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The Effects of Exercise on Working Memory in Adults

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Abstract

Background: Working memory (WM) is a crucial element of cognitive function. A reduction in WM capacity may adversely impact the quality of life and elevate the risk of developing neurodegenerative diseases in the future. Presently, no established medication can effectively prevent cognitive decline.

Objective: Over the past decade, numerous research articles have investigated the consequences of exercise on cognitive function, mainly focusing on WM in adults.

Methods: Critical reading of several pieces of literature discussing exercise's effect on WM. A search for scientific articles was conducted using online databases such as PubMed and Google Scholar.

Results: Exercise improves WM through neuroplasticity. Post-exercise improvement in WM can be seen in every age studied. Exercise can reduce the risk of neurodegenerative diseases by maintaining the integrity of the substantia alba.

Conclusion: Exercise emerges as a cost-effective strategy accessible to many individuals. It can potentially prevent declines in cognitive function, positively impacting both present and future quality of life.

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INTRODUCTION

Cognitive decline is a physiological consequence of normal aging, although it can progress to a pathological state.[1] People who were physically inactive when they were younger are more likely to experience more significant cognitive decline in old age than people who exercised regularly when they were younger.[2] An essential aspect of higher cognitive function is executive function, including working memory (WM).[3] Working memory represents an advance over the conventional concept of short-term memory. The main difference between the two lies in the importance of working memory on information processing, an essential element of higher-order cognitive functions.[1] The manipulation of information involves the ability to retain information simultaneously, enabling its subsequent manipulation for more intricate tasks such as arithmetic, decision-making, problem-solving, and the like.[1,5] WM is directly correlated with cognitive ability and is frequently utilized as a predictor for assessing cognitive function in each individual.[6,7] MCI (Mild Cognitive Impairment) in older adults typically manifests as impairment in short-term memory.[8] In younger adults, impairment in the short term may be asso-ciated with severe depression or neurological disorders, affecting their overall quality of life.[1] There is a need for low-cost strategies to improve neurocognitive function in healthy individuals and prepare them for healthy aging. These strategies are accessible to all without significant side effects.

In recent decades, significant progress has been made in understanding the pathogenesis of age-related neurodegenerative diseases. However, currently, there are no effective treatments for these deeply distressing neuro-degenerative diseases. In recent years, exercise has proven to be the most effective and cost-effective treatment for preventing or slowing the progression of age-related neuro-degenerative diseases.[9] Over the past five years, numerous peer-reviewed journal publications have examined the outcomes of exercise on cognitive function, with a particular focus on working memory. This literature review aims to inspect studies published in the past decade on the outcome of exercise on working memory. The purpose is to explore whether physical exercise can lower the risk of neurodegenerative diseases, with the expectation that this review will raise public awareness of the importance of incorporating exercise into one's lifestyle.

METHODS

Data Retrieval and Collection Procedures

This literature review gathered information from studies relevant to the research problem through online databases. The articles obtained included original articles, research articles, meta-analyses, and systematic reviews, which were then filtered based on inclusion and exclusion criteria. The selected articles were limited to those published within the last ten years. Inclusion criteria: adults (>18 years) who are healthy. Interventions involving physical exercise, studies covering topics related to WM and cognition. Exclusion criteria: adults diagnosed with cognitive disorders, interventions involving food or animals. For PICO analysis, the problem is adult, the indicator is exercise, a comparator does not exercise, and the outcome is working memory. The clinical question derived from the research problem is: "How

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does exercise influence working memory in adults?"

Search algorithm

Search for articles as references through PubMed and Google Scholar databases using keywords ((adult) AND (exercise)) AND ("Working Memory"). Journal language in English and journal publication's years range from 2013 to 2023.

RESULTS

The selected articles of 28 manuscripts from 18.159 searching manuscripts are then tabulated by displaying the essential points of each manuscript for discussion, as listed in Table 1.

