Effects of foam rolling intervention on lactate clearance and cognitive function after high-intensity exercise with incremental load

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Abstract: Foam rolling (FR) intervention has attracted attention in the sports field. However, its effects on lactate clearance, mental fatigue, and cognitive function associated with fatigue after high-intensity exercise are unknown. Therefore, this study examined whether FR intervention is an effective fatigue recovery tool. Eighteen healthy adults (10 males and 8 females; 21.8 ± 1.7 years) without exercise habits participated in the study. Participants performed high-intensity exercise on an ergometer with a progressive load. The FR intervention postexercise was compared with the control condition. Measurements were lactate, vigor/fatigue by POMS2, cognitive function (cognitive task performance), and leg and body rating of perceived exertion (RPE) pre- and postexercise and postintervention (i.e., 5 min postexercise). This study showed a significant reduction in the blood lactate concentration post-FR intervention. In addition, greater lactate clearance by FR was correlated with faster recovery of executive function in those with greater lactate clearance, although cognitive fatigue was not identified after high-intensity exercise. Moreover, lactate clearance was not significantly correlated with RPE in the FR condition, whereas RPE decreased with greater lactate clearance in those with greater lactate clearance in the control condition. The study results indicate that FR intervention may be effective as a recovery tool for exhausting exercises. However, when implementing it in the field, whether priority should be given to the recovery of physiological parameters or RPE should be carefully considered.

Keywords: Foam Roller, Fatigue, POMS2, recovery

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INTRODUCTION

Many sports competitions involve high-intensity interval exercises with repeated sprints and jumps. Ball sports, such as basketball and handball, require high-intensity interval exercise for extended periods, with little time between halves or sets. High-intensity interval exercise, repeated with such short rest periods, results in a noticeable decrease in performance (fatigue) in the second half of the match. Factors contributing to exercise-induced fatigue could involve functional impairment at the peripheral and central levels, such as acidosis associated with lactic acid accumulation (Robergs, Ghiasvand and Parker, 2004), mental fatigue (Marcora, Staiano and Manning, 2009), and cognitive fatigue (Ochi et al., 2018; Ochi et al., 2022). Cook and Beaven (2013) recommended that recovery to a good psychological state post-exercise is important for maintaining performance, and recovery of both peripheral and central functions post-exercise is an urgent issue. However, existing recovery methods, such as cold water immersion (Higgins, Greene and Baker, 2017) and full-body aerobic exercise, e.g., rowing ergometer (Raeder et al., 2017), are difficult to implement during a game due to the time, location, and rules of the competition. To maintain mental and physical functions until the latter half of the match, a new recovery method that can be implemented in a limited space and in a short time is required.

Foam rolling (FR) is commonly used as a recovery method in several cases. Adamczyk et al. evaluated the effects of FR intervention after squat jumps at maximal effort for 1 min (Adamczyk, Gryko and Boguszewski, 2020). They reported significantly ($p < 0.05$) greater lactate clearance in the FR than in the

intervention condition at 30 min post-exercise. In addition, Akinci et al. implemented circuit-based high-intensity exercise at 85% intensity calculated from the heart rate reserve method and measured lactate levels before the exercise training, before the recovery period, and 5 and 20 min of the recovery period to examine the effects of FR intervention on lactate levels (Akinci, Zenginler Yazgan and Altinoluk, 2020). They reported that FR intervention did not alter lactate concentrations. However, these studies may not have adequately evaluated the effects on muscles that are primarily active and fatigued during exercise because of the long time elapsed after the exercise and the fact that it is a whole-body exercise. Moreover, the acute effects of recovery methods on lactate clearance, mental fatigue, and cognitive fatigue, which have been implicated in poor performance, are unknown. In addition, only a few studies have compared FR lactate reduction rates between men and women, and the physiological conditions and methodologies involved in lactate reduction rates remain unclear. This study was designed to determine whether FR improves lactate clearance, mood decline, and cognitive fatigue after exhaustive exercise and whether gender differences exist in these effects, thereby providing a foothold for elucidating the mechanism of FR recovery.

