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Review

Skill Sports and E-sports on Cognitive Function

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Abstract: Recent findings in physical activity epidemiology suggest that physical activity and exercise may help prevent cognitive decline and dementia. However, there is still no consensus on the causal relationship between cognitive function and physical activity or sedentary behavior, nor on the direction of this relationship. In addition to electronic sports (e-sports), which can be played without restrictions on age, sex, time, or location, recent research has examined the relationship between cognitive function and different types of sports and exercise, focusing on motor skill demands. This review explores the background and mechanisms underlying the recommendation of open-skill exercise (OSE) for preventing and mitigating cognitive decline, as well as maintaining and enhancing cognitive function. Furthermore, it discusses the role of OSE and e-sports as lifelong sports. Latent Heritable Confounder Mendelian Randomization has confirmed a causal relationship between physical activity and cognitive function in non-dementia patients, while finding no significant association between cognitive function and sedentary time. Prospective studies suggest that exercise habits, physical fitness, and performance may help inhibit cognitive decline and the onset of dementia. However, intervention studies have not reached a consensus on the effectiveness of exercise in improving cognitive function among the general elderly population or patients with mild cognitive impairment and dementia. In conclusion, aerobic OSE appears to be more effective in preventing cognitive decline and dementia associated with aging compared to closed-skill exercise. E-sports has the potential to integrate cognitive engagement with physical activity, social interaction, and stress reduction, making it a unique and holistic approach to brain health. In other words, e-sports represents a versatile intervention that simultaneously addresses multiple aspects of health.

Keywords: open-skill exercise; closed-skill exercise; e-sports; cognitive function

1. Introduction

Both domestically and internationally, the prevalence of mild cognitive impairment (MCI) and dementia is increasing alongside the aging population, not only in Europe and North America but also across various Asian countries [1]. In Japan, dementia ranks as the leading cause of conditions requiring long-term care certification [2]. Moreover, a meta-analysis has reported that the annual conversion rate from MCI diagnosed in medical institutions to all forms of dementia is never lower than 9.6% [3]. These facts highlight the urgent need to prevent and manage MCI and dementia as critical public health issues.

Recent research in physical activity epidemiology suggests that physical activity and exercise may help suppress cognitive decline and dementia [4]. However, there is still no consensus on the causal relationship and directionality between cognitive function, physical activity, and sedentary behavior in the general population [4, 5]. In addition, recent studies have examined the relationship between cognitive function and brain activity in the context of exercise and sports characteristics,

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irrespective of age or gender, from the perspective of motor skill demands [6]. This research has drawn considerable attention to the potential role of sports in preventing cognitive decline and dementia [7].

According to recent reviews, open-skill exercise (OSE; e.g., racket sports) is more effective than closed-skill exercise (CSE; e.g., running, swimming) in preventing and mitigating cognitive decline and dementia [6]. Furthermore, one study reported that individuals who participated in racket sports had a longer lifespan compared to those who were inactive or engaged in non-sport activities [7]. More recently, electronic sports (e-sports) have been explored for their potential to enhance cognitive function and prevent cognitive decline, garnering increasing attention in this field [8]. Unlike traditional sports, e-sports can be played without restrictions on age, gender, time, or location, and they do not require physical contact or face-to-face interaction [9]. These unique characteristics suggest that e-sports participation may expand in the future.

This review first summarizes the causal relationship and directionality between cognitive function, physical activity, and sedentary behavior in older adults. Furthermore, it examines correlations between cognitive function and other relevant factors such as exercise habits and physical fitness, as well as the effects of physical activity and exercise interventions. Additionally, this review discusses the epidemiological study of motor skills, focusing on exposure indicators that have not been previously analyzed. In this context, we provide an overview of motor skill classifications and summarize the characteristics of sports programs that are particularly suited for preventing cognitive impairment and dementia, including the potential benefits of e-sports. Finally, we explore the rationale behind recommending OSE for cognitive health, discussing its role in preventing and improving cognitive decline and its value—along with e-sports—as a lifelong physical activity.

