RESEARCH ARTICLE

The impact of long-term endurance training on cognitive function and emotional state in community-dwelling elderly

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Cognitive decline and emotional disorders are prevalent in the aging population. Physical exercise has emerged as a promising intervention to promote brain health, but the long-term effects of aerobic training on cognitive and emotional functioning in older adults remain unclear. This study aimed to investigate the effects of a 12-month endurance exercise program on cognitive performance and emotional well-being in community-dwelling older adults. 120 sedentary older adults including 44 males and 76 females with mean age of 68.4 ± 5.2 years old were randomly assigned to either a 12-month supervised endurance training program (n = 60) or a control group (n = 60). The control group received health education and maintained their usual physical activity level. Cognitive function was assessed using a comprehensive neuropsychological test battery evaluating attention, executive function, processing speed, memory, and visuospatial ability. Emotional state was measured using validated questionnaires for depression, anxiety, stress, and quality of life. Cardiorespiratory fitness (maximal oxygen uptake (VO2 max)) was determined by a maximal exercise test. Assessments were conducted at baseline, 6 months, and 12 months. The results showed that the endurance training group exhibited significant improvements in VO2 max compared to that in control group (*P* < 0.01). Exercisers demonstrated better performance on tests of attention, executive function, memory, and processing speed at both 6 and 12 months than that of baseline (*P* < 0.01) and control group (*P* < 0.01). The exercise group also reported significantly lower levels of depression, anxiety, stress and higher quality of life scores at follow-up assessments (*P* < 0.01). Gains in VO2 max mediated the cognitive and emotional benefits of exercise (*P* < 0.05). The 12-month endurance exercise program enhanced cognitive functioning and emotional well-being in older adults, likely mediated by gains in cardiorespiratory fitness. Promoting regular aerobic exercise might be an effective strategy to maintain brain health and quality of life with advancing age.

Keywords: endurance training; cognitive function; emotional well-being; cardiorespiratory fitness; VO2 max.

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Introduction

Global population ageing is a rapidly accelerating phenomenon, with projections suggesting that the number of people aged 60 and over will more than double, from approximately 900 million in 2015 to a staggering 2 billion by 2050 [1]. Age advances emerge as the primary risk factor for cognitive decline and dementia, conditions that severely undermine independence and substantially erode the quality of life for older adults [2]. Late-life depression and anxiety are also prevalent mental health issues that frequently co-occur with cognitive deficits [3]. As the elderly population continues to grow, identifying modifiable lifestyle factors to promote "successful aging" and reduce the burden of age-related cognitive and emotional disorders is a critical public health priority.

Adherence to a regimen of physical exercise has consistently exhibited a positive association with improved brain health within the elderly demographic [4]. Interventions incorporating aerobic activities have evinced their aptitude to facilitate enhancements in cognitive performance, particularly in domains such as executive functioning, processing speed, and memory, not only among healthy older individuals but also those afflicted with mild cognitive impairment [5-7].Exercise may benefit cognition by increasing brain volume and connectivity, reducing inflammation, modulating neurotransmitters, and stimulating production of growth factors involved in neuronal survival and plasticity [8, 9]. Enduring commitment to endurance training has garnered widespread recognition for its salutary effects on emotional well-being. Within the elderly demographic, elevated degrees of physical activity exhibit an inverse correlation with the prevalence of depressive and anxiety-related symptomatology and disorders [10, 11]. Evidence from randomized controlled trials has corroborated aerobic exercise as an efficacious therapeutic approach for late-life depression, engendering clinical outcomes commensurate with those achieved through antidepressant pharmacotherapy and psychotherapeutic interventions [12, 13]. The mood-enhancing effects of exercise are thought to be related to physiological adaptations including altered serotonergic and noradrenergic neurotransmission, reduced HPA axis reactivity, and increased neuroplasticity in emotion regulation regions [14]. Several gaps in knowledge regarding the effects of long-term exercise on cognitive and emotional health in older adults remain unaddressed. Most exercise studies in older populations have been short-term interventions lasting less than 6 months, limiting the understanding of the impact of sustained, long-term exercise programs extending beyond a year. Further, prior studies have often used non-aerobic activities as control conditions, making it difficult to isolate the specific effects of aerobic exercise. Moreover, cognitive function and emotional state are usually investigated separately, despite their frequent co-occurrence and shared underlying neural mechanisms.

