Blood Flow Restriction Improves Executive Function after Walking

TAKESHI SUGIMOTO[1], TADASHI SUGA[1], KEIGO TOMOO[1], KENTO DORA[1], ERNEST MOK[1], HAYATO TSUKAMOTO[1,2,3], SHINGO TAKADA[4], TAKESHI HASHIMOTO[1], and TADAO ISAKA[1]

[1]Faculty of Sport and Health Science, Ritsumeikan University, Kusatsu, Shiga, JAPAN; [2]Research Organization of Science and Technology, Ritsumeikan University, Kusatsu, Shiga, JAPAN; [3]Neurovascular Research Laboratory, Faculty of Life Sciences and Education, University of South Wales, Pontypridd, UNITED KINGDOM; and [4]Faculty of Lifelong Sport, Department of Sports Education, Hokusho University, Ebetsu, Hokkaido, JAPAN

ABSTRACT

SUGIMOTO, T., T. SUGA, K. TOMOO, K. DORA, E. MOK, H. TSUKAMOTO, S. TAKADA, T. HASHIMOTO, and T. ISAKA. Blood Flow Restriction Improves Executive Function after Walking. *Med. Sci. Sports Exerc.*, Vol. 53, No. 1, pp. 131–138, 2021. **Purpose:** Blood flow restriction (BFR) walking is recognized as a beneficial strategy for increasing skeletal muscle mass and strength. No study has examined the effect of BFR exercise on cognitive functions, including executive function (EF). In this study, we examined the effect of BFR walking on EF. **Methods:** We performed two studies, at rest and exercise, with BFR or non-BFR (NBFR) in a crossover design. Sitting rest was performed for 15 min (study 1, $n = 8$). Exercise was programmed at five sets of 2-min walking at 5 $km \cdot h^{-1}$ with 1-min rest intervals (study 2, $n = 16$). The BFR condition was achieved using 200 mm Hg pressure cuffs placed around the proximal region of the thighs. The NBFR condition involved no pressure cuffs. EF was assessed using the color–word Stroop task before and after each condition. **Results:** In study 1, there were no significant effects on EF parameters for both BFR and NBFR conditions, suggesting that BFR alone does not improve EF. In study 2, incongruent reaction time shortened after BFR walking compared with that before walking ($P = 0.001$). Furthermore, the reverse Stroop interference score decreased after BFR walking compared with that before walking ($P < 0.001$). **Conclusion:** These findings suggest that, even with a mild exercise, BFR walking improves EF independently of the effect of BFR alone or walking alone. **Key Words:** COGNITIVE FUNCTION, BRAIN HEALTH, LACTATE, NITRIC OXIDE, PERCEIVED EXERTION

Long-term exercise intervention improves cognitive executive function (EF) in various populations, including older individuals and patients with chronic diseases (1). In addition, acute bouts of both aerobic and resistance exercises improved postexercise EF (2–8). The degree of exercise-induced EF improvement is mediated by differences in exercise intensity and duration (5–7). However, high-intensity and/or long-duration exercises are often difficult because of declining health in cardiovascular and musculoskeletal systems in older individuals and patients with chronic disease (9). Furthermore, increases in exercise intensity and duration are considered barriers to exercise participation (10). Therefore, exercise with both low intensity and short duration through which EF can be improved is useful for improving the applicability of exercise and adherence to exercises.

Address for correspondence: Tadashi Suga, Ph.D., Faculty of Sport and Health Science, Ritsumeikan University, 1-1-1 Nojihigashi, Kusatsu, Shiga 525-8577, Japan; E-mail: t-suga@fc.ritsumei.ac.jp.
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Blood flow restriction (BFR) exercise is recognized as a beneficial strategy for increasing skeletal muscle mass and strength via aerobic or resistance exercise (11). Even with applications of low intensity and/or short duration, BFR exercise induces muscle hypertrophy and strength gain in manners similar to those obtained after high-intensity exercise (11). Furthermore, these positive effects can be obtained by a mild exercise such as walking (12,13), potentially via increasing endocrine responses and activating muscle protein synthase signaling (12,14). The BFR walking also improves some physical functions, including aerobic capacity (i.e., peak oxygen consumption) (12,13,15). No study has examined the effect of BFR exercise on cognitive functions, including EF.

