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Review

Benefits of Badminton for Preventing Cognitive Decline and Dementia

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Abstract: Badminton is one of the most popular racket sports played by all age groups worldwide. Anyone can practice and play badminton as a leisure or competitive sport, regardless of age, experience, or skill level. It does not require physical contact among players or expensive equipment. Compared with closed-skill exercises (e.g., running and swimming), open-skill exercises (e.g., badminton and table tennis) have been reported to significantly improve cognitive function and prevent cognitive decline. This mini review aimed to investigate the findings related to badminton intervention for cognitive function, with attention to the modifiable risk factors of dementia in adults. Additionally, we outlined the characteristics of badminton's physical demands. This narrative review encompassed studies reported from 2013 to 2023 from multiple databases, including PubMed and Google Scholar. Keywords such as "badminton", "dementia", "cognitive function", "physical activity", and "depression" were used to identify relevant articles. Various studies, including randomized controlled trials, cohort studies, and case–control studies, were selected to provide a comprehensive overview of badminton intervention. Quantitative data analysis suggests that at a cognitive level, high-intensity badminton can enhance cognitive function with at least 10 min of play once weekly or 20 min of play once weekly on average, whereas moderate-intensity badminton can be effective when played for at least 30 min once weekly or 35 min twice weekly on average. For modifiable risk factors, recreational badminton for about 3 h weekly could effectively manage blood pressure. For body fat percentage and fasting serum glucose levels, recreational badminton for about 10 h weekly exerted positive effects. For depressive states, a moderate-intensity badminton program for 100 min weekly was effective. For lipid profiles associated with dementia occurrence, prolonged badminton intervention for more than 3 months may be beneficial. The characteristics presented here indicate that intervention with regular badminton exercise could effectively improve cognitive function and prevent cognitive decline in older adults.

Keywords: physical activity; open-skill sports; racket sports; cognitive function; preventive intervention; non-pharmacological intervention

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1. Introduction

Badminton is a racket sport that is one of the most popular sports, known for its mass appeal in fitness and entertainment worldwide [1–3]. Competitive badminton is the fastest racket sport in terms of shuttlecock velocity, reaching speeds as high as 426 km/h. It demands agility, endurance, technique, psychological stability, physical fitness, and visuomotor integration [1,4,5].

The world population is rapidly growing and reached 7 billion in 2012, with 562 million (8%) individuals aged ≥65 years. In 2015, the number of older people increased by 55 million (8.5% of the total population). The older population is estimated to reach approximately 1.6 billion from 2025 to 2050 [6]. Currently, approximately 55 million individuals experience dementia, and this number is predicted to increase to 78 million by 2030 and 139 million by 2050 [7].

There are 12 modifiable risk factors for preventing and intervening with dementia, including physical inactivity, obesity, depression, social isolation, diabetes, hypertension, head injury, smoking, air pollution, alcohol use, hearing loss, and low educational level [8]. While many studies have focused on the technical and tactical aspects [2,9–13], a recent systematic review suggested that playing badminton improves overall health across all age groups, from children to older adults [14]. Previous studies have reported the benefits of badminton for physical, social, and psychological health [14–17]. Regarding physical health, several studies and a review demonstrated the effects of badminton on cardiac and respiratory functions, including increasing maximal oxygen uptake (VO_2max) and bone mineral density, decreasing asthma, lowering risk of coronary heart disease, and improving body shape and physical abilities (e.g., speed, flexibility, endurance, strength, vertical jump, muscle coordination, manipulation, and motor skills). Regarding social health, badminton positively impacts social relationships, personal development, mood regulation, and intrinsic motivation, while also providing psychological benefits such as improved cognitive function, alertness, concentration, attention, depressive symptoms, and general motivation [14,16,17].

Regarding the results of these studies on modifiable risk factors for dementia, badminton helps manage hypertension [16]. Midlife hypertension is associated with decreased brain volumes and increased white matter hyperintensity volume [8]. Badminton may reduce social isolation and physical inactivity by exerting its positive effects on social relationships and intrinsic motivation. Social contact, recognized as a protective factor, enhances cognitive maintenance and encourages beneficial actions, whereas isolation can be a prodromal symptom of dementia and depression [8]. Regarding physical inactivity, engaging in moderate-to-vigorous physical activity at least weekly for 25 years, or >2.5 h weekly for $\geq$10 years, reduces the risk of dementia [8]. While badminton intervention improved depressive states [17], whether antidepressants reduce the risk of dementia remains an open question [8]. Moreover, severe head injury is associated with extensive hyperphosphorylated tau pathology [8]. Badminton exercise may reduce the risk of head injury from falls via its positive effects on muscle strength, endurance, flexibility, and other physical abilities. On the contrary, while dyslipidemia is a well-known risk factor for atherosclerotic cardiovascular disease [18], it may not be a direct risk factor for dementia. However, better cardiovascular health is related to a lower risk of dementia [8]. Badminton has been reported to be more associated with high-density lipoprotein (HDL) cholesterol levels than other aerobic exercises [19]. Thus, badminton is likely to be effective for dementia prevention due to its impact on improving modifiable risk factors.