METHODS

Experimental setup

This study examined the immediate effects of FR, which can be performed in a confined space and for a limited time, on lactate clearance and cognitive function after high-intensity exercise with

progressive loading. In addition, this study examined these effects separately in males and females. A randomized repeated measures experimental design was used to compare the two conditions: control and FR. Participants were instructed to visit the laboratory twice with a ≥48 h break. The measurement was conducted before the intervention (pre), after the intervention (post), and 5 min postintervention. The psychological scales completed included the Profile of Mood States 2nd Edition (POMS2) (Yokoyama and Watanabe, 2015) and participant ratings of perceived exertion (RPE) (Saenz et al., 2014). The parameters measured were executive function, psychological scale scores, and blood lactate concentration, which were assessed respectively to prevent the blood lactate concentration measure from affecting executive function and psychological status.

Participants

A total of 22 right-handed Japanese-speaking young adults (12 males and 10 females) agreed to participate from October 2023 to January 2024. The inclusion criteria were as follows: no regular exercise habits, no daily use of a foam roller, native Japanese speaker, and no history of neurological, psychiatric, or respiratory diseases. All participants were instructed to refrain from eating or drinking anything other than mineral water 2 h before starting the experiment. In this study, data analysis was conducted with 18 participants (10 males and 8 females) because four participants were excluded because of their inability to perform the FR intervention after a high-intensity exercise. Table 1 shows the participants' characteristics. Post hoc sensitivity analysis performed

using this sample with 80% power and α = 0.05 demonstrated sufficient sensitivity to detect repeated-measures effects exceeding $f = 0.31$ as computed using G*Power (3.1.9.2; The G*Power Team).

High-intensity exercise with a progressive load

High-intensity exercise with progressive loading was performed using an ergometer (828E, Monark, Sweden). Participants performed an ergometer exercise for 3 min at a load of 0.5 KP as a warm-up, followed by a 1-min rest period. After the break, males and females performed ergometer exercises with a progressive increase in load of 0.5 KP/min. The participants performed the ergometer exercise and were instructed to pedal in time with a metronome (Smart Metronome; Tomohiro Ihara, Japan) set at 60 bpm. The exercise was stopped when the pedaling speed could no longer be sustained. During the exercise, strong verbal encouragement was provided to elicit maximum effort. Exercise time and heart rate (HR) pre- and postintervention were measured during each session.

FR intervention

Figure 1 shows the FR intervention methods using a foam roller (Stretch Roll SR-002, Dream Factory, Umeda, Japan). A physical therapist instructed the participants at preintervention. FR intervention was initiated with knee flexors followed by knee extensors. FR intervention was performed on the right and then on the left side. The FR area of the knee flexor muscle group was defined as the proximal knee fossa

to the sciatic tuberosity (Reiner et al., 2022). The knee extensor was defined as the superior anterior iliac spine to the top of the patella (Kasahara et al. 2022, Nakamura et al., 2022). One FR cycle was defined as one distal rolling movement followed by one proximal rolling movement performed in 4 s (Behm et al., 2020). The intervention intensity was directed to be the maximum intensity that the participant could tolerate (Kasahara et al., 2022). The intervention time for each area was 60 s, and the participants were instructed to prepare for the intervention for the next area during the 20-s interval. A metronome (Smart Metronome; Tomohiro Ihara, Japan) at 60 bpm was used as a control.

Psychological measurements

POMS2 contains 35 items and evaluates seven mood states (anger-hostility, confusion-bewilderment, depression-ejection, fatigue–inertia, tension–anxiety, vigor-activity, and friendliness). This study used only the 10-item subset on vigor-activity and fatigue–inertia to reduce the participant's psychological burden.

RPE was recorded during pre- and postexercise intervention to assess psychological exercise intensity.

Blood lactate concentration

Lactate Pro 2 (AKRAY Europe B.V. Prof. J.H Bavincklaan 51,183 AT, Amstelveen, the

Netherlands), a handheld point-of-care analyzer, was used for enzymatic amperometric detection. It requires 0.3 μl of a whole blood sample and a short time (15 s) to measure the lactate level. Lactate Pro 2 measurement ranges from 0.5 to 25.0 mmol/L. In this study, only lactate values between 0.5 and 25 were included.