2. Physical Activity Epidemiology for Dementia and Cognitive Decline

According to the 2024 report of the Lancet Commission on dementia prevention, intervention, and care [10], in addition to the previously identified 12 modifiable risk factors, vision loss and high low-density lipoprotein cholesterol have been added, bringing the total to 14 modifiable risk factors. Since physical inactivity is listed as a potential risk factor for dementia, it is recommended that adults aged 65 and older engage in 150 minutes of moderate-intensity physical activity and 75 minutes of vigorous-intensity physical activity per week [11].

2.1. Causal Relationship Between Physical Activity, Sedentary Behavior, and Cognitive Function

The causal relationship between physical activity and cognitive function in non-demented adults remains unclear. In other words, while physical activity may enhance cognitive function, individuals with better cognitive function may also be more likely to engage in physical activity. One method used to investigate this bidirectional association is latent heritable confounder Mendelian randomization. Cheval et al. [5] applied this method and reported a bidirectional relationship between physical activity and general cognitive function.

Mendelian randomization is an epidemiological approach that treats the random inheritance of genetic variations as a natural experiment, allowing for the estimation of potential causal effects of modifiable risk factors (exposures) on health outcomes in observational study designs. Since genetic variations associated with exposure are randomly assigned at conception, the results related to health outcomes are assumed to be unaffected by reverse causality, as genetic variations remain unchanged.

Cheval et al. [5] analyzed pooled data from two large-scale genome-wide association studies: the UK Biobank (40–69 years old) and COGENT (8–96 years old). The dataset included 257,841 samples for general cognitive function and 91,084 samples for physical activity measured via accelerometers. Their analysis revealed that moderate to vigorous-intensity physical activity has a potential causal effect on cognitive function, but no significant causal effect was observed in the reverse direction—meaning that increased cognitive function did not lead to higher levels of physical activity.

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Regarding sedentary behavior, there is no conclusive evidence linking it to cognitive function, but it is considered a modifiable lifestyle factor [12]. A recent systematic review [13] reported that prolonged sedentary behavior increases the risk of dementia and that different types of sedentary behavior have either positive or negative associations with cognitive domains. However, Mendelian randomization analyses have found no conclusive evidence supporting a causal relationship between specific types of sedentary behavior (passive or active) and cognitive function [14] or dementia [15].

2.2. Association Between Exercise Habits and Dementia

Longitudinal studies on exercise habits and dementia have demonstrated the effectiveness of aerobic exercise as a preventive factor [16]. The Hisayama Study, a prospective cohort study, examined the relationship between exercise habits and all-cause dementia as well as dementia subtypes. The absence of regular exercise was identified as a risk factor for Alzheimer's disease (AD) [17]. Additionally, research suggests that physical activity during adolescence is associated with a reduced risk of dementia later in life, emphasizing the importance of establishing exercise habits early on. Overall, numerous observational studies have indicated that regular exercise and physical activity contribute to dementia prevention [16].

2.3. Association Between Physical Fitness or Motor Performance and Dementia

Declines in muscle strength and gait speed are recognized as risk factors for dementia [18]. For example, a prospective study on muscle strength and AD incidence in older adults found that individuals with higher baseline muscle strength experienced slower cognitive decline and aging-related cognitive changes. Compared to those with preserved lower limb function, individuals with lower limb function decline had twice the risk of developing AD [18]. The Hisayama Study also demonstrated that low grip strength over a fifteen-year period was a risk factor for AD incidence [19].

These findings suggest that maintaining physical strength and motor function may help prevent cognitive impairment and dementia. However, most of these findings come from prospective studies, and a definitive causal relationship has yet to be established. Recently, some reviews have proposed that physical performance could serve as an early biomarker for AD risk [20]. While physical fitness and motor function can be objectively assessed, the underlying mechanisms remain unclear.

2.4. Effects of Exercise Interventions on Cognitive Function

A meta-analysis of randomized controlled trials (RCTs) in non-demented older adults found that aerobic exercise moderately improved cognitive functions, including attention, memory, and executive function [21]. However, the LIFE Study [22], which compared long-term exercise interventions with health education programs, reported no significant differences in cognitive function outcomes after intervention. This suggests that exercise interventions in late life may have limited effects on cognitive function, with no significant differences observed in the incidence of MCI and dementia after two years of intervention.