A previous review [20] and a meta-analysis [21] indicated that physical activity is potentially effective for dementia, including cognitive function improvement. Aerobic physical activity for 6 months has shown benefits in functional ability in early Alzheimer's disease, proving superior to stretching and toning exercises [22]. A systematic review demonstrated that open-skill exercise (OSE) has greater cognitive benefits than closed-skill exercise (CSE), leading to significant improvements in cognitive function in children and older adults [23]. A meta-analysis [24] and a systematic review [25] indicated that regardless of baseline age, OSE positively affects executive function, including inhibitory control and cognitive flexibility, compared to CSE. Another recent review reported that aerobic physical activities prevent cognitive decline and dementia and that OSE, including badminton, protects cognitive function more effectively compared to CSE [15]. Additionally, the cognitive benefits of table tennis, an OSE involving aerobic physical activity, were suggested to elicit changes in neuroplasticity in multiple brain networks underlying cognitive aspects, potentially preventing cognitive decline and dementia [7].

A badminton intervention program improved executive function in adults with mild intellectual disability [26]. A study using magnetic resonance imaging (MRI) and functional MRI (fMRI) in professional badminton players demonstrated that badminton training and practice are associated with increased gray matter concentration in the cerebellum and functional alterations in fronto-parietal connectivity [27]. These alterations may promote visuospatial integration in badminton players [5,27]. In healthy older adults, acute badminton or bicycling interventions increased neurotrophic factors and myokines, and chronic OSE, including badminton, significantly increased the brain-derived neurotrophic factor (BDNF), supporting the effectiveness of chronic OSE training in improving functional integrity [28]. Furthermore, a recent functional near-infrared spectroscopy (fNIRS) study showed that a single session of badminton induced neural efficiency in the prefrontal cortex without increasing brain activation compared to running in young adults [29]. Thus, badminton exerts positive effects on several aspects of cognitive function.

Therefore, to investigate the findings regarding badminton interventions for the prevention of cognitive decline and dementia, this mini review focused on the effects of badminton intervention on cognitive function in adults, particularly examining modifiable risk factors such as physical activity and depression, which are crucial risk factors for dementia [30]. Additionally, we outline the characteristics and aspects of badminton's physical demands.

2. Methods

This narrative review employed a comprehensive methodology to assess the impact of badminton on cognitive function. Comprehensive electronic searches were conducted using PubMed and Google Scholar, chosen for their broad scientific coverage of badminton and brain function. This review included English-language studies on badminton and cognitive function published between 2013 and 2023, as this period reported the most multifaceted benefits of badminton. The search strategy utilized the following keyword combinations to identify relevant articles specifically addressing intervention of badminton for brain function: "badminton", "dementia", "cognitive function", "physical activity", and "depression".

Given the diverse viewpoints and methodologies, a broad range of articles, including randomized controlled trials, cohort studies, and case-control studies, were selected for this review. Based on the title and abstract, studies were included following a predetermined detailed screening process. Data were extracted by synthesizing the main findings related to badminton and cognitive function or the modifiable risk factors of dementia in adults. Finally, quantitative data were analyzed to provide meaningful insights into preventing cognitive decline and dementia.

