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Effect of intermittent isometric handgrip exercise protocol with short exercise duration on cognitive performance

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Abstract

The handgrip exercise, a small muscle exercise, is useful for exercise therapy, particularly in the elderly and bedridden patients. The isometric handgrip (IHG) exercise has been utilized in training programs to reduce resting blood pressure; however, the acute effects of the IHG exercise on cognitive performance are not fully understood. The present study aimed to investigate the effect of an intermittent IHG exercise protocol with short exercise duration, which minimizes the arterial blood pressure response to exercise, on cognitive performance. Twenty-two young healthy subjects performed the intermittent IHG exercise protocol, which consisted of 30-s IHG and 45-s recovery × 16 trials; the exercise intensity of the IHG exercise was 30% of the maximal voluntary contraction. Cognitive performance was evaluated before and after the exercise with the Go/No-Go and memory recognition tasks. Specifically, the reaction time (RT) and performance accuracy were measured. The intermittent IHG exercise protocol did not change the RT or performance accuracy of either the Go/No-Go task ($P=0.222$ and $P=0.260$, respectively) or the memory recognition task ($P=0.427$ and $P=0.245$, respectively). These findings suggest that the intermittent IHG exercise protocol with short exercise duration may not provide enough stimulation to improve cognitive performance despite being useful as a safe exercise therapy in the elderly and in patients with cardiovascular disease.

Keywords: Static exercise, Go/No-Go task, Memory recognition task, Exercise pressor reflex, Executive function

Background

Cognitive function is an essential component of most daily activities [1, 2], but it is changeable and determined by many physiological factors. For example, aging and cardiovascular disease have been reported to attenuate cognitive function [3, 4]. Therefore, by one method or another, cognitive dysfunction must be prevented to maintain quality of life for the elderly and any other patients [5]. Previous studies have reported that both dynamic and static (isometric) exercise training improved cognitive performance and cardiovascular function [6–9]. However, in general, dynamic exercise rather than isometric exercise is recommended as exercise therapy in the elderly or any patients who have a higher blood pressure response to exercise [10–15] because the dynamic exercise-induced increase in arterial blood pressure (ABP) is lower than that induced by isometric exercises [16].

Importantly, it is difficult in some cases for the elderly and patients who have limitations moving large muscle groups to perform dynamic whole-body exercises, e.g., cycling, walking, etc. On the other hand, it has been reported that exercise training using the isometric handgrip (IHG) exercise protocol (2-min IHG at 30% maximal voluntary contraction (MVC) and 3-min recovery × 4 trials) reduces resting blood pressure and improves arterial stiffness as well as endothelial function [17–24].

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Moreover, our recent study demonstrated that the acute IHG exercise protocol improved cognitive performance [25]. These findings indicate that the IHG exercise may be a better exercise mode for cardiovascular and cognitive therapies, particularly in the elderly and bedridden patients, compared with dynamic whole-body exercise because the IHG exercise is a useful small muscle exercise that can be easily performed in various conditions, such as in a supine position in a hospital bed.

One important problem using an isometric small muscle exercise for the elderly and patients with cardiovascular disease is that their exercise pressor response is larger compared with healthy young adults [10, 26, 27]. Exercise with a large blood pressure response is often contraindicated in patients with cardiovascular disease because an unusually large increase in blood pressure during exercise may increase the risk of cardiovascular events. In addition, the IHG exercise may augment the blood pressure response more than dynamic whole-body exercise [16].

It is noteworthy that a previous study [28] indicated that in the IHG exercise protocol, the ABP response can be modified by maintaining the total exercise volume while decreasing the contraction time and increasing the frequency of IHG contractions. Indeed, our pilot study [29] confirmed that the intermittent IHG exercise protocol with short duration maintaining the same total exercise volume as the traditional IHG exercise protocol resulted in a 26% lower pressor response to exercise (mean ABP; 99 mmHg vs. 124 mmHg, $P = 0.007$, $n = 7$) compared with that of the IHG exercise protocol that reduces resting ABP as reported previously [19, 20]. More recently, our study [25] demonstrated that the acute traditional IHG exercise protocol improved cognitive performance. Moreover, previous studies [30–32] using dynamic exercise with whole body or large muscle groups suggest that the same total exercise volume would have an equally positive effect on cognitive performance regardless of different exercise duration and frequency. Therefore, we hypothesized that the acute intermittent IHG exercise protocol with short exercise duration that maintains the total exercise volume as the traditional IHG protocol [25] improves cognitive performance with a lower blood pressure response.

