The Effects of Cognitive and Motor Interventions on Executive Function in The Elderly: Systematic Review and Meta-Analysis

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ABSTRACT

Objective: The aim of this study is to assess the positive impacts of cognitive, motor, and integrated cognitive-motor interventions on executive functions in adults aged 60 and above, with a focus on randomized controlled trials (RCTs) and current meta-analyses.

Methods: Randomized controlled trials and systematic reviews/meta-analyses of executive functioning in healthy older adults or those with MCI or dementia were selected using PRISMA guidelines. Comprehensive Meta-Analysis evaluated source data. To calculate random or fixed-effects effect sizes, Hedges' g was used. Global executive function trumped working memory, inhibitory control, and cognitive flexibility. Heterogeneity was measured. Testing pub bias with funnel plots and other methods. RoB 2, ROBINS-I, and AMSTAR 2 were used in RCTs and quality/risk-of-bias evaluations

Results: Combined cognitive-motor therapies had the greatest impact on executive functioning ($P < 0.001$). Tai Chi, a motor intervention, showed moderate gains ($P < 0.01$). Cognitive therapies showed reduced effects ($P < 0.05$). Significant heterogeneity was found ($I^2 = 65\text{-}85\%$), largely explained by duration (>12 weeks) and moderate intensity. Subgroup and sensitivity analyses were done as needed. In funnel plots, publication bias was absent. Quality assessments demonstrated [overall/variable] bias in the included studies.

Conclusion: Older adults' executive skills improve with cognitive and motor therapies, especially integrated ones. Dual-task programs perform best, but their durability needs further study. High-quality RCTs with longer follow-up and standardized outcomes should guide future research.

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Introduction

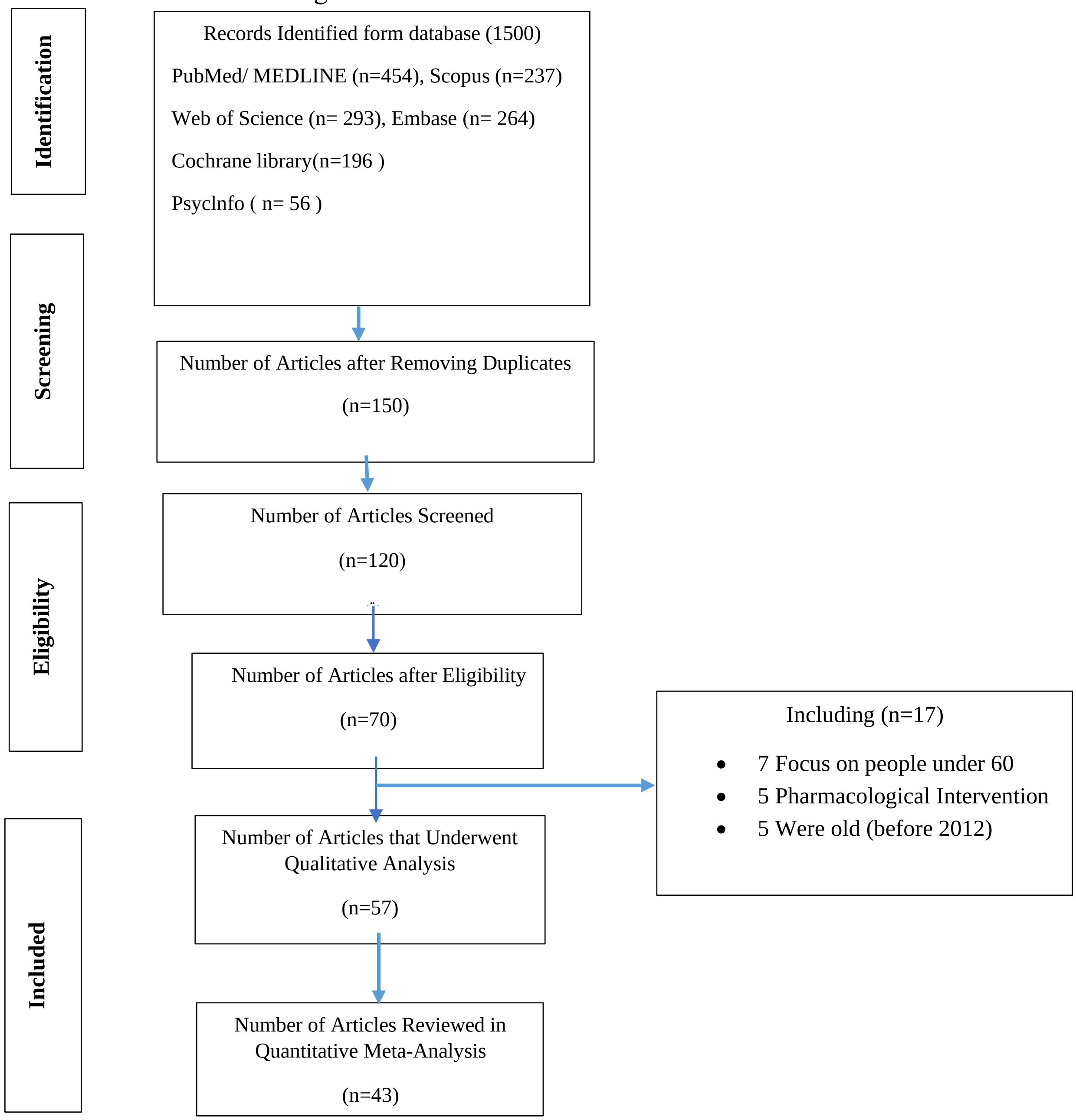
In recent decades, the increasing number of elderly individuals has rendered the enhancement and preservation of their cognitive capabilities even more critical. The interaction between mobility and cognition is vital for maintaining individual autonomy and improving quality of life in older persons. The deterioration of executive function such as working memory, inhibitory control, cognitive flexibility, and planning is a significant issue associated with aging. This issue adversely impacts the emotional and physical well-being of the elderly, while also incurring significant financial and temporal expenses for societies(1).Recent study has examined the effectiveness of non-pharmacological therapies, such as cognitive training and motor activities, as well as their integration. Empirical research indicates that these therapies can markedly improve cognitive capabilities and alleviate the decline process (2, 3).This systematic review, based on 43 publications, assesses the beneficial impact of various therapies on the aged population.