Behavioral measurements

Schneider's (2020) (Schneider, 2020) spatial Stroop task was used to measure executive function. This task was created using web-building platforms (Lab.js v19.1.0) (Shevchenko, 2022). In each experiment, participants made a spatially compatible key-press response to classify the spatial meaning of a stimulus presented at an irrelevant position. Stimulus meaning and position were either matched (congruent) or mismatched (incongruent) in the trial: 16 congruent and 16 incongruent. Visual alerting cues (squares) were briefly presented at the two potential stimulus positions 500 ms before the onset of the stimulus. Although previous studies have used multiple stimulus types (arrows or words) and spatial dimensions (horizontal or vertical), this study employed arrow stimulus-type tasks. In addition, because preliminary experiments revealed that reaction times tended to be slower in vertical than in horizontal spatial dimension tasks, and the load on the task was assumed to be higher (fatigue was more likely to occur); therefore, vertical spatial dimension tasks were used in the present study.

Participants pressed a key indicating up ("y") or down ("b") to classify the direction of an up- or

down-pointing arrow positioned above or below fixation (Figure 2). The correct answer ratio assigned to yes and no was 50%. Each stimulus was separated by an interstimulus interval showing a fixation cross for 2 s to avoid prediction of the subsequent trial's timing. The stimulus remained on the screen until the patient responded or for 1 s. This study adopted Stroop interference, a specifically defined cognitive process, to elucidate the effects of an acute bout of exercise on executive function by calculating the incongruent–congruent contrast, which is assumed to represent Stroop interference.

Data from 16 participants (8 males and 8 females) were used only for the cognitive task because data for 2 of the 18 participants could not be obtained.

Statistical analysis

The R software (4.3.2), Rstudio (2023.12.0 + 369), "EZR on R Commander (Kanda, 2013)," and the "anovaun" package were used for all analyses. A three-way analysis of variance (ANOVA) was performed to compare the conditions, times, and sex. First, Mauchly's sphericity test was used to determine whether sphericity was maintained. When the sphericity assumption was confirmed, a three-way ANOVA with Greenhouse–Geisser's epsilon correction was performed; otherwise, only a three-way ANOVA was performed. The effect size classification was set where $\eta_p^2 < 0.01$ was considered small; 0.02–0.1, medium; and >0.1, large (Cohen, 1988). The corresponding *t*-test with Holm's correction was used to determine the significant differences obtained from ANOVA. To clarify the relationships between the parameters and

171 executive performance, Pearson's correlation analyses were performed. Statistical significance was set a

172 priori at $P < 0.05$ for all comparisons.

173

174 ***Ethics approval***

175 This study was conducted following the Declaration of Helsinki and was approved by the ethics

176 committee of the Niigata University of Health and Welfare, Niigata, Japan (approval number 19170-

177 231019). Participants were informed about their data confidentiality and provided written informed consent

178 to participate in the study.

179

180 **RESULTS**

181 ***Physiological parameters***

182 Table 2 shows the results of HR, RPE, total exercise time, and kp max in the control and FR

183 conditions. No significant differences in PRE values were observed between the two conditions for all measures.

184 HR increased significantly immediately postexercise in both conditions ($P < 0.01$). RPE (leg/body) was

185 significantly higher at POST and 5 min compared with PRE in both conditions ($P < 0.01$) but significantly

186 lower at 5 min compared with POST ($P < 0.01$). In addition, sex differences were observed in the total

187 exercise time and load at postexercise ($P < 0.01$), which were significantly higher in males than in females.

188 However, no significant differences were observed between the conditions.

Figure 3 shows the changes in lactate values. A three-way ANOVA (conditions vs. time vs. sex) showed no significant interactions (F (2, 32) = 1.0047, P = 0.3774, η_p^2 = 0.0591). A two-way ANOVA (conditions vs. time) showed a significant interaction (F (2 ,32) = 4.0433, P < 0.05, η_p^2 = 0.2017) and a main effect of time (F (2, 32) = 275.1504, P < .0001, η_p^2 = 0.9450). The post hoc test results in the control condition showed significantly higher values at POST and 5 min than those at PRE (P < 0.01), but no significant difference was observed between POST and 5 min. In the FR condition, POST and 5 min values were significantly higher than PRE (P < 0.01). In addition, 5 min was significantly lower than POST (P < 0.01).