In the present study, we investigated the acute effect of the intermittent IHG exercise protocol with short exercise duration (30-s IHG at 30% MVC and 45-s recovery × 16 trials) on cognitive performance. The findings of the present study are expected to provide important information as to whether the intermittent IHG exercise with short exercise duration is a useful exercise mode for preventing cognitive dysfunction, particularly in the elderly and any patients who have a high exercise pressor reflex and limitations with moving large muscles.

Methods

Ethical approval

This experimental protocol was approved by the Institutional Review Board at Toyo University (Approval Number: TU2019-039), and each subject provided written informed consent prior to participation in accordance with the principles of the Declaration of Helsinki.

Subjects

Twenty-two healthy volunteers participated in this study (18 men and 4 women; mean age, 22.0 ± 1.0 years; height, 169.6 ± 7.9 cm; weight, 60.9 ± 10.4 kg). None of the subjects had cerebrovascular or cardiovascular disease; all subjects were not taking any medications and were nonsmokers. Each subject abstained from caffeine for 12 h and strenuous exercise and alcohol for 12 h. The experiment was performed at least 4 h after a light meal.

Experimental procedure

On the same day, before the experiment, all subjects practiced the intermittent IHG exercise protocol and completed at least one practice block of each task (Go/No-Go tasks; 30 trials and memory recognition; 10 words) to minimize learning effects. The intermittent IHG exercise protocol with short exercise duration (EX) and control condition (CON) were performed on different days randomly to counterbalance across the subjects. On the day of the CON, each subject was asked to read a Japanese scientific magazine for the same experimental period as the EX (20 min) instead of performing the EX. On the day of the EX, each subject performed three repetitions of their MVC of the IHG exercise on the left hand (non-dominant hand) to determine the exercise intensity for the experiment. After a sufficient resting time (more than 30 min), each subject performed the EX, which consisted of sixteen 30-s isometric contractions at 30% of MVC separated by 45-s rest between IHG exercise trials with the non-dominant hand. In both conditions, before and after the EX and CON, the subjects performed the cognitive tasks. All studies were performed experiments on the same time (8AM–13PM) of day for both conditions at a constant temperature (24℃). In our pilot study [29], we confirmed that the response of the mean arterial pressure to the EX (intermittent IHG exercise protocol) was lower (99 ± 11 mmHg vs. 124 ± 8 mmHg, $P = 0.007$, $n = 7$) than that of the traditional IHG exercise protocol (four 2-min isometric contractions at 30% of MVC separated by 3 min of rest) used previous study [33].

Measurements

Cognitive performance (Go/No-Go tasks, memory recognition task)

Cognitive performance in this study was measured using the Go/No-Go tasks [34] and the memory recognition task [35], which require executive function and memory recognition, respectively. To evaluate cognitive performance, the mean reaction time (RT) and performance accuracy of the Go/No-Go task and memory recognition task were calculated.

Go/No-Go task: each trial started with a blank screen for 2.5 s, followed by a reparatory stimulus (green square) presentation at the center of the computer screen for 1 s. Then, one square of several possible colors (red, blue, yellow, or purple) was presented at the center of the computer display for 1 s. The red and blue squares represented the Go signal, and the yellow and purple squares represented the No-Go signal. If the Go signal was displayed, the subjects were asked to press the left button of the computer mouse with their right index finger as quickly as possible. If the No-Go signal was displayed, the participants were asked to refrain from responding. The Go/No-Go task consisted of 60 trials with equal probability (30 Go trials and 30 No-Go trials).

Memory recognition task: first, 30 Japanese words were presented at a rate of 1 word per 1 s for memorization. Approximately 5 min after the Go/No-Go task, the subjects performed the memory recognition portion of the test. To assess memory recognition performance, 60 words (30 distracters) were presented every 2 s, and at each word presentation, the subjects answered as quickly as possible whether that word was presented during the memorization period.

Cardiovascular measures

Heart rate (HR) was measured using a lead II electrocardiogram (bedside monitor, BMS-3400; Nihon Kohden, Tokyo, Japan). ABP was monitored continuously using a finger photoplethysmography (Finapres Medical Systems, Amsterdam, the Netherlands). Systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP) were obtained from the ABP waveform. The HR, SBP, DBP, and MAP data were averaged using 30-s data points at the resting baseline and end of the intervention (last set). To identify the change in these parameters during EX, 30 s averages were calculated during the 4th, 8th and 12th sets of EX. The psychological arousal level was evaluated using the felt arousal scale (FAS; 1: low arousal to 6: high arousal) immediately after the cognitive tasks [36].