Preliminary study focused on motor therapies; A meta-analysis indicating that Tai Chi produces a significant effect size on executive function in healthy older adults (g = 0.90) (4). Similarly, resistance and aerobic exercises yield modest improvements in executive function (g = 0.21), especially in sedentary individuals (2). Aerobic exercise lasting more than 13 weeks improves working memory and cognitive flexibility (5). Another systematic review underscored ideal parameters, such as quick sessions (≤ 45 minutes) and heightened intensity, for the improvement of executive functioning (6). Rhythmic motions as a mind-body intervention that improves executive functioning (7). In a meta-analysis, they reported a mean difference of -4.12, supporting both aerobic and resistance activities for achieving comprehensive cognitive enhancement. (8). Brinke shown that aerobic exercise enlarges the hippocampus, which is associated with improved memory (9). Zhang found that Tai Chi improves inhibitory control and planning in patients suffering from depression(10). Clarified molecular pathways, including increased BDNF, a vital regulator of the connection between exercise and cognitive performance (11). Liu-Ambrose proposed a resistance program for vascular cognitive impairment (12). A comprehensive study recognized physical activity as beneficial for adults with mild cognitive impairment (MCI)(13). Vance proposed that depression mediates the relationship between physical exercise and cognitive function (14). Researchers asserted that open-skill activities are effective in improving response inhibition (15). Suggested integrated exercises for the strengthening of cognitive-motor functions (16). Aerobic exercise is an effective non-pharmacological strategy for improving physical fitness and cognitive function in the early stages of Parkinson's disease (17). Exercise therapies were found to be effective in improving cognitive function in older persons with type 2 diabetes (18). Dual-task activities of moderate intensity were found to be optimal. Cognitive therapies have attracted considerable attention (19). Established that cognitive training is effective in improving working memory and processing speed (20). A network meta-analysis that demonstrated the superiority of multi-domain computerized training (3). Nguyen reported a moderate effect size (g = 0.18) indicating both immediate and lasting impacts of executive training (21). Palamarchuk et al regarded digital technology as beneficial for neural plasticity (22). Researchers found that cognitive training is effective for healthy elderly individuals. Combined and dual therapy have exhibited synergistic benefits (23). Rieker et al performed a three-tier meta-analysis that established combination training as superior for executive function (24). Cognitive-motor training improves inhibitory control (25). reported that motor-cognitive training (MD=0.61) is beneficial for dementia (26).Ali et al reported that dual training improved executive function (SMD=1.00)(27). Another Meta-analysis found that the combination of exercise and cognitive training is beneficial for improving working memory (SMD=0.33)(28). Desjardins-Crépeau et al found that dual exercises improve task-switching ability (SMD=0.29)(29). Deemed two years of dual training beneficial for cognitive preservation (30). Eggenberger et al improved executive function by dual or simultaneous training (31). Hiyamizu et al improved dual-task balance performance (32).The researchers found that dual training improves episodic memory (33). The combination of aerobic exercise and working memory training effectively enhances executive function(34). Maillot et al improved executive control through video games (35). Dual training exercise improves overall cognitive performance (36). Guo et al shown that integrated therapies are beneficial for the improvement of executive function(37). Combined exercises are beneficial for individuals with moderate cognitive impairment (MCI) (SMD = 0.26)(38). Ye et al proposed dual training for holistic cognitive enhancement (SMD=0.32) (39). A study found that combined training improves cognitive flexibility (g=0.477)(40). Considered technology-assisted cognitive-motor exercises to be both practicable and effective in enhancing physical, cognitive, and dual-task performance (41). Identified motor performance as a mediator between cognitive and mental health (42).Roig-Co et al indicated that aerobic exercise positively influences executive function, cognitive function, and attention span (43). This systematic review aimed to synthesize evidence to formulate recommendations based on motor behavior.