A systematic review of RCTs in individuals with MCI found that exercise interventions significantly improved language fluency, but no significant improvements were observed in other cognitive domains [23]. However, Suzuki et al. [24] designed a cognitive task-based exercise and conducted RCTs in Japanese MCI patients, showing improvements in processing speed and language ability. Furthermore, among individuals with amnestic MCI, exercise was reported to slow brain atrophy, suppress cognitive decline, and enhance memory.

A recent meta-analysis of RCTs on AD [25] suggested that physical activity and exercise can improve cognitive function or delay cognitive decline. However, methodological challenges remain, and the dose-response relationship between exercise intensity and cognitive improvement is still unclear. Some studies suggest that the total volume of daily physical activity may be more important than specific exercise routines for cognitive benefits [26], indicating a potential avenue for future research.

A Bayesian model-based network meta-analysis [27] examining the optimal exercise dosage and type for cognitive enhancement in older adults found a non-linear relationship between exercise volume and cognitive improvement. The study identified a minimum threshold of 700 METs-min/week for clinically significant cognitive benefits. Additionally, resistance training required lower exercise volumes to achieve cognitive benefits compared to aerobic exercise, displaying an inverted U-shaped dose-response pattern.

Furthermore, Klimova and Dostalova [28] reviewed exercise interventions in healthy older adults, highlighting the unique cognitive benefits of dance-based exercise, which promotes neuroplasticity and reduces MCI progression risk. Notably, exercise interventions in MCI patients demonstrated improvements in executive function, delayed recall, and verbal fluency [29]. Mind-body exercises (e.g., Tai Chi, Baduanjin, and dance) were particularly effective. However, to date, no meta-analyses have examined the dose-response relationship between exercise and cognitive function in dementia populations.

While this section focuses on the cognitive benefits of exercise in older adults and MCI populations, Section 3 delves deeper into the mechanisms underlying cognitive benefits from the perspective of motor skill acquisition.

2.5. Physical Activity and Exercise Guidelines for MCI and Dementia

Recently, a common international guideline on physical activity and exercise has been published to prevent and manage MCI and dementia [30]. Although physical activity and exercise have been proposed as effective interventions for preventing and managing MCI and dementia, no international guidelines had been established until now.

This guideline consists of the following three themes: Topic 1: Can physical activity and exercise delay the incidence of MCI or dementia in people without MCI or dementia? The guideline suggests that while physical activity may contribute to the prevention of dementia, including AD and vascular dementia, it is not necessarily more effective than MCI education in preventing MCI or dementia. Although 100% of experts agree with this proposition, they acknowledge that the evidence remains uncertain. Therefore, physical activity should be considered as part of a multifactorial intervention. Experts also pointed out that physical activity and exercise interventions may complement other preventive measures.

Topic 2: Can physical activity and exercise delay the incidence of dementia in MCI patients? Currently, there is no conclusive evidence supporting the role of physical activity and exercise in slowing the progression from MCI to dementia. Additionally, 100% of experts agree that individuals with MCI who also have movement disorders should not be encouraged to engage in exercise.

Topic 3: Can physical activity and exercise improve cognition and impairment in dementia patients? The guideline suggests that patients with moderate dementia may consider physical activity and exercise as a means to maintain cognitive function. Compared to conventional care, exercise may help stabilize functional decline. Additionally, 86% of experts agree that physical activity and exercise are important for maintaining cognitive reserve and function in dementia patients. Furthermore, physical activity and exercise may have beneficial effects on emotional well-being, but these benefits should be balanced against potential risks.

The above summarizes the results of physical activity epidemiology research on preventing and mitigating cognitive decline and dementia. As pointed out in the preface, recent research from the perspective of sports skills has also accumulated, and Yamasaki [6] has reviewed this topic in a published article. Therefore, the research content and findings are introduced in the following sections.

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3. Cognitive Function and Dementia Prevention, and Exercise and Sports Skills

3.1. Classification of Sports Skills

Sports skills can be broadly classified into OSE and CSE. While these categories provide a useful framework, many sports exhibit characteristics of both to varying degrees [6,31].