This study sought to address these issues by examining the effects of a 12-month, moderate-intensity endurance training program on comprehensive measures of cognitive performance and emotional well-being in sedentary older adults compared to a non-exercise control group. It was hypothesized that sustained engagement in long-term aerobic exercise would yield widespread improvements in cognitive functioning, most notably in fluid abilities encompassing executive function, processing speed, and memory domains. Furthermore, enhancements in emotional well-being were postulated, manifested through reduced levels of depression, anxiety, and stress, coupled with an elevated quality of life, when contrasted with a sedentary control group. Gains in cardiorespiratory fitness (VO2 max) were also expected to mediate the cognitive and emotional benefits of exercise. Elucidating the long-term effects of aerobic exercise on cognitive and emotional health in older adults has important implications for the development of lifestyle interventions to promote successful aging and reduce the burden of age-related cognitive and mood disorders. The findings of this study could inform public health guidelines and clinical recommendations regarding the optimal type, intensity, and duration of exercise for maintaining brain health in late life.

Materials and methods

Participants

Sedentary, community-dwelling adults aged 60-80 years were recruited through local advertisements in Zhengzhou, Henan province, China and screened for eligibility. Individuals were excluded if they were currently diagnosed with or had a history of neurological or psychiatric disorders, had significant health conditions that contraindicated exercise, reported engaging in regular physical activity (> 20 min/day, ≥ 2 days/week) in the past 6 months, scored ≤ 24 on the Mini-Mental State Exam (MMSE), indicating possible cognitive impairment, had physical limitations that prevented walking. The final sample size consisted of 120 eligible participants including 44 males and 76 females with 22 males and 38 females in each of the endurance training and control groups. All participants were provided with written informed consent and completed baseline assessments. Using a computer-generated sequence, they were randomly allocated to either the endurance training (n = 60) or control (n = 60) group. Assessors were blinded to group assignment. All procedures of this study were approved by the Ethics Committee of Henan Vocational College of Water Conservancy and Environment, Zhengzhou, Henan, China.

Interventions

For a period spanning 12 months, the endurance training group engaged in three weekly supervised exercise sessions. Each session initiated with a 5-minute warm-up segment followed by 30 minutes of moderate-intensity walking/jogging and culminated with a 5-minute cool-down phase. The intensity level underwent meticulous monitoring through heart rate measurements and perceived exertion ratings with a gradual escalation from 50 - 60% of maximum heart rate (HRmax) during the initial 4-week period, progressing to 60 - 75% HRmax for the remaining duration of the program. The control group participants were instructed to maintain their habitual daily activities and refrain from commencing any new exercise regimens for the entire study period with monthly phone calls to monitor activity levels and provide educational materials about healthy aging. Both groups were asked to refrain from making any major lifestyle changes and to inform the study team of any new medical issues or medications.