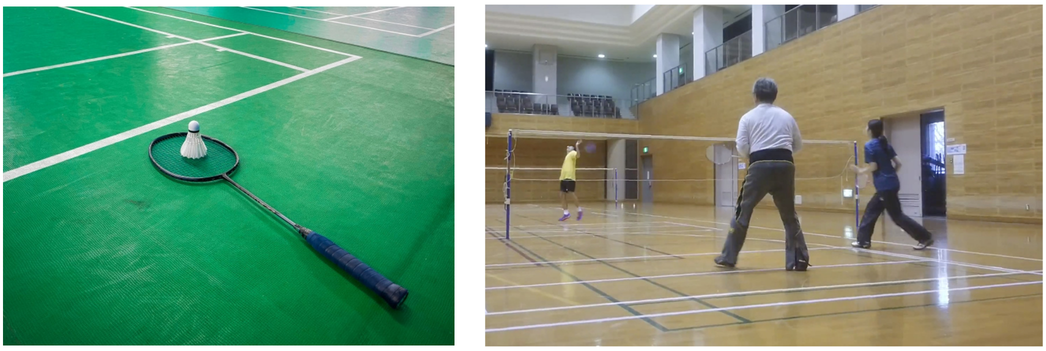
3. Characteristics of Badminton

3.1. The History of Badminton

Badminton is a sport that can be traced back to ancient civilization. It was initially played in 1873 in England, and it originated from "poona" or "poona Badminton", which was played by the British army in India in the mid-19th century [3]. This sport rapidly increased in popularity and became a national sport, particularly in Asian countries, such as Japan, China, South Korea, Indonesia, and Malaysia, and some European countries, such as Denmark, the Netherlands, and the United Kingdom. Currently, badminton is one of the most popular racket sports worldwide. It has been played by more than 200 million individuals across different ages and experiences since its inclusion in the Olympic Games [4,9]. Moreover, badminton was included in the Paralympics for the first time in the 2021 Paralympic Games in Tokyo. However, it was first played by people with disabilities in the 1990s [31]. In addition, aside from the Paralympics, deaf badminton has been gaining attention since its initial inclusion in the 1985 Deaflympics held in Los Angeles [32].

3.2. Match Characteristics of Badminton

Although badminton is a globally relished and inexpensive leisure sport played by individuals of various ages, it also requires mass fitness to jump, lunge, turn quickly, and rapid arm swing [1–3]. Badminton has five disciplines: men's and women's singles, men's and women's doubles, and mixed doubles [4]. Individual opposing players (singles) or pairs (doubles) play on opposite halves of a rectangular court measuring 5.2 × 13.4 m and divided by a 1.55 m high net [33] (Figure 1).



(**a**) (**b**)

Figure 1. A badminton racket and a shuttle (**a**), adapted from photo AC (https://www.photo-ac.com/, accessed on 1 March 2024), and three players, ranging from adolescents to older adults, engaged in a recreational rally with a shuttle about to be hit by a singles player on the back court, whereas the doubles players are trying to predict its trajectory and move to the front court (**b**).

Badminton, the fastest racket sport in terms of shuttlecock velocity, with a rotation as fast as 426 km/h [5,33], is characterized by a combination of agility, endurance, and repetitive efforts for actions of short duration and high intensity combined with short rest periods [1,4,5].

In badminton, each rally begins with a long or short serve [10,11,13], and a rally ends once a player makes a mistake or the shuttlecock hits the floor [33]. An elite badminton match lasts almost 30–40 min and is characterized by an average effective playing duration of 31% (10–15 m) [10,12], rally time of 3–9 s, and resting time of 6–15 s [4,10,12,34,35]. Players define various shots during the match depending on numerous tactile choices [4,35]: the smash (aggressive and downward from overhead shot), the clear (overhead shot with a flat or rising trajectory toward the back of the opposite court), the drop (a smooth and downward shot from above the head toward the front of the opposite court), hairpin net shot (an accurate shot from near the net), the lob (offensive and rising shot toward the back of the opposite court), the push shot (aggressive and downward shot), and the drive shot (the offensive powerful and a flat shot from middle body height).

Because shuttlecocks are made of goose feathers weighing 5 g (or plastic feathers in leisure games) planted into a cork, the wind easily affects projectile flight [33], and the trajectories vary by 0.2 s for short-range smash and 1.5 s for the clear or lob [34]. Because badminton players must choose several kinds of shots depending on the opponent(s) and shuttle positions [33] to hit the shuttlecock from various heights, angles, and speeds with a badminton racket, which is relatively flexible compared with other racket sports [9], they require not only agility, speed, strength, flexibility, precision, and stamina but also sophisticated motor coordination and skills to track the opponent(s), racket, and shuttlecock [4,5].

3.3. Physiological Characteristics of a Badminton Match

Badminton requires a mean heart rate (HRmean) of >90% of the singles player's maximum HR (HRmax) or a high percentage of their VO_2max or relatively low lactic value during a match [4,35,36]. Table 1 shows the physiological characteristics of elite male and female badminton players [4,35]. Elite badminton players require high physiological demands [4,35]. Furthermore, the maximum serum lactate concentration during the male and female matches was 5.87 and 5.4 mmol/L, respectively [4]. In contrast, other previous studies reported that the maximum lactate values of elite players were between 2 and 5 mmol/L on average [34,35]. These relatively low lactic values indicate that the aerobic system is active during a match [4,7]. The intermittent actions during a badminton match are demanding on both the aerobic (60–70%) and anaerobic (approximately 30%)

systems, where the anaerobic alactic system known as adenosine triphosphate creatinine phosphate system contributes more than the anaerobic lactic (glycolytic) system [4,34,35].

Table 1. Average of physical values during a badminton match. Adapted from Phomsoupha et al. [4] and Faude et al. [35].

