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Introduction

The brain has the ability to adapt to imposed demands by altering its neuroplasticity, which results in learning and acquiring new skills (Hötting, 2013). Evidence from both animal and human studies agree that exercise promotes neuroplasticity in the brain which then results in the improvement of different cognitive functions and thereby improving an individual's ability to respond to new demands (Hötting, 2013). Additional cross-sectional studies have shown cardiorespiratory fitness level (VO_2) is directly related to optimal brain function and higher cognitive performance as well as delaying the onset of neurodegenerative disorders (Basso, 2022). It is clear that exercise is a fundamental part of maintaining and improving health. In a study with older adults, an intervention of anaerobic exercise helped improve cognitive frailty (Yoon, 2018). Another study examining the effects of aerobic and anaerobic exercise on a young population group found that both anaerobic and aerobic exercise helped improve cognitive performance, but anaerobic exercise was more effective in decreasing reaction time and completion time of different tests than aerobic (Mekari, 2020). Many of these studies utilize similar cognitive tests. Common tests include the STROOP test, Corsi's blocking test, trail making tests, and the symbol digit modalities test (SDMT) among others. The standard STROOP test lists color words with different ink colors and tests the participants reaction time to read the ink color of each word. The Corsi's blocking test measures short-term memory. It involves a researcher tapping out a sequence with the participant mimicking the researcher. The sequence is made more complicated as time goes on and continues until the participant's performance declines. A trail making test is made up of two-timed parts. Part A is made up of 25 circles on a piece of paper and the participant is instructed to draw a line from one circle to the next in ascending numerical order. For part B, the 25 circles include numbers and letters and the participant is instructed to connect them in ascending order. The participants are timed when they start. A symbol modalities test has participants match specific geometric figures with numbers given a reference sheet within 90 seconds. Responses can be written or given verbally and are scored at the end.

Different modalities like yoga, badminton and interval running training all have proven to be effective methods of exercise training to improve cognitive function such as quicker processing speed and improved working memory (Bhatia, 2016; Wang, 2015). However, in individuals with dementia, neither aerobic nor anaerobic proved to have a significant beneficial impact on cognitive abilities (Lamb, 2018) suggesting that greater beneficial impacts of either exercise intensity is limited to those who are healthy to moderately healthy. Since each individual presents with a range of brain function as well as fitness, understanding the nature of the imposed exercise (aerobic, anaerobic) as well as the range of modalities or types of physical activity that result in improved brain function is helpful to the exercise science practitioners. Therefore, the purpose of this paper is to examine how exercise intensity and modality impact cognitive performance.