Several studies determined the effect of BFR exercise on cerebral activation (16,17). Dalsgaard et al. (16) reported that BFR aerobic exercise increased cerebral arterial-venous differences (i.e., cerebral uptake) in levels of lactate, which is an important energy substrate in the human brain (18); thus, BFR exercise can accelerate cerebral lactate metabolism. Aerobic exercise–induced EF improvements are associated with accelerated cerebral lactate metabolism (2), potentially via increasing blood lactate levels (2,6,8). We demonstrated a close relationship between changes in EF and blood lactate levels induced by exercise (8). Therefore, we hypothesized that BFR exercise improves postexercise EF because of increases in

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blood lactate levels. To test this hypothesis, we examined the effect of BFR walking on postexercise EF improvements.

METHODS

Participants. Eight (age = 21.3 ± 0.3 yr, height = 174.8 ± 1.8 cm, weight = 68.2 ± 3.3 kg) and 16 (age = 21.4 ± 0.5 yr, height = 172.9 ± 1.0 cm, weight = 64.3 ± 2.1 kg) healthy males participated in studies 1 and 2, respectively. The subjects had performed physical exercise (e.g., aerobic exercise) for 2–4 h·wk^{-1}. The subjects were free from neurological, cardiovascular, pulmonary disorders, color blindness, and abnormal vision. Informed written consent was obtained from all subjects. This study was approved by the Ethics Committee of Ritsumeikan University and conducted according to the Declaration of Helsinki.

Experimental design. Two studies were performed at rest and walking in a crossover design. All subjects completed both BFR and non-BFR (NBFR) conditions for each study, with a randomized and counterbalanced order. The subjects were instructed to avoid strenuous physical activity in the 24 h before the experiment. The subject also abstained from food, caffeine, and alcohol for 12 h before the experiment and was not taking any medications that may affect cognitive performance.

Each study included three visits to the laboratory over approximately 2 wk. On the first visit, subjects received detailed explanation of experimental sessions. Then the subjects completed a familiarization where they practiced the three types of the color-word Stroop task (CWST) for a minimum of 10 times each until they achieved consistent scores. Furthermore, to minimize the excessive response to BFR, the subjects were familiarized with BFR maneuver at sitting rest.

On the experimental day, subjects practiced the three CWST types to a minimum of five times to minimize a learning effect. The subjects rested for 5 min before undergoing measurements of cardiovascular parameters and blood metabolites and then performed the CWST. Thereafter, the subjects were exposed to either with BFR or NBFR session. The subjects performed the CWST immediately after the completion of the session.

Cardiovascular parameters were measured five times at rest session or during walking session. Fingertip blood samples were collected before the CWST. Felt arousal scale (FAS) and visual analog scale (VAS) were measured immediately after the CWST. In study 2, perceived exertion was assessed for five times during walking session.

Experimental condition. In the BFR conditions, tourniquet cuffs were wrapped around the proximal region of the subject's thighs. To familiarize the subjects with the BFR maneuver, occlusion pressure was initially inflated at 100 mm Hg for 30 s and then released for 10 s in a sitting position. After the first BFR familiarization, the BFR pressure was gradually increased by 25 mm Hg with 30-s holding and 10-s releasing. This BFR familiarization process was repeated until a final occlusion pressure at 200 mm Hg was reached. In the NBFR conditions, subjects rested in the sitting position for the same interval (i.e., about 4–5 min) as a control procedure of the BFR feminization.

Immediately before the BFR session, the cuffs were inflated to 200 mm Hg for BFR at sitting position for study 1 and at standing position for study 2. This BFR pressure remained until cessation of the experimental session. In study 1, sitting rest was performed for 15 min. In study 2, exercise was programmed at five sets of 2-min walking at 5 km·h^{-1} with 1-min rest intervals, which is the total 15 min.

Cardiovascular parameters. Heart rate (HR) was measured continuously via telemetry (RS400; Polar Electro Japan, Tokyo, Japan). Systolic and diastolic blood pressures were measured using a mercury manometer (FC-110ST; Focal, Chiba, Japan). Mean arterial pressure (MAP) was calculated as ([systolic blood pressure − diastolic blood pressure] / 3 + diastolic blood pressure).