DISCUSSION

The Outcome of Exercise on Working Memory in Adults

The theory underlying the hypothesis that exercise can affect cognition was presented by Davey. He theorized that sports, as a stressor, can impact arousal levels akin to anxiety or temperature. Heightened arousal increases mental resources in the Brain, which leads to optimizing cognitive function.[38] However, one research study suggested that exercise of any intensity can not significantly improve WM. This study used a relatively simple assessment tool using colors and letters, so no improvements in working memory were observed.[10] In contrast, other studies that utilized more complex assessment instruments successfully demonstrated a significant increase in WM.[12,16,19] Exercise-induced improvement in WM is linked to various mechanisms, including increased prefrontal cortex activity, neuroplasticity, and elevated neurotransmitter levels.[12,13,15,16,22] Chen et al. detected heightened prefrontal cortex and hippocampal activity using fMRI after exercise, crucial for executive functions including WM.[24] Result studies indicate exercise can increase Brain-Derived Neurotrophic Factor (BDNF) that can stimulate neurogenesis & increase WM.[21,23,39]

One study proposes that the duration of cognitive improvement lasts for more than 2 hours after exercise.[16] Drolette and Meadows (2022) are the only studies investigating the periodic duration of WM improvement by measuring event-related potentials (ERPs) in EEG after intervention.[24] Data based on ERPs indicate that cognitive function remains elevated even >24 hours after exercise. In addition to EEG, Periodic assessment of WM can also be conducted using serum BDNF.[30,40] The increase in BDNF serum observed for 8 hours following moderate-intensity exercise positively affects memory function and influences other bodily organs, including the heart, vasculature, and respiration. Indirectly, this can yield positive benefits for brain health by facilitating and enhancing exercise capacity.[41,48]

The cognitive benefits of exercise are not mediated by age.[28,42] It should be emphasized that the improvement in WM can vary for each individual due to the influence of external and internal factors. Internal factors include baseline performance during pre-tests. Individuals with low baseline values experience the most remarkable improvement in WM after the intervention, while individuals with high baseline values during pre-tests experience a more minor increase in WM after exercise.

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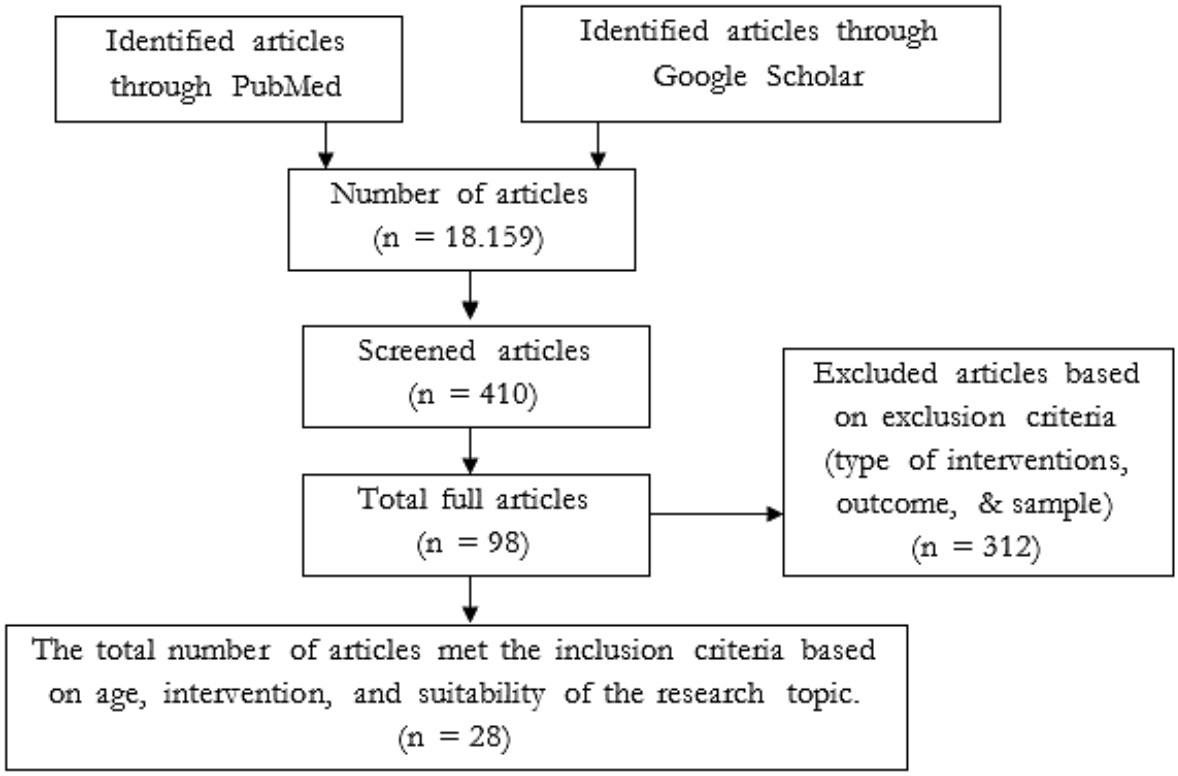