Psychological parameters

A three-way ANOVA (conditions vs. time vs. sex) showed no significant interaction between vigor (F(2, 32) = 1.6850, P = 0.2015, η_p^2 = 0.0953) and fatigue (F(2, 32) = 1.0022, P = 0.3783, η_p^2 = 0.0589) in POMS2. A two-way ANOVA (conditions vs. time) showed a main effect of time on vigor (F(2, 32) = 7.5235, P < 0.01, η_p^2 = 0.3198) and fatigue (F(2, 32) = 163.5833, P < 0.0001, η_p^2 = 0.9109). A post hoc test using Holm correction revealed that vigor was significantly lower in POST than in PRE (P < 0.01). Fatigue was significantly higher at POST and 5 min compared with PRE (P < 0.0001). In addition, POST was significantly higher than 5 min (P < 0.0001).

Relationship between parameters and performance

Figure 4 shows lactate and executive function changes in pre- and postintervention. A significant correlation trend was found in the FR condition ($r = 0.41$, $P = 0.086$). Sex-specific results showed a significant correlation for males ($r = 0.706$, $P < 0.05$), but not for females ($r = 0.13$, $P = 0.747$). No significant correlation was found in the control condition ($r = -0.38$, $P = 0.118$).

Figure 5 reveals lactate and RPE (leg/body) changes pre- and postintervention. No significant correlation was found in the FR condition, but a significant correlation was found in the control (leg: $r = 0.778$, $P < 0.01$, body: $r = 0.669$, $P < 0.01$).

DISCUSSION

The acute effects of FR intervention on lactate clearance, psychological parameters, and cognitive function after progressively increasing load exercise were examined, resulting in exhaustion to propose FR as a new recovery method that can be implemented in a limited space in athletes. The results revealed that, regardless of sex, the arterial blood lactate concentration, which increased after exhaustive exercise, decreased in the FR condition, indicating that the FR intervention enhanced the lactate clearance effect. Interestingly, cognitive function improved after FR intervention compared with that in those with greater lactate clearance, and this effect was significantly greater in males than in females. This finding indicates that FR intervention may also be useful in improving exercise-induced cognitive decline (cognitive fatigue), particularly in males.

This study showed significant increases in HR at pre- and postexercise in both FR and control conditions, without significant differences between them. In addition, the Karvonen method (Karvonen and Vuorimaa, 1988) demonstrated that exercise intensity at postexercise was 85.3 ± 11.0% in the FR condition and 83.6% ± 10.4% in the control condition, without a significant difference between the two conditions. Based on these results, we concluded that all participants could perform the same extent of exercise in both conditions.

First, we examined the effect of FR intervention on lactate clearance. In the present study, the ergometer exercise was performed with progressive loading by applying a strong load to the lower extremities, and the FR intervention targeted the bilateral knee extensors and flexors. In this study, arterial blood lactate concentrations significantly increased immediately at postexercise in both conditions, and no difference was observed between the conditions. Thereafter, no lactate concentration changes were observed in the control condition, but in the FR condition, arterial blood lactate concentration significantly decreased postintervention. These results indicate that FR intervention immediately after exhaustive exercise is useful for increasing lactate clearance. A previous study reported that increased arterial blood lactate concentrations after high-intensity exercise were significantly lower in active recovery groups that performed low- or high-intensity exercise than in passive recovery groups that did not receive any intervention (Riganas et al., 2015; Menzies et al., 2010). More interestingly, no significant difference in the increasing effect of ROM was observed between the FR and sham rolling conditions, which simulated the FR intervention movements (Warneke et al., 2023). These findings indicate that active recovery, such as FR, may again increase the blood flow in active tissues and

increase lactate clearance (Bogdanis et al., 1996). In addition, FR intervention increases regional perfusion (Hotfiel et al., 2017), indicating that FR intervention may further increase lactate clearance.