OSE refers to sports and physical activities performed in unpredictable environments that require adaptation to dynamic external rhythms. These sports, which fall under Categories 3 and 4 of exercise and sports characteristics (Table 1), demand synchronization with external rhythms and pace, greater cognitive and decision-making demands, and continuous adaptive movement. Representative OSE sports include table tennis, tennis, and badminton [6]

In contrast, CSE refers to exercises performed in relatively stable, self-regulated, and predictable environments. These activities, classified into Categories 1 and 2 (Table 1), include swimming, running, and cycling. The primary characteristics of CSE involve self-paced rhythms, minimal cognitive demands related to external stimuli, and fewer decision-making elements [6].

Rather than forming distinct divisions, OSE and CSE exist on a continuum, representing two ends of a spectrum. Higher category numbers (e.g., Category 4) indicate a greater emphasis on open skills, whereas lower category numbers (e.g., Category 1) indicate a greater emphasis on closed skills.

Table 1. Classification of Sports Based on Skill Type.

Skill type and its continuum	Category	Sports
OSE ↑	4	Tennis, Table Tennis, Badminton, Basketball, Volleyball, Soccer, Handball, American Football, Wushu, Martial Arts, Fencing, Korfball, Hockey, Baseball
	3	Sailing, Canoe Slalom
	2	Athletics, Cross-Country Skiing
↓ CSE	1	Swimming, Running, Triathlon, Cycling, Gymnastics, Archery, Shooting, Brisk Walking, Track Bike

Abbreviation: CSE, closed-skill exercise; OSE, open-skill exercise.

3.2. Differential Effects of OSE and CSE on Cognitive Function

Recent review papers have suggested that, compared to CSE, OSE is not only the most effective exercise type for maintaining cognitive function in healthy, independent older adults but also beneficial for younger individuals in preventing cognitive decline and stimulating brain activity [6,31]. In addition, the Copenhagen City Heart Study reported that OSE is associated with increased lifespan [7]. Whether this association extends to cognitive decline prevention and dementia risk reduction remains an interesting research question.

OSE and CSE differ significantly in terms of environmental stability and cognitive demands [6]. This distinction has been explored in recent studies [31–33]. In a systematic review by Gu et al. [32], 19 studies (14 observational studies and 5 intervention studies; participants aged 9.6 to 70.5 years) were analyzed. Among the observational studies, 7 out of 14 reported superior cognitive benefits of OSE compared to CSE. In the intervention studies, 3 out of 5 demonstrated that OSE improved cognitive functions such as visuospatial attention, problem-solving, auditory perception, inhibitory control, and cognitive flexibility in both children and older adults.

A meta-analysis by Zhu et al. [33] reviewed 19 studies (15 cross-sectional studies and 4 intervention studies; participants aged 9.6 to 69.4 years). The cross-sectional studies found that OSE had a greater effect on cognitive functions, particularly inhibitory control and cognitive flexibility, compared to CSE. However, intervention studies showed no significant difference between OSE and CSE in improving cognitive function, highlighting the need for long-term studies to confirm OSE's effectiveness.

Another meta-analysis and systematic review by Heilmann [31], which included 19 studies (participants aged 10.2 to 69.9 years), confirmed that OSE was more effective than CSE in enhancing executive functions, with cognitive flexibility showing the greatest improvement, followed by inhibitory control and working memory. These findings indicate that OSE has beneficial effects on cognitive function across all age groups, including older adults [31–33].

3.3. The Mechanism of Cognitive Function Improvement by OSE

This section describes the mechanisms underlying cognitive function improvement. There are many different sports in the OSE (Table 1), but in this section, we introduce key examples such as racket sports (e.g., table tennis and badminton) [34,35] and martial arts (e.g., judo) [36].

Aerobic exercise is generally known to improve cardiovascular risk factors, enhance neurotrophic factor expression, promote amyloid beta metabolism, increase cerebral blood flow, and reduce inflammation, all of which contribute to maintaining and improving cognitive function [6].

Among racket sports, table tennis is characterized by moderate-intensity aerobic activity (approximately 96%). It has been shown to induce neuroplastic changes in multiple brain networks, including motor-related and visual processing regions (particularly the motion-visual areas), as well as the frontal cortex. These neuroplastic adaptations help maintain or improve cognitive functions, particularly executive function and sensorimotor coordination, thereby reducing the risk of age-related cognitive decline and dementia [34]. Badminton, which relies primarily on aerobic metabolism (60–70%) [35], has been associated with increased cerebellar gray matter volume and functional changes in the frontoparietal junction, which may enhance visuospatial integration in players.