Figure 1. Reference search flow through PubMed & Google Scholar databases

Table 1. Data attraction from included studies

No	Title	Article types (Author, Year)	Important points
1	Inter-individual differences in Working Memory improvement after acute mild and moderate aerobic exercise	Original article (Yamazaki et al., 2018)	Randomized controlled trial. Working memory (WM) does not significantly improve with moderate-intensity aerobic exercise. Interventions: cycle ergo meter & 2-back-0back test.
2	Aftereffects of Cognitively Demanding Acute Aerobic Exercise on Working Memory	Original article (Kamijo and Abe, 2019)	Randomized controlled trial. Interventions: Cycle ergo meter & 2-back task. Aerobic exercise can improve WM.
3	Effects of Exercise Modes on Neural Processing of Working Memory in Late Middle-Aged Adults: An fMRI Study	Original article (Chen et al., 2019)	Cross-sectional Interventions: physical fitness & WM fMRI task. Exercise can prevent neurodegeneration caused by age or disease.

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4	Acute exercise effects predict training changes in cognition and connectivity	Original article (Voss et al., 2020)	Randomized clinical trial Interventions: Aerobic exercise Improved WM.
5	The relationship between different visuospatial working memory in older adults: a cross-sectional study	Original article (Guo et al., 2016)	Cross-sectional Any exercise increases cognitive function compared to no exercise.
6	BDNF Responses in Healthy Older Persons to 35 Minutes of Physical Exercise, Cognitive Training, and Mindfulness: Associations with Working Memory Function	Original article (Håkansson et al., 2017)	Randomized controlled trial BDNF & WM increased after exercise. Interventions: Physical exercise using interactive Xbox Kinect™.
7	Acute Exercise Improves Prefrontal Cortex but not Hippocampal Function in Healthy Adults.	Original article (Basso et al., 2015)	Randomized controlled trial Interventions: stationary bike. It improved WM last >2 hours or more post-exercise.
8	Age-Related Cognitive Impairment in Apparently Healthy Older Adults	Original article (Sage, 2019)	Quasi-randomized, controlled intervention. Cardio aerobic exercise. Reduced symptoms of age-related cognitive impairment.
9	Exercise and cognitive function: A randomized controlled trial examining acute exercise and free-living physical activity and sedentary effects	Original article (Loprinzi and Kane, 2015)	Randomized controlled trial Aerobic exercise with moderate intensity within 30 minutes can improve concentration. Interventions: treadmill exercise.
10	Shedding Light on the Effects of Moderate Acute Exercise on Working Memory Performance in Healthy Older Adults: An fNIRS Study	Original article (Stute et al., 2020)	Pre-test and post-test. Improvements in WM occurred during the 15-minute post-test, 30-minute post-test, 45-minute post-test, and possibly beyond. Interventions: Stationary bicycle.
11	Examining the Effect of Increased Aerobic Exercise in Moderately Fit Adults on Psychological State and Cognitive Function	Original article (Basso et al., 2022)	Randomized controlled trial Exercise can promote healthy aging and prevent neurological disorders caused by aging. Interventions: Stationary bicycle.
12	The Influence of Acute Physical Activity on Working Memory	Original article (Zach and Shalom, 2016)	Post-test and Pre-test Interventions: running, volleyball, etc. Improved WM.
13	Differential Effects of Acute Exercise on Distinct Aspects of Executive Function	Original article (Weng et al., 2015)	Pre-test and post-test Interventions: cycling Increased WM last > 30 minutes