Perceived exertion. The Borg's 15-point and category ratio scales were used to assess RPE and leg discomfort, respectively, during walking.

Blood metabolites. Blood glucose and lactate levels were measured using glucose (Medisafe FIT Blood Glucose Meter; Terumo, Tokyo, Japan) and lactate (Lactate Pro 2; Arkray, Kyoto, Japan) analyzers, respectively.

Psychological conditions. A six-point FAS was used to assess arousal on the CWST. VAS was used to assess three psychological conditions (i.e., mental fatigue, ability to concentrate, and motivation) on the CWST. Each VAS was labeled from 0 mm (i.e., not at all) to 100 mm (i.e., extremely).

EF. The CWST was administered to determine EF (2–8). In brief, the stimulus words were four color names ("red," "yellow," "green," and "blue"), and they were presented on a 98-inch display. The three types of the CWST consisted of two color text tasks (i.e., congruent and incongruent tasks) and one control black text task (i.e., neutral task). One trial of each type of the CWST consisted of 24 stimulus words. The three CWST types were repeated for each three trials. The reaction time and response accuracy for each trial were collected, and the mean values of the three trials of each CWST type were calculated for analysis. The reverse Stroop interference score, a specific parameter of inhibitory control (IC), was defined as the difference between reaction times of the neutral and incongruent tasks (2–8). This score was calculated as ([reaction time of incongruent task − reaction time of neutral task] / reaction time of neutral task × 100).

Statistical analysis. The data are expressed as the mean ± SEM. Comparison of measured variables during BFR and NBFR conditions was analyzed using a paired Student's *t*-test. Changes in measured variables throughout experimental session between the two conditions were analyzed using two-way (2 conditions × 2 times) repeated-measures ANOVA. If the sphericity assumption was not met, Greenhouse–Geisser corrections were used. Specific differences were identified with a paired Student's *t*-test or Bonferroni *post hoc* test. The statistical significance level was defined at $P < 0.05$. All statistical analyses were

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conducted using IBM SPSS software (version 19.0; IBM Corp, Armonk, NY).

The Cohen's *d* effect size using the pooled SD was calculated to determine the magnitude of a difference in the reverse Stroop interference score between before (i.e., baseline and preexercise) and after (i.e., immediately postexercise and postexercise recovery periods) R-EX and S-EX. The Cohen's *d* effect size was interpreted as small (0.20–0.49), medium (0.50–0.79), or large (>0.80). Partial eta square (η_p^2) value was determined as a measure of the effect size for main effects of condition and time or interaction effect.

RESULTS

Study 1. Changes in cardiovascular parameters and blood metabolites before and after BFR and NBFR conditions are summarized in Table 1. HR analysis revealed significant main effects for condition and time and a significant interaction effect. HR increased immediately after BFR rest, but not after NBFR rest, compared with that before rest ($P = 0.005$), with large effect size ($d = 1.13$). HR throughout rest was higher with BFR than with NBFR (76.9 ± 3.3 vs 66.2 ± 2.2 bpm, $P = 0.007$), with large effect size ($d = 1.33$). MAP analysis revealed a significant main effect for condition. MAP throughout rest did not differ between BFR and NBFR conditions (90.3 ± 2.9 vs 88.9 ± 2.4 mm Hg). Blood lactate analysis revealed no significant main effects for condition and time and no significant interaction effect. Blood glucose analysis revealed a significant interaction effect. However, blood glucose levels before and after rest did not differ between conditions or time points.

Changes in EF parameters before and after BFR and NBFR rest sessions are shown in Figure 1. Analyses of reaction times for three CWST types revealed no significant main effects for time and condition and no significant interaction effects. Analyses of response accuracies for three CWST types also revealed no significant main effects for time and condition and no significant interaction effects (data not shown). Furthermore, the reverse Stroop interference score analysis revealed no significant main effects for time and condition and no significant interaction effect.

Changes in psychological conditions for the CWST before and after BFR and NBFR conditions are summarized in Table 2. Arousal analysis revealed no significant main effects for time and condition and no significant interaction effect. Analyses of all three psychological conditions also revealed no significant main effects for time and condition and no significant interaction effect.

