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Original Article

Factors influencing executive function by physical activity level among young adults: a near-infrared spectroscopy study

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Abstract. [Purpose] Prevention of dementia requires early intervention against it. To ensure that early interventions are effective it is crucial to study the cognitive functions related to dementia in young adulthood. Moreover, it is needed not only to verify the cognitive function test but also to elucidate the actual brain activity and the influence of related factors on the brain activity. To investigate the factors influencing cognitive function among young adults and examine the differences in executive function by physical activity level. [Subjects and Methods] Forty healthy university students (mean age, 20.4 years) were classified into two groups by cognitive function score (HIGH and LOW), determined according to Trail Making Test performance and Stroop task processing time. We then assessed what factors were related to cognitive function by logistic regression analysis. Executive function was determined by brain blood flow using near-infrared spectroscopy during the Stroop task, and was then compared by physical activity levels (determined according to number of steps per hour). [Results] Full-scale Intelligence Quotient according to the 3rd Wechsler Adult Intelligent Scale and number of steps per hour influenced cognitive function score, with odds ratios of 1.104 and 1.012, respectively. Oxy-hemoglobin concentrations in areas related to executive function during the Stroop task were significantly higher among those in the high physical activity group than among those in the low physical activity group. [Conclusion] The study revealed that Full-scale Intelligence Quotient and a number of steps per hour are factors associated with the cognitive functions in young adulthood. In addition, activity in execution function related area was found to be significantly higher in the high physical activity group than in the low physical activity group, suggesting the importance of physical activity for enhancing young adulthood cognitive functions.

Key words: Physical activity, Cognitive function, NIRS

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INTRODUCTION

Dementia involves irreversible damage to the brain, making preventative efforts for dementia exceedingly important. Factors such as smoking status, diet, physical activity (PA), and body mass index (BMI) have all received attention because of their relationships with dementia risk among elderly people. PA in particular has received attention because it can help

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suppress cognitive functional decline and reduce the risk of dementia in the elderly. In a previous systematic review, a longitudinal study revealed that the risk of cognitive decline among individuals with high PA was low1). Furthermore, among men, Dik et al. reported a positive correlation between level of PA between the ages of 15 and 25 years and information processing speed in old age2). This fact supports the link between PA and cognitive functions, and further suggests that early-stage PA might help delay cognitive functional decline later in life. Thus, from a preventive point of view, it appears that interventions and countermeasures must begin earlier on in life. However, very little research has been conducted on the relationship between executive function and PA among young adults, and none of them were neuroimaging studies or examined the factors related to these variables. One study investigated the association between PA and cognitive function among young to middle-aged adults [18–50 years], the results of which supported the positive effect of PA on cognitive function3). However, the PA considered in these reports were estimated via a questionnaire, rather than detailed objective measurements. Furthermore, these studies used a variety of cognitive function tests as outcome measures. The purpose of this study was to examine which factors—including dementia risks for older adults, PA, Intelligence Quotient (IQ) and past activity—influence cognitive function in young adults. Additionally, we carried out a comparative study of individuals with differing PA levels, examining how their brain activities during cognitive tasks differ, based on evidence that PA influences cognitive function.

SUBJECTS AND METHODS

Forty healthy subjects participated voluntarily in this study (all right-handed, 20.4 ± 1.1 years, 15 females, 25 males). We obtained written informed consent from all subjects after giving them a complete description of the study before each data collection session. All subjects had normal or corrected-to-normal vision, normal color vision, and were native Japanese speakers. None of the subjects had a history of neurological, major medical, or psychiatric disorders, and none were taking any medication at the time of measurement. This study was approved by the ethics committee of the International University of Health and Welfare (approval no. 13-49). A variety of demographic variables were measured, including age, gender, BMI, education, average sleep time and lifestyle factors were obtained for all subjects using a questionnaire. The lifestyle factors assessed included history of playing sports (including type of sport played, duration, and competitive level), time spent exercising in a week, medical history, smoking and drinking history, playing leisure activities, presence or absence of a family history of dementia, self-efficacy for exercise4). To assess intelligence, we utilized the Wechsler Adult Intelligence Scale, 3rd edition5) (WAIS-III). Specifically, we calculated the full-scale IQ (FIQ), verbal IQ (VIQ), and performance IQ (PIQ).