	Elite Male Players	Elite Female Players
HRmean (bpm) [35]	166 ± 6	170 ± 10
HRmax [4]	188.0	193.4
%HRmax (%) [35]	90.3 ± 3.7	88.4 ± 5.1
VO_2mean (mL kg^{-1} min^{-1}) [35]	46.0 ± 4.5	36.4 ± 2.8
VO_2max (mL kg^{-1} min^{-1}) [4]	56.3	45.8
%VO_2max (%) [35]	74.8 ± 5.3	72.6 ± 7.2

Abbreviation: HRmean, mean HR; HR max, maximum HR; %HRmax, percentage of HRmax; VO_2, oxygen uptake; VO_2mean, mean VO_2; VO_2max, maximum VO_2; %VO_2max, percentage of VO_2max.

Because singles male players showed greater predicted VO_2max values than doubles players (50.6 vs. 45.5 mL kg^{-1} min^{-1}, respectively), singles players significantly require greater aerobic capacity [36]. After the match starts, HR increases quickly and remains at a relatively steady state with significantly greater HRmean values (88.8 ± 5.2% of HRmax) in singles, whereas HR plateaus earlier and fluctuates during the match (HRmean, 75.5 ± 8.8% of HRmax) in doubles [35,36]. Singles players showed HR > 90% of HRmax during more than half the playing time, whereas doubles players exhibited greater variability, with HR values between 70% and 80% of HRmax for the majority of the playing time [36]. In addition, singles players reached high intensity levels of 80–90% HRmax for twice the duration compared to doubles players [37]. Moreover, singles players require more steps and flexibility during a match, with approximately 90% of shots being extreme fore and rear court shots (i.e., clear, drop, hairpin net, and lob) and more overhead shots (i.e., smash, clear, and drop) than doubles players. In contrast, doubles players choose more types of faster shots [36,37].

Regarding injuries to badminton players, most players get injuries during a match (72%) [1]. The incidence was significantly lower in the players under 18 years old than those between 18 and 25 years old and over 25 years old (28, 45, and 42/1000 players/year, respectively) [1]. The mean incidence in senior amateur players was 0.134/1000 h [38]. The accidents occur most frequently in badminton clubs (55%), followed by company sports (15%), recreational sports (15%), and school sports (12%) [1]. According to the Abbreviated Injury Scale, moderate injuries were found in more than 50%, with 56% of the severe injuries being found in the >25-year-old group [1]. The injuries are most commonly found in the lower extremities, with 22.4% to the knee and 18.3% to the leg [1,38]. The shoulder was most frequently injured in the upper extremities (11.8%) [38]. Sprain injuries were most common (56%), followed by 13% of Achilles tendon ruptures, 10% of torn ankle ligaments, and 5% of fractures [1]. In contrast, in amateur players, muscle injuries were most common to the muscles (39.1%), followed by sprains, ligament, and tendon injuries (30.9%) [38]. The severity of injuries was correlated with the length of time players were away from badminton [1]. After the injuries, 12% of players gave up badminton and 28% gave up regular badminton for more than 8 weeks [1,38]. Although acute injuries to limbs may frequently occur and badminton injuries occur in 1–5% of all sports injuries, the incidence was significantly lower compared with soccer [1,38]. Considering amateur senior badminton players, adequate warming up and stretching before playing badminton may prevent injuries and allow them to continue regular badminton.

3.4. Physical Activity as an OSE

Physical exercises are categorized into OSE and CSE [15,24,25]. OSE requires performing in dynamic, more unpredictable, and externally paced environments, whereas CSE requires performing in relatively consistent, controllable, self-adjustable, and more predictable environments [15,25]. The performance properties of badminton are complex.

This fast-paced and unpredictable sport requires visual focus, sustained attention, rapid decision making, working memory to track and forecast opponent(s) motions, and quick, high-intensity reactions to the constantly changing trajectories [4,15]. Thus, badminton is classified as an OSE [15,25,29]. Singles players focus on strategies that emphasize movement in the court and quick return to the center after each shot. In contrast, doubles players train to improve their reactions to fast shuttles in faster games [36]. In comparison with singles players, doubles players require faster reactions and forecast the opponents' tactics, motions, and the shuttle's trajectory because it is difficult to predict which opposing player will hit the shuttle aside from serves, and doubles matches are more complicated, requiring the use of diverse tactics and faster shots [36]. Therefore, doubles players may require more effort to acquire the cognitive demands, active decision making, and ongoing adaptability and adapt to the externally paced environment characterized by OSE.

