Normal pace walking beneficial to young participants' executive abilities

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Research Article

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ABSTRACT

BACKGROUND Exercise can improve cognitive function. The impact of acute exercise on cognition is related to exercise intensity. This study aimed to explore whether slow walking had a beneficial effect on cognition.

METHODS Thirty healthy young people walked in a resting position and walked slowly on a walking machine, and completed the Stroop test. Near-infrared spectroscopy was used to monitor the hemodynamic changes of the prefrontal cortex during the entire experiment.

RESULTS Studies showed that slow walking did not stimulate higher average cerebral oxygen in the PFC, but the peak cerebral oxygen in cognitive tests during walking was higher, and better results were achieved, which was reflected in faster reaction times and higher accuracies.

CONCLUSION For healthy young people, even a slow walk is therefore good for cognition

KEY WORDS walking, Stroop test; executive function; near-infrared spectroscopy (NIRS); prefrontal cortex (PFC)

INTRODUCTION

Exercise has a beneficial effect on cognitive functions(1, 2). Different exercise intensities and durations, and types of cognitive tasks have differing degrees of influence(1, 3). Chronic long-term exercise and acute physical exercise are beneficial to the improvement of cognitive function. Long-term aerobic exercise improves cognitive function, including executive abilities, by improving cerebrovascular regulation(4). Single acute physical exercise also directly affects the cerebral blood flow(5), and has beneficial effects on cognitive abilities(6).

The intensities of single acute exercise affect cognition. According to the American College of Sports Medicine (ACSM) guidelines(7), to improve cardiorespiratory endurance and the intensity of muscle aerobic metabolism, the target heart rate of medium-to-high-intensity aerobic exercise should reach 40% or more of the reserve heart rate. At this time, the output of the heart per minute is higher than in the resting state, and the cerebral blood flow is increased, thereby increasing the activation and effective use of the task-related areas of the prefrontal cortex, to improve cognitive functions(3). Due to the inverted U-shaped relationships between brain oxygenation and exercise intensity, as exercise intensity further increases, blood flow to the brain and oxygen delivery may also decrease as cardiac output decreases(8). Compared with moderate intensity exercise, high intensity exercise may therefore actually impair cognitive function due to a decrease in cerebral oxygenation(9).

Compared to running, walking is a common and relaxing low intensity mode of aerobic exercise. Respiratory rhythm and body temperature do not increase during exercise, and the heart rate reserve is ≤ 30%, which has little effect on cardiac output. Walking is a common exercise mode for many elderly people or patients with chronic heart and lung diseases. Pang et al. reported that long-term functional community walking (8 weeks) was beneficial to the cognitive function of elderly patients with stroke(10). However, it is not known if low intensity exercise like walking has the same acute beneficial effects on cognitive function as medium to high intensity exercise.

Because the ability to walk and perform cognitive tasks at the same time is a key aspect of daily life, this study designed a dual-task experiment of walking and execution, to determine whether the executive function in the walking state was better than the static state in performing cognition (Stroop test) and motor tasks (slow walking) as a single task (ST) and simultaneously as a dual task (DT), respectively. The near-infrared spectroscopy system (NIRS) was used to monitor the hemodynamic changes of the bilateral prefrontal cortex (PFC) in real time. Because the PFC plays an important role in motor control, cognition, and dual task performance(11, 12), comparing cerebral oxygen parameters of the PFC under different task conditions and analyzing the influence of walking on execution ability are necessary.

METHODS

Subjects

Thirty right-handed participants aged 19−33 years (14 males and 16 females), with an average formal education of 15 ± 0.48 years, were recruited. The participants had sufficient sleep (> 7 hours), and did not drink alcohol or take drugs on the day of testing. All participants had normal or corrected vision, had no color discrimination disorders, and no known history of bone and joint disease or cardiopulmonary disease. Each participant provided informed written consent, and the research protocol was approved by the Ethics Committee of the Third Affiliated Hospital of Soochow University, and comply with the Declaration of Helsinki.

Stroop Tset

The Stroop test is a color naming test developed by Stroop (1953). Subjects are asked to identify and state the ink color as soon as possible based on specific conditions. The test consists of three parts: the Stroop Word, Stroop Color, and Stroop Color-Word tests.