Evaluation of outcomes

Comprehensive battery of neuropsychological tests and questionnaires were administered at the times of baseline, 6 months, and 12 months, respectively, which covered the primary cognitive outcomes including attention, executive function, processing speed, memory, and visuospatial ability. Attention was tested using Trail Making Test Part A [15] and Digit Span Forward [16]. Executive function was examined using Trail Making Test Part B [15], Stroop Color-Word Test [17], and Verbal Fluency Test [18]. Processing speed was measured using Digit Symbol Substitution Test [16] and Grooved Pegboard Test [19]. Memory was tested using Rey Auditory Verbal Learning Test [20] and Logical Memory [16]. Visuospatial ability was measured using Block Design [16] and Hooper Visual Organization Test [21]. In addition, emotional state was evaluated with Geriatric Depression Scale [22], Beck Anxiety Inventory [23], Perceived Stress Scale [24], and World Health Organization (WHO) Quality of Life-BREF (https://www.who.int/tools/whoqol) [25]. The cardiorespiratory fitness (VO2 max) was evaluated through a graded maximal exercise test conducted on a treadmill, complemented by a TrueOne 2400 metabolic cart (ParvoMedics, Salt Lake City, UT, USA) for the analysis of respiratory gas exchange. The criteria employed to confirm the attainment of VO2 max comprised with (1) reaching a plateau in oxygen uptake despite further escalations in workload intensity, (2) a respiratory exchange ratio exceeding 1.10, and (3) a heart rate within 10 beats per minute of the age-predicted maximum. The body mass index (BMI) was calculated by measurements of height and weight. The Physical Activity Scale for the Elderly (PASE) questionnaire [26] was selected to track physical activity levels external to the study-mandated exercise sessions. Adherence to the training regimen was quantified as the percentage of sessions attended out of the total possible 144 sessions.

Statistical analysis

SPSS version 25.0 (IBM, Armonk, NY, USA) was employed for statistical analysis in this study. Comparisons of baseline characteristics between groups were facilitated through independent t-tests for continuous variables and chi-square tests for categorical variables. Cognitive and emotional outcomes were subjected to mixed-model repeated-measures ANOVA with time (baseline, 6 months, 12 months) serving as the within-subjects factor and groups of endurance training and control as the between-subjects factor. *P* values were used to identify significant differences between the groups with $P < 0.05$ considered as statistically significant difference and $P < 0.01$ considered as very significant difference. A Bonferroni correction was applied to account for multiple comparisons within each cognitive domain and emotional measure, resulting in an adjusted significance threshold of $P < 0.01$. PROCESS macro version 3.5 for SPSS (www.processmacro.org) was used for mediation analysis to examine whether modifications in VO2 max mediated the effects of exercise on cognitive and emotional outcomes exhibiting significant group disparities. The groups of endurance training and control were set as the independent variables, while the changes in VO2 max from baseline to 12 months as the mediators and changes in the cognitive or emotional variable as the dependent variables. The age, sex, education, and baseline scores were used as covariates.

Results and discussion

Sample characteristics

Of the 120 participants, 109 (91%) completed the 12-month trial with 55 in endurance training group and 54 in control group. The reasons for drop-out were medical issues unrelated to the intervention (n = 6), loss of interest (n = 3), and relocation (n = 2). Completers and non-completers did not exhibit any significant differences across baseline characteristics. The participant cohort had a mean age of 68.4 ± 5.2 years old and an average educational attainment of 15.0 ± 2.8 years with 62% identifying as female. The average body mass index (BMI) was 26.8 ± 4.3 kg/m^2, indicating an overweight status among participants. At baseline, the endurance training and control groups were well-matched concerning demographic factors, cognitive performance, mood symptomatology, and fitness markers with no significant differences (Table 1).

Adherence and safety

Adherence to the 12-month endurance training program was 83% (SD = 14%). The average intensity of exercise was 65% (SD = 8%) of HRmax. No serious adverse events occurred in each group. The endurance training group reported more joint pain (n = 12) and muscle soreness (n = 18) than that in controls (6 joint pain and 5 muscle soreness), but these symptoms were mild and did not cause any participants to discontinue the program.

Cardiorespiratory fitness

The endurance training group had significantly greater increases in VO2 max than that in controls at both 6 months ($P < 0.01$) and 12 months ($P < 0.01$). VO2 max increased by 18% from baseline to 12 months in the exercise group compared to a 4% increase in controls. These findings aligned with prior studies reporting robust improvements in cardiorespiratory fitness with aerobic exercise training in older adults [20]. The large effect sizes observed suggested that the endurance training program was highly effective in enhancing cardiovascular efficiency, likely due to the sustained duration and moderate-to-vigorous intensity of the walking/jogging protocol. Elevated cardiorespiratory fitness has been associated with reduced risk of cognitive impairment, dementia, and mortality in late life [23], underscoring the potential of aerobic exercise to promote successful aging.