PA was measured using a uniaxial accelerometer (Lifecorder Plus; Suzuken Co. Ltd., Nagoya, Japan). Specifically, the accelerometer was used to measure number of steps per day, activity energy expenditure, and total energy expenditure. The accelerometer was attached to subjects' waists and PA was measured continuously over one week. During this period, subjects were asked to keep the accelerometer on their person at all times except for when bathing or sleeping.

The cognitive function score was calculated based on the performance times of the two forms of the Trail Making Test [TMT-A and TMT-B] and that of the Stroop task. This Stoop task was administered in the form of an experimental session comprising 30 trials (15 neutral trials and 15 incongruent trials) in random order with an inter-stimulus interval of 26 sec. Words remained on the screen until participants gave a response, with a maximum possible response time of 2 sec. Measurement was performed after three times in order to give subjects a chance to practice the task. Participants were asked to respond by pressing a button in the index finger, and we measured the time it took for them to press the button from the point of stimulus onset. A reaction time measurement device was used to detect electrical signals that were emitted at the start of each trial. The Stroop task response set was measured from time to time signals as the basis for answering challenge subjects. Additionally, this electrical signal was used to synchronize the reaction time measuring device with the near-infrared spectroscopy (NIRS) instrument. Because the contrast between incongruent and neutral conditions yields the most appropriate measure for Stroop interference6), the Stroop interference time was calculated by subtracting the reaction time of the neutral trial from that of the incongruent trial, as per previous studies7, 8). In order to evaluate cognitive ability, we calculated a cognitive function score by averaging the z-scores of each cognitive function test (Equation 1). Participants were then divided into two cognitive function score groups according to whether their score was higher or lower than the mean score.

Equation 1. Calculation of cognitive function scores power output (score) from the spreadsheet Excel software; where Z [TMT-A]=z-score of TMT-A performance time, Z [TMT-B]=z-score of TMT-B performance time, Z [ST]=z-score of Stroop interference time.

$$\text{Cognitive function score}=\{Z[\text{TMT-A}] + Z[\text{TMT-B}] + Z[\text{ST}]\}/ 3$$

Brain activity in the areas corresponding to executive function was assessed in terms of blood flow during the Stroop test via NIRS. The NIRS was performed using the ETG-4000 optical tomography system (Hitachi Medical Corp., Tokyo, Japan). We focused on the left dorsolateral prefrontal cortex (DLPFC; FT7), as this area has been reported to be active among young people taking the Stroop test. According to the international 10/10 system—an expanded version of the International 10/20 System—32 transmitting and receiving optical probes were placed in a grid pattern at 3-cm intervals, with Fpz and FT7 as reference points on the head midline (joining the root of the nose and the occipital protuberance; Fpz and Oz were calculated at 10% above each point and FT7 at 40% anterior to the horizontal line between Fpz and Oz)7, 9). In a previous study8), the FT7 area was deemed to correspond to the left DLPFC. To reduce artifacts due to probe shifting during measurements, subjects were fixed with a Philadelphia collar to restrict their head and neck movements. As exercise-related changes in hemoglobin concentration can create artifacts, subjects were not allowed to exercise before undergoing the NIRS. Furthermore, during the test, subjects were asked to focus their gaze on the center of the display to limit any influence from eyeball movement. Measurements were obtained by syncing with the personal computer used for the Stroop test using the electrical signal input into the NIRS apparatus at the beginning of the test. The sampling frequency of the NIRS was 10 Hz.