Effects of Anaerobic Exercise Training on Cognition

Anaerobic exercise involves short bouts of high intensity exercise, often greater than 80% of VO_{2max}. Resistance training can also be used as a high intensity training mode. High intensity interval training, or HIIT, provides numerous physical benefits such as increased strength and improved cardiorespiratory function. Within recent years, more research has been found highlighting the potential HIIT has for improving cognitive function. A randomized controlled trial conducted by Yoon and colleagues (2018) tested the effects of high resistance training on the cognition of older individuals with cognitive frailty. Cognitive frailty is characterized by concurrent physical frailty and potentially reversible cognitive impairment. Two different 4-month interventions included high-speed resistance exercise training group (n=22) and a control group (balance and band stretching, n=23). Frailty score, cognitive function, including memory, processing speed, cognitive flexibility, working memory, executive function were assessed at baseline, 8 weeks and 16 weeks. In the high-speed resistance exercise training group, participants exercised three times a week for 1 hour. Each session consisted of a 10 min warm up, 40 min of resistance training (seated row, one leg press, lateral raises, squats etc.) and a ten min cool down. The control group was instructed to continue with their daily activities and perform static and dynamic stretches using exercise bands twice weekly for one hour. Researchers found that exercise improved performance significantly in the tests for cognitive function (processing speed and executive function, both $p < 0.05$). Frailty symptoms included predominantly weakness (49% of participants), slowness (35%), low physical activities (26%), exhaustion (21%), and 9% shrinking when baseline measurements were taken. The scores of the Frontal Assessment Battery (FAB) test, which measures abstract reasoning, motor programming, and verbal fluency, significantly increased from baseline to 16 weeks in the intervention group (12.00 ± 2.45 to 13.70 ± 2.11). There was a significant decrease in processing speed over 16 weeks across the intervention group (pre 54.15±28.43sec; post 48.26±27.33sec). The intervention group also saw a significantly increase in grip strength (pre 21.45±6.58kg; post 23.60±7.76kg) isokinetic 60˚/sec peak torque (pre 65.05±25.82; post 71.20±36.68) and isokinetic 180˚/sec average power per rap (pre 68.32±40.60; post 82.09±44.63) compared to the control group from baseline to 16 weeks. The study concluded that high-speed resistance exercise training approaches are effective in improving cognitive function in older adults with cognitive frailty and that this type of program is a safe and feasible intervention to implement for older adults with cognitive frailty. In addition to anaerobic resistance training, HIIT training that stresses the cardiovascular system also has positive impacts on cognition. A 6 week study conducted by Mekari and colleagues (2020) investigated the effects of a high intensity interval (HIIT) exercise program compared to a moderate intensity continuous exercise (MICE) program on the cognitive performance of young healthy adults. 25 adults (age= 32±8 years) were randomized into two protocols, MICE and HIIT, on a stationary bike. An initial assessment of maximal aerobic capacity (VO_{2max}) was assessed using a protocol where the initial workload was set at 1W/kg body mass and was increased by 15W every minute until the participant was exhausted. Oxygen uptake (VO_2) was measured every 30 seconds using an automated cardiopulmonary system. The MICE protocol utilized continuous cycling at 60% peak power output for 34 minutes. Both exercise protocols were conducted three times a week. The time increased to 39 minutes after the second week and the intensity was increased by 15W for the last two weeks. The HIIT group completed 15 second intervals at 100% peak power output with 15 seconds of recovery in between. This was continued for 2 sets of 20 minutes with five minutes of recovery in between. After the first two weeks, the time was increased to 45 minutes and the intensity was increased by 15W during the last two weeks. The number of sessions per week (three) remained the same. Cognitive performance was tested using a computerized modified STROOP task and a trail making test. Post training results showed that reaction time was shorter for both HIIT (pre 980.43±135.27ms; post 860.04±75.63ms) and MICE (pre 1008.45± 218.76ms; post 987.77± 188.20ms). However, further analysis showed a shorter reaction time in the HIIT group for the switching task (executive task) compared to the MICE (pre 980.43±135.27ms; post 860.04±75.63ms). A trail making test was used to measure processing speed. Performance in Trail A did not change after training for both groups, but for Trail B performance was improved after training for both groups. A faster completion time for the Trail B test (seconds) was also isolated to the HIIT group (pre 42.35 ± 14.86s; post 30.35 ± 4.13s). Peak power output significantly increased for both MICE (pre 180±41.4; post 213±43.0) and HIIT (pre 207±44.9; post 217±42.2). However, for improving cognitive performance, the findings show that HIIT was more effective than MICE in inducing larger cognitive improvements within the same time constraints. Possible reasons for the improvement include a greater release of brain-derived neurotrophic factor (BDNF). BDNF is a growth factor that facilitates neuroplasticity and enhances optimal cognition (Mekari, 2020). Its release is also intensity dependent, so HIIT can produce higher levels of BDNF during exercise compared to MICE. Additionally, a higher cardiac output, like HIIT, results in a higher cerebral blood flow, which helps improve cognitive performance. While this study by Merkari et al. used a young adult population, additional studies have found that both aerobic and anaerobic exercise activities provide benefits for older adults. Cassilhas (2007) investigated the impact of a 24 week of resistance training at two different intensities on cognitive functions in the elderly. Sixty-two elderly individuals were randomly assigned to three groups: CONTROL (*N* = 23), experimental moderate (EMODERATE; *N* = 19), and experimental high (EHIGH; *N* = 20). The volunteers were assessed on physical, hemodynamic, cognitive, and mood parameters before and after a resistance exercise program. The exercise program targeted the main muscle groups used for everyday activities. Six exercises were included using specific equipment (chest press, leg press, vertical traction, abdominal crunch, leg curl, and lower back) The ACSM recommendations were followed for the exercises and for motivation. Training for the experimental groups consisted of three, 1 hour sessions per week.