Cognitive function

Table 1. Baseline characteristics of the study sample.

Variable	Endurance training (n = 60)	Control (n = 60)	*P* value
Age (years old)	68.5 ± 5.4	68.2 ± 5.1	0.78
Female	37 (62%)	37 (62%)	1.00
Education (years)	15.1 ± 2.9	14.9 ± 2.7	0.69
BMI (kg/m^2)	26.6 ± 4.1	27.0 ± 4.5	0.61
VO2 max (ml/kg/min)	23.5 ± 4.6	23.1 ± 4.3	0.64
MMSE	28.2 ± 1.5	28.4 ± 1.4	0.45

Notes: BMI: body mass index. MMSE: mini-mental state exam.

Table 2. Cognitive outcomes at baseline, 6 months, and 12 months.

Measure	Group	Baseline	6 months	12 months	Group x Time *P* value
Attention					
TMT-A (sec)	Exercise	38.2 ± 10.4	34.5 ± 9.8**	33.6 ± 9.5**	0.002
	Control	37.9 ± 11.1	37.0 ± 10.7	36.8 ± 10.5	
Digit Span Forward	Exercise	9.8 ± 2.2	10.2 ± 2.3	10.3 ± 2.4*	0.02
	Control	9.9 ± 2.1	10.0 ± 2.2	10.0 ± 2.1	
Executive function					
TMT-B (sec)	Exercise	87.4 ± 28.5	78.2 ± 26.1**	73.6 ± 25.0**	< 0.001
	Control	88.1 ± 29.3	85.9 ± 28.7	84.2 ± 28.0	
Stroop C-W (items)	Exercise	32.5 ± 8.2	35.2 ± 8.8**	37.1 ± 9.4**	0.006
	Control	32.8 ± 7.9	33.4 ± 8.1	33.9 ± 8.4	
Verbal Fluency	Exercise	42.0 ± 10.6	45.3 ± 11.4**	48.2 ± 12.5**	< 0.001
	Control	41.6 ± 11.2	42.1 ± 10.9	42.8 ± 11.3	
Processing speed					
Digit Symbol (items)	Exercise	52.4 ± 10.3	55.8 ± 11.0**	58.5 ± 11.7**	< 0.001
	Control	51.9 ± 9.7	52.6 ± 9.9	53.1 ± 10.2	
Pegboard (sec)	Exercise	89.5 ± 14.8	84.7 ± 13.5**	80.6 ± 12.1**	0.002
	Control	90.2 ± 15.5	88.4 ± 14.9	87.1 ± 14.0	
Memory					
RAVLT - Total (words)	Exercise	43.2 ± 9.1	47.5 ± 10.3**	50.8 ± 11.4**	0.004
	Control	42.8 ± 8.7	43.7 ± 9.0	44.5 ± 9.4	
LM - Delayed (story units)	Exercise	24.1 ± 6.8	26.4 ± 7.5**	28.0 ± 8.2**	0.008
	Control	23.7 ± 7.2	24.2 ± 7.0	24.8 ± 7.3	
Visuospatial ability					
Block Design	Exercise	28.6 ± 8.0	29.5 ± 8.4	30.3 ± 8.9	0.21
	Control	28.1 ± 7.6	28.4 ± 7.8	28.8 ± 8.1	
Hooper (items)	Exercise	23.4 ± 5.2	24.1 ± 5.5	24.6 ± 5.8	0.18
	Control	23.0 ± 4.9	23.2 ± 5.0	23.5 ± 5.2	

Note: TMT: Trail Making Test. C-W: Color-Word. RAVLT: Rey Auditory Verbal Learning Test. LM: Logical Memory. *$P < 0.01$. **$P < 0.001$ compared to control group at the same time point.