4. Benefits of Badminton for Cognitive Function

Physical activity and exercise enhance cognitive performance in all age groups [15,23,39,40]. Concerning older adults, previous reviews suggested that physical activity improves immediate memory and cognitive flexibility, enhances and maintains brain and cognitive functions, and reduces cognitive decline in later life [23,39]. A previous review based on neuroimaging studies in children and the elderly reported that physical activity influences brain structure, resulting in greater gray matter volumes in the hippocampus, prefrontal cortex, and basal ganglia and improved white matter integrity in older adults [39]. Another review referencing several imaging modalities (fMRI, fNIRS, and electroencephalography) indicated that physical exercise, regardless of type, reinforced cognitive function, which was attributed to increased hippocampal and basal ganglia volumes, greater white matter integrity, and enhanced cerebral blood flow and alternations in neurotransmitter release in the central nervous system across all ages [40]. Furthermore, physical activity and exercise effectively improve functional ability and cognition in elderly patients with Alzheimer's disease [20–22].

OSE (e.g., badminton, table tennis, and tennis) has demonstrated greater corticospinal excitability, motor cortex function, and faster reaction times with better accuracy than CSE (e.g., swimming, running, cycling, and resistance training). Moreover, OSE has more advantages in enhancing inhibitory control of cognition, namely suppressing activities in the current situation compared with CSE [15,25,40]. Compared with CSE, OSE has superior effects in terms of improving cognitive function, particularly inhibition and cognitive flexibility, which are important for executive function in all age groups [23,24].

Concerning badminton exercise, both acute and chronic (i.e., regular) badminton exercises are effective for many kinds of cognitive functions at various frequencies, intensities, and volumes [41] (Table 2). Based on a study performing the Stroop task test in young adults, acute OSE (high intensity, a single session of badminton match, 10 min; separated three times with an average interval, 5.8 $\pm$ 1.4 days) can intervene in inhibitory functions more effectively than CSE (running) [42]. Furthermore, based on a fNIRS study in young adults, OSE induces the neural efficacy of the prefrontal cortex because a single session of badminton match (high intensity, 10 min; separated three times with an average interval, 6.1 $\pm$ 1.8 days) reinforces inhibitory control without increased hemodynamics in the prefrontal cortex [29]. Moreover, acute exercise (moderate-intensity badminton match, 30 min/session; 2 times with a 7-day interval) showed higher BDNF and executive function than running exercise in young men [43]. Furthermore, although both acute physical exercises (high intensity, 30 min badminton or cycling) can effectively increase serum BDNF, insulin-like growth factor 1 (IGF-1), and interleukin-6 (IL-6) levels promptly in healthy older people, acute badminton exercise elevated serum IL-6 levels compared with bicycle exercise, mediating some positive effects for brain health and cognitive functions [28].

Regarding chronic training (high intensity, 40 min training once weekly for 12 weeks), because both OSE (badminton, table tennis, and hockey) and CSE (strength–endurance training) can effectively increase basal serum BDNF and IL-6 levels, with statistical significance observed for OSE, regular OSE training has been shown to be superior in improving some aspects of structural/functional brain integrity compared with CSE [28]. Several observational studies and a review also revealed the effects of regular OSE on cognitive flexibility, visuospatial working memory, visuospatial attention, and inhibitory control in older adults [23,44,45]. Previous studies have supported the positive effects of longer badminton exercises on cognitive function. Badminton exercise training (moderate intensity, 40 min/training, thrice weekly for 12 weeks) improved executive function in inhibitory control and working memory in adults with mild intellectual disabilities [26]. In elite young adult badminton players, years of badminton training were associated with greater visuomotor integration, suggesting that badminton training elevates sports-related skills in eye–hand coordination [5]. Furthermore, habitual badminton participation in older adults showed a significantly faster reaction in the Stroop task and greater improvement in the trail making test compared with sedentary controls, indicating greater executive function [46].

Considering the 12 modifiable risk factors, excluding depression [8], badminton has been highlighted for its potential in preventing and intervening in dementia. An 8-week recreational badminton program (1 h, thrice weekly) and a submaximal running intervention in adult women led to decreased systolic and diastolic blood pressure and HR [16]. Similarly, a badminton intervention developed by the Badminton World Federation for young men and women (moderate intensity, the Badminton World Federation shuttle time; 50 min, twice weekly for 5 weeks) resulted in a reduced HR [17]. Regular badminton exercise (over 3.34 ± 1.53 h/week) among older adults improved blood pressure [47]. Moreover, extended badminton exercise (9.72 ± 2.16 h/week) in older adults led to a better body fat percentage and lower fasting serum glucose levels compared to shorter exercise durations or a control group of older adults [48]. Cardiovascular health, which is linked to dementia occurrence [8], is positively impacted by badminton. Although dyslipidemia, a well-known risk factor for atherosclerotic cardiovascular disease [18], is not directly linked to dementia, it is a significant modifiable factor. Although total cholesterol, HDL, low-density lipoprotein, and triglycerides were not altered after badminton or submaximal running (recreational, 1 h, thrice weekly for 8 weeks) in adult women [16], both longer badminton and CSE (e.g., jogging, swimming, and biking) were positively associated with HDL, with badminton exercise (regularly badminton, lasting 30 min, at least thrice weekly in 3 months) increasing HDL levels more significantly in adults, including older adults [19].