Study 2. RPE and leg discomfort throughout walking were higher with BFR than with NBFR (12.7 ± 0.4 vs 8.7 ± 0.4 and 5.5 ± 0.4 vs 1.5 ± 0.3, respectively, $P < 0.001$ for both), with large effect size ($d = 2.26$ and 3.08, respectively).

HR analysis revealed significant main effects for condition and time and a significant interaction effect. HR increased immediately after BFR and NBFR walking compared with that before walking ($P < 0.001$ for both), with large effect size ($d = 5.20$ and 4.15, respectively). HR throughout walking was higher with BFR than with NBFR (115.0 ± 2.7 vs 95.9 ± 1.9 bpm, $P < 0.001$), with large effect size ($d = 2.04$). MAP analysis revealed significant main effects for condition and time and a significant interaction effect. MAP increased immediately after BFR walking, but not after NBFR walking, compared with that before walking ($P < 0.001$), with large effect size ($d = 1.68$). MAP throughout walking was higher with BFR than with NBFR (101.2 ± 2.0 vs 87.0 ± 1.9 mm Hg, $P < 0.001$), with large effect size ($d = 1.82$). Blood lactate analysis revealed significant main effects for condition and time and a significant interaction effect. Blood lactate increased after BFR walking, but not after NBFR walking, compared with that before walking ($P < 0.001$), with large effect size ($d = 1.40$). Blood lactate was also higher after BFR walking than after NBFR walking ($P < 0.001$), with large effect size ($d = 1.60$). Blood glucose analysis revealed no significant main effects for condition and time and no significant interaction effect.

Changes in EF parameters before and after BFR and NBFR walking sessions are shown in Figure 2. Analysis of reaction time for incongruent task analyses revealed a significant main effect for time ($F_{1, 15} = 8.53$, $P = 0.011$, $\eta_p^2 = 0.36$) and a significant interaction effect ($F_{1, 15} = 7.39$, $P = 0.016$, $\eta_p^2 = 0.33$). The incongruent reaction time was shortened after BFR walking, but not after NBFR walking, compared with that before

TABLE 1. Cardiovascular and blood metabolite responses before and after BFR and NBFR conditions.

	BFR Condition		NBFR Condition		*P* Values		
	Pre	Post	Pre	Post	Condition	Time	Interaction
Study 1							
HR, bpm	67.4 ± 2.4	77.9 ± 4.0*,**	67.6 ± 2.7	65.4 ± 2.4	**0.046**	**0.022**	**0.003**
MAP, mm Hg	90.9 ± 2.0	91.5 ± 3.4	88.0 ± 2.6	89.2 ± 2.5	**0.032**	0.591	0.667
Blood glucose, mg·dL^{-1}	94.3 ± 1.7	99.0 ± 2.1**	97.8 ± 2.9	96.6 ± 2.6	0.753	0.133	**0.027**
Blood lactate, mM	1.0 ± 0.1	1.0 ± 0.1	1.1 ± 0.1	1.0 ± 0.1	0.528	0.785	0.732
Study 2							
HR, bpm	65.7 ± 1.5	121.1 ± 3.5*,**	65.7 ± 1.6	96.9 ± 2.1**	**<0.001**	**<0.001**	**<0.001**
MAP, mm Hg	87.6 ± 2.0	101.9 ± 2.4*,**	86.5 ± 1.7	86.8 ± 2.1	**<0.001**	**<0.001**	**<0.001**
Blood glucose, mg·dL^{-1}	97.3 ± 1.6	100.4 ± 0.8	96.8 ± 1.3	96.3 ± 1.2	0.118	0.171	0.125
Blood lactate, mM	1.0 ± 0.0	1.9 ± 0.2*,**	1.0 ± 0.0	0.9 ± 0.0**	**<0.001**	**<0.001**	**<0.001**

Values are presented as mean ± SEM. Bold *P* values indicate significant main effects of time and condition and a significant interaction effect ($P < 0.05$ for all).
*Significant difference ($P < 0.01$) between conditions.
**Significant difference ($P < 0.05$) between time points.
Pre, before session; Post, immediately after session.