Second, the effects of FR intervention on executive function were examined. In the present study, executive function task performance did not decrease at pre- or postexercise to exhaustion, and the progressive load exercise leading to exhaustion did not induce cognitive fatigue. Progressive exercise to exhaustion has long been associated with impaired cognitive function, including executive function (Chmura, Nazar and Kaciuba-Uściłko, 1994); however, the effects are not always clear. Recently, Sudo et al. reported that the type of cognitive task was not associated with cognitive performance after a high-intensity exercise (Sudo et al., 2022). Therefore, exercise conditions such as progressive load exercise and the spatial Stroop task possibly failed to induce cognitive decline in the study participants. Conversely, exercise in extreme environments, such as hypoxic environments, decreases cognitive function (Ochi et al., 2018; 2022). To verify whether FR intervention is effective in restoring exercise-induced cognitive decline, it should be investigated under different exercise conditions, such as a hypoxic environment.

This study demonstrated that the amount of lactate change was significantly correlated with changes in executive function task performance immediately postexercise and post-FR intervention in the FR condition. This result indicated that executive function may be recovered in patients with increased lactate clearance. Previous studies have reported that elevated blood lactate levels after exhaustive exercise are associated with a significantly worsened attentional process (Coco et al., 2009). Therefore, increasing lactate clearance

due to FR may contribute to improved cognitive decline (cognitive fatigue) due to increased lactate values. In addition, previous studies have shown that low- and moderate-intensity exercises improve Stroop task performance (Byun et al., 2014; Yanagisawa et al., 2010). The exercise-induced increase in body perfusion (Mulser and Moreau, 2023) may increase nutrient (glucose and oxygen) supply to the brain. Although the relationship between cognitive improvement and increased brain perfusion by exercise remains unclear, the increase in whole-body perfusion due to FR intervention may contribute to improved executive function.

Finally, we examined the effects of FR intervention on psychological parameters. These results indicated that FR intervention did not affect the vigor and fatigue of POMS2. The results support the findings of a previous study (Pernigoni et al., 2023) in which FR intervention was administered to female basketball players and had no effect on perceived recovery (TQR) or fatigue level. However, in professional male soccer players, a larger effect size (Conhen's d = 1.08) was reported on TQR recovery in the FR intervention condition compared with the control condition after 24 h of training (Rey et al., 2019). These differences in results may be due to the methods of FR intervention. Pernigoni et al. (2023) and Ray et al. (2019) performed a 20-min FR intervention on the entire lower extremity, including the quadriceps, hamstrings, triceps, and abductor and adductor muscle groups. Conversely, this study found that the FR intervention was 4 min for knee extensors and knee flexors. A capacitance–response relationship has been found for the effect of FR on ROM increase (Sullivan et al., 2013). The enhancement of psychological parameters through FR may also be associated with the capacity–response relationship, necessitating further research for a clearer understanding.

The results revealed that in terms of RPE, which represents the tightness to exercise, a greater decrease in lactate in the control condition was associated with a lower RPE. However, in the FR condition, no significant correlation was observed between changes in lactate and RPE. These differences may be related to the FR intervention method. A push-up bar was used as the FR intervention method for the knee flexors (Figure 1A, 1B). Furthermore, intervention for the knee extensors was performed in a plank posture (Figure 1C, 1D). In this study, the intervention effects were examined in participants who did not use the foam roller daily; therefore, the FR intervention itself may have affected RPE. Therefore, while lactate clearance increased in the FR condition, the effect of improved tightness to exercise may not have occurred. The on-field implementation of FR interventions requires careful consideration of whether priority should be given to the recovery of physiological parameters or the recovery of subjective fatigue levels.