The groups did a 10-min warm-up on the cycle ergometer followed by stretching exercises. Loads were 50% of 1 repetition max (RM) for the EMODERATE group and 80% of 1 RM for the EHIGH group. Both groups alternated body segments with two series of eight repetitions for each series. Participants rested for 1 min 30 s between series and for 3 min between one apparatus and the next. The CONTROL group did not do overload training but did attend sessions at the center (CEPE) once a week to do warm-up and stretching, following the same protocol as the experimental groups (six exercises alternated by segment with two series of eight repetitions, with the same intervals for rest). This CONTROL group model was used to dismiss the bias of neuromotor learning and social interaction factors that might hide the real effect of resistance training on the cognitive factors. The neuropsychological assessment used the following tests: Wechsler Adult Intelligence Scale III (testing central executive/digit span, forward and backward: assessing short-term memory), Wechsler Memory Scale-Revised (assessing visual modality of short-term memory), Toulouse-Pieron's concentration attention test (assessing attention) and Rey-Osterrieth complex figure (assessing long-term episodic memory). The researchers found more improvement in the cognitive performance of the experimental groups after the intervention with moderate and high resistance exercise compared with the CONTROL group on the following tests measured by a computer taking the average of correct answers: digit span forward (0.51±0.20 and 0.50±0.19 vs -0.47±0.19), Corsi's block-tapping task backward (0.97±0.25 and 0.95±0.22 vs0.0±0.24), similarities (1.08±1.32 and 1.05±1.45 vs -2.75±0.18) and Rey-Osterrieth complex figure immediate recall (8.38±1.26 and 8.31±1.22 vs 5.17±0.98). Only for the EHIGH group were errors in the Toulouse-Pieron test reduced (-4.85±6.27 vs 0.15±0.22). This better performance of the groups after the period of intervention suggests an improvement in short and long term memories, with better functioning of the central executive, and improvement in attention and lower neglect. However, no statistically significant differences were seen in the comparison of the two experimental groups, showing that both moderate and high intensities had a similar effect on cognitive performance in the elderly. While this study supports several others that both anaerobic and aerobic exercise can benefit the cognitive performance of healthy to moderately healthy older adults, there appears to be little to no impact of either exercise intensity on those with dementia. The role of exercise in reducing the cognitive decline of individuals with dementia remains unclear. This is due to the scarceness of randomized controlled trials with large enough participants and methodological quality to support a clear intervention route (Lamb, 2018).

Lamb and partners studied the effects of moderate to high intensity exercise on cognitive function on elderly people with mild to moderate dementia. Individuals were randomized to either an aerobic and strength conditioning group (n=329) or a control group (n=165). The primary outcome measure was the Alzheimer disease assessment scale. In the experimental group, individuals attended group sessions at the gym twice a week for at least an hour. Participants also did an hour of home exercises once a week. Exercises consisted of arm dumbbell exercises, cycling at a moderate and high intensity depending on tolerance level, and sit to stand with a weighted belt. Baseline measurements were taken and participants were followed up with 6 and 12 months after randomization. After 12 months, the mean Alzheimer disease assessment in the exercise group had increased to 25.2 ±12.3 in and 23.8 ±10.4 in the control group compared to the baseline of 21.8 ±7.7 and 21.4±9.6 respectively, showing that the exercise group continued to decline with treatment. It was concluded that while exercise can induce some physical improvements, it does not slow down cognitive impairments associated with mild to moderate dementia. In summary, both high intensity resistance training, high intensity aerobic training and even moderate aerobic training appear to offer improvements in cognition for both young and old. However, in the presence of underlying disease, exercise does not appear to have any impact. This may be due to the accumulation of neuronal and physiological damage negating any benefits exercise can induce (Sanders, 2020).