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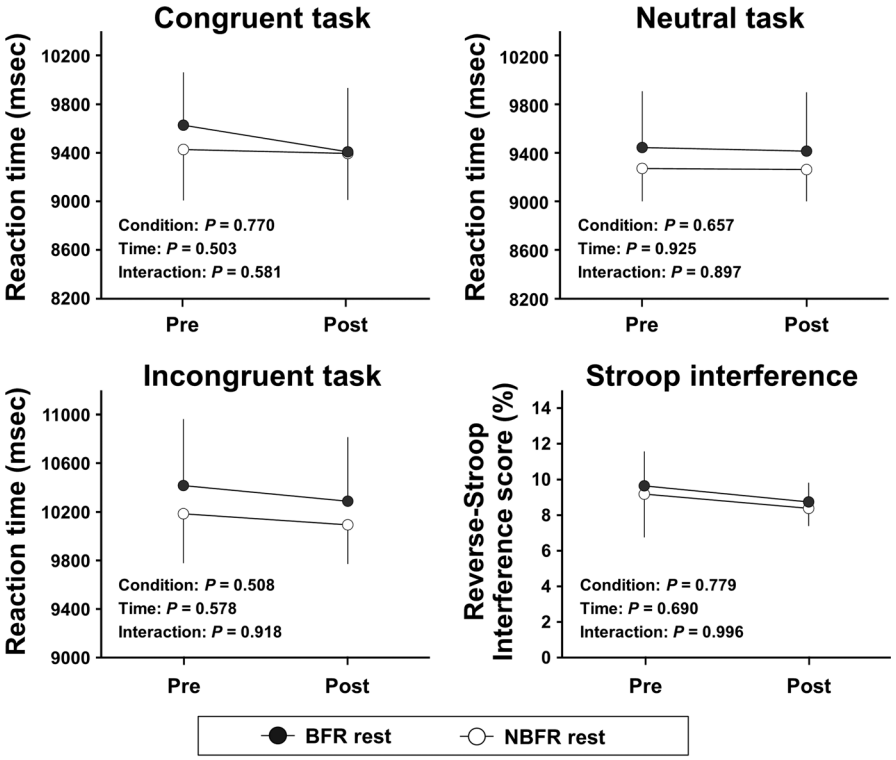

FIGURE 1—Change in EF before and after BFR and NBFR rest sessions. Values are presented as mean ± SEM.

walking ($P = 0.001$), with medium effect size ($d = 0.59$). A trend toward significance was observed with a shorter incongruent reaction time after BFR walking than that after NBFR walking ($P = 0.064$), with small effect size ($d = 0.32$). Analyses of reaction times for congruent and neutral tasks revealed no significant main effects of condition and time and no significant interaction effects. Analyses of response accuracies for all three CWST types also revealed no significant main effects for condition and time and no significant interaction effect (data not shown).

The reverse Stroop interference score analysis revealed a significant main effect for time ($F_{1,\ 15} = 13.16$, $P = 0.002$, $\eta_p^2 = 0.47$) and a significant interaction effect ($F_{1,\ 15} = 11.07$, $P = 0.005$, $\eta_p^2 = 0.42$). A trend toward significance was observed for a main effect for condition ($F_{1,\ 15} = 3.47$, $P = 0.082$, $\eta_p^2 = 0.19$). The reverse Stroop interference score decreased after BFR walking, but not after NBFR walking, compared with that before walking ($P < 0.001$), with large effect size ($d = 1.52$). This score was also lower after BFR walking than after NBFR walking ($P = 0.003$), with large effect size ($d = 1.29$).

Arousal analysis revealed significant main effects for condition and time and a significant interaction effect. Arousal increased after BFR and NBFR walking compared with that before walking ($P \leq 0.01$ for both), with large and medium effect sizes ($d = 1.57$ and 0.77), respectively. Arousal after walking was higher with BFR than with NBFR ($P = 0.022$), with medium effect size ($d = 0.74$). Mental fatigue analysis revealed a significant main effect for time and a significant interaction effect. Mental fatigue increased immediately after BFR

TABLE 2. Psychological conditions for the color–word Stroop task before and after BFR and NBFR conditions.