Statistical analysis

The values are expressed as the mean ± SD. Changes in HR, SBP, DBP, and MAP during EX were assessed with a one-way repeated-measures analysis of variance (ANOVA). Regarding the data of CON, changes in these values were assessed using a paired t-test because of two data points (the baseline and end of experimental period). Absolute changes in the RT and performance accuracy of the cognitive task and the arousal level during the Go/No-Go and memory tasks were assessed by a two-way (time: pre- and post-test × condition: CON and EX) repeated-measures ANOVA. The effect size were calculated as *eta-squared* (η^2) for all ANOVA outcome or *Hedges'* g_{av} for t-test using the spreadsheet provided by Lakens [37]. The ANOVAs were followed by the Bonferroni's multiple post hoc test. A P-value < 0.05 was considered significant.

Results

The cardiovascular responses to the EX and CON are shown in Table 1. In the CON, the cardiovascular responses did not change from the baseline value ($t_{21} > 0.359$, $P > 0.271$, *Hedges'* $g_{av} > 0.052$). During the EX, HR did not increase ($F_{1,21} = 1.246$, $P = 0.298$, $\eta^2 = 0.010$). Conversely, SBP, DBP, and MAP increased ($F_{1,21} > 21.214$, $P < 0.001$, $\eta^2 > 0.182$). The psychological response during the cognitive tasks is shown in Table 2. The FAS remained unchanged during the cognitive tasks in the CON, but increased in the EX ($F_{1,21} = 4.915$, $P = 0.038$, $\eta^2 = 0.060$); post hoc comparisons using the Bonferroni test indicated that the increase in the FAS during cognitive tasks was observed after the EX ($P = 0.013$). However, the EX did not change the RT or performance accuracy in the Go/No-Go task ($F_{1,21} = 1.581$, $P = 0.222$, $\eta^2 = 0.020$ and $F_{1,21} = 1.340$, $P = 0.260$, $\eta^2 = 0.027$, respectively, Fig. 1) or in the memory recognition task ($F_{1,21} = 0.657$, $P = 0.427$, $\eta^2 = 0.012$ and $F_{1,21} = 1.428$, $P = 0.245$, $\eta^2 = 0.020$, respectively, Fig. 2) despite an exercise-induced increase in the FAS.

Discussion

The intermittent IHG exercise protocol with short exercise duration, which minimizes the blood pressure response, did not improve cognitive performance despite causing an exercise-induced increase in the psychological arousal level. This intermittent IHG protocol is useful as a safe and effective exercise mode in the elderly and in patients with cardiovascular diseases who have a higher risk of cardiovascular events; however, this exercise stimulation is not sufficient for improving cognitive

Table 1 Cardiovascular measurement at resting baseline, end of the intervention (last set) and during intermittent isometric handgrip exercise protocol with short duration

	Baseline	4th set	8th set	12th set	Last set	*P* values
HR, beats/min						
CON	67 ± 9	-	-	-	66 ± 9	*P* = 0.723
EX	67 ± 8	67 ± 6	68 ± 8	68 ± 7	69 ± 7	*P* = 0.298
SBP, mmHg						
CON	116 ± 12	-	-	-	118 ± 11	*P* = 0.271
EX	116 ± 7	127 ± 11*	127 ± 10*	126 ± 12*	127 ± 11*	*P* < 0.001
DBP, mmHg						
CON	69 ± 7	-	-	-	71 ± 8	*P* = 0.306
EX	67 ± 5	76 ± 8*	76 ± 7*	76 ± 8*	76 ± 9*	*P* < 0.001
MAP, mmHg						
CON	88 ± 9	-	-	-	89 ± 9	*P* = 0.290
EX	86 ± 5	96 ± 9*	96 ± 9*	96 ± 10*	96 ± 10*	*P* < 0.001

Values are mean ± SD (*n* = 22)

HR heart rate, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *MAP* mean arterial pressure, *CON* control condition, *EX* intermittent IHG exercise protocol with short duration. *$P < 0.05$ vs. Baseline

Table 2 The psychological arousal level during the cognitive tasks

	CON		EX		*P* value (interaction)
FAS	Pre	Post	Pre	Post	*P* = 0.038
	3.0 ± 1.0	3.0 ± 0.7	2.9 ± 0.9	3.4 ± 0.9*†	

Values are mean ± SD (*n* = 22)

FAS felt arousal scale, *CON* control condition, *EX* intermittent IHG exercise protocol with short duration. *$P < 0.05$ vs. Pre, †$P < 0.05$ vs. CON

performance. To improve the clinical applicability of these findings, we must further investigate and identify an adequate mode of small muscle exercise that can be applied to safely improve cognitive performance for the elderly and patients with cardiovascular disease.