Color names (red, blue, and green) in the Stroop Word experiment were written in black ink, which was the reading task.

Stroop color: the color name was in the circle of the same color, which was a named task.

Stroop Color-Word: the color name was printed with different colored ink (e.g., “blue” printed using green ink), which was the inhibition condition task.

Each section included 50 experiments, which were displayed on paper. The participants were asked to name the experiment from left to right (10 columns) and top to bottom (five rows). The total reaction times and correct numbers (corrected the first time, modified with a no count) were recorded by two professionally trained investigators. If the scores were inconsistent, a third person was also consulted.

Hemodynamic data collection

We used a dual-channel NIRS system(EGOS-600A; Enginmed Bio-Medical Electronics, Suzhou, China), equipped with built-in LEDs with near-infrared wavelengths of 760, 810, and 840 nm. According to the Beer-Lambert law, Δ[oxy-Hb] and Δ[deoxy-Hb] were calculated, to measure the hemodynamic responses of the participants' foreheads. In these experiments, Δ[oxy-Hb] values were more reliable and sensitive to exercise-related changes in cerebral blood flow (21593013), which were used to characterize changes in the PFC.

According to the international 10-20 electrode system, two pairs of light detectors were placed at Fp1-F7 and Fp2-F8, corresponding to light sources placed at Fp1 and Fp2 at a distance of 3 cm and 4 cm from the two detectors, respectively. To detect hemodynamic parameters in tissues with a depth of 2−3 cm, the investigators helped the individuals wear and fix the NIRS probe for each participant. Before wearing, the forehead was wiped with an alcohol-soaked cotton ball, and the participant's hair was arranged to reduce the influences of oil and cosmetics. The outside of the probe was fixed by a bandage to reduce interference from natural light and to prevent the probe from falling during the experiment. The equipment used high-pass and low-pass filtering to reduce noise interferences. The probe was worn during the entire experiment, with sampling of the device every 2 seconds.

Gait parameter acquisition

To provide a quiet- and interference-free test environment and to reduce the impact on cognitive testing and cerebral oxygen parameters, we chose to complete the test indoors. Due to a limitation of test space, to reduce the influence of turning while walking, we chose to use a treadmill. Confirmation of the running speed of the treadmill was conducted during the preparation phase. The participants were asked to walk on the treadmill at the same speed as their daily walks, using a finger pulse oximeter to monitor their heart rate below 57% HRMax [207- (0.67 × age)] (17468581), RPE < 9, to determine the treadmill speed according to the participant's subjective feelings and heart rates. Gait monitoring equipment was located on both sides of the treadmill, which was used to monitor and analyze the gait parameters of the participants in real time, including the step length of the left and right feet, stride length, the percentage of the support phase, the swing phase of the left and right feet during walking, and the walking speed of left and right feet.

Rating of perceived exertion

Perceived effort rating (RPE) is a subjective exercise effort rating developed by Borg. We used the Borg scale to evaluate the exertion of the participant, ranging from 6−20. A score of 7−11 represented "very, very light to very light effort", and a score of 13−14 represented "a little effort." A score of 15−19 represented "very, very hard work", and 20 represented "work harder to the greatest extent."

Procedures

The participants had 15 minutes to adapt before the start of the experiment, involving familiarity with walking on the treadmill, adjustment of the appropriate speed, understanding the Stroop test rules, and completing the exercise (practice version).

The following steps were then completed, during which the PFC oxygenation was measured. (1) Measuring the baseline values of brain oxygen parameters in the standing position, (2) measuring the cognitive ST, (3) measuring the walking ST, and (4) performing both cognitive and walking tasks at the same time, using the dual-task evaluation RPE from beginning to end.

The experiments were conducted in a quiet and isolated room. Air conditioning was adjusted to maintain a temperature 20−24℃ to reduce the influence of sweating on the sensitivity of the instrument probe.