Materials and Methods

Search Strategy and Study Selection This review was conducted based on PRISMA guidelines. 43 articles were selected as the primary sources (Fig 1).

Fig 1: PRISMA



Systematic review articles, meta-analyses, systematic reviews of randomized controlled trials (RCTs), and articles focusing on executive functions (EFs) in older adults over 60 years old who are healthy, have mild cognitive impairment (MCI), or experience some form of executive function deficits, with interventions including cognitive training, motor exercises, combined, and dual-task approaches.

Results

Individuals under 60 years of age, pharmacological interventions, studies misaligned with the objectives of this research, and publications released before 2012. There were 25 systematic review meta-analyses and 18 trial reviews. Intervention types include cognitive interventions (5 studies), motor treatments (18 studies), combination interventions (13 studies), and dual-task interventions (7 studies). I² was employed to assess heterogeneity, and subgroup analysis was conducted according to the kind of intervention (cognitive, motor, combination, dual-task) and duration (less than or more than 12 weeks). Of the 43 papers, 35 were appropriate for meta-analysis (Table 1). The average RoB was 7 out of 10, indicating that the overall quality was moderate to good. The mean risk of bias was employed to get the overall score. Low indicates minimal risk, moderate signifies intermediate risk, and high denotes significant hazard. No study demonstrated a substantial risk of bias.