Judo, classified as an aerobic sport (approximately 70%), also induces neuroplasticity through similar mechanisms as racket sports. Judo training has been shown to increase gray matter volume in key brain areas, including the frontal lobe (responsible for planning and executing movement), prefrontal cortex (involved in working memory and cognitive processing), parietal and occipital lobes (which process visual information), and the middle and inferior temporal gyri (associated with motor learning and memory) [36]. Additionally, judo training enhances functional connectivity in key neural networks, such as the sensorimotor network (involved in movement preparation and execution), visual network (critical for target positioning and motion trajectory tracking), and cerebellar network (which regulates posture, balance, and movement coordination) [36]. These neural adaptations contribute to improved cognitive functions, such as memory and executive function, as well as physical performance, including fall prevention [36].

Based on these findings, aerobic OSE appears to be more effective than CSE in counteracting age-related cognitive decline and reducing dementia risk. However, to effectively promote OSE interventions for older adults living in the community, further long-term studies are needed. Future research should focus on identifying the most effective OSE types for dementia prevention, assessing their safety for older adults, and evaluating their cost-effectiveness.

4. Cognitive Function and E-Sports

The global rise in age-related cognitive impairments has necessitated innovative approaches to maintaining and enhancing cognitive health. MCI and dementia pose significant public health challenges with profound economic and social implications, particularly in rapidly aging societies such as Japan and South Korea [37]. This issue is further complicated by the bidirectional relationship between cognitive impairment and frailty in older adults. Park et al. [38] demonstrated significant associations between physical function, mental function, and frailty status in community-dwelling older adults, highlighting the complex interplay between these factors.

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While conventional exercise interventions have been shown to enhance cognitive function, they face significant limitations in terms of long-term sustainability and participant adherence. Di Lorito et al. [39] conducted a systematic review and meta-analysis, revealing that adherence to exercise interventions among older adults with MCI and dementia often declines substantially over time, with dropout rates reaching 17–18%. This decline is largely attributed to motivational barriers. O'Neil-Pirozzi et al. [40] emphasized that motivation is a critical determinant of both initiating and adhering to physical and cognitive exercise programs in older adults. Traditional interventions often fail to sustain engagement due to perceived monotony, lack of immediate feedback, and insufficient psychosocial reinforcement. These factors can significantly undermine the effectiveness of programs, regardless of their theoretical benefits.

In response to these challenges, e-sports integrated with advanced technologies have emerged as a promising approach to cognitive rehabilitation and enhancement, offering potential solutions to the motivational and adherence limitations of conventional interventions.

E-sports, defined as competitive video gaming conducted in structured environments, go beyond traditional gaming by incorporating organized competition and sophisticated technologies such as virtual reality (VR), augmented reality (AR), and artificial intelligence (AI). These technologies transform gaming into cognitively demanding experiences. Unlike traditional exercise interventions, which often struggle with participant retention and engagement [39], e-sports leverage intrinsic motivational elements—including competition, achievement, social interaction, and immersion—that can significantly enhance adherence and long-term participation. This strong motivational foundation addresses a critical gap in conventional cognitive interventions, potentially leading to improved long-term outcomes through sustained engagement [40].

This section examines the growing body of evidence supporting e-sports as effective tools for enhancing cognitive function while identifying current research gaps and future directions in this rapidly evolving field.

4.1. The Neurocognitive Demands of E-Sports

E-sports engage multiple cognitive domains simultaneously, creating complex neural activation patterns that promote brain health. Research by Campbell et al. [41] highlights e-sports as a unique window into neurocognitive expertise, demonstrating that professional gamers exhibit enhanced visual attention, cognitive flexibility, and information processing capabilities compared to non-gamers. The cognitive architecture recruited during e-sports participation extends beyond simple reaction time and encompasses higher-order cognitive processes such as strategic planning, decision-making under time constraints, and adaptive problem-solving.

