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Cognitive function at rest and during exercise following breakfast omission

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HIGHLIGHTS

- Effects of exercise after breakfast omission on cognition are poorly understood.
- We examined effects of exercise on cognitive function with or without breakfast.
- Exercise intensity was adjusted so that heart rate was kept at 140 beats·min^{-1}.
- At rest, executive function was impaired following breakfast omission.
- Nevertheless, executive function improved during exercise in both conditions.

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ABSTRACT

It has been suggested that breakfast omission, as opposed to breakfast consumption, has the detrimental effects on cognitive function. However, the effects of acute exercise following breakfast omission on cognitive function are poorly understood, particularly during exercise. The purpose of this study was to examine the interactive effects of breakfast and exercise on cognitive function. Ten participants completed cognitive tasks at rest and during exercise in the breakfast consumption or omission conditions. Blood glucose concentration was measured immediately after each cognitive task. We used cognitive tasks to assess working memory [Spatial Delayed Response (DR) task] and executive function [Go/No-Go (GNG) task]. The participants cycled ergometer for 30 min while keeping their heart rate at 140 beats·min^{-1}. Accuracy of the GNG task was lower at rest in the breakfast omission condition than that in the breakfast consumption condition (Go trial: $P = 0.012$; No-Go trial: $P = 0.028$). However, exercise improved accuracy of the Go trial in the breakfast omission condition ($P = 0.013$). Reaction time in the Go trial decreased during exercise relative to rest in both conditions ($P = 0.002$), and the degree of decreases in reaction time was not different between conditions ($P = 0.448$). Exercise and breakfast did not affect the accuracy of the Spatial DR task. The present results indicate that breakfast omission impairs executive function, but acute exercise improved executive function even after breakfast omission. It appears that beneficial effects of acute exercise on cognitive function are intact following breakfast omission.

1. Introduction

Blood glucose is the primary source of energy for the brain at rest [1]. Blood glucose concentration increases after the consumption of breakfast following overnight fasting [2–4], while it remains low without taking breakfast [5]. This implies that energy source of the brain might be reduced without breakfast, which possibly leads to the impairment of brain function. Indeed, a number of studies reported that cognitive function such as working memory [5, 6] and executive function [5] was better following breakfast consumption as compared with that following breakfast omission [5–8]. Furthermore, for cognitive function, low glycemic index (GI) breakfast seems to be better than high GI breakfast [9–12], possibly due to stable glucose supply to nerve cell and/or favorable modulation of neurotransmitters and hormones [13].

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Collectively, the available literatures suggest that breakfast omission potentially has detrimental effects on cognitive function. However, most studies were conducted in younger children and adolescent, and little is known about the interaction between breakfast and cognitive function in healthy young adults. Hence, we focused on the association between breakfast and cognitive function in healthy young adults.

In contrast to the potential detrimental effects of breakfast omission, it has been suggested that acute exercise improves cognitive function [14–18]. The beneficial effects of acute exercise on cognitive function appear to be fairly robust at moderate intensity. Several studies examined the combined effects of breakfast consumption and exercise on cognitive function [9, 19, 20]. However, the effects of acute exercise following breakfast omission on cognitive function are poorly understood. In particular, it is unclear how acute exercise affects cognitive function during exercise following breakfast omission. Understanding this provides suggestion to those who perform physical activity following breakfast omission.

Breakfast provides the primary metabolic fuel (i.e. blood glucose) for the brain. Maintenance of an adequate blood glucose concentration is required to maintain optimal cognitive function [10], and enhancing glucose availability appears to improve cognitive performance [7]. Ide et al. indicated that brain glucose utilization increases during moderate exercise [21] although blood lactate is also taken up in the brain as an energy fuel during exercise [22, 23]. This suggests that blood glucose still contributes to brain metabolism during moderate exercise. Hence, we hypothesized that the beneficial effects of acute exercise on cognitive function may be attenuated following breakfast omission. Conversely, if the beneficial effects of exercise on cognitive function are still intact even after breakfast omission, we expected that moderate exercise would improve cognitive function following breakfast omission.

The cognitively demanding tasks may be more sensitive to some variables, which indicates that selection of cognitive task is a key factor to examine the interaction between breakfast and cognitive function. A previous study has shown that breakfast consumption was more beneficial on cognitively demanding tasks as compared with simple cognitive tasks [5]. This suggests that there is an interaction between task difficulty and breakfast consumption, and that demanding cognitive tasks are more vulnerable to breakfast consumption and/or omission. Thus, in the present study, we used a demanding dual task that evaluates executive function and working memory [24] to examine the interaction between breakfast and higher cognitive function.