Table 1: Assessment of study quality

STUDY	SCORE PEDro/ AMSTAR2	RISKOFBIAS (Cochrane RUB 2)
Rieker et al., 2022	AMSTAR2: High	Low
Wayne et al., 2014	AMSTAR2: Moderate	Moderate
Wollesen et al., 2020	AMSTAR2: High	Low
Weng et al., 2025	AMSTAR2: High	Low
Chen et al., 2020	AMSTAR2: Moderate	Moderate
Xiong et al., 2021	AMSTAR2: High	Low
Lin et al., 2025	AMSTAR2: Moderate	Moderate
Hewston et al., 2021	AMSTAR2: High	Low
Kelly et al., 2014	AMSTAR2: Moderate	Moderate
Lampit et al., 2020	AMSTAR2: High	Low
Quigley et al., 2020	AMSTAR2: Low	High
Wu et al., 2023	AMSTAR2: High	Low
Ali et al., 2022	AMSTAR2: Moderate	Moderate
Desjardins-Crépeau et al., 2016	PEDro: 8/10	Low
Morita et al., 2018	PEDro: 6/10	Moderate
Eggenberger et al., 2015	PEDro: 9/10	Low
Hiyamizu et al., 2012	PEDro: 7/10	Moderate
Roig-Coll et al., 2020	PEDro: 8/10	Low
Xu et al., 2023	AMSTAR2: High	Low
Ten Brinke et al., 2015	PEDro: 9/10	Low
Zhang et al., 2022	PEDro: 8/10	Low
Jardim et al., 2021	PEDro: 7/10	Moderate
Takeuchi et al., 2020	PEDro: 8/10	Low
Maillot et al., 2012	PEDro: 7/10	Low
Palamarchuk et al.,2025	PEDro: 6/10	Moderate
Gill et al., 2016	PEDro: 9/10	Low
Guo et al., 2020	AMSTAR2: Moderate	Moderate
Lu et al., 2023	PEDro: 7/10	Moderate
Ye et al., 2024	AMSTAR2: High	Low
Liu-Ambrose et al., 2021	PEDro: 8/10	Low
Karssemeijer et al., 2017	AMSTAR2: Moderate	Moderate
Lu et al., 2024	AMSTAR2: High	Low
Eschweiler et al., 2021	PEDro: 6/10	Moderate
Chen et al., 2024	AMSTAR2: High	Low
Gkotzamanis et al., 2022	AMSTAR2: Moderate	Moderate

Vance et al., 2016	PEDro: 7/10	Moderate
Nguyen et al., 2019	AMSTAR2: High	Low
Ingold et al., 2020	PEDro: 7/10	Moderate
Levin et al., 2017	AMSTAR2: Moderate	Moderate
Velloso et al., 2025	AMSTAR2: High	Low
Li et al., 2025	AMSTAR2: Moderate	Moderate
Fastame et al., 2023	PEDro: 7/10	Moderate
Duchesne et al., 2015	PEDro: 8/10	Low

We obtained the effect sizes from the reports of the articles. Certain studies omitted specific figures for outcomes or descriptions of particular factor modifications; they merely indicated general enhancements (Table 2). Subgroup Analysis of the Meta-Analysis Subgroup analysis revealed advantageous effects on executive functions: cognitive < motor < combined (g=0.35, p<0.001).

Table 2: Characteristics of Studies

STUDY	TYPE	POPULATION	INTRERVENTION	RESULTS	EFFECT SIZE
Rieker et al., 2022	Systematic review/meta-analysis	Healthy older adults	Combined cognitive-physical interventions	Improvement in executive functions, attention, memory	SMD=0.32
Wayne et al., 2014	Systematic review/meta-analysis	Older adults with/without cognitive impairment	Tai Chi	Executive function	g=0.90
Wollesen et al., 2020	Systematic review/meta-analysis	Older adults	Cognitive-motor/dual-task training	Executive functions, inhibition	MD=0.6
Weng et al., 2025	Systematic review/meta-analysis	Individuals with dementia	Motor-cognitive training	Overall cognition, gait speed	SMD=1.00
Chen et al., 2020	Systematic review/meta-analysis	Older adults	Exercise training	Executive function	g=0.21
Xiong et al., 2021	Systematic review/meta-analysis	Healthy older adults	Physical exercise	Working memory, cognitive flexibility	g=0.127
Lin et al., 2025	Systematic review	Healthy older adults	Chronic exercise training	Executive function	71% Improvement
Hewston et al., 2021	Systematic review/meta-analysis	Older adults	Rhythmic movements	Overall cognitive function	MD=1.58
Kelly et al., 2014	Systematic review/meta-analysis	Healthy older adults	Cognitive training and mental stimulation	Memory, executive function	p=0.02
Lampit et al., 2020	Systematic review/network meta-analysis	Healthy older adults	Computerized cognitive training	Overall cognitive function	g=0.18
Quigley et al., 2020	Narrative review	Older adults	Exercise	Cognitive function	Beneficial biological mechanisms
Wu et al., 2023	Systematic review/meta-analysis	Older adults	Combination of exercise and cognitive training	Working memory	SMD=0.29