Oxygenated hemoglobin (oxy-Hb) was used to represent changes in brain blood flow during the Stroop test. We focused our analysis on channels at related regions of the FT7, including 1, 4, 5, and 8. Arithmetic means were calculated for changes in oxy-Hb for each channel during each of the 15 neutral and incongruent trials. Next, data for each channels were averaged according to oxy-Hb changes in the left DLPFC region. The change in oxy-Hb 2 seconds before each task was displayed was set as the baseline, with the peak occurring 4–11 seconds after the task began. The degree of oxy-Hb change was calculated from the baseline to peak, and this value was used to calculate the arithmetic mean. Subsequently, the mean change in oxy-Hb during the neutral trials was subtracted from that during the incongruent trials (incongruent − neutral). The resultant value was used as an index of brain blood flow during the Stroop task.

Catrine et al.'s criteria[10, 11)] for PA were used. Specifically, subjects with less than 313 steps per hour were considered to have low PA, those with 314–417 steps per hour had moderate PA, and those with 418 or more steps/hour had high PA. Oxy-Hb concentration variations during the Stroop task were then compared among the three groups by NIRS.

First, participants were allocated to HIGH and LOW cognitive function groups according to their cognitive function score. Then, unpaired t-tests were used to compare the variables of interest between the HIGH group and LOW groups. While the lifestyle factors were compared using cross-tabulation, χ^2 tests, and residual analysis. Furthermore, Spearman's correlation coefficient was used to assess the correlations between variables. We also conducted logistic regression analysis, calculating odds ratios (OR) and 95% confidence intervals (CI), with the cognitive function score as the dependent variable and all variables that were significant ($p<0.05$) in the group comparison as independent variables. Kruskal Wallis test were used to compare the mean change in oxy-Hb concentration in the left DLPFC region during the Stroop task among the three PA groups, both overall and for each channel corresponding to the left DLPFC region. Significant interactions were investigated via multiple comparisons. In addition, because we considered that IQ might have had an influence on the Stroop task, it was compared between groups using Kruskal Wallis test for the FIQ, VIQ, and PIQ scores. All statistical analyzes were performed using SPSS Statistics 22 (IBM Corp., Armonk, NY, USA).

RESULTS

We observed significant differences in FIQ, VIQ, number of steps, and total energy expenditure between the LOW and HIGH cognitive function groups (Table 1). Regarding lifestyle factors, we observed significant differences between the two groups in terms of competitive level and smoking history. The results of the logistic regression analysis revealed that FIQ and number of steps were significantly related to cognitive function score. Specifically, the OR of the FIQ score and number of steps were 1.104 (95% CI: 1.025–1.19) and 1.012 (95% CI: 1.002–1.022), respectively (Table 2). The results of multiple comparisons after on Kruskal Wallis test indicated that the high PA group showed significantly higher oxy-Hb changes in the left DLPFC region during the Stroop interference than did those in the low PA group (Table 3). This same pattern was found in the analysis by each channel (channels 1, 4, 5, and 8; Table 3).

DISCUSSION

We analyzed the factors related to cognitive function of young adults, including factors of cognitive decline in the elderly, intelligence, the past activities history. Our results indicated a significant difference in FIQ, VIQ, number of steps, total energy expenditure, health awareness, smoking history and competitive level of sports between the LOW and HIGH cognitive function groups (Table 1). However, according to the results of a logistic regression analysis, only FIQ and number of steps were significant contributors to cognitive function score (Table 2). Furthermore, differences in PA levels was confirmed that affects the brain activity during the cognitive task using NIRS. There are reports about the relationship between PA and cognitive functions in some of the previous studies[12–14)] about young adulthood. However, there is no report that analyzed related factors of the cognitive function and considered the relationship between the factors and the brain activity during a cognitive task.