	BFR Condition		NBFR Condition		*P* Values		
	Pre	Post	Pre	Post	Condition	Time	Interaction
Study 1							
Arousal	2.8 ± 0.3	2.8 ± 0.3	2.5 ± 0.2	2.6 ± 0.2	0.528	0.785	0.732
Mental fatigue, mm	34.8 ± 10.2	26.9 ± 6.4	22.3 ± 8.1	21.9 ± 9.8	0.161	0.276	0.380
Ability to concentrate, mm	57.1 ± 7.9	66.9 ± 9.2	68.9 ± 7.3	72.3 ± 3.5	0.352	0.167	0.288
Motivation, mm	69.3 ± 6.1	73.3 ± 7.0	71.8 ± 5.6	77.0 ± 5.6	0.581	0.134	0.680
Study 2							
Arousal	2.3 ± 0.2	3.6 ± 0.2*,**	2.2 ± 0.2	2.9 ± 0.2**	**0.035**	**<0.001**	**0.046**
Mental fatigue, mm	21.3 ± 3.2	56.0 ± 5.1*,**	32.4 ± 6.5	38.1 ± 5.4	0.559	**<0.001**	**0.009**
Ability to concentrate, mm	63.9 ± 4.7	62.5 ± 6.8	55.0 ± 4.7	61.4 ± 5.5	0.223	0.461	0.416
Motivation, mm	67.3 ± 4.0	68.5 ± 6.0	62.1 ± 4.6	68.6 ± 3.4	0.476	0.134	0.422

Values are presented as mean ± SEM. Bold *P* values indicate significant main effects of time and condition and a significant interaction effect ($P < 0.05$ for all).
*Significant difference ($P < 0.05$) between conditions.
**Significant difference ($P < 0.05$) between time points.

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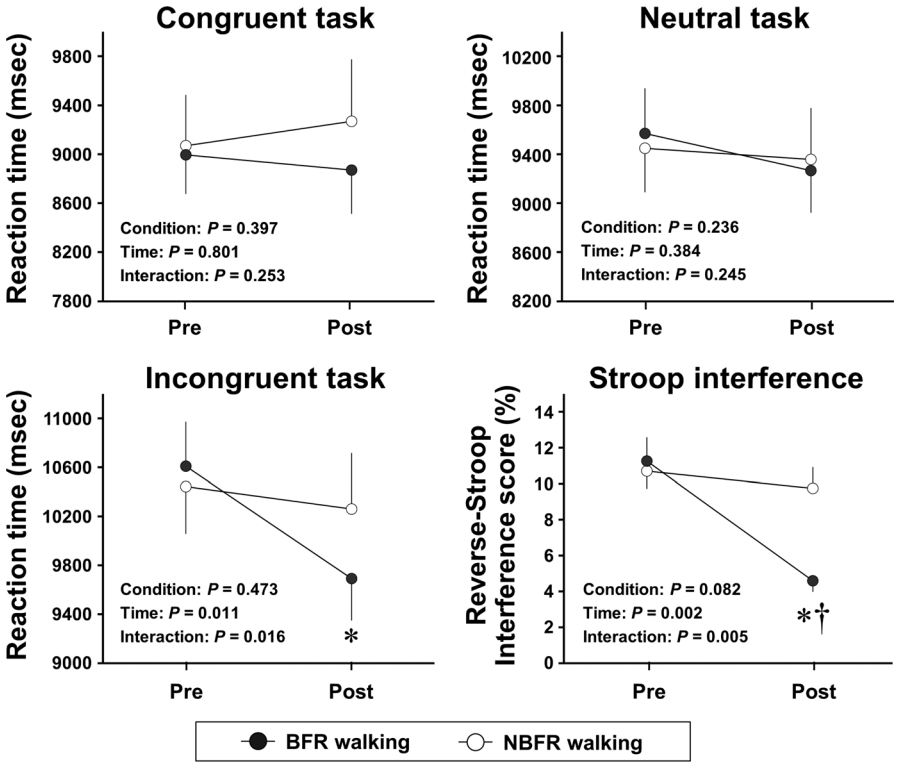

FIGURE 2—Change in EF before and after BFR and NBFR walking sessions. Values are presented as mean ± SEM. *Significant difference ($P < 0.01$) between conditions. †Significant difference ($P < 0.001$) between time points.

walking, but not after NBFR walking, compared with that before walking ($P < 0.001$), with large effect size ($d = 2.03$). A trend toward significance was observed with higher mental fatigue after BFR walking than that after NBFR walking ($P = 0.074$), with large effect size ($d = 0.85$). Analyses of ability to concentrate and motivation revealed no significant main effects for time and condition and no significant interaction effect.