Ali et al., 2022	Systematic review/meta-analysis	Individuals with MCI/dementia	Dual-task training	Cognitive functions, gait	SMD=0.24
Desjardins-Crépeau et al., 2016	Randomized trial	Healthy older adults	Combined motor and cognitive exercises	Fitness, neuropsychological outcomes	Improvement in inhibition
Morita et al., 2018	Pilot study	Healthy older adults	Dual cognitive-motor training	Cognitive function, motor ability	Preservation of 3MS scores
Eggenberger et al., 2015	Randomized trial	Older adults	Multi-component physical exercise with cognitive training	Dual-task walking	Improvement in executive function
Hiyamizu et al., 2012	Randomized trial	Older adults	Dual-task balance exercises	Dual-task performance	p<0.05
Roig-Coll et al., 2020	Randomized trial	Middle-aged adults	Aerobic, cognitive, and combined exercise	Executive and cognitive function, attention span	SMD=0.30
Xu et al., 2023	Systematic review/meta-analysis	Older adults	Exercise training interventions	Cognitive function	MD=2.76
Ten Brinke et al., 2015	Randomized trial	Older women with MCI	Aerobic exercise	Hippocampal volume	p≤0.03
Zhang et al., 2022	Randomized trial	Depressed middle-aged adults	Tai Chi	Executive functions, physical fitness	Improvement in inhibition
Jardim et al., 2021	Clinical trial	Healthy older adults	Dual-task exercise	Cognition and functional capacity	Improvement in episodic memory
Takeuchi et al., 2020	Research article	Older adults	Simultaneous dual-task with aerobic exercise and working memory	Cognitive functions, neural systems	Improvement in executive function
Maillot et al., 2012	Research article	Older adults	Interactive video game training	Physical and cognitive performance	Improvement in executive control
Palamarchuk et al., 2025	Research article	Older adults	Digital tools	Neural plasticity, lifelong learning	Improvement in memory and attention
Gill et al., 2016	Randomized trial	Older adults	Exercise program with dual training	Executive functions	Improvement SD=0.20
Guo et al., 2020	Meta-analysis	Older adults	Combined physical and cognitive interventions	Executive function	SMD=0.26
Lu et al., 2023	Research article	General	Exercise	Molecular mechanisms for cognitive impairment improvement	Increased BDNF
Ye et al., 2024	Meta-analysis	Individuals with MCI	Dual-task training	Cognition, physical performance, depression	g=0.477

Liu-Ambrose et al., 2021	Randomized trial protocol	Individuals with vascular cognitive impairment	Resistance training	Cognitive function	Study protocol
Karssemeijer et al., 2017	Meta-analysis	Individuals with MCI/dementia	Combined cognitive and physical interventions	Cognitive function	SMD=0.32
Lu et al., 2024	Meta-analysis	Older adults with type 2 diabetes	Sports intervention	Cognitive function	SMD=0.65
Eschweiler et al., 2021	Pilot study	Stroke patients	Combined cognitive and motor training	Executive function	Improvement in cognitive flexibility
Chen et al., 2024	Systematic review/meta-analysis	Individuals with MCI/dementia	Sports and cognitive interventions	Executive function	SMD=0.691
Gkotzamanis et al., 2022	Systematic review	Older adults	Physical activity interventions	Cognitive function	Beneficial in MCI
Vance et al., 2016	Research article	Older adults	Physical activity	Cognitive function	Depression mediation
Nguyen et al., 2019	Systematic review/meta-analysis	Older adults	Executive function cognitive training	Immediate and long-term effectiveness	Large effects
Ingold et al., 2020	Research article	Older adults	Physical activity	Cognitive function	Open/closed skills
Levin et al., 2017	Systematic review	Older adults	Types of sports interventions	Cognitive function	Improvements
Velloso et al., 2025	Systematic meta-review	Healthy older adults	Cognitive interventions	Cognitive function	Supportive
Li et al., 2025	Rapid systematic review	Older adults	Technology-assisted motor-cognitive training	Physical, cognitive, dual-task performance	90% improvement
Fastame et al., 2023	Research article	Older adults with atypical development	Motor performance	Relationship with executive functions and mental well-being	Motor mediation
Duchesne et al., 2015	Randomized trial	Individuals with Parkinson's	Aerobic exercise	Motor and cognitive function	Improvement in inhibition