When combined with technologies such as VR and AR, e-sports create immersive environments that intensify cognitive engagement. Lachowicz et al. [42] documented significant improvements in concentration and alternating attention following short-term VR training among e-athletes. These findings suggest that technological enhancements in gaming environments may amplify the cognitive benefits derived from e-sports participation. The sensory-rich environments created by these technologies stimulate multiple neural pathways, facilitating cross-modal integration and cognitive flexibility.

4.2. Neurobiological Mechanisms Underlying Cognitive Enhancement

The cognitive benefits associated with e-sports participation can be attributed to several neurobiological mechanisms. Foremost among these is neuroplasticity—the brain's ability to reorganize itself by forming new neural connections. E-sports, particularly those incorporating VR technology, have been shown to induce neuroplastic changes in brain regions associated with attention, memory, and executive function [43]. These structural and functional adaptations provide the neural foundation for cognitive enhancement.

Beyond neuroplasticity, e-sports participation enhances cerebral blood flow, ensuring optimal delivery of oxygen and nutrients to neural tissues. This increased perfusion supports the metabolic demands of active neural networks and promotes the release of neurotrophic factors such as brain-derived neurotrophic factor (BDNF). BDNF plays a crucial role in learning, memory formation, and neuroprotection, acting as a molecular mediator of experience-dependent plasticity. The immersive nature of VR-enhanced e-sports may further augment these effects by creating emotionally engaging experiences that modulate arousal and attention networks [44].

Additionally, the stress-reducing effects of e-sports contribute to cognitive enhancement by regulating the hypothalamic-pituitary-adrenal axis. Chronic stress is associated with hippocampal atrophy and impaired cognitive performance, particularly in memory-related domains. The engaging and rewarding nature of e-sports can mitigate stress responses, thereby preserving cognitive function through neuroendocrine pathways. This stress regulation mechanism may be particularly relevant in light of Bae et al.'s [45] findings on the trajectories of subjective cognitive decline and frailty in older adults, where psychological factors were found to significantly influence cognitive health trajectories.

4.3. Domain-Specific Cognitive Effects of E-Sports

Executive function encompasses cognitive processes essential for goal-directed behavior, including working memory, inhibitory control, and cognitive flexibility. Research by Sañudo et al. [46] demonstrated that aerobic exercise combined with VR significantly improved cognitive flexibility and selective attention in young males. This finding suggests that integrating physical activity with virtual environments—a growing trend in e-sports—may particularly enhance executive control networks.

Furthermore, Toth et al. [47] provided converging evidence for the cognitive link between exercise and e-sports performance. Their dual systematic review revealed that executive functions trained through e-sports transfer to physical performance contexts and vice versa, suggesting shared neural substrates. This bidirectional relationship highlights the potential for synergistic effects when e-sports are combined with physical activity interventions. Such synergistic effects are further supported by Thapa et al. [48], who demonstrated that a combination of electrical muscle stimulation and resistance exercise significantly improved both physical and cognitive function in middle-aged and older women, suggesting multiple pathways through which physical activation enhances brain function.

Memory systems—including episodic, semantic, and procedural memory—also benefit significantly from e-sports engagement. VR-based cognitive interventions have shown promise in enhancing memory retention and spatial navigation abilities. A meta-analysis by Rosa et al. [49] examining the effects of VR-based serious games in cognitive interventions found moderate to large effect sizes for memory improvement, particularly in older adults and individuals with cognitive impairments.

The immersive nature of VR environments facilitates context-dependent learning and memory encoding. By creating rich associative networks, these environments enhance both the acquisition and retrieval of information. Thapa et al. [50] demonstrated that a VR-based intervention program significantly improved cognition in older adults with MCI, with particular benefits for visuospatial memory and episodic recall. These memory enhancements may be especially valuable given Bae et al.'s [45] observation that subjective cognitive decline is an early indicator of potential frailty development in community-dwelling older adults, suggesting that memory-focused interventions could serve as preventative measures against broader functional decline.

Attentional networks—including sustained, selective, and divided attention—are primary targets for e-sports-based cognitive enhancement. Lachowicz et al. [42] found that short-term VR training significantly improved concentration and alternating attention in e-athletes. These improvements in attentional control translate to enhanced information processing capabilities across multiple cognitive domains.