Significant group-by-time interactions were found for the endurance training group compared with the control group in the attention test (Trail Making A) (P = 0.002), executive function (Trail Making B) ($P < 0.001$), Stroop Color-Word ($P = 0.006$), Verbal Fluency ($P < 0.001$), processing speed (Digit Symbol) ($P < 0.001$), Pegboard ($P = 0.002$), memory (RAVLT total) ($P = 0.004$), and Logical Memory delayed ($P = 0.008$). Exercisers performed significantly better than controls on these measures at both 6 and 12 months ($P < 0.01$). From baseline to 12 months, the endurance training group improved 12% on Trail Making A, 16% on Trail Making B, 14% on Stroop Color-Word, 15% on Verbal Fluency, 12% on Digit Symbol, 10% on Pegboard, 18% on RAVLT, and 16% on Logical Memory, whereas the control group showed minimal changes of 1-5% on these tests. No significant group differences were observed for visuospatial ability tests (Table 2). The cognitive domains most responsive to endurance training in this study including executive function, processing speed, and memory aligned with those frequently reports to be benefit from shorter-term aerobic exercise in prior trials [5-7]. However, the effect sizes observed in this study were larger than the small-to-moderate effects typically seen in interventions lasting < 6 months [6]. Sustained aerobic exercise over a longer time period may lead to greater cumulative physiological adaptations that translate to larger cognitive gains. It has been hypothesized that long-term exercise exerts neuroprotective effects by chronically reducing inflammation and oxidative stress, improving cerebrovascular function, and promoting neurogenesis and synaptogenesis [8]. These mechanisms might be enhanced with extended training and underlie the larger cognitive benefits found with 12 months versus 6 months of endurance exercise in the present study. Notably, no significant effects of endurance training on visuospatial ability were found in this study. Some studies have reported exercise-related enhancements in visuospatial skills [15], while others have not [16]. Visuospatial performance tends to be preserved longer in aging and may require more intensive or targeted cognitive training to show improvements. It is also possible that 12 months is not sufficient to alter this cognitive domain, which appears to be less sensitive to exercise than executive and memory abilities.

Emotional state

The endurance training group reported significantly greater reductions in depression (GDS) ($P < 0.001$), anxiety (BAI) ($P < 0.001$), and stress (PSS) ($P < 0.001$) and increases in quality of life (WHOQOL-BREF) ($P < 0.001$) compared to that of controls at 6 and 12 months. Emotional improvements in the exercise group ranged from 25 - 40% versus 5 - 10% in controls from baseline to 12 months. The emotional benefits of long-term endurance training were particularly striking with exercisers showing 25 - 40% reductions in depression, anxiety, and stress symptoms compared to only 5 - 10% changes in controls. The magnitude of these mood enhancements was substantially larger than previously reported in exercise intervention studies for late-life depression, which typically showed moderate effects [12, 13]. Our findings suggested that sustained aerobic exercise had more potent and enduring impacts on emotional well-being. Regular exercise has been shown to alleviate depression and anxiety by increasing monoaminergic neurotransmission, reducing chronic stress responses, and promoting plasticity in emotion regulation brain regions [14]. These physiological adaptations may progressively accumulate over time, producing incremental emotional benefits, consistent with our findings of continued mood improvements at 6 and 12 months.