Dementia risk among elderly adults is reported to be related to a genetic predisposition, as evidenced by a family history of dementia[15)]. Other, non-genetic risk factors include smoking, BMI, PA, eating habits, and leisure activities[16, 17)]. In the present study, the lifestyle factors that we chose to examine were specifically those related to dementia in the elderly. The results indicated a significant difference between the cognitive function groups in terms of smoking history and competitive level of sports (Table 1). The smoking rates were also higher in the HIGH group than in the LOW group. However, we did not specify the extent of smoking in smoking status and questions paper table of the previous test cognitive function, we cannot clarify the precise impact of smoking on cognitive function in this study. On the other hand, subjects' competitive level in sports was found to be significantly higher among those in the HIGH group than among those in the LOW group (Table 1). This accords with findings that athletes exhibit better performance for cognitive tasks and basic attention compared to non-athletes[18)]. On

Table 1. Camprison of the between cognitive function score HIGH group and LOW group evaluation item value

	HIGH cognitive function group (n=18)	Low cognitive function group (n=22)
	cognitive function score<0.19	cognitive function score>0.19
TMT-A (sec)	20.8 ± 2.9	26.6 ± 4.2*
TMT-B (sec)	41.9 ± 9.7	49.6 ± 8.0*
Stroop interference in reaction time (msec)	98.4 ± 50.6	161.6 ± 69.3*
Age (years)	20.5 ± 1.2	20.4 ± 1.1
Gender (F/M)	7/11	8/14
BMI (kg/m^2)	21.6 ± 2.8	22.2 ± 3.5
Average sleep time (hour)	6.0 ± 0.7	5.9 ± 1.0
Education (year)	13.7 ± 1.2	13.1 ± 1.2
FIQ (score)	122.7 ± 13.4	110.9 ± 12.9*
VIQ (score)	69.0 ± 9.6	61.9 ± 8.5*
PIQ (score)	53.6 ± 7.4	49.0 ± 8.7
Number of steps per hour	397.9 ± 97.8	326.1 ± 88.9*
Activity energy expenditure (kcal/day)	236.9 ± 99.5	190.3 ± 68.6
Total energy expenditure (kcal/day)	1526.2 ± 220.0	1405.6 ± 179.4*
Self-efficacy for exercise (score)	11.9 ± 2.9	11.3 ± 4.2
Medical history n %		
Smoking	4 (22.2%)	1 (4.5%)*
Family history of dimentia (within three degrees of consanguinity)	3 (16.7%)	6 (27.3%)
Leisure	12 (66.7%)	8 (36.4%)
Sports history		
Type of sport		
No experience	2 (11.1%)	3 (13.6%)
Non-contact sports	9 (50.0%)	13 (59.1%)
Contact sports	7 (38.9%)	6 (27.3%)
Duration of sports (years)		
0	2 (11.1%)	3 (13.6%)
1–4	2 (11.1%)	5 (22.7%)
5–9	5 (27.8%)	8 (36.4%)
≥10	10 (55.6%)	6 (27.3%)
Compentitive level of sports		
Recreational	10 (55.6%)	17 (77.3%)
Competitive	8 (44.4%)	4 (18.2%)*
Semiprofessional	0 (0.0%)	1 (4.5%)
Exercise time (hours), n (%)		
0	8 (44.1%)	12 (54.5%)
Within 2	5 (27.7%)	4 (18.2%)
≥3	5 (27.7%)	6 (27.3%)

Values are mean ± SD. HIGH cognitive function group; A subject's cognitive function score was calculated from the Z score of the TMTA execution time, the TMTB execution time, and the stroop interference time. The subjects with lower scores than the median cognitive function score were designated as the high cognitive function group, Low cognitive function group; The subjects with higher scores than the median cognitive function score were designated as the low cognitive function group; FIQ: full-scale IQ; VIQ: verbal IQ; PIQ: performance IQ; Semiprofessional: Semi-professional level of the sports was defined as the national tournament. *p<0.05.