DISCUSSION

Despite absence of significant effect of BFR rest on EF parameters, the incongruent reaction time shortened after BFR walking. Furthermore, the reverse Stroop interference score decreased after BFR walking. These positive effects were not observed for NBFR walking. Therefore, BFR walking improves EF independently of the effect of BFR alone or walking alone.

This study demonstrated that a BFR walking protocol with a 15-min duration improved postexercise EF, including IC, and the improvement rate of the IC (i.e., decrease in the reverse Stroop interference score) before and after BFR walking was 59% ($d = 1.52$), which was similar to that for high-intensity interval exercise with a 33-min duration (52%, $d = 1.94$) and for moderate-intensity continuous exercise with a 40-min duration (51%, $d = 2.39$) (6). Furthermore, it was more than twofold higher than both low-intensity continuous exercises with 20- and 40-min durations (~27%, $d = 0.82$ and 0.85, respectively) (7). In addition, the improvement rate of IC for BFR walking was comparable with that for high-intensity resistance exercise with a 17-min duration (64%, $d = 1.24$) and was approximately 1.8-fold higher than that for low-intensity resistance exercise with a 17-min duration (33%, $d = 0.68$) (5). Therefore, despite it being a mild exercise, BFR walking can rapidly and effectively improve postexercise EF, particularly IC, in a manner similar to other protocols of aerobic and resistance exercises with higher intensities and longer durations.

Systemic lactate is used in the human brain during exercise as an important energy substrate to replace glucose (18). The degree of aerobic exercise–induced EF improvements is associated with blood lactate levels (2,3,6–8), which is probably due to increasing cerebral lactate metabolism (2). Although blood lactate was not altered by BFR alone or walking alone, they were significantly, but slightly, increased by BFR walking. In addition, Dalsgaard et al. (16) reported that low-intensity aerobic exercise with BFR increased cerebral lactate metabolism immediately after exercise compared with before exercise. Thus, the potential impact of BFR exercise on postexercise EF improvement may be due to increases in circulating lactate levels and cerebral lactate metabolism. Nevertheless, Rasmussen et al. (19) reported that an increase in cerebral lactate metabolism was observed with blood lactate levels of more than 2 mM. The blood lactate levels immediately after BFR walking were only 1.9 mM. Furthermore, it was less than that immediately after effective aerobic exercise protocols to improve postexercise IC (2–4,6–8). Therefore, in addition to systemic and cerebral lactate metabolism, other factors may play roles in postexercise EF improvement induced by BFR walking.

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Byun et al. (20) demonstrated that aerobic exercise–induced increase in arousal correlated with postexercise EF improvement and cerebral neural activation. Their result suggests that exercise-induced modulation in perceptual responses, such as arousal, may play a role in improving EF. Although FAS-measured arousal was not altered by BFR alone, the arousal was increased after BFR. Furthermore, arousal after walking was higher with BFR than with NBFR. Both BFR aerobic and resistance exercises elevate blood norepinephrine (17,21), which is a modulator of arousal (22). Therefore, augmentation of the norepinephrine-arousal system may be one for postexercise EF improvement induced by BFR walking.