High-intensity badminton can enhance cognitive function with at least 10 min once weekly or 20 min once weekly on average [28,29,42]. In contrast, moderate-intensity badminton is effective with at least 30 min once weekly or 35 min twice weekly on average [26,43]. For blood pressure, recreational badminton for about 3 h weekly showed benefits [16,47]. Regarding body fat percentage, lean body mass, and fasting serum glucose levels, recreational badminton for about 10 h weekly had positive effects [48]. The lipid profile did not reveal definitive insights [16], but continuing badminton intervention for more than 3 months may be beneficial [19].

Table 2. An overview of studies examining the effect of badminton on brain health in adults.

Authors	Participant and Study (1. Study Design; 2. Participants; 3. Exercise Experience or Intervention; 4. Main Outcome Measures, and 5. Cognitive Function)	Main Findings
Chen et al., 2022 [5]	1. Observational study 2. Elite badminton players (n = 28; F:M = 14:14; age: 21.35 ± 2.65 years) 3. Badminton training for years 4. Compensatory tracking task, time/movement, and estimation task 5. Visuomotor integration and temporal prediction	(Compensatory tracking task) - Strong positive association between compensatory tracking task performance and years of training experience. (Time/movement estimation task) - No significant correlation between years of training and time/movement estimation accuracy. - Years of badminton training were associated with better visuomotor integration.

Table 2. *Cont.*

Authors	Participant and Study (1. Study Design; 2. Participants; 3. Exercise Experience or Intervention; 4. Main Outcome Measures, and 5. Cognitive Function)	Main Findings
Patterson et al., 2017 [16]	1. Intervention study 2. Healthy, untrained premenopausal women ((n = 36; age: 34.3 ± 6.9 years), badminton, n = 13; Running, n = 12; Control, n = 8)) 3. Recreational badminton or running; intervention: 1 h/session; thrice weekly for 8 weeks. 4. BP, HR, TChol, HDL, LDL, TG, and psychological well-being questionnaires (Exercise Motives Inventory-II)	(BP) - Mean arterial pressure and systolic and diastolic BP were reduced in both groups. (HR) - Resting HR was lower in both groups. (TChol, HDL, LDL, HDL: LDL ratio, and TG) - Not altered in both badminton and running groups. (Psychological well-being questionnaires) - Affiliation motives were higher in the badminton group.
Chen et al., 2022 [17]	1. Intervention study 2. Young adults with intellectual disability (n = 18; F:M = 4:14; age: 22.28 ± 1.84 years) 3. Moderate intensity. Shuttle time badminton starter lessons; intervention: 50 min/session, twice weekly for 5 weeks. 4. BP, Resting HR, EEG, 6 MWT, badminton skills assessment, and SDS	(BP) - No significant changes were found. (HR) - Significantly reduced resting HR. (EEG) - Increased left frontal alpha asymmetry seemed to be reflective of emotion. (6 MWT) - Significantly longer distances in 6 MWT. (Badminton skills assessment) - Better performance in badminton skills. (SDS) - SDS scores were more reduced in the badminton group than in the control group with no significance. Lower SDS scores expressed higher frontal alpha asymmetry.
Nassef et al., 2020 [19]	1. Observational study 2. Taiwanese aged 30–70 years, aerobic exercise group (n = 2461; F:M = 1310:1151), badminton group (n = 29; F:M = 8:21) 3. Regularly, badminton; 30 min/session; at least thrice weekly for 3 months 4. HDL	(HDL) - It was positively associated with aerobic exercise and badminton compared with no exercise, with badminton being more significant.
Wang et al., 2023 [26]	1. Interventional study 2. Adults with mild intellectual disability (n = 15; F:M = 5:10; age: 36.0 ± 3.64 years) 3. Moderate-intensity badminton intervention protocol: 10 min/warm-up; 40 min/training; 10 min/cool down; thrice weekly for 12 weeks 4. The Stroop test, n-back test, and task-switching test 5. Inhibitory control, working memory, and cognitive flexibility	(Stroop test) - Consistent and inconsistent conditions demonstrated significantly improved accuracy. (n-back test) - Response time and accuracy significantly improved. (Task-switching test) - Improvements were nonsignificant, with some improvements in cognitive flexibility. - Twelve weeks of badminton intervention may effectively improve the executive function of adults with mild intellectual disability.
Behrendt et al., 2021 [28]	1. Interventional study 2. Healthy older adults, acute intervention group; n = 24; F:M = 12:12; age: 65.83 ± 5.98 years, chronic OSE; n = 6; age: F:M = 4:2; age: 64.50 ± 6.32 years, chronic CSE; n = 9; age: F:M = 6:3; age: 64.89 ± 3.51 years 3. Acute intervention; high-intensity badminton or bicycling; 30 min/session; chronic intervention; high-intensity chronic OSE (badminton/hockey/table tennis) or chronic CSE (strength training/endurance training); 40 min/session; once weekly for 12 weeks 4. Serum and plasma BDNF, IGF-1, and IL-6	(Acute effects) - Serum and plasma BDNF, IGF-1, and IL-6 levels were increased in badminton or bicycling. IL-6 levels significantly increased compared with bicycling. (Chronic effects) - Basal serum BDNF and IL-6 levels increased, whereas the basal IGF-1 level decreased in the chronic OSE, with no differences between exercises. - In the short term, badminton and bicycling efficiently increased neurotrophic factors and myokines, whereas chronic OSE efficiently improved basal serum BDNF levels.