Table 2. Summary of multiple logistic regression analysis results for cogniitive function score

Independent variable	Odds ratio, 95% Cl
FIQ score	1.104 (1.025–1.190)*
Number of steps per hour	1.012 (1.002–1.022)*

FIQ: full-scale IQ; *p<0.05

Table 3. Differences in FIQ, VIQ, PIQ score and oxy-Hb changes (total and each channel) among the different physical activity groups (based on number of steps)

	Number of steps per hour		
	≤313 (n=12)	314–417 (n=18)	≥418 (n=10)
FIQ (score)	113.5 (99.5–124.8)	120.5 (111.8–128.8)	115.0 (101.5–117.0)
VIQ (score)	64.0 (58.8–76.5)	64.5 (58.5–69.0)	62.0 (58.5–68.5)
PIQ (score)	47.5 (43.5–53.9)	55.0 (53.3–60.9)	47.0 (41.5–57.1)
Differences in oxy-Hb signals			
Left FT7 area			
ch 1	−0.086 (−0.029–0.061)	0.016 (−0.045–0.029)	0.036 (0.017–0.071)*
ch 4	−0.058 (−0.034–0.033)	0.085 (−0.020–0.029)	0.040 (0.017–0.050)*
ch 5	−0.020 (−0.014–0.022)	0.001 (−0.025–0.021)**	0.039 (0.025–0.056)*
ch 8	0.006 (−0.021–0.007)	0.003 (−0.011–0.028)**	0.043 (0.029–0.076)*
Total	−0.004 (−0.019–0.029)	0.005 (−0.014–0.025)	0.035 (0.029–0.060)*

Values are median (range). *Significant differences between the ≤313 steps per hour group and the ≥418 steps per hour group ($p<0.01$); **Significant differences between the 314–417 steps per hour group and the ≥418 steps per hour group ($p<0.05$); FIQ: full-scale IQ; VIQ: verbal IQ; PIQ: performance IQ; oxy-Hb: oxygenated hemoglobin

the other hand, one study found no difference in the orientation and execution of attention and visuospatial working memory between professional and amateur soccer players19). It is possible that the competition level of subjects in this study does not correspond to the sporting events and competition levels among athletes in previous studies, so there is a need for a more detailed study on the impact of competitive level on cognitive function.

IQ has been reported to be related to cognitive and executive function. Previous study indicated that TMT-A time was negatively correlated with PIQ score20), while FIQ score has been shown to be related to Stroop test performance21). These reports20, 21) showed the relationship between IQ and executive function test scores, and supported the results of this research. Meanwhile, IQ in late adolescence has been found to be strongly correlated with PA and health22). Importantly, while we observed a correlation between VIQ and total energy expenditure ($r=0.35$), we observed no relationship between IQ and number of steps. There are different possibilities and the results of this study are to evaluate the IQ and PA by using the questionnaire in the previous study. Notably, the number of steps significantly predicted cognitive function in this study (Table 2). Specifically, the HIGH group had a significantly higher number of steps and total energy expenditure than did the LOW group (Table 1). PA has been found to relate to activity mainly in the prefrontal and temporal cortices23). Another study indicated that maximum oxygen uptake, gray matter volume, and performance on Stroop and spatial working memory tests among elderly adults were all found to relate to prefrontal cortex activity. Indeed, maximum oxygen intake was found to relate specifically to activity in the DLPFC24). Another study indicated that adolescent PA among males had a stimulating effect on executive functions in adulthood, thus emphasizing the importance of an active lifestyle among adolescent males25). Taken together, these results all suggest that maintaining and improving PA and total energy expenditure may help in maintaining brain function.