Aerobic Exercise Training Effects on Cognition

Aerobic training, such as running and walking, is one of the most common forms of exercise. The added movement increases cardiac output and blood flow redistribution to the exercising muscle. brain blood flow is also increased, and therefore the brain may be positively impacted by aerobic exercise. Sanders et al. (2020) conducted a randomized controlled trial to determine how the magnitude of exercise impacted the cognition of patients with dementia. Sixty nine patients with dementia (age= 82.3 ± 7.0 years) were recruited for a 24-week aerobic and strength training program with a low (weeks 1-12) and high-intensity (weeks 13-24) phase or placed into a control group (n=30) with no exercise or an exercise group (n=39). In the exercise group, patients participated in a walking and lower limb strength training program (RPE 9-11, target heart rate 57-63% HRmax) with 12 weeks low and 12 weeks high-intensity training (RPE 15-16, 83-89% HRmax) offered three times/week. The target intensity of sessions was determined in correspondence with the American College of Sports Medicine guidelines. Four lower limb exercises were performed during the strength sessions in a fixed sequence: knee extension while sitting, plantar flexion (toe standing), hip abduction, and hip extension. A chair was used for support. Each session, the muscle contractions were either isometric, concentric, or eccentric (12 isometric, 12 concentric, and 12 eccentric contraction sessions were offered throughout the exercise intervention). The target RPE was used to determine the intensity because no significant increases in heart rate were expected. In the low intensity phase, the target RPE was 9–11. In the high intensity phase, the RPE was 13–16. The control intervention consisted of flexibility exercises and recreational activities. The flexibility exercises included upper and lower body exercises such as neck or shoulder rotation and stretching knee flexors and extensors. No weights were used. Additionally, recreational activities such as board games or social visits were performed depending on the participants' preference. The cognitive aspects assessed, including verbal memory, visual memory, executive function, inhibitory control, psychomotor speed, were tested at baseline and after 6, 12, 18, 24, and 36 weeks. Tests included a global cognition test, Trail Making Test A, Digit Span Forward and Backward and the STROOP test. Post training results showed that the exercise intervention caused a significant increase in 6 minute walk time from baseline (278+/- 89.4m) to 24 weeks (289 +/- 95.0m). However, the results showed no significant effects of the exercise vs. control intervention on any of the cognitive measures. While this study suggests no benefits of exercise in dementia patients, not all studies agree.

A randomized control trial conducted by Nanna Sobol and colleagues (2018) tested the hypothesis that physical activity can improve cognitive function in individuals affected by mild Alzheimer's disease. The purpose of this study was to assess the effect of moderate-intensity aerobic exercise on cardiorespiratory fitness and the correlation between VO_{2peak} and changes in cognition and neuropsychiatric symptoms in patients. A group of 55 individuals with mild Alzheimer's (52-83 years) were randomized into a control group (n= 26) and an intervention group (n=29) that consisted of supervised moderate to high aerobic exercise (70–80% of maximal heart rate) over the course of 16 weeks. Measurements of VO_{2peak}, cognitive qualities such as mental speed and attention using the Symbol Digit Modalities Test (SDMT) were taken at baseline and at 16 weeks. Neuropsychiatric symptoms (Neuropsychiatric Inventory, NPI) were also taken at baseline and again at 16 weeks. The researchers found a 13% increase in VO_{2peak} in the intervention group (Pre VO_{2peak}= 21.9 ± 5.9; Post 24.8 ± 7.4). Data combined from the intervention and control group revealed positive associations between changes in VO_{2peak} and NPI (Rho = - 0.41, p = 0.042) and in SDMT (Rho = 0.36, p = 0.010). As seen in Figure 3 of the study, a higher VO2 max was associated with higher SDMT (Symbol Digit Modalities Test) scores, indicating a higher level of mental speed and attention. It was concluded that improvements in VO_{2peak} due to exercise appears to be associated with improvements in cognition and neuropsychiatric symptoms in individuals with mild Alzheimer's disease. Compared to healthy older adults, both aerobic and anaerobic exercise are able to have a greater beneficial impact on different aspects of cognitive performance.

Coetsee and colleagues conducted a study to determine the effects of different exercise modalities on cognitive function in healthy older adults. Sixty-seven inactive individuals were randomly assigned to a resistance training group (RT), high intensity aerobic training (HIIT), moderate continuous aerobic training (MCT) and a control (CON) for 16 weeks. The primary interest was to see if HIIT had a higher impact on older adults' cognition and physical fitness compared to MCT and RT. Cognitive performance was measured using a STROOP task and physical function with the Timed Up and Go test (TUG) and submaximal Bruce treadmill test. Participants in the RT group did upper and lower extremity resistance exercises using machines and free weights performed at 50%, 75% and 100% of the individual's 10 repetition maximum (RM). After 8 weeks the load was increased to 75%, 85% and 100%. The MCT group did continuous walking on a treadmill at 70-75% of maximal heart rate (HRmax) for 47 minutes.