Statistical analysis

The participant's average Δ[oxy-Hb] and Δ[deoxy-Hb] values during the baseline level were counted, with the Stroop test alone, walking, and the Stroop test during walking, to compare whether there were differences in cerebral hemodynamics at different task stages. A total of 10% of the experimental data were removed before and after each segment to reduce interference. One-way analysis of variance was used to analyze differences in brain oxygen parameters between groups at each task stage, and the data were tested for homogeneity of variance ($P > 0.05$), using analysis of variance and Bonferroni analysis for multiple comparisons. The paired t-test was used to analyze the left and right side PFC brain oxygen data, Stroop times, correct numbers, and the walking parameter comparisons between ST and DT. The Shapiro-Wilk's test was used to test the normality of the parameter distribution.

All statistical analyses used SPSS statistical software for Windows, version 26.0 (SPSS, Chicago, IL, USA) and figures were constructed using Prism 8.0 software (GraphPad, San Diego, CA, USA). Statistical significance was designed as $P < 0.05$.

RESULTS

Behavioral data

All 30 participants completed the experiments with a walking speed of 2.26 ± 0.41 km/hour. The gait parameters of walking ST and DT are shown in Table 1. The results showed that gait parameters (step length, stride length, pace, etc.) were not significantly different between walking ST and DT.

Stroop test data

Dual-task cognitive performance was better than single-task performance (Fig.1). When considering the advanced degree of education of the participants, to avoid the ceiling effect, when counting the correct number, two cases that were all correct were deleted.

Using the Stroop word test, the DT time (21.14 ± 0.72 seconds) was shorter than that of the ST time (21.28 ± 0.98 seconds), and the correct number of DTs (49.08 ± 0.23) was greater than that of the ST (48.50 ± 0.45) (removal of all correctness, and a total of 12 cases were analyzed), but the difference was not statistically significant ($P = 0.640$ and 0.294, respectively).

Using the Stroop color test, the DT time (31.96 ± 1.32 seconds) was shorter than that of the ST time (32.37 ± 1.22 seconds), and the correct number of DTs (48.14 ± 0.41) was greater than that of the ST (47.86 ± 0.41) (22 cases analyzed), but the difference was not statistically significant ($P = 0.594$ and 0.650, respectively).

Using the Stroop Color-Word test, the DT time (49.18 ± 1.68 seconds) was shorter than that of the ST time (56.92 ± 2.29 seconds), and the correct DT number (46.19 ± 0.69) was greater than that of the ST (44.15 ± 0.91) (26 cases analyzed), showing significant differences ($P < 0.001$ and 0.018, respectively).

Hemodynamic changes

According to the results of the analysis of variance, compared with the baseline value in the standing position, the hemodynamics of PFC Δ[oxy-Hb] did not significantly change when walking slowly, but during the cognitive tasks, both cognitive ST and DT significantly increased.

There was no significant difference in the mean value of Δ[oxy-Hb] between the cognitive ST and DT, but the peak value of Δ[oxy-Hb], DT was significantly greater than that of the cognitive ST, which was present in three parts of the Stroop test(Fig.2 and 3).

For the Δ[deoxy-Hb] of the PFC, there was no significant change in each stage.

DISCUSSION

This study investigated the effects of walking on the execution abilities (Stroop test) of young participants. RPE and HR confirmed that it was always controlled at a low exercise intensity, involving the normal pace of daily walks. The main findings indicated that simple daily walking promoted performance of the Stroop test, which was reflected in a shorter total reaction time and a higher correct number.

Physical exercise is one of the best non-drug methods to delay cognitive decline and can help improve executive functions(13, 14). In this study, low intensity exercise had a positive effect on cognitive functions (i.e., executive functions), which was reflected in the participants' faster response speeds and fewer errors. These results supported the findings of previous studies. Acute aerobic exercise can lead to positive physiological adaptations in the central nervous system and stimulate cognitive abilities after aerobic exercise, especially the ability to interfere with control, which is an important part of executive functions.

A previous study reported that higher exercise intensity (vigorous intensity or high intensity interval training) could benefit more from acute aerobic exercise(15). However, this study found that even low intensity exercise (45% HRmax) had beneficial cognitive effects.

Walking tasks occupy prefrontal lobe resources(16), and more complex walking tasks (such as obstacle walking) affect the activation of the prefrontal lobe, leading to poor performance in cognitive tasks(17). To reduce the impact of the task difficulty of walking on the activation of the prefrontal lobe, the subjects completed the routine walking speed on a horizontal treadmill.