A decrease in muscle oxygenation level (e.g., oxygen saturation and oxygenated hemoglobin/myoglobin) is not induced by walking at the speed of 5 $km \cdot h^{-1}$ used in this study (23). The effect of BFR on muscle oxygenation level during walking has not been reported. Nevertheless, a decrease in muscle oxygenation level during low-intensity resistance exercise is greater with BFR than with NBFR (24,25). Furthermore, a similar result was observed for aerobic cycling exercise (26). Thus, BFR results in muscle hypoxia during both resistance and aerobic exercises. In addition, changes in intramuscular high-energy phosphates (e.g., decreased phosphocreatine and increased inorganic phosphate) during low-intensity resistance exercise is greater with BFR than with NBFR (24,25,27); by contrast, no such changes were observed with BFR alone (28). Therefore, a combination of BFR and exercise may lead to the increases in both hypoxic and metabolic responses of the exercising muscles, which may activate the sympathetic nervous system via peripheral chemoreceptors and/or metaboreceptors (29). The increases in these local peripheral responses induced by BFR exercise may be associated with improved postexercise EF and augmented norepinephrine-arousal system via activation of the sympathetic nervous system (30).

BFR exercise may have the potential to increase the production of circulating nitric oxide (NO) (17,31), derived from endothelial cells (31). NO is a neurotransmitter in the brain (32); thus, NO could help postexercise EF improvement induced by BFR walking. Flavanol-rich cocoa consumption enhanced EF improvements after moderate-intensity aerobic exercise (4), possibly by increasing NO production (33). Therefore, the impact of BFR on NO production may contribute to improve postexercise EF.

Long-term intervention of BFR alone, performed with repeated bouts of a short BFR duration (i.e., 5 min), is effective for protecting against muscle atrophy and strength loss in subjects with disuse muscle atrophy due to immobilization and orthopedic surgeries (34,35). This BFR protocol can be considered as ischemic preconditioning and may increase endothelial cell-derived NO production (36). By contrast, BFR rest was applied for 15 min to exclude the effect of BFR alone on postexercise EF improvement induced by BFR walking, and it was ineffective in improving postexercise EF. If increased NO production is an important factor in improving EF, the BFR rest may be inadequate for postexercise EF improvement because a long BFR duration without exercise impairs NO production due to the increased reactive oxygen species (37). Taken together, a clinical BFR protocol (i.e., ischemic preconditioning) may have the potential to improve EF without exercise.

BFR walking has been performed with various protocols (12–15,38,39). For example, walking speed is ranged from 3 to 6 $km \cdot h^{-1}$. Ozaki et al. (14) used a walking speed at 6 $km \cdot h^{-1}$ with a slope of nearly 4°, to examine the effect of BFR walking on muscle protein synthase signaling. We used a 5-$km \cdot h^{-1}$ walking speed without slope for the BFR walking because walking speed faster than at least 4.5 $km \cdot h^{-1}$ is considered to be required to increase blood lactate levels (38). Nevertheless, this walking speed was faster than that used in some studies (12,13,15,38,39). Furthermore, a BFR pressure at 200 mm Hg is higher than in some studies (15,39). In addition, RPE and leg discomfort were higher during BFR walking than during NBFR walking. The exacerbated perceived exertion responses are considered barriers to participation of BFR walking (10). Perceived exertion responses during BFR exercise can be mitigated by decreasing exercise intensity and/or BFR pressure (40,41); however, decreases in these variables may reduce its acute and chronic positive effects (27,42). Listening to music mitigates the increase in RPE during aerobic exercise without decreasing the positive effects on EF (3). To enhance adherence to BFR walking, further studies are needed to develop effective strategies to minimize perceived responses during this exercise.

We recruited healthy young males; however, effective exercise programs to improve EF are more important for older individuals and patients with chronic diseases. Skeletal muscle weakness (e.g., decreased muscle mass and strength) and exercise intolerance (e.g., decreased exercise endurance and peak oxygen consumption) are poor prognostic factors for various conditions, including cognitive dysfunctions, in older individuals and patients with chronic diseases (43,44). BFR exercises, including walking, may be beneficial in comprehensively and effectively improving these poor prognostic factors (11) and have been prescribed for older individuals and patients with chronic diseases (13,15,45). To enhance the effectiveness of BFR walking in the clinical setting, further studies are needed to determine the effect of BFR walking on EF in various populations.

In conclusion, even with a mild exercise mode, BFR walking improved EF independently of effect of BFR or walking alone. This finding suggests that BFR walking may be a beneficial strategy for improving cognitive functions.

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The authors have no conflicts of interest to report. The results of the present study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. In addition, these results do not constitute endorsement by the American College of Sports Medicine.

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