Some epidemiological longitudinal studies [38, 39] have reported that both dynamic and isometric exercise training (chronic exercise influence) improved cognitive performance, and thus confirm the validity of the findings presented in epidemiological cross-sectional study [40]. The mechanism of these exercise training-improved cognitive function remains unknown, but previous findings suggest that the physiological adaptation to exercise training, e.g., direct (brain volume) [41] and indirect (resting blood pressure, insulin resistance, physical

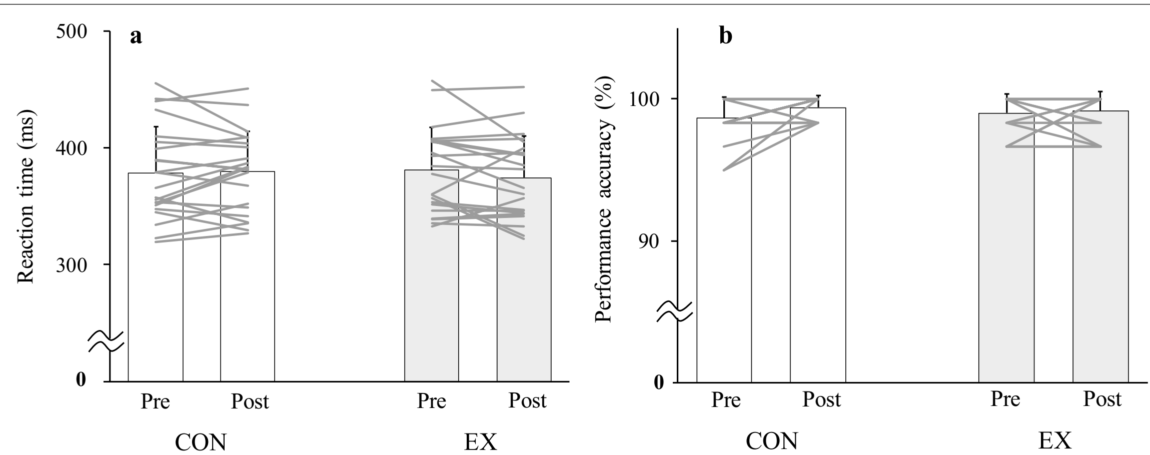

Fig. 1 Reaction time (**a**) and performance accuracy (**b**) of the Go/No-Go task in the CON (control condition) and EX (intermittent IHG exercise protocol with short duration) (*n* = 22)

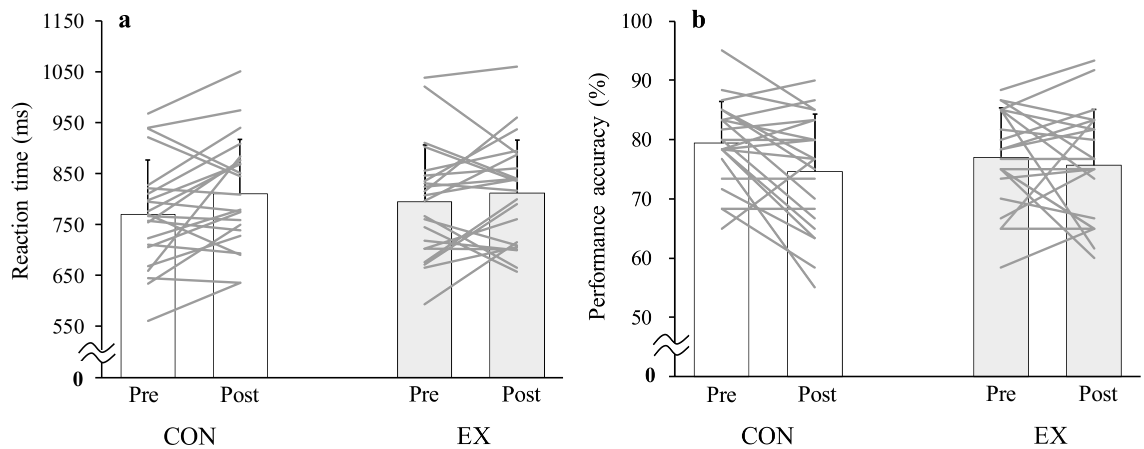

Fig. 2 Reaction time (**a**) and performance accuracy (**b**) of memory recognition task in the CON (control condition) and EX (intermittent IHG exercise protocol with short duration) ($n = 22$)

fitness) physiological factors [38, 39, 42–44], is associated with the improvement in cognitive function.

