmogorov-Smirnov test was used to assess the normality of the data, and Levene's test was applied to evaluate the homogeneity of variances. Based on the data characteristics, the Mann-Whitney U test was employed for nonparametric comparisons. All statistical analyses were conducted using SPSS version 21, with statistical significance set at $p < 0.05$.

Figure 1. Linear Motion Device (LM-01)

[DOI: 10.18502/ehj.v11i1.19000]

Results

Descriptive indicators

Descriptive statistics for the 110 participants in this study are summarized in the table 1. As illustrated, hand dominance, the number of participants, and the mean and standard deviation of participants' age are reported based on levels of physical activity.

Tables 2 and 3 summarize the average errors for short and long distances, respectively. In the short-distance motor memory task, active participants exhibited significantly lower mean errors compared to inactive participants (1.11 cm vs. 2.31 cm). This difference was evident not only in the overall mean but also among right-handed participants. Notably, inactive left-handed participants displayed the highest error (3 cm). These findings suggest that physical activity may improve motor memory accuracy in short-distance tasks among older adults. (Table 2)

Table 3 also reports the mean error of the participants for the long-distance movement task. In the long-distance motor memory task, similar to the short-distance task, participants who were physically inactive made more errors than their active counterparts. The mean error for the active group was 1.11 cm, while the inactive group showed a higher mean error of 3.47 cm. These findings further emphasize the positive impact of physical activity on motor memory performance, extending across both short and long distances.

To assess data normality, the Kolmogorov–Smirnov test was applied. The results indicated a significant deviation from normality for both the short-distance task (M = 1.71, SD = 1.02, $p = 0.001$) and the long-distance task (M = 2.29, SD = 1.55, $p = 0.001$). Due to the non-normal distribution and violation of parametric test assumptions, the Mann–Whitney U test was employed to compare differences between the active and inactive groups.

Mann–whitney U test results

The results of the Mann-Whitney U test revealed significant differences in motor memory errors between active and inactive elderly participants across both short- and long-distance reproduction tasks ($p < 0.05$). In the short-distance condition, the active group exhibited fewer errors (mean = 1.11 cm) compared to the inactive group (mean = 2.31 cm). Similarly, for the long-distance task, the active participants again demonstrated superior performance, making fewer errors (mean = 1.11 cm) than their inactive counterparts (mean = 3.47 cm). These findings suggest that physical activity is associated with enhanced motor memory performance in older adults, regardless of task distance. The detailed results of the Mann-Whitney U tests are presented in Table 4.

Table 1. Summarizes the descriptive statistics for handedness, sample size, and the mean and standard deviation of participants' ages, categorized by physical activity level

Variable		Active group (n = 55)	Inactive group (n = 55)	Total (n = 110)
Age (Mean ± SD)		69.4 ± 3.1	69.5 ± 3.3	69.4 ± 3.2
Handedness	Right-handed	51 (92.7%)	54 (98.2%)	105 (95.5%)
	Left-handed	4 (7.3%)	1 (1.8%)	5 (4.5%)
Education level	Less than high school	12 (21.8%)	15 (27.3%)	27 (24.5%)
	High school diploma	30 (54.5%)	28 (50.9%)	58 (52.7%)
	College degree or higher	13 (23.7%)	12 (21.8%)	25 (22.7%)
Marital Status	Married	40 (72.7%)	42 (76.4%)	82 (74.5%)
	Single/Widowed/Divorced	15 (27.3%)	13 (23.6%)	28 (25.5%)
Medication Use	Yes	49 (89.1%)	50 (90.9%)	99 (90.0%)
	No	6 (10.9%)	5 (9.1%)	11 (10.0%)

Table 2. Average error (cm) in short movement distance by physical activity level and dominant hand

Physical activity level	Handedness	Mean (cm)	Standard deviation (cm)	Range of score (cm)
Active	Right	1.06	0.113	0.95 - 1.17
	Left	1.75	0.250	1.50 - 2.0
	Whole	1.11	0.109	1.0 - 1.22
Inactive	Right	2.30	0.117	2.18 - 2.42
	Left	3.00	0.136	2.86 - 3.14
	Whole	2.65	0.127	2.18-3.14

[DOI: 10.18502/ehj.v11i1.19000]

Table 3. Average error (cm) in long movement distance by physical activity level and dominant hand

Physical Activity Level	Handedness	Mean (Cm)	Standard Deviation (Cm)	Range Of Score (Cm)
Active	Right	1.02	0.07	0.95-1.09
	Left	2.25	0.15	2.10-2.40
	Whole	1.11	0.08	1.03-1.19
Inactive	Right	3.41	0.10	3.31-3.51
	Left	5.00	0.25	4.75-5.25
	Whole	3.47	0.11	3.36-3.58

Table 4. Mann–Whitney U test results for motor memory errors

Variable	Group	N	Median	Mean ± SD	DOF	Z value	p	Effect size (r)
Short Distance Error	Active	51	1	1.11 ± 0.11	1.026	- 6.129	< 0.05	0.58
	Inactive	55	2	2.31 ± 0.12				
Long Distance Error	Active	51	1	1.11 ± 0.08	1.552	- 8.816	< 0.05	0.87
	Inactive	55	4	3.47 ± 0.11				

Discussion

This study aimed to compare motor memory performance in physically active and inactive elderly individuals and to examine the potential role of physical activity in enhancing motor-related cognitive functions. The findings indicate that physically active older adults significantly outperformed their inactive counterparts in motor memory tasks, particularly at short (10 cm) and long (30 cm) intervals. The active group exhibited mean errors of 1.11 cm in both short- and long-interval tasks, compared to 2.31 cm and 3.47 cm, respectively, in the inactive group ($p < 0.001$). These results suggest that physical activity enhances motor memory, with a more pronounced effect on tasks requiring greater precision. In addition to the overall superior performance of the active group, a detailed analysis revealed that active participants consistently exhibited low motor memory errors across both short- and long-distance tasks (mean = 1.11 cm in both conditions). Conversely, the inactive group displayed a marked increase in errors at the longer distance (mean = 3.47 cm compared to 2.31 cm at the short distance). This pattern indicates that physical activity not only enhances motor memory accuracy but also maintains performance consistency across varying task demands. In contrast, inactive individuals struggled to sustain motor memory accuracy as task distance increased.