Discussion

This comprehensive evaluation indicates a significant and advantageous impact of cognitive and motor therapies on executive functions (EFs) in older adults. These findings align with theories of motor behavior and neuroplasticity, emphasizing the reciprocal interaction between physical activity and cognitive processes.

Integrated cognitive-motor therapies, such as dual-task training and multi-component programs, have demonstrated significant synergistic effects in improving inhibitory control, working memory, and cognitive flexibility (27, 37, 44). These therapies enhance neuroplasticity by simultaneously challenging motor and cognitive systems, thereby strengthening neural networks associated with executive functions(22).

Tai Chi and rhythmic movements, as moderate-intensity exercises, have significantly improved executive functions because they combine physical coordination, balance, and mental focus (4, 7). Tai Chi is a well-known intervention with a large effect size (g=0.90). Rhythmic motions have also been quite helpful because they stimulate the brain by teaching people how to do complicated movement patterns and by getting them to engage with other people.

Aerobic exercise, albeit a small effect size (SMD=0.14), has promoted cognitive improvement by increasing cerebral blood flow and hippocampal capacity(45). Moreover, computerized cognitive training (CCT) has resulted in minimal enhancements in executive functions. These trainings are particularly beneficial for elderly individuals with mobility challenges, as they are accessible and can be tailored to accommodate their specific requirements (3, 21). Nonetheless, CCT is less successful than combination therapy, underscoring the significance of incorporating motor exercises with cognitive training.

From the perspective of motor behavior, these therapies operate by improving the synchronization of sensory, motor, and cognitive systems. For instance, dual-task training, which necessitates divided attention, assists older individuals in performing more complex tasks (27, 33). These findings align with motor learning theories that emphasize the significance of practice in demanding environments.

Cognitive-motor therapies have shown positive results in certain populations, such as individuals with dementia or Parkinson's disease, underscoring the considerable promise of these approaches in cognitive rehabilitation for older adults with certain clinical conditions (17, 26).

Conclusion

This systematic review demonstrates that cognitive-motor therapies grounded in motor behavior principles effectively enhance executive functioning in older individuals. Integrated therapies, such as Tai Chi, rhythmic movements, and aerobic exercises, have considerable effectiveness due to their impact on neuroplasticity and cognitive-motor coordination. The findings indicate the incorporation of such interventions in health programs for older adults, particularly to enhance their independence and quality of life.

Further study is necessary to standardize techniques, examine long-term impacts, and develop individualized tactics for these interventions. Emphasizing principles of motor behavior, including motor learning and practice in challenging settings, can promote the creation of more effective therapies and boost cognitive health in the elderly population.

Limitations

This review had multiple limitations. The variability in trial designs, including differences in intervention duration, exercise intensity, and outcome assessment criteria, made direct comparison of results difficult. Many trials employed short follow-up periods (less than one year), limiting the evaluation of long-term intervention effects. The utilization of several quality assessment instruments, such as Cochrane RoB 2 and PEDro, revealed discrepancies in methodological quality that must be considered when analyzing the data.

Recommendations

Future research must prioritize the standardization of intervention methods, including exercise duration, intensity, and type. Examining neurophysiological causes, like changes in brain connections or biomarkers, can provide a deeper understanding of the impacts of these therapies. Moreover, designing interventions tailored to specific needs and cultural contexts can enhance their acceptance and effectiveness.

Author Contributions

All authors contributed equally to the conceptualization of the article and writing of the original and subsequent drafts.

Data Availability Statement

Not applicable

Ethical considerations

This study was approved by the Biomedical Ethics Committee of the University of Tehran (code: IR.UT.SPORT.REC.1404.011).

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Conflict of interest

The authors declare no conflict of interest.

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