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Original Article

Differential effects of physical activity and sleep duration on cognitive function in young adults

Kazuko Kato [a], Kunihiro Iwamoto [b], Naoko Kawano [c], Yukihiro Noda [d], Norio Ozaki [b], Akiko Noda [a,*]

[a] Department of Biomedical Sciences, Chubu University Graduate School of Life and Health Sciences, 1200 Matsumoto-cho, Kasugai, Aichi 487-8501, Japan
[b] Department of Psychiatry, Nagoya University Graduate School of Medicine, 65 Tsurumai-cho, Showa-ku, Nagoya, Aichi 466-8550, Japan
[c] Institute of Innovation for Future Society, Nagoya University, 65 Tsurumai-cho, Showa-ku, Nagoya, Aichi 466-8550, Japan
[d] Division of Clinical Sciences and Neuropsychopharmacology, Graduate School of Pharmacy, Meijo University, 150 Yagotoyama, Tempaku-ku, Nagoya, Aichi 468-8503, Japan

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Abstract

Purpose: Although exercise and sleep duration habits are associated with cognitive function, their beneficial effects on cognitive function remain unclear. We aimed to examine the effect of sleep duration and daily physical activity on cognitive function, elucidating the neural mechanisms using near-infrared spectroscopy (NIRS).
Methods: A total of 23 healthy young adults (age 22.0 ± 2.2 years) participated in this study. Exercise amount was assessed using a uniaxial accelerometer. We evaluated total sleep time (TST) and sleep efficiency by actigraphy. Cognitive function was tested using the N-back task, the Wisconsin Card Sorting Test (WCST), and the Continuous Performance Test-Identical Pairs (CPT-IP), and the cortical oxygenated hemoglobin levels were measured with NIRS.
Results: Exercise amount was significantly correlated with reaction time on 0-back and 1-back tasks ($r = -0.602$, $p = 0.002$; $r = -0.446$, $p = 0.033$, respectively), whereas TST was significantly correlated with %corrects on the 2-back task ($r = 0.486$, $p = 0.019$). Multiple regression analysis, including exercise amount, TST, and sleep efficiency, revealed that exercise amount was the most significant factor for reaction time on 0-back and 1-back tasks ($\beta = -0.634$, $p = 0.002$; $\beta = -0.454$, $p = 0.031$, respectively), and TST was the most significant factor for %corrects on the 2-back task ($\beta = 0.542$, $p = 0.014$). The parameter measured by WCST and CPT-IP was not significantly correlated with TST or exercise amount. Exercise amount, but not TST, was significantly correlated with the mean area under the NIRS curve in the prefrontal area ($r = 0.492$, $p = 0.017$).
Conclusion: Exercise amount and TST had differential effects on working memory and cortical activation in the prefrontal area. Daily physical activity and appropriate sleep duration may play an important role in working memory.

Keywords: Cortical oxygenation; Executive function; Exercise; Sustained attention; Total sleep time; Working memory

1. Introduction

Exercise is known to be associated with cognitive function, but its effects differ depending on the type of exercise and methodology in cognitive function tests.[1–3] Our recent study on left ventricle responses to exercise in athletes suggested that habitual exercise may play an important role in effective hemodynamics.[4] Regular aerobic exercise alleviated the age-related reduction in brain hemodynamics by more than a decade in healthy men aged 18–79 years.[5] Exercise increases the level of oxyhemoglobin (OxyHb) in the frontal cortices and enhances advantages in cognition.[6,7] The benefits of exercise training, such as spatial learning and recall, hippocampal cell activity, and brain-derived neurotrophic factors, were impaired after chronic moderate sleep restriction.[8] Sleep and exercise influence each other through complex, reciprocal interactions including multiple physiological and psychological pathways;[9] however, their beneficial interaction on cognitive function has yet to be clarified.

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* Corresponding author.
E-mail address: anoda@isc.chubu.ac.jp (A. Noda)

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Poor sleep quality increases affective symptomatology as well as the interaction between stress and performance on an emotional memory test and sustained attention task. It is also associated with a negative cognitive bias, with a concomitant decrease in sustained attention to non-emotional stimuli in undergraduate students.[10,11] Sleep restriction represents an important facet of modern life that leads to cognitive performance declines, including lapses of attention, slowed working memory, reduced cognitive throughput, and perseveration of thought.[12,13] An epidemiological study demonstrated that fatigue and short and long sleep duration were associated with both objectively assessed and self-reported decreases in cognitive function in the general population.[14] Given the importance of early detection and prevention of sleep-related cognitive impairment, sleep management may be clinically beneficial.