Mediation by VO2 max

Change in VO2 max from baseline to 12 months significantly mediated the effects of endurance training on executive function (Trail Making B indirect effect), Stroop Color-Word indirect effect, processing speed (Digit Symbol indirect effect), memory (RAVLT indirect effect), Logical Memory indirect effect, depression (GDS indirect effect), and quality of life (WHOQOL-BREF indirect effect) with VO2 max values as -0.14 ($P = 0.02$), -0.18 ($P = 0.01$), 0.22 ($P = 0.003$), 0.31 ($P = 0.004$), 0.25 ($P = 0.01$), -0.20 ($P = 0.01$), 0.27 ($P = 0.006$), respectively. The cognitive and emotional benefits of aerobic exercise appeared to be mediated by gains in cardiorespiratory fitness. Changes in VO2 max accounted for 30 - 50% of the effects of endurance training on executive function, processing speed, memory, depression, and quality of life. These results aligned with prior studies reporting that the magnitude of fitness improvements predicted the degree of cognitive enhancement from exercise [17, 18]. Fitter individuals also tended to have lower incidence of depression and higher well-being [19]. The cardioprotective effects of exercise such as reduced blood pressure, inflammation, and insulin resistance have been linked to better brain health [20]. Although the precise neurobiological mechanisms awaited further investigation, our findings indicated that improving cardiovascular fitness was an important pathway by which long-term aerobic exercise benefited cognition and mood in older adults. The 12-month endurance training program exhibited a high degree of tolerance among sedentary older adults as evidenced by the remarkable 83% adherence rate and the absence of any severe adverse occurrences. The tailored progression and moderate intensity likely contributed to the intervention's acceptability and safety profile. Participants were empowered to steadily elevate their fitness capacities without experiencing excessive strain or sustaining injuries. Furthermore, the group-based format might have served as a catalyst for heightened motivation and enjoyment, facilitated by the social interaction and support garnered therein. From a public health perspective, walking is an accessible, low-cost activity that can be readily incorporated into the daily lives of older people to promote cognitive and emotional well-being. Strengths of this study included the randomized, controlled design, long intervention duration, comprehensive neuropsychological and mood assessment, objective fitness measurement, and excellent retention rate. The participants were representative of the general older adult population in terms of demographic characteristics and physical health status. The endurance training program used a simple walking/jogging protocol that could be easily implemented in community settings. However, this study included the predominantly well-educated sample, which might restrict generalizability to more diverse populations. The control group received health education but not an active comparison intervention, so some of the effects might be due to social interaction. More targeted control conditions such as non-aerobic exercise and cognitive training would help to isolate the specific effects of endurance activity. Further, the study was constrained by limited statistical power, precluding the detection of discrepancies in the prevalence of clinically diagnosed cognitive impairment or mood disorders. More extensive trials with prolonged follow-up periods are warranted to determine whether sustained engagement in exercise can forestall or delay the onset of such conditions. Furthermore, the integration of neuroimaging techniques could shed light on the underlying neural mechanisms driving the observed cognitive and emotional changes.

This randomized controlled investigation provided evidence that a 12-month, moderate-intensity endurance training program elicited significant improvements in cognitive performance and emotional well-being among sedentary older adults. The cognitive gains were most pronounced in fluid abilities such as executive function, processing speed, and memory, while the emotional benefits encompassed substantial reductions in depressive symptoms, anxiety, and stress levels, accompanied by enhancements in quality-of-life indices. These cognitive and mood enhancements were mediated in large part by gains in cardiorespiratory fitness. The findings suggested that prolonged aerobic exercise had broad benefits for brain health in late life and should be encouraged as part of a healthy aging lifestyle. Promoting long-term exercise participation might help to reduce the burden of age-related cognitive and emotional disorders and enhance quality of life in the rapidly growing older population.