On the other hand, investigating the effect of acute exercise (one bout of exercise) on cognitive performance can be isolated from the chronic exercise-induced effects and consequently provides important information regarding the acute influence of exercise on brain function because one bout of exercise does not alter brain volume, insulin resistance, physical fitness, etc. Under these backgrounds, many previous studies have investigated the acute effect of one bout of exercise on cognitive performance. One previous study [45] reported that dynamic exercise improves cognitive performance. The authors also manipulated cerebral blood flow, but changes in cerebral blood flow did not modify cognitive performance. Thus, the authors concluded from these results that acute exercise-stimulated neural activation rather than cerebral metabolism improved cognitive performance. Another study [46] demonstrated that cognitive performance was improved after acute high-intensity interval training, and this improvement is associated with exercise-induced lactate production. It is noteworthy that these acute exercise-induced improvements in cognitive function occur without a chronic physiological adaptation, for example, caused by exercise training.

Conversely, the acute effect of small muscle exercises on cognitive performance is poorly understood. Our recent study [25] demonstrated that the traditional IHG exercise protocol improved cognitive performance. In addition, a previous study reported that an acute dynamic exercise-induced increase in arousal level was associated with increased brain neural activity and cognitive performance [47]. However, in contrast to these previous studies and our hypothesis, the intermittent IHG exercise protocol with short exercise duration did not improve cognitive performance despite an increase in the FAS (arousal level). This finding highlights two important points in this research area. First, small muscle exercise may be different from large muscle exercise with regard to improvement in cognitive performance. One previous study [48] that reported on an acute isometric exercise using a larger muscle (leg extension–quadriceps femoris muscle), compared with IHG exercise, noted improved cognitive performance. Thus, small muscle exercises may be limited in their ability to improve cognitive performance. Indeed, the increase in the FAS during exercise in the present study was lower than that during the large muscle isometric exercise (0.5 vs 1–2) [48]. Second, we used the intermittent IHG exercise protocol with short exercise duration to prevent a large blood pressure response, and during this exercise protocol, the HR sample entropy was larger than that of the traditional IHG exercise protocol, which included longer contractions (2-min at 30% MVC IHG and 1-min recovery × 4 trials, corresponding to the same amount of exercise as the intermittent IHG exercise protocol in this study) [28]. These findings indicate that the intermittent IHG exercise protocol in the present study provided a lower sympathetic stimulus and thus autonomic stimulation may be not enough to improve cognitive performance. Importantly, our previous study found that the traditional acute IHG exercise protocol (2-min at 25% MVC IHG and 3-min recovery × 4 trials) increased blood pressure to a larger extent and improved cognitive performance [25]. Thus, the IHG exercise may be a useful exercise mode to improve cognitive performance, but we must consider an adequate exercise protocol (strength, duration, frequency and so on) using IHG to safely improve cognitive performance. To perform this rehabilitation exercise in the elderly and in patients with cardiovascular diseases, we must further investigate and establish an adequate IHG exercise protocol based on the balance between sufficient autonomic stimulation and preventing a large blood pressure response.

Potential limitations of the present study should be considered. Since we recruited only young healthy adults, the present results cannot be generalized to older or hypertensive individuals. However, given that exercise training-induced cardiovascular adaptations improve cognitive performance, older and hypertensive individuals may gain a large cognitive improvement through exercise therapy. Further investigations regarding this point in the clinical research area must be performed.

Conclusions

In contrast to our hypothesis, the intermittent IHG exercise protocol with short exercise duration did not improve cognitive performance despite causing an exercise-induced increase in the psychological arousal level. To improve the clinical applicability of these findings, we must further investigate and establish an adequate IHG exercise protocol based on the balance between sufficient autonomic stimulation and preventing a large blood pressure response.

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Authors' contributions
SS, SO: conception and design of research; SS, TW, HW, SA, SO performed experiments; SS, TW, HW analyzed data; SS, SO, SA interpreted results of experiments; SS prepared figures; SS, SO drafted manuscript. All authors edited and revised manuscript. All authors approved final version of manuscript.

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Availability of data and materials
The datasets used and analyzed during current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Experimental protocol was approved by the Institutional Review Board at Toyo University (Approval Number: TU2019-039).

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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