It is notable that the number of steps was one of the factors relating to cognitive function score, especially because we used this variable as the basis (based on Catrine et al.10, 11)) for subjects' PA levels in the analysis of executive function using NIRS. Importantly, the three PA groups showed no statistically significant differences in FIQ, VIQ, or PIQ score (Table 3). Our results suggest that high levels of PA sustain activity in brain regions associated with the Stroop effect. Previous studies have also reported increased DLPFC activity during the Stroop task26) and the FT7 area in particular has been identified as corresponding to the DLPFC in prior research using NIRS8). Areas with increased oxy-Hb concentrations are judged, during NIRS, to have higher levels of neural activity. As the oxy-Hb concentration was much higher in the FT7 area in the high PA group in this study, it seems that greater PA relates to higher DLPFC activity, and thus greater executive function. High PA has been found to increase expression of insulin-like growth factor 1 (IGF-1), which enhances neurogenesis and angiogenesis, and vascular endothelial growth factor, which stimulates vasculogenesis and angiogenesis; thus, PA may influence the brain activity, angiogenesis, and neurogenesis of the brain27). IGF-1 in particular has diverse neuroprotective effects aside from angiogenesis and neurogenesis, including improving neuronal excitability and cognitive function28). In addition, high PA appears to alter the function of neurotransmitters to increase the expression of factors associated with synaptic plasticity, such as the glutamatergic system29). PA and fitness in adolescents have also both been found to relate to improved cognitive function in adults via an increase in the production of IGF-125). Thus, our results imply that maintaining high PA helps promote DLPFC activity. Meanwhile, young adulthood with a higher cognitive function level may be more likely to have a higher physical activity level, so there is a need to consider other factors as well.

Our overall results show that FIQ and number of steps were associated with cognitive function score in young adults. Furthermore, via NIRS, we observed differing levels of activity in the DLPFC according to PA level. The results emphasize the importance of an active lifestyle among young adults as well as the elderly. A main limitation of this study was that the sample size is small. Thus, interpretation of these results must be carried out carefully. Further, as noted above, follow-up studies are needed to clarify the relationships between PA and cognitive ability.