Processing speed, a fundamental cognitive resource that underpins higher-order cognition, also benefits from e-sports engagement. Stanmore et al. [51] conducted a meta-analysis examining the effects of active video games on cognitive function and found significant improvements in processing speed across diverse populations. These effects may be particularly beneficial for older adults, for whom reduced processing speed often represents an early marker of cognitive decline. Park et al. [38] highlighted the interrelationship between cognitive processing speed and physical function, noting that interventions targeting either domain often yield benefits in both. This suggests that integrated approaches may provide optimal outcomes for preserving functional independence.

4.4. E-Sports Applications for the Elderly

E-sports can be applied across all stages of life, but this section focuses on their applications for older adults. Perhaps the most compelling benefits of e-sports for cognitive enhancement lie in aging populations and individuals with cognitive impairments. Yang et al. [37] demonstrated that VR and exercise training improved brain function, cognitive abilities, and physical health in older adults with MCI. Their randomized controlled trial found improvements across multiple cognitive domains, suggesting potential for both the prevention and remediation of age-related cognitive decline.

Ferreira et al. [52] further confirmed the efficacy of multimodal exercise combined with AR for cognitive enhancement in community-dwelling older adults. Their findings highlight the potential for technology-enhanced interventions to support cognitive health in naturalistic settings, potentially expanding access to cognitive rehabilitation resources. This approach aligns with Park et al.'s [38] findings on the interrelationship between physical function, cognitive function, and frailty, suggesting that integrated interventions addressing multiple domains simultaneously may yield optimal outcomes for preserving independence in older adults.

For clinical populations with neurodegenerative conditions, e-sports offer promising avenues for cognitive rehabilitation. Sokolov et al. [53] reviewed serious video games and VR applications for preventing and treating cognitive decline due to aging and neurodegeneration. Their work suggests that well-designed gaming interventions may complement traditional therapeutic approaches, potentially improving outcomes through increased engagement and adherence. Given Bae et al.'s [45] observation that subjective cognitive decline and frailty trajectories are influenced by modifiable factors, e-sports interventions targeting these pathways may serve as valuable tools for altering unfavorable cognitive aging trajectories.

4.5. Technological Innovations Enhancing Cognitive Impact

4.5.1. Integration

The evolution of VR technology has significantly expanded the cognitive potential of e-sports. Sakhare et al. [54] demonstrated that combining physical exercise with cognitive training in VR positively impacts brain health and cognition in older adults. This integration of physical and cognitive demands within immersive environments represents a major advancement over traditional cognitive training approaches. The neurobiological mechanisms underlying the effectiveness of VR include enhanced sensory integration, embodied cognition, and presence—the subjective experience of being in a virtual environment. These factors collectively intensify cognitive engagement, potentially accelerating neural adaptations and skill acquisition. Richlan et al. [55] reviewed the efficacy of virtual training for sports performance enhancement and found that VR-based interventions produced "real effects," suggesting a strong transfer of skills from virtual to real-world contexts.

4.5.2. Applications

AR technology overlays digital information onto the physical world, creating hybrid environments that simultaneously engage both physical and cognitive systems. Ferreira et al. [52] demonstrated that multimodal exercise combined with AR significantly improved cognition in community-dwelling older adults. The spatial mapping required to interact with AR environments may be particularly beneficial for visuospatial processing and spatial cognition—cognitive domains often affected in the early stages of dementia.

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The accessibility of AR applications, which often require only a smartphone or tablet rather than specialized hardware, may facilitate broader implementation of cognitive enhancement programs. This accessibility, combined with the potential for integrating AR elements into daily activities, positions AR-enhanced e-sports as promising tools for reinforcing "everyday cognition." This aligns with Park et al.'s [38] emphasis on the importance of implementing interventions that can be seamlessly incorporated into community settings to maximize their reach and public health impact.

4.5.3. Adaptive Algorithms and Personalization

AI integration represents the next frontier in e-sports-based cognitive enhancement. Adaptive algorithms capable of adjusting difficulty levels in real time optimize the challenge-skill balance—a critical factor in maintaining cognitive engagement and achieving flow states. These personalized approaches ensure that participants consistently operate at the edge of their capabilities, maximizing cognitive demand without inducing frustration or disengagement.