The HIIT group performed four intervals of 4 min treadmill walking at 90-95% HRmax with recovery periods. The HIIT and RT groups showed showed the most significant improvements in reaction time from pre- to post-test on the STROOP Neutral subtask (from 28.42 ± 5.76 sec to 23.16 ± 2.85 sec vs 30.03 ± 5.22 sec to 25.51 ± 3.65 sec) respectively. The MCT and CON groups improved some, but not statistically significantly. Overall, there was a 18.51%, 15.05%, 6.33% improvement in lower level cognitive function for the HIIT, RT and MCT interventions, respectively. The performance of the CON group improved by 11.02%. During the STROOP Incongruent task, there was a 23.88%, 27.35%, and 17.80% improvement in higher level (executive) cognitive function for the MCT, RT and HIIT intervention respectively. It was concluded that MCT was most beneficial for the improvement of executive cognitive function, whereas HIIT had a higher beneficial effect on information processing speed. RT at a moderate intensity was more beneficial for improvement in information processing speed compared to MCT, and executive cognitive function compared to HIIT. The beneficial effects of both intensities of exercise are not just limited to adults but are also seen in children.

Exercise of both aerobic and anaerobic forms has been shown to greatly improve executive function and academic success in elementary school children. A randomized trial by Catherine Davis and colleagues (2011) tested the hypothesis that exercise would cause cognitive improvements, including in academic performance, in overweight children. One hundred seventy one sedentary, overweight children ages 7-11 years were randomized into either 13 ± 1.6 weeks of an aerobic exercise program, participating in either 20 min or 40 min per day, or a control condition (no activity). Blinded psychological evaluations including the Cognitive Assessment System and Woodcock-Johnson Tests of Achievement measured cognition and academic achievement in the children. Functional magnetic resonance imaging assessed brain activity during executive function tasks showed an increase in activity in the prefrontal cortex, which controls executive function, in the exercise group, consistent with research done on adults. Results also showed a dose response correlation between exercise and executive function, showing that students exposed to either the low or the high dose of the exercise program had higher Planning scores than the control (pre low: 98±1.6; post low: 102±1.7 and pre high: 101±1.6; post high: 107±1.4 compared to the control pre: 99±1.6; post 102±1.7). There was also evidence of higher bilateral prefrontal cortex activity in the exercise group as seen in Figure 2 after the exercise protocols. Additionally, there was a dose response benefit of exercise on mathematics achievement for students exposed to either the low or high dose of exercise (Pre control: 104±1.7; post 104±1.4; Pre low: 104±1.8; post 105±1.6; pre high: 106±1.6; post 107±1.4). They did not find a difference between the exercise dose groups which agrees with previous findings. Beyond helping to maintain a healthy body weight and reduce risks associated with obesity, these results suggest that exercise may be an effective and relatively simple way to support optimal cognitive development in children. These cognitive benefits are also seen in teens in similar studies.

Venckunas and colleagues conducted a study to determine whether 7 weeks of interval running training was effective at improving both aerobic fitness and cognitive performance. Eight individuals (age 15-18 years) were recruited for the experimental group. 10 additional secondary school students were recruited for the control group. The dependent variables in the study were changes in maximal oxygen uptake, running capacity, and cognitive abilities such as cognitive flexibility, working memory, and short-term memory. The independent variable was training intervention. The experimental group consisted of an interval running program testing their performance running 200 m and 2,000 m. Cycling maximal oxygen uptake to measure VO_2 and cognitive function was measured before and after the intervention. Cognitive performance was measured using the odd-even test, the Schulte-Gorbov test, the free recall test, and the forward digit-span task test examining unpredictable and predictable task switching and free recall. The control group was made up of 10 healthy age-matched subjects who continued their active lifestyle and were tested in the same way as the experimental group, but did not complete any regular training. For the experimental group, the subjects performed a 20 min warm up, then individually ran as fast as possible. The 200m and 2000m running performance and cycling maximal oxygen uptake increased together with improved results on cognitive flexibility for unpredictable task switching seen in the amount of correct answers (pre 93.4±3.7; post 95.5±2.3) and reduced reaction time for predictable task switching (pre 231.8±37.7ms; post 210.07±31.0ms). The main finding of this study was that cognitive flexibility improved after an interval training program of 7 weeks. This was reflected in the increased number of correct answers for a task (pre 93.4±3.7 post 95.5±2.3).