The purpose of this study was to examine the interactive effects of breakfast and exercise on cognitive function. In particular, we focused on how acute exercise alters cognitive function following breakfast omission. We also measured blood glucose concentration immediately after each cognitive task to examine the association between blood glucose concentration and cognitive function at rest and during exercise. Given that many young adults often skip breakfast, it appears that they perform physical activity at school or work without taking energy in the morning. Therefore, it is essential to accumulate data to understand how acute exercise alters cognitive function after breakfast omission. We believe that our study is practically important, and our findings will provide new findings about exercise-cognition interaction in a fasted state.

2. Material and methods

2.1. Participants

Ten male participants (mean ± SD, age = 22.3 ± 2.1 yr; height = 1.70 ± 0.06 m; body mass = 70.4 ± 8.5 kg; body mass index = 24.4 ± 2.0 kg/m^2) took part in this experiment. The participants were physically active (i.e., they engaged in moderate physical activity at least 2–3 days per a week) but were not engaged in strenuous physical activity on a regular basis. All the participants did not have any history of cardiovascular, cerebrovascular, respiratory disease, learning difficulties, or visual impairments. They were able to complete cognitive tasks and exercise protocol in this study. They refrained from intense exercise for 48 h before each experiment. This study was approved by the ethics committee of Fukuoka University and was in accordance with the Declaration of Helsinki. All participants gave written informed consent to participation.

2.2. Physiological parameters

Blood glucose and lactate concentrations were measured at rest and immediately after the cognitive tasks during exercise. The right earlobe was cut with Contact Activated Lancet (BD safety lancet, 21 G gauge, 1.8 mm depth, Becton Dickinson and Company, New Jersey, USA) and 2 μL capillary blood was collected into glucose sensor. Blood glucose concentration was measured by glucose oxidase method using blood glucose monitor (Glutest Ace, Sanwa Kagaku, Nagoya, Japan) [25, 26]. Blood lactate concentration was determined with the lactate oxidase method using an automated analyzer (Lactate Pro, Arkray, Kyoto, Japan). Ratings of perceived exertion (RPE; 6–20 Borg scale) [27] was recorded immediately after each cognitive task. An electrocardiogram (ECG) was measured using a three-lead system to confirm that HR was maintained at the target level during exercise. Ventilatory parameters were measured using a gas analysis system (ARCO-2000, ARCO System, Chiba, Japan). Oxygen uptake (VO_2), minute ventilation (VE), and respiratory exchange ratio (RER) were averaged during the cognitive task.

2.3. Cognitive task

The cognitive task of the present study was a combination of Spatial Delayed Response (Spatial DR) task and Go/No-Go (GNG) task [24, 28, 29]. The details of the cognitive task were described in the previous study [24, 28]. In brief, the Spatial DR task assessed working memory, and the GNG task assessed executive function. The participants performed the cognitive task while seated on a cycle ergometer (75XLII, COMBI Wellness, Tokyo, Japan). The cognitive task started with the Spatial DR task, followed by the GNG task. At the beginning of the Spatial DR task, the participants remembered the location where the visual stimulus was presented. Then, they responded by pressing a portable ten-key with the right index finger after the GNG task. The ten-key included the numbers 1 through 9 in three rows of three. The numbers ran in order from left to right, and bottom to top. Each button of the ten-key except for 5 corresponded to the location where the visual stimulus was presented. In the GNG task, the participants pressed the shift button with the left index finger on a Go trial, while they continued pressing the shift button on a No-Go trial. The cognitive tasks continued until the participants completed 30 trials of both tasks. In the Spatial DR task, the accuracy of the task was used to assess working memory and error trials were defined as incorrect responses to the remembered location. In the GNG task, executive function was evaluated using the accuracy and reaction time in the Go trial. Error trials were defined as omitting the response in the Go trial, or an incorrect response in the No-Go trial.

2.4. Experimental procedure

The participants performed the experiment on two separate days. A few days before the first day of the experiment, the participants completed practice blocks of the tasks at rest and during cycling until they were familiar with the task. In both conditions, the participants finished the same meal at 7:00 PM one day before the experiment. On the days of the experiment, the participants performed the cognitive task at rest and during exercise in either breakfast consumption or omission condition. In the breakfast consumption condition, they had two rice balls (Energy: 350 kcal, Carbohydrate: 74.1 g, Protein: 9.8 g, Fat: 1.5 g) and water as a breakfast at 7:00 AM. Rice contains a high percentage of