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14	Physical activity, mental exercise, and cognitive functioning in an Italian sample of healthy elderly males	Original article (Pruneti et al., 2019)	Interventions: walking, jogging, running. Aerobic exercise for 3 hours per week may prevent future pathological decline.
15	The effects of acute high-intensity interval exercise on the temporal dynamics of working memory and contralateral delay activity	Original article (Drollette and Meadows, 2022)	Pre-test & post-test. Interventions: Treadmill. High-intensity interval short bouts can improve WM and last 24 hours after the exercise ends.
16	Effect of Single Bout of Moderate and High-Intensity Interval Exercise on Brain-Derived Neurotrophic Factor and Working Memory in Young Adult Females	Original article (Shah et al., 2022)	Pre-test & post-test. Interventions: Treadmill. Moderate to high-intensity exercise can improve WM significantly in young adult females.
17	Exercise engagement drives changes in cognition and cardiorespiratory fitness after eight weeks of aerobic training in sedentary aging adults at risk of cognitive decline.	Original article (Hinchman et al., 2022)	Pre-test and Post-test Interventions: treadmill, elliptical, stationary bike. It decreased WM in healthy elderly.
18	White matter microstructure mediates the relationship between cardiorespiratory fitness and spatial working memory in older adults.	Original article (Oberlin et al., 2016)	Single-blind randomized controlled exercise intervention. Interventions: cardio-respiratory fitness. The results indicate that aerobic exercise is associated with improved micro-structure of the substantia nigra.
19	Exercise holds immediate benefits for affect and cognition in younger and older adults.	Original article (Hogan, Mata, and Carstensen, 2013)	Interventions: Stationary bike. Exercise has the effect of increasing WM in all age ranges compared to the controls.
20	The Effect of Single Bout of Acute Exercise on Working Memory Performance	Original article (Deo et al., 2018)	Pre-test and post-test Interventions: stepping rhythm Exercise with moderate intensity can increase WM & overall cognitive function.
21	Distinct effects of acute exercise and breaks in sitting on working memory and executive function in older adults: A three-arm, randomized cross-over trial to evaluate the impact of training with and without breaks in sitting on cognition	Original article (Wheeler et al., 2020)	Randomized controlled trial Interventions: treadmill Moderate aerobic exercise stimulates BDNF production and improves executive function, including WM.

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22	Dual-task training on cognition and resistance training improved balance and working memory in older people.	Original article (Norouzi et al., 2019)	Randomized controlled trial Motor-cognitive dual-task training showed better improvement in WM than Motor-motor dual-task training.
23	White matter plasticity in healthy older adults: The effects of aerobic exercise	Original article (Mendez Colmenares et al., 2021)	Randomized controlled trial Interventions: treadmill. The plasticity of the white matter can be stimulated by aerobic exercise.
24	Combined and Isolated Effects of Acute Exercise and Brain Stimulation on Executive Function in Healthy Young Adults	Original article (Hussey et al., 2020)	Interventions: treadmill within 20 minutes Aerobic exercise such as walking and running for 20 minutes can improve WM.
25	The effect of mind-body exercise on memory in older adults: a systematic review and meta-analysis	Review article (Ye et al., 2021)	Interventions: Yoga, tai chi. Review of 12 RCT articles. Yoga can improve WM.
26	The Acute Effect of High-Intensity Exercise on Executive Function: A Meta-Analysis	Review article (Moreau and Chou, 2019)	Interventions: Cycling, running, etc. Review of 28 articles. The higher the training intensity, the greater the benefits of improving the WM.
27	Effects of physical exercise on executive function in cognitively healthy older adults: A systematic review and meta-analysis of randomized controlled trials: Physical exercise for executive function	Review article (Xiong et al., 2021)	Interventions: Aerobic, resistance, mind-body exercise. Review of 25 RCT articles. Physical exercise, especially aerobics, positively improves WM, cognitive flexibility, and inhibitor control.
28	Effects of physical activity interventions on cognitive outcomes and academic performance in adolescents and young adults: A meta-analysis	Review article (Haverkamp et al., 2020)	Interventions: acute & chronic physical activity. Review of 44 cross-over RCT articles There are strong indications that exercise at any intensity positively impacts cognitive performance in young people.