Aerobic exercise has been shown to improve executive function in both children and adults, increasing their VO_{2max}, leading to increased blood flow to the brain and improving their cardiovascular system resulting in enhanced cognitive performance. Both anaerobic and aerobic exercise induce benefits with aerobic training appearing to be most effective in improving executive cognitive function and anaerobic enhancing information processing speed.

Exercise Modality Impact on Cognition

Exercise modes can vary and affect different muscle groups and amount of muscle involvement and have the potential to improve cognitive performance differently. A randomized controlled trial conducted by Zhang and colleagues examined how different sports affected cognitive performance of 150 individuals ages 60-70 years. The participants were divided into five groups: swimming (group A), running (group B), square dancing (group C) and tai chi (group D) and control (group E) with 30 people in each group. Participants received the exercise intervention for 18 months with measurements taken at baseline, 6, 12, and 18 months after intervention. The P300 test was used to measure cognitive function in the participants. The exercise intensity was held at 65-75% of maximal heart rate. Participants in the exercise groups did 30-60 min of exercise for four days a week. Results showed after the exercise intervention, reaction time (in ms) for the P300 test for the participants was remarkably shorter (Group A: pre 361.1 ± 22; post 328 ± 23; Group B: pre 360.3 ± 21; post 321 ± 24; Group C: pre 370.2 ± 20; post 301 ± 21). The tai chi group (Group D) showed the most significant improvement compared to baseline (pre 369.4±25ms; post 310 ± 25ms) compared to the other exercise interventions. This study showed that exercise of several different modalities can improve the cognitive function of older adults. Since exercise in any form helps increase blood flow to the brain and improves BDNF factors, these recreational activities can be successful in enhancing cognitive function. Likewise, additional studies researched whether traditional exercise or a different modality of exercise such as yoga could be beneficial for cognitive performance.

Bhatia and colleagues (2016) conducted a single-blind randomized controlled trial to determine whether yoga training or physical exercise training enhanced cognitive function in patients with schizophrenia. Consenting, clinically stable, adult outpatients with schizophrenia (*n* = 286) completed baseline assessments and were randomized to treatment as usual (TAU), supervised yoga training with TAU (YT) or supervised physical exercise training with TAU (PE). The exercise interventions, were given by qualified instructors to the participants in 1 hr sessions every day for 21 days except for Sunday. The PE intervention included brisk walks, followed by jogging and directed aerobic exercises. The YT group utilized different postures and breathing exercises. After 21 days of supervision, the participants in the PE and YT groups were advised to continue at home and to keep record of their activity. Compliance records were collected at 3 and 6 months follow-up. Cognitive aspects such as attention, working memory, emotion, spatial memory and face memory were tested. After 6 months, results showed that speed index of attention domain in the YT group showed greater improvement (pre -1.34±1.90 post -1.05±1.54) than PE (pre -0.80±1.48 post -1.10±1.38) at follow-up. Compared to the TAU group, the YT intervention performed significantly better for spatial memory at 21 days and 6 months (pre -0.68±2.2, post -0.2±1.63; pre -0.68±2.2, post 0.11±1.54), for face memory at 21 days, 3 months and 6 months (pre -2.40±5.72 post -0.99±3.12; pre -2.40±5.72 post 0.11±2.03; pre -2.40±5.72, post -0.28±2.17) and emotion at 6 months (pre -1.02±2.48 post -0.02±1.43) in the speed index. However, improvements in the PE group were greater than the YT group for face memory at 21 days and at 3 months (pre -0.88±1.33, post -0.20±1.67; pre -0.88±1.33 post-0.11±1.43) and for working memory at 6 months (pre -1.52±1.29 post 1.00±1.06) both exercise interventions proved to be significantly better than the control, TAU group, over the course of the program. The trial indicated sustained benefits of brief supervised yoga training and physical exercise for several cognitive domains in the same individuals. Understanding the mechanism of the beneficial effects of these interventions may help individualize therapies in the future. Sport activities can also be used as means to condition through recreation activities and result in cognitive improvements.