Additionally, AI-driven systems can track performance metrics across various cognitive domains, identifying specific areas for targeted intervention. This precision-based approach to cognitive enhancement represents a significant improvement over one-size-fits-all cognitive training programs, potentially increasing both effectiveness and efficiency. The potential for personalization is particularly relevant given Bae et al.'s [45] observation that individual trajectories of cognitive decline and frailty vary substantially. This suggests the need for tailored interventions that address specific risk factors and functional profiles.

4.6. Research Gaps and Future Directions

Despite promising evidence supporting e-sports as tools for cognitive enhancement, several research gaps remain. Longitudinal studies examining sustained cognitive benefits are scarce, limiting our understanding of long-term outcomes. The optimal parameters for e-sports interventions—including intensity, duration, frequency, and specific game characteristics—are still not well defined.

Additionally, individual difference factors that may moderate intervention effectiveness require further investigation. Age, baseline cognitive status, technology familiarity, and genetic factors could all influence responsiveness to e-sports-based cognitive interventions. Understanding these moderating variables will enable more precise targeting of interventions to those most likely to benefit. Bae et al. [45] identified several factors influencing the trajectories of subjective cognitive decline and frailty in older adults, including psychological variables and physical activity levels. Future research should explore how these factors might interact with e-sports interventions to determine which subpopulations would derive the greatest benefit.

Standardization of outcome measures is another critical research need. The heterogeneity of cognitive assessments across studies complicates cross-study comparisons and meta-analyses. Developing standardized cognitive assessment batteries specifically for e-sports research would facilitate more rigorous evaluation of intervention efficacy. Park et al. [38] emphasized the importance of comprehensive assessment approaches that capture both cognitive and physical function domains. Future e-sports research should adopt similar multi-domain assessment protocols to fully characterize intervention effects.

Additionally, research should explore the potential synergies between e-sports and other cognitive enhancement approaches, including physical exercise, nutrition, sleep optimization, and pharmacological interventions. Multimodal approaches may yield greater cognitive benefits than any single intervention alone by simultaneously addressing multiple mechanisms of cognitive decline. Thapa et al. [48] demonstrated enhanced outcomes through a combination of electrical muscle stimulation and resistance exercise, suggesting that integrating e-sports with other modalities may produce synergistic benefits.

While traditional exercise-based interventions have well-documented cognitive benefits, their effectiveness is often limited by adherence challenges and motivational barriers [39,40]. E-sports and technology-enhanced interventions address these limitations through their inherently engaging, customizable, and socially interactive qualities. The immersive and gamified nature of e-sports provides immediate feedback, progressive challenge calibration, and intrinsic reward structures, all of which significantly enhance motivation and long-term adherence—critical factors that conventional approaches often fail to adequately address.

As technology continues to evolve and research progresses in addressing these gaps, e-sports may increasingly become a central component of comprehensive cognitive health strategies. Their ability to combine cognitive engagement with physical activity, social interaction, and stress reduction positions them as uniquely holistic approaches to brain health. Given the established interrelationships between physical function, cognitive function, and frailty status [38], as well as the observed influence of modifiable factors on cognitive and functional trajectories [45], e-sports represent a versatile intervention modality capable of addressing multiple dimensions of health simultaneously.

5. Conclusions

This review first summarizes research findings in physical activity epidemiology from the perspective of preventing and reducing the incidence of MCI and dementia. In particular, it explores the potential mechanisms underlying cognitive decline prevention and dementia mitigation through motor learning theory, focusing on aerobic-oriented OSE and e-sports.

To date, epidemiological studies have primarily examined the effects of physical activity and exercise in terms of energy metabolism. However, this review highlights the importance of OSE and e-sports within the context of aerobic exercise. Looking ahead, it remains an open question whether increased participation in OSE and e-sports across all age groups could help prevent cognitive decline and reduce the incidence of dementia, or conversely, whether such participation could enhance neuroplastic activation in younger populations.

Furthermore, there is a pressing need to develop age-inclusive participation strategies aimed at expanding competitive engagement across generations. Addressing this challenge will be essential in maximizing the long-term benefits of OSE and e-sports for cognitive health.

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