Because the participants were always walking at slower speeds during the experiments, based on monitoring and control of the heart rate, the increase of heart rate during exercise was not obvious, resulting in an average brain oxygen value of PFC during DT, which was not significantly higher than that of the cognitive ST.

However, studies have shown that the RT of the Stroop test in young participants was related to HbO2 in the PFC, and that a faster RT was related to higher HbO2 availability(9). We therefore suggest that the beneficial effect of walking on cognition may be due to higher peak cerebral oxygen, which has nothing to do with changes in systemic hemodynamics, because the heart rate during walking does not increase significantly compared with the resting state. The higher peak cerebral oxygen may therefore originate from the local self-regulation of cerebral blood vessels(18, 19).

In addition to the contribution of higher brain oxygen levels to cognition, exercise may promote cognition in other ways. Stritt reported that exercise increased serotonin (5-HT) levels, even with low intensity exercise(20), and 5-HT played an important role in many cognitive processes. Tsai reported that acute exercise-induced neurocognitive changes were associated with real-time changes in circulating levels of neuroprotective growth factors, and acute exercise increased the amplitude of the event-related potential, P3(21).

In the present study, the treadmill speed of each participant was fixed when adjusted during the preparatory phase. Constant speed may affect changes in gait parameters. However, studies have shown that the motor systems of young participants had strong adaptabilities. When performing cognitive tasks at the same time, there was no significant change in gait parameters including walking speed(22), which is consistent with our results. To reduce the interference of cognitive tasks, the experiments were conducted in a quiet room, which was not consistent with a daily walking environment. A complex environment affects cognition(23, 24), so future studies will include an environment resembling that in normal life.

The sample size of this study was small, and the population consisted mostly of single adults, who were healthy young participants. Studies have shown that exercise had lower cognitive gains for the elderly, and whether the conclusions of this study are applicable to the elderly remains to be further studied. Moreover, we have considered some deficiencies in the methodology. The NIRS system we used only allowed measurements in a limited area of the PFC, and current studies have shown that the functional activity of other areas of the brain changed during exercise(25). Future research may use a multi-channel NIRS device to include a larger area. However, this study conducted research from the perspective of cerebral hemodynamics, which can be further explored and analyzed from the perspective of neuroelectrophysiology and biomarkers.

CONCLUSION

Slow walking had a beneficial effect on the executive ability of young participants. By monitoring the hemodynamics of bilateral PFC during walking, this benefit may have been related to the peak cerebral oxygen of DT. However, the results of this study were limited, and it is still necessary to increase the types of participants and to improve monitoring techniques to improve the breadth of applications of the conclusions and mechanisms of the research.

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AUTHOR CONTRIBUTIONS

Jianan Zhang helped with the conception and design, analysis, revising, and final approval of the article. Fan Xie and Yue Shi helped with the interpretation of data, drafting, revising. Lisha Xiang and Ya Wang were in charge of data acquisition and statistical analyses. Yi Zhang was the outcome assessor. All authors read and approved the final manuscript.

DECLARATION OF CONFLICTING INTERESTS

The authors declare no conflicts of interest.

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AVAILABILITY OF DATA AND MATERIALS

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study protocol was approved by the Ethics Committee of the Third Affiliated Hospital of Soochow University (approval number: 2020-146). All participants read and signed informed consent forms before they were included in this study.