A study conducted by Chun-Hao Wang and others (2015) studied cognitive processing and neural oscillations, between badminton players and sedentary individuals. Neural oscillations are repetitive patterns of neural activity, and can show differences between an individual's visio-spatial processing. The study compared time-frequency electroencephalographic (EEG) activity from collegiate female badminton players (*n* = 12, aged 20.58 ± 2.75 years) and age and gender matched sedentary non-athletic controls (*n* = 13, aged 19.08 ± 2.10 years) while completing visuo-spatial attention and working memory tasks. Initially, a 7 day physical activity recall questionnaire was used to estimate levels of physical activity in order to successfully screen participants. Only eligible participants who passed the criteria for the questionnaire went on to complete the cognitive task. A non-delayed and a delayed matching-to-sample test, which consisted of one visuo-spatial attention (non-delay) condition and one visuo-spatial working memory (delay) condition were used to investigate the differences visuo-spatial capacity. In the attention condition, two rectangles were shown on the screen simultaneously: one was placed in the center and another was placed either left or right of the center. Participants determined whether the red dots in the two different rectangles were spatially identical or not. In the working memory condition, the first stimulus (S1) was presented for 180 ms on either the right or left of the central fixation, and the second stimulus (S2) appeared for 500 ms in the center of the screen and replaced the fixation during the 1.5 s-delay. Participants then studied the red (in web version) dot position in the first stimulus (S1), and then decided whether the position of the red dot in the second stimulus (S2) was the same. Oscillatory power, defined as the square of the modulus of the resulting complex number, was then averaged across trials. The researchers found that players responded faster than controls on the task without an increase in error responses in both conditions (non- delayed players: 496.95 ±52.91sec; control: 577.25 ±85.66sec. Delayed players: 766.87 ±47.17sec; control: 810.64±58.23sec). Additionally, the players, relative to controls, exhibited higher task-related modulations in theta power, a measurement of neural oscillation (2.01 ± 1.07 dB vs. −0.30 ± 1.26 dB) and lower beta power (−1.45 ± 1.02 dB vs. −0.42 ± 1.32 dB) the working memory condition compared to the control. Significantly, the behavior-EEG correlations revealed that better attention performance was associated with lower beta power, while greater working memory was related to higher theta power. It was concluded that individuals who partake in long-term participation in sport training for a sport with high visuo-spatial demands, such as badminton players, show better visuo-spatial processing since the badminton players outperformed the nonathletic control on visuo-spatial cognitive tasks with the data consistent with faster processing speed in athletes. This study shows that cognitive functions relate to sports participation, which would prove to be beneficial for those who have cognitive difficulties or individuals with attention deficit hyperactivity disorder.

Conclusion

In conclusion, exercise of many kinds can significantly improve people's cognitive abilities among varying ages. Moderate intensity aerobic exercise has been beneficial in improving the mental speed and attention of individuals with Alzheimers (Sobol, 2018) as well as in children (Davis, 2011) and healthy older adults (Coetsee, 2017). In comparison, anaerobic exercise successfully improved the cognitive frailty of older adults (Yoon, 2018). For healthy young adults, it is suggested that HIIT or anaerobic exercise, may be more efficient in improving cognitive performance than moderate intensity training or aerobic since the HIIT group observed shorter reaction times and completion times for the given tests (Mekari, 2020). In multiple studies, both anaerobic and aerobic exercise have showed similar improvements in participants cognitive performance in the elderly (Cassilhas, 2007) and in children (Davis, 2011). Another study observed that moderate training most improved executive cognitive function, whereas

HIIT had the most impact on information processing speed (Coetsee, 2017). Additionally, different modalities like badminton, yoga, tai chi, swimming, running, and even square dancing all helped improve cognitive function in some aspect. These improvements are due to several things including increased VO_{2max}, which is directly related to cognitive function and performance (Venckunas, 2016) in addition to neuroplasticity which is enhanced by exercise and helps the body and mind better respond to new demands (Hötting, 2013). Increased blood flow to the brain as a result of exercise also helps increase BDNF factors which help facilitate neuroplasticity and therefore better cognitive performance (Mekari 2020). Higher intensity, or anaerobic exercise appears to have a heightened ability to release more BDNF factors compared to aerobic (Mekari, 2020). While both intensities can have beneficial impact, it appears to be limited to healthy to moderately healthy individuals, with no significant benefit observed for those with dementia. This could be due to the presence of accumulated neuronal and physiological damage which would negate any benefits of exercise (Sanders, 2020). Whether anaerobic or aerobic, both intensities have the potential to significantly improve different aspects of cognitive abilities for individuals of all ages who are in moderately good health. For the exercise practitioner, this information can help in designing individualized exercise plans, with outcomes of improved fitness as well as cognitive function.

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