Table 2. *Cont.*

Authors	Participant and Study (1. Study Design; 2. Participants; 3. Exercise Experience or Intervention; 4. Main Outcome Measures, and 5. Cognitive Function)	Main Findings
Takahashi et al., 2023 [29]	1. Intervention study 2. Healthy students (n = 24; F:M = 9:15; age: 20.4 ± 0.2 years) 3. High-intensity singles badminton game or running; 10 min; 3 times separated by an average interval, 6.1 ± 1.8 days 4. Color–word Stroop task, fNIRS, and TDMS 5. Inhibitory control, hemodynamics in the prefrontal cortex during the Stroop task, and pleasure and arousal states	(Color–word Stroop task) - Reaction times were shorter for badminton compared with running. Reaction times were shorter for badminton for incongruent conditions relative to neural conditions. (fNIRS) - Although oxy-Hb levels in the left prefrontal cortex significantly increased, no differences between badminton and running were observed in the incongruent condition compared with the neutral condition. (TDMS) - The arousal state after badminton and running interventions was significantly higher. - A single badminton session enhances inhibitory control and arousal without brain activation.
Takahashi et al., 2019 [42]	1. Intervention study 2. Healthy students (n = 20; F:M = 12:8; age: 20.9 ± 0.2 years) 3. High-intensity singles badminton game or running; 10 min; 3 times separated by an average interval, 5.8 ± 1.4 days. 4. Stroop/reverse Stroop test 5. Inhibitory function and information processing speed	(Stroop task) - Only badminton intervention improved performance on the Stroop incongruent test compared to the control. (Reverse Stroop test) - No differences between badminton and running. - A single session of badminton selectively enhances inhibitory function relative to running.
Hung et al., 2018 [43]	1. Intervention study 2. Young adult males (n = 20; age: 23.15 ± 2.48 years) 3. Moderate-intensity badminton match or running; 30 min/session; 2 times with a 7-day interval. 4. Serum BDNF and task-switching paradigm 5. Executive function	(Serum BDNF) - Badminton exercise resulted in significantly higher serum BDNF levels. (Task-switching paradigm) - A nearly significantly smaller global switch cost was observed relative to running. - Badminton enhances BDNF levels more than running.
Zubir et al., 2021 [46]	1. Observational study 2. Sedentary older adult participants (n = 36; F:M = 15:21; age: 55–69 years) 3. Regular players: badminton/running/cycling/swimming 4. Sternberg working memory task, Trail making test, Stroop test, and MoCA 5. Working memory, executive function, and cognitive aging	(Sternberg working memory) - Regular badminton and CSE groups showed better working memory. (Trail making test) - The regular badminton group showed better Trail making test scores and greater reaction time scores in the Stroop test. (MoCA) - No significant differences. - Regular badminton players showed superior cognitive performance to sedentary control in older adults.
Zubir et al., 2022 [47]	1. Observational study 2. Healthy badminton players aged >55 years, high- (n = 18; age: 64.2 ± 2.81 years) and low-playing time groups (n = 18; age: 63.3 ± 2.59 years) 3. Recreational, high- (9.72 ± 2.16 h/week) and low-playing time groups (3.34 ± 1.53 h/week) 4. Resting BP, mean arterial BP, Sternberg working memory task	(BP) - Resting systolic BP and mean arterial BP were significantly lower in the high-playing time group than in controls, whereas mean arterial BP tends to be lower in the low-playing time group. (Stemberg working memory task) - No significant differences for all groups. - The highly regular badminton playing group had better BP than the control group.