The N-back task, Wisconsin Card Sorting Test (WCST), and Continuous Performance Test-Identical Pairs (CPT-IP) are widely used in studies of cognitive function in young adults.[15,16] The N-back task has been used in many human studies to investigate the neural basis of the prefrontal cortex on working memory processes.[16,17] Working memory refers to a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning.[18] The WCST, a neurocognitive test, is frequently used for evaluating executive function.[19,20] Executive functions are the high-level cognitive processes that facilitate new ways of behaving and that optimize one's approach to unfamiliar circumstances.[21] The CPT-IP measures sustained attention or vigilance that requires identification of identical stimulus pairs within a continuously presented series of stimuli[22] and has been used extensively in psychiatric research, especially in studies concerned with the role of sustained attention in schizophrenia.[23] These cognitive functions are related to the frontal lobe.[16,21,24]

Near-infrared spectroscopy (NIRS) allows for noninvasive measurements of regional cerebral blood flow by assessing the relative concentration of oxyhemoglobin (OxyHb) with high temporal resolution.[25] The approach has been applied to the examination of psychiatric patients as well as healthy individuals.[25,26] Psychiatric patients had slower and reduced increase in prefrontal activation when compared to healthy controls.[25] A recent NIRS study revealed an increase in frontal brain activation during walking in healthy young adults.[27] We have previously examined the effects of 1 night of insufficient sleep (i.e., sleep duration less than 4 h) on cognitive function using N-back task (2-back), WCST, and CPT-IP, and cortical oxygenation as assessed by NIRS in healthy adults. Our findings suggested that 1 night of insufficient sleep lowered sustained attention, vigilance, and vigor using the Profile of Mood States, which was accompanied by decreased cortical OxyHb levels in the frontal lobe.[28,29] NIRS offers several advantages over functional magnetic resonance imaging (fMRI), such as feasibility for measurement of concentration changes in oxygenated hemoglobin, finer temporal resolution, and ease of administration, in addition to being noninvasive and portable.[30] Thus, evaluation of the cortical oxygenation response using NIRS may facilitate our understanding of the role of exercise and sleep in cognitive function related to daily life and industrial safety.

Accordingly, we hypothesized that daily physical activity and sleep duration would have differential involvement on working memory, executive function, and sustained attention. In this study, we investigated the effects of daily physical activity and sleep duration on these cognitive functions using NIRS to elucidate neural mechanisms in healthy young adults.

2. Methods

2.1. Study participants

A total of 23 healthy young adults (13 males and 10 females; age 22.0 ± 2.2 years) participated in this study. Participants had no underlying medical diseases, were nonsmokers, were moderate drinkers of alcohol, and did not use drugs. The subjects exhibited no problems in their social lives, and all were healthy, which was confirmed by a medical doctor who conducted structured clinical interviews testing for DSM-IV axis I disorders. The nocturnal sleep duration on the night immediately preceding the test was adjusted to 6–8 h, because cortical oxygenation and cognitive function are known to be significantly lower following a night of insufficient sleep versus a night of sufficient sleep.[28] For NIRS measurements, the participants were examined in a natural sitting position, without any surrounding distraction. The recording environment was a sound-attenuated room. Participants were tested individually.

The Chubu University and the Nagoya University Ethics Committees approved all procedures associated with the study. Written informed consent was obtained from all participants after the nature of the study and the procedures involved were explained to them.

2.2. Assessment of physical activity

During measurements, participants wore a uniaxial accelerometer (Lifecorder GS/Me; Suzuken Co. Ltd., Nagoya, Japan) on their belts.[31,32] Measurements were taken over the course of a week; the number of steps walked and exercise amount per week were also evaluated.

2.3. Actigraphy

Actigraphy was performed over 5−7 days for all participants. We measured total sleep time (TST), sleep efficiency (calculated as TST/time spent in bed × 100), bedtime, and wake-up time. The actigraph unit (Ambulatory Monitoring Inc., New York, NY, USA) was worn around the wrist of the nondominant hand and was set to store data in 1 min increments. We analyzed actigraphy data using the algorithm supplied by the ActionW-2 clinical sleep analysis software package for Windows (Ambulatory Monitoring Inc.) and a sleep diary. Sleep and activity levels were scored according to the Cole-Kripke formula.[33,34] Diary-derived sleep parameters of bedtime and wake-up time were used to ascertain and set the analysis interval for the actigraphy device.[35]

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