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References

1. United Nations, Department of Economic and Social Affairs, Population Division. 2015. World Population Ageing 2015.
2. Harada CN, Natelson Love MC, Triebel KL. 2013. Normal cognitive aging. Clin Geriatr Med. 29(4):737-752.
3. Gulpers B, Ramakers I, Hamel R, Köhler S, Oude Voshaar R, Verhey F. 2016. Anxiety as a predictor for cognitive decline and dementia: A systematic review and meta-analysis. Am J Geriatr Psychiatry. 24(10):823-842.
4. Northey JM, Cherbuin N, Pumpa KL, Smee DJ, Rattray B. 2018. Exercise interventions for cognitive function in adults older than 50: a systematic review with meta-analysis. Br J Sports Med. 52(3):154-160.
5. Smith PJ, Blumenthal JA, Hoffman BM, Cooper H, Strauman TA, Welsh-Bohmer K, *et al*. 2010. Aerobic exercise and neurocognitive performance: a meta-analytic review of randomized controlled trials. Psychosom Med. 72(3):239-252.
6. Colcombe S, Kramer AF. 2003. Fitness effects on the cognitive function of older adults: a meta-analytic study. Psychol Sci. 14(2):125-130.
7. Zheng G, Xia R, Zhou W, Tao J, Chen L. 2016. Aerobic exercise ameliorates cognitive function in older adults with mild cognitive impairment: a systematic review and meta-analysis of randomised controlled trials. Br J Sports Med. 50(23):1443-1450.
8. Stillman CM, Cohen J, Lehman ME, Erickson KI. 2016. Mediators of physical activity on neurocognitive function: A review at multiple levels of analysis. Front Hum Neurosci. 10:626.
9. Cotman CW, Berchtold NC, Christie LA. 2007. Exercise builds brain health: key roles of growth factor cascades and inflammation. Trends Neurosci. 30(9):464-472.
10. Schuch FB, Vancampfort D, Firth J, Rosenbaum S, Ward PB, Silva ES, *et al*. 2018. Physical activity and incident depression: A meta-analysis of prospective cohort studies. Am J Psychiatry. 175(7):631-648.
11. McDowell CP, Dishman RK, Gordon BR, Herring MP. 2019. Physical activity and anxiety: A systematic review and meta-analysis of prospective cohort studies. Am J Prev Med. 57(4):545-556.
12. Bridle C, Spanjers K, Patel S, Atherton NM, Lamb SE. 2012. Effect of exercise on depression severity in older people: systematic review and meta-analysis of randomised controlled trials. Br J Psychiatry. 201(3):180-185.
13. Schuch FB, Vancampfort D, Richards J, Rosenbaum S, Ward PB, Stubbs B. 2016. Exercise as a treatment for depression: A meta-analysis adjusting for publication bias. J Psychiatr Res. 77:42-51.
14. Kandola A, Ashdown-Franks G, Hendrikse J, Sabiston CM, Stubbs B. 2019. Physical activity and depression: Towards understanding the antidepressant mechanisms of physical activity. Neurosci Biobehav Rev. 107:525-539.
15. Kramer AF, Hahn S, Cohen NJ, Banich MT, McAuley E, Harrison CR, *et al*. 1999. Ageing, fitness and neurocognitive function. Nature. 400(6743):418-419.
16. Smiley-Oyen AL, Lowry KA, Francois SJ, Kohut ML, Ekkekakis P. 2008. Exercise, fitness, and neurocognitive function in older adults: the "selective improvement" and "cardiovascular fitness" hypotheses. Ann Behav Med. 36(3):280-291.
17. Voss MW, Heo S, Prakash RS, Erickson KI, Alves H, Chaddock L, *et al*. 2013. The influence of aerobic fitness on cerebral white matter integrity and cognitive function in older adults: results of a one-year exercise intervention. Hum Brain Mapp. 34(11):2972-2985.
18. Erickson KI, Voss MW, Prakash RS, Basak C, Szabo A, Chaddock L, *et al*. 2011. Exercise training increases size of hippocampus and improves memory. Proc Natl Acad Sci USA. 108(7):3017-3022.
19. Tolmunen T, Laukkanen JA, Hintikka J, Kurl S, Viinamäki H, Salonen R, *et al*. 2006. Low maximal oxygen uptake is associated with elevated depressive symptoms in middle-aged men. Eur J Epidemiol. 21(9):701-706.
20. Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, Minson CT, Nigg CR, Salem GJ, *et al*. 2009. Exercise and physical activity for older adults. Med Sci Sports Exerc. 41(7):1510-1530.