Table 2. *Cont.*

Authors	Participant and Study (1. Study Design; 2. Participants; 3. Exercise Experience or Intervention; 4. Main Outcome Measures, and 5. Cognitive Function)	Main Findings
Zubir et al., 2022 [48]	1. Observational study 2. Healthy older adult badminton players, high (n = 18; age: 64.2 ± 2.81 years) and low-playing time groups (n = 18; age: 63.3 ± 2.59 years) 3. Recreational, high- (9.72 ± 2.16 h/week) and low-playing time groups (3.34 ± 1.53 h/week) 4. Body fat percentage, lean body mass, fasting serum glucose	(Body fat percentage) - Lower in the high-playing time group than in the control and tended to be lower than the low-playing time group. (Lean body mass) - Higher in the high-playing time group than in the control. (Fasting serum glucose) - Lower in the high-playing time group than in the control. - Older adults who played more badminton showed favorable body composition and glycemic states.

Abbreviation: BP, blood pressure; HR; heart rate; TChol, total cholesterol; HDL, high-density lipoprotein; LDL, Low-density lipoprotein; TG, triglyceride; EEG, electroencephalographic recording; 6 MWT, 6 min walk test; SDS, Self-Rating Depression Scale; OSE, open-skill exercise; CSE, closed-skill exercise; BDNF, brain-derived neurotrophic factor; IGF-1, insulin-like growth factor 1; IL-6, interleukin-6; fNIRS, functional near-infrared spectroscopy; TDMS, Two-Dimensional Mood Scale; MoCA, the Montreal Cognitive Assessment.

5. Benefits of Badminton for Depression

Depression is a risk factor that can be modified to prevent and intervene with dementia [8], and earlier-life depression has become a crucial risk factor for dementia [30]. Because depressive symptoms are a major risk factor influencing subjective cognitive impairment in middle-aged (50–64 years) and older individuals (≥65 years), depressive symptoms should be managed from middle ages to prevent cognitive decline and dementia [49]. A previous study identified that an inclusive badminton program designed by the Badminton World Federation (moderate intensity, 50 min, twice weekly for 5 weeks) reduced depressive symptoms in young adults (19–26 years) with intellectual disabilities [17]. Besides increasing fun and social engagement motives, badminton benefits social health, relationships, personal development, mood regulation, and intrinsic motivation [16,17]. Therefore, badminton may prevent depression because loneliness directly contributes to the depressive state [50].

6. Summary and Conclusions

We reported that the intervention of badminton is beneficial in improving cognitive function and preventing cognitive decline. Furthermore, badminton players had a 6.2-year longer life expectancy, associated with the second highest life expectancy benefit following tennis in sedentary individuals ranging from young to old [51]. Badminton requires extreme steps, quick changes in direction jumps, and rapid arm swings from wide-range body positions. Although the incidence of badminton injuries increases with age [1], it is significantly lower than other OSE (e.g., soccer) [1]. Considering older adults, a previous study revealed that amateur senior badminton players were injured with a mean rate of 0.134/1000 h, with the highest affected lesions occurring in the knee and shoulder in approximately 20% and 12% in the lower and upper extremities, respectively [38]. Additionally, osteoarthritis is one of the causes of the most common disabilities in older adults, with high prevalence in the spine, followed by the hand, knee, shoulder, and hip [52]. Singles players require greater aerobic capacity and more extreme steps and overhead shots than doubles players [36,37]. A significant correlation was found between the severity of injuries and time absent from badminton [1].

Playing doubles in badminton may be less physically demanding for older adults, enabling habitual play without injury. Additionally, compared to singles players, doubles players engage in more tasks characterized by OSE in complex environments, potentially enhancing cognitive function due to the game's complexity. The analyzed data suggest that regularly playing recreational badminton for several hours weekly could positively impact modifiable risk factors for dementia. Furthermore, engaging in at least 30 min of moderate-intensity badminton weekly could help prevent cognitive decline. Thus, playing doubles as a recreational activity, habitually and without injury, might be sufficient and safe to prevent cognitive decline and extend life expectancy in older adults.

However, this study has limitations in strengthening the evidence for preventing cognitive decline and dementia through badminton intervention in older adults. First, there is limited research on the direct impact of badminton on cognitive function in adults. Second, few studies have investigated brain processes or functions, such as neurotrophic factors or functional imaging. Third, there is a lack of quantitative data on badminton intervention. Because recreational badminton matches can be categorized as high intensity in male adults [53], classifying their intensity is difficult. Fourth, no studies have examined the physiological demands and cognitive differences between singles, doubles, and mixed doubles in older people. Lastly, it is important to verify whether badminton is superior to other exercises in intervening in cognitive decline and dementia. Further multicenter longitudinal randomized analyses are needed to address these issues. Once resolved, a standardized and optimal badminton exercise program is expected to be established.

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