These findings are consistent with prior research. For instance, Hubner et al. found that acute exercise enhances cortical activation, improving motor control by enabling older adults to better utilize frontal brain capacities during such tasks. Similarly, acute exercise has been identified as a potential intervention to enhance motor memory consolidation in older adults (24). In support of these results, Xu et al. (25) and Zerbo (26) reported that regular physical activity is associated with improvements in memory, attention, and processing speed among older adults. Additionally, a meta-analysis by Sofi et al. (27) demonstrated that even low- to moderate-intensity physical activity can enhance memory and slow cognitive decline in older adults. Endurance training, as noted by De la Rosa et al. (28) and Falck et al. (29), is particularly effective in improving memory and cognitive performance in aging populations. A systematic review by Ghoth et al. (30) further highlighted the cognitive benefits of aerobic exercise and mind-body practices, such as yoga. Building on this evidence, Nagamatsu et al. (31) reported that consistent resistance training in older adults with mild cognitive impairment enhances motor memory and cognitive abilities related to movement control, attributable to increased brain plasticity. Similarly, Voelcker-Rehage and Niemann (32) found that combining aerobic and resistance exercises improves the structure and function of brain regions associated with motor learning, leading to greater accuracy and reduced reaction times in motor tasks. Collectively, these findings underscore the critical role of physical activity in promoting cognitive and motor health in older adults.

Structural changes in the brain, particularly hippocampal atrophy, play a significant role in age-related declines in motor memory. Physical activity contributes to the preservation of motor memory function by stimulating the production of neurotrophic factors, such as insulin-like growth factor-1 (IGF-1) and brain-derived neurotrophic factor (BDNF). These factors promote neurogenesis, angiogenesis, and neuroplasticity in brain regions associated with motor memory, including the motor cortex and cerebellum (33-36). For instance, Cotman and Berchtold also highlight the relationship between aerobic exercise and cognitive functions, including motor memory. They note that exercise enhances hippocampal function, which is essential for certain types of motor memory. This implies that aerobic activity may improve motor memory (37). Furthermore, Mang et al (38) showed that aerobic exercise can enhance BDNF levels, which in turn positively influences motor learning and memory. They emphasize that BDNF plays a crucial role in neuroplasticity, particularly in the context of motor, suggesting that aerobic exercise can facilitate the acquisition and retention of motor skills by increasing BDNF production. These results suggest that physical activity supports the maintenance of motor memory by

[DOI: 10.18502/ehj.v11i1.19000]

strengthening neural pathways related to motor control, particularly in tasks requiring high precision.

These physiological changes are essential for maintaining cognitive functions, including motor memory. Molecular mechanisms also contribute to these benefits; exercise enhances the activity of enzymes involved in the Krebs cycle, improving brain energy metabolism, while simultaneously reducing the expression of harmful enzymes such as caspase-3, COX-2, and beta-amyloid, which are implicated in neurodegenerative processes (39, 40). These mechanisms play a pivotal role in enhancing motor precision and coordination in older adults. Thus, physical activity preserves motor memory and promotes overall cognitive health in older adults.

Conclusion

The findings of this study indicate a positive association between regular physical activity and motor memory in older adults. This may reflect the potential role of structured exercise programs in preventing cognitive decline, promoting functional independence, and enhancing quality of life among the elderly population. These findings suggest that exercise is not merely a physical health intervention but also a cornerstone of cognitive health preservation. Promoting active lifestyles among older adults is an essential step toward fostering healthier aging and improving health outcomes in aging communities.

Study limitations

This study has several limitations. The use of convenience sampling limits the generalizability of the findings to the broader population of older adults. Additionally, factors such as dietary habits and prior cognitive or motor training were not fully controlled, which may have influenced performance outcomes. Future research should consider assessing variables such as gender, baseline physical activity levels, and cognitive status to provide deeper insights into the mechanisms underlying the observed benefits. Furthermore, this study did not evaluate task-specific factors, such as variations in cognitive demand between short- and long-distance reproduction tasks, which may affect motor memory performance. Moreover, comparative studies examining the effects of different types of physical activity—including balance training, aerobic exercise, and mind-body practices such as tai chi and yoga—on motor memory performance are recommended.

Conflict of interests

The authors declare no conflict if interests.

Acknowledgments

The authors sincerely appreciate the participation of all elderly individuals in this study.

Funding

This research received no external funding.

Authors' contributions

Conceptualisation, MSH, AMR, ZE and AM; Data curation, AMR; Formal analysis, MSH and AM; Investigations, AMR; Methodology, MSH, AMR and ZE; Project administration, MSH; Resources, AMR and AM; Writing (original draft), MSH, AMR, ZE; Writing (review and editing), MSH and AM. All authors have read and agreed to the published version of the manuscript.

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[DOI: 10.18502/ehj.v11i1.19000]