External factors include the type of exercise, assessment instruments, duration of intervention, and assessment time.[19]

The Importance of the Aging Process on Working Memory

As individuals age, both anatomical and functional changes occur in the Brain. In comparison, anatomical changes in aging are less understood than functional changes in functional connectivity related to attention, memory, and executive function. In healthy individuals, decreased functional connectivity is associated with reduced cerebral blood flow (CBF) and declining metabolic conditions.[21] From an anatomical perspective, age-related decline in

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working memory is thought to be associated with structural changes in the cerebral microcirculation. These structural changes are marked by decreased density, suggesting reduced blood flow to the Brain, leading to reduced cognitive performance.[19] Additionally, aging is associated with hormonal imbalance, increased low-grade inflammation, and elevated ROS (Reactive Oxygen Species). eENOS (Endothelial Nitric Oxide Synthase) dysfunction leads to reduced nitric oxide (NO) production, leading to endothelial dysfunction manifesting as ischemia and microhemorrhages in the cerebral microvasculature, contributing to cognitive impairment. Prolonged neurotoxin accumulation can also further reduce cerebrovascular function, manifesting as neurodegeneration.[43]

The mechanisms by which aging affects working memory are not fully understood. One theory is that structural changes leading to reduced blood flow in the Brain and reduced white matter are associated with reduced working memory. However, physiological aspects of normal aging, including poor meta-bolism, increased ROS, low-grade inflammation, and endothelial dysfunction, may affect functional connectivity and cognitive ability.

Understanding The Influence of Exercise on the Aging Process

Blood flow and shear stress increase during exercise, possibly stimulating acute and chronic age-related vascular changes. With age, increased reactive oxygen species (ROS) and hormonal imbalances contribute to endothelial dysfunction and promote the development of atherosclerosis. Ultimately, this endothelial dysfunction leads to impaired function or reduced effectiveness of cerebral blood flow (CBF) regulatory mechanisms. The resulting reduction in CBF leads to the development of cerebral hypoperfusion, brain dysfunction, and cognitive impairment. Regular exercise adjusts nitric oxide bioactivity, therefore capable of reducing central arterial stiffness and attenuating age-related vascular dysfunction. Exercise can also maintain myocardial metabolic health by reducing oxidative stress and enhancing antioxidant enzymes.[43–45]

Understanding The Outcome of Exercise on The Prevention of Neurodegenerative Diseases

Starting at age 65, cognitive decline can occur at varying degrees of severity, from mild cognitive impairment due to aging factors to the most severe dementia.[46] Studies have shown that exercise may help prevent age-related working memory impairment and cognitive decline through increased BDNF production after exercise.[10,15] Other studies have shown it may lower the severity of Alzheimer's disease and other neurological disorders.[47] Results indicate that higher cardio-respiratory fitness (CRF) intensity is associated with maintained integrity of the micro-structure of white matter. A statistical relationship was found between CRF and improvement in working memory, which is related to white matter tracts comprising various neural networks. Anatomically, age-related cognitive decline can be observed from reductions in brain macro-structures, such as the substantia nigra, to white matter micro-structures, leading to declines in cognitive performance. CRF exercise may be essential to preserve white matter and working memory function in people 65 and older.[27,48] Another study found that aerobic exercise can stimulate white matter plasticity. Using T1w/T2w imaging tools, it has been shown