REFERENCES

1) Blondell SJ, Hammersley-Mather R, Veerman JL: Does physical activity prevent cognitive decline and dementia?: a systematic review and meta-analysis of longitudinal studies. BMC Public Health, 2014, 14: 510. [Medline] [CrossRef]
2) Dik M, Deeg DJ, Visser M, et al.: Early life physical activity and cognition at old age. J Clin Exp Neuropsychol, 2003, 25: 643–653. [Medline] [CrossRef]
3) Cox EP, O'Dwyer N, Cook R, et al.: Relationship between physical activity and cognitive function in apparently healthy young to middle-aged adults: a systematic review. J Sci Med Sport, 2016, 19: 616–628. [Medline] [CrossRef]
4) Marcus BH, Selby VC, Niaura RS, et al.: Self-efficacy and the stages of exercise behavior change. Res Q Exerc Sport, 1992, 63: 60–66. [Medline] [CrossRef]
5) Wechsler D: Japan edition of WAIS-III publication committee translation ed. Japan edition of WAIS-III adult intelligence test method implementation and scoring manual. Japan Culture and Science, 2006.
6) Schroeter ML, Zysset S, Kupka T, et al.: Near-infrared spectroscopy can detect brain activity during a color-word matching Stroop task in an event-related design. Hum Brain Mapp, 2002, 17: 61–71. [Medline] [CrossRef]
7) Yanagisawa H, Dan I, Tsuzuki D, et al.: Acute moderate exercise elicits increased dorsolateral prefrontal activation and improves cognitive performance with Stroop test. Neuroimage, 2010, 50: 1702–1710. [Medline] [CrossRef]
8) Hyodo K, Dan I, Suwabe K, et al.: Acute moderate exercise enhances compensatory brain activation in older adults. Neurobiol Aging, 2012, 33: 2621–2632. [Medline] [CrossRef]
9) Jurcak V, Tsuzuki D, Dan I: 10/20, 10/10, and 10/5 systems revisited: their validity as relative head-surface-based positioning systems. Neuroimage, 2007, 34: 1600–1611. [Medline] [CrossRef]
10) Tudor-Locke C, Craig CL, Brown WJ, et al.: How many steps/day are enough? For adults. Int J Behav Nutr Phys Act, 2011, 8: 79. [Medline] [CrossRef]
11) Tudor-Locke C, Craig CL, Thyfault JP, et al.: A step-defined sedentary lifestyle index:<5000 steps/day. Appl Physiol Nutr Metab, 2013, 38: 100–114. [Medline] [CrossRef]
12) Boucard GK, Albinet CT, Bugaiska A, et al.: Impact of physical activity on executive functions in aging: a selective effect on inhibition among old adults. J Sport Exerc Psychol, 2012, 34: 808–827. [Medline] [CrossRef]
13) Heisz JJ, Vandermorris S, Wu J, et al.: Age differences in the association of physical activity, sociocognitive engagement, and TV viewing on face memory. Health Psychol, 2015, 34: 83–88. [Medline] [CrossRef]
14) Pérez L, Padilla C, Parmentier FB, et al.: The effects of chronic exercise on attentional networks. PLoS One, 2014, 9: e101478. [Medline] [CrossRef]
15) Donix M, Burggren AC, Suthana NA, et al.: Family history of Alzheimer's disease and hippocampal structure in healthy people. Am J Psychiatry, 2010, 167: 1399–1406. [Medline] [CrossRef]
16) Gelber RP, Petrovitch H, Masaki KH, et al.: Lifestyle and the risk of dementia in Japanese-American men. J Am Geriatr Soc, 2012, 60: 118–123. [Medline] [CrossRef]
17) Akbaraly TN, Portet F, Fustinoni S, et al.: Leisure activities and the risk of dementia in the elderly: results from the Three-City Study. Neurology, 2009, 73: 854–861. [Medline] [CrossRef]
18) Voss MW, Kramer AF, Basak C, et al.: Are expert athletes 'expert' in the cognitive laboratory? A meta-analytic review of cognition and sport expertise. Appl Cogn Psychol, 2010, 24: 812–826. [CrossRef]
19) Verburgh L, Scherder EJ, van Lange PA, et al.: Executive functioning in highly talented soccer players. PLoS One, 2014, 9: e91254. [Medline] [CrossRef]
20) Ardila A, Pineda D, Rosselli M: Correlation between intelligence test scores and executive function measures. Arch Clin Neuropsychol, 2000, 15: 31–36. [Medline] [CrossRef]
21) Arffa S: The relationship of intelligence to executive function and non-executive function measures in a sample of average, above average, and gifted youth. Arch Clin Neuropsychol, 2007, 22: 969–978. [Medline] [CrossRef]
22) El-Kholy T, Elsayed E: Association of physical activity and health status with intelligence quotient of high school students in Jeddah. J Phys Ther Sci, 2015, 27: 2039–2043. [Medline] [CrossRef]
23) Erickson KI, Raji CA, Lopez OL, et al.: Physical activity predicts gray matter volume in late adulthood: the Cardiovascular Health Study. Neurology, 2010, 75: 1415–1422. [Medline] [CrossRef]
24) Weinstein AM, Voss MW, Prakash RS, et al.: The association between aerobic fitness and executive function is mediated by prefrontal cortex volume. Brain Behav Immun, 2012, 26: 811–819. [Medline] [CrossRef]
25) Ferro DA, Deijen JB, Koppes LL, et al.: The effects of physical activity and fitness in adolescence on cognitive in adulthood and the role of insulin-like growth factor I. J Phys Act Health, 2016, 13: 392–402. [Medline] [CrossRef]
26) Mead LA, Mayer AR, Bobholz JA, et al.: Neural basis of the Stroop interference task: response competition or selective attention? J Int Neuropsychol Soc, 2002, 8: 735–742. [Medline] [CrossRef]
27) van Praag H: Exercise and the brain: something to chew on. Trends Neurosci, 2009, 32: 283–290. [Medline] [CrossRef]
28) Russo VC, Gluckman PD, Feldman EL, et al.: The insulin-like growth factor system and its pleiotropic functions in brain. Endocr Rev, 2005, 26: 916–943. [Medline] [CrossRef]
29) Molteni R, Ying Z, Gómez-Pinilla F: Differential effects of acute and chronic exercise on plasticity-related genes in the rat hippocampus revealed by microarray. Eur J Neurosci, 2002, 16: 1107–1116. [Medline] [CrossRef]