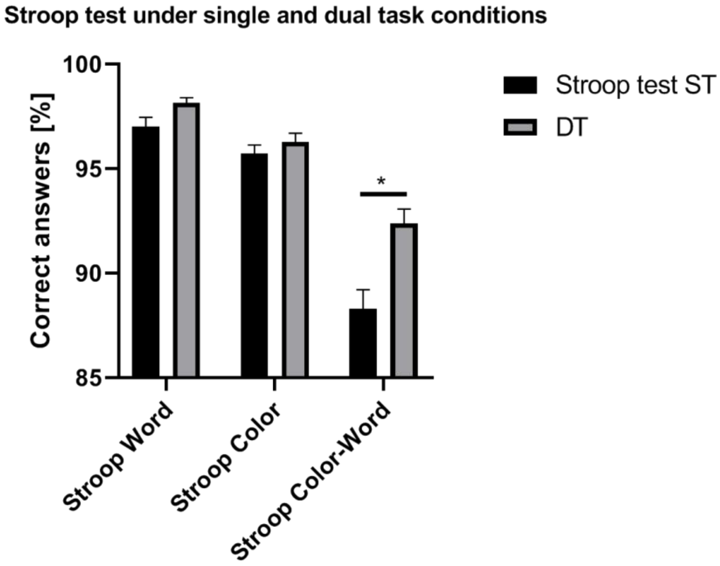
CONSENT FOR PUBLICATION

Not applicable.

Table 1. Gait spatiotemporal parameters for walking ST and DT group.

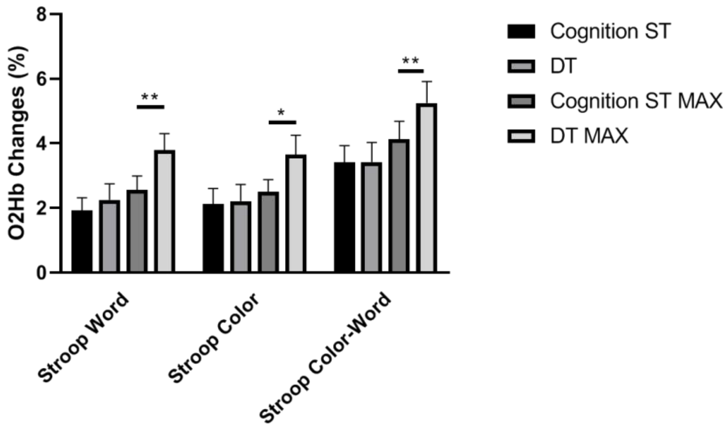
Spatiotemporal parameters		**Walking ST group**		**DT group**		***P***
		Mean	**SD**	**Mean**	**SD**	
Step length (metres)	Left	0.766	0.146	0.762	0.131	0.684
	Right	0.767	0.147	0.763	0.131	0.642
Stride length (metres)		1.534	0.292	1.525	0.262	0.641
Step time (seconds)	Left	1.422	0.310	1.420	0.278	0.940
	Right	1.433	0.323	1.418	0.275	0.474
Stride time (seconds)		2.873	0.645	2.845	0.598	0.440
Gait speed (m/s)		0.468	0.102	0.462	0.106	0.682

Figure 1. Stroop test under single and dual task conditions



*:P < 0.05

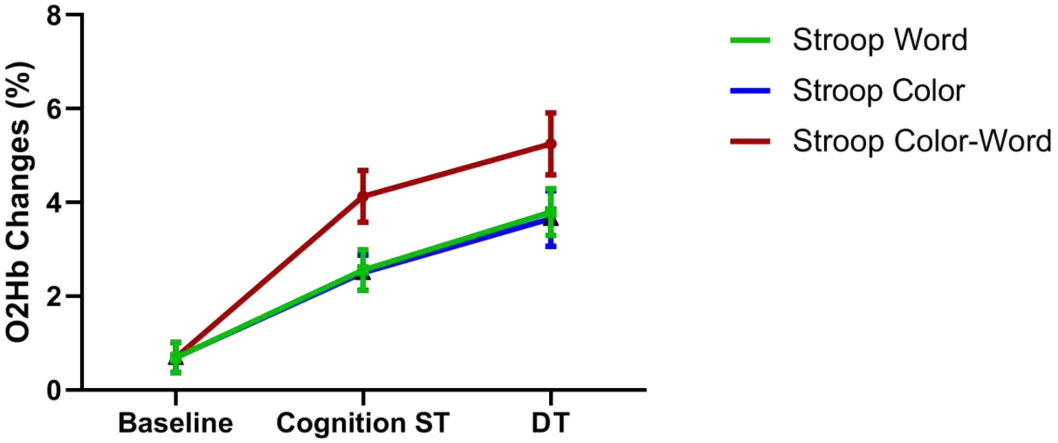
Figure.2 Changes of PFC brain oxygen parameters



*: P < 0.05

**: P < 0.01

Figure.3 Changes of brain oxygen parameters during stroop test



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