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that white matter tracts are susceptible to age-related decline but still exhibit some degree of plasticity.[14,23] Certain sports that place high demands on cognitive function may provide more benefits in maintaining specific areas in the Brain involved during exercise. Moderate-intensity aerobic exercise of 3 hours per week is sufficient to increase cognitive function for adults and prevent pathological cognitive decline, thereby facilitating healthy aging.[30] Research by three other studies also states that a similar notion, an exercise can protect against age-related or pathological cognitive decline in the frontal lobes and hippocampus.[12,13,20] This is consistent with a meta-analysis study that suggested in a sample of healthy 60-year-olds, exercise is a safer strategy to improve memory in general, WM, and long-term memory in particular.[34]

The journals reviewed show that exercise is beneficial in maintaining cognitive function by stimulating brain plasticity, preserving white matter, and safeguarding memory function, thus preventing pathological cognitive decline. Exercise can lower the risk of developing neurodegenerative diseases, increasing the likelihood of achieving healthy aging.

Understanding Better Types of Exercise to Improve Working Memory.

The most commonly encountered intervention is aerobic exercise using various modalities such as stationary bikes or cycle ergo meters.[13,15–19,22,28] Other studies employ a treadmill.[24,25] The author only found two research studies with anaerobic exercise interventions.[24,25] One research study comparing HIIT (High-Intensity Interval Training) with MIIT (Moderate-Intensity Interval Training) showed that HIIT was more effective than MIIT in improving WM function.[25] Greater cognitive outcomes obtained with higher intensity exercise.[24,35]

Other research used open-skill (tennis, badminton, etc.) and closed-skill (jogging, swimming, cycling, etc.) as interventions, improving WM compared to the control group that does not exercise.[12,14] Especially for open-skill sports, there is a more remarkable improvement in cognitive function compared to closed-skill sports.[21] Aerobic exercise, such as walking, specifically designed to improve CRF, is more effective than yoga as a control group.[34,36]

Most journal sports types are aerobic exercises (treadmill, cycle-ergo meter). Only a few journals used anaerobic exercise interventions (HIIT), yoga, open-skill (tennis, badminton), and closed-skill (jogging, swimming). Regardless of the type of exercise, all provide an increase in WM. However, there is still no clear proof of which kind of exercise is most effective in improving WM. Further research on this topic is needed.

CONCLUSION

Exercise can improve cognitive function, especially short-term memory, and help maintain healthy brain structure. This condition is achieved through complex mechanisms such as plasticity, neurotransmitter secretion, and BDNF secretion. Improved working memory and cognitive function after exercise can be seen in many subjects, from young and middle-aged to older adults. However, there are different differences in the degree of improvement, which may be influenced by internal factors between individuals, exercise intensity, type of

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exercise, and even limitations of the study itself. Regardless of age, higher intensity, duration, and exercise habits are modifiable factors that determine the degree of improvement in short-term memory after exercise. There is no clear evidence of which type of exercise is most effective for improving WM. However, in extreme situations where an individual is at risk for neurodegenerative diseases such as MCI or dementia, the most effective type of exercise in these situations is sports that require more cognitive tasks, such as open-ended skills, card games, and others. Meanwhile, aerobic & anaerobic exercise have been shown to increase WM and cognitive performance in all age groups significantly studied. Exercise protects brain structure as we age and is a cost-effective strategy for most people that can prevent severe declines in quality of life in the future.

Criticism and Suggestions

Most scientific papers discuss the outcome of aerobic exercise on WM, while other types of exercise, such as yoga and other combination exercises, are rarely explored. More research papers need to be published that focus more on assessing the duration of cognitive improvements over days or longer rather than just assessing them once after "exercise." Research on the effects of improved working memory on real-world performance has yet to be conducted.

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