There are limitations to this study. First, the mechanisms underlying the study results are unknown. The results indicate that FR intervention increases lactate clearance and has a concomitant effect on executive function; however, the detailed mechanism by which this occurs is unknown. Future studies should examine the effects of FR intervention on regional and cerebral perfusion and changes in lactate clearance and cognitive function. The second is the target population. As mentioned above, the FR intervention for male athletes showed fatigue recovery effects (Rey et al. 2019), but not for female basketball players (Pernigoni et al., 2023). Therefore, the differences between those who have exercise habits and older adults, as well as the differences in athletic specialties and sex among athletes, should be examined in the future. Finally, the effect of FR

intervention on exercise-induced cognitive decline (cognitive fatigue) is discussed. In this study, a correlation was observed between increased lactate clearance and improved cognitive task performance, but cognitive fatigue was not observed in the participants. Using exercise conditions in which cognitive fatigue occurs and accumulating verification, FR intervention can be proposed for the competitive scene as a contribution to the improvement of not only peripheral but also central fatigue.

CONCLUSION

The results revealed that lactate clearance increased as an acute effect of FR intervention after exhaustive exercise in healthy young adults. Furthermore, the greater the effect, the greater the recovery of executive function. However, FR intervention does not decrease RPE by exhaustive exercise; therefore, careful consideration should be given to whether recovery of physiological parameters or recovery of RPE should be prioritized when implementing FR intervention in the field.

Conflict of Interest

The author declares that the author has no conflict of interest.

Data availability statement

The datasets generated and analyzed during the current study are not publicly available but are available

315 from the corresponding author, who was an organizer of the study.

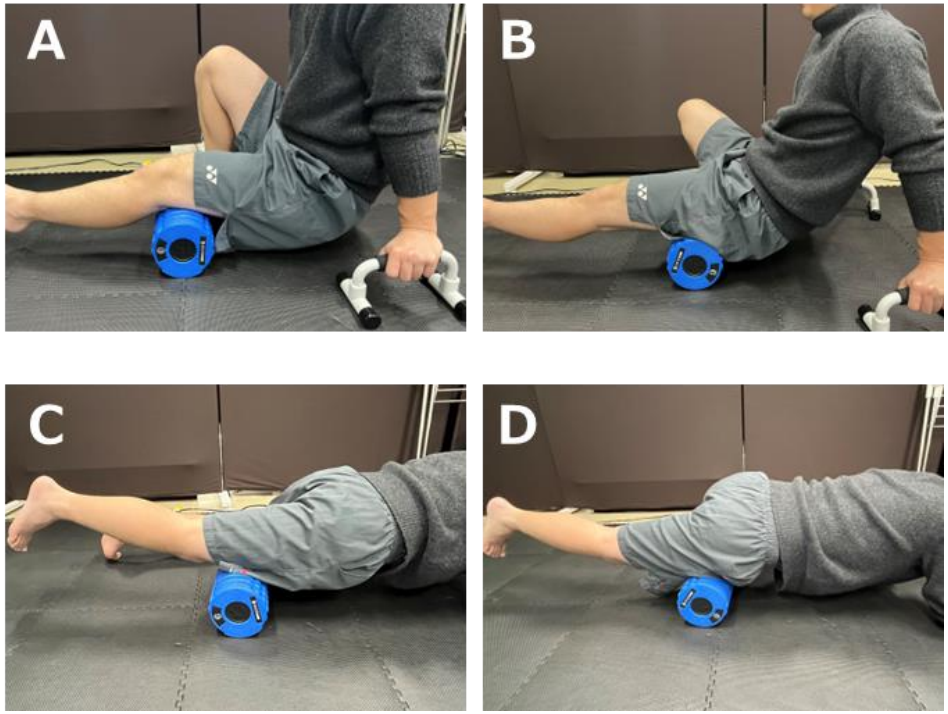

Figure 1. Figures 1A and B show the intervention method for the knee flexors. A push-up bar was used and the sole of the non-intervention side was instructed to contact the ground. 1A shows the distal part of the knee flexors, and 1B shows the proximal part. FR intervention was performed in the A-B range. Figures 1C and 1D show the intervention for the knee extensors, where the non-intervention knee was instructed to touch the ground. 1C shows the distal part of the knee extensors and 1D shows the proximal part, and FR intervention was performed in the range of C-D. The FR intervention was performed bilaterally for 60 seconds at a speed of 1 repetition per 2 seconds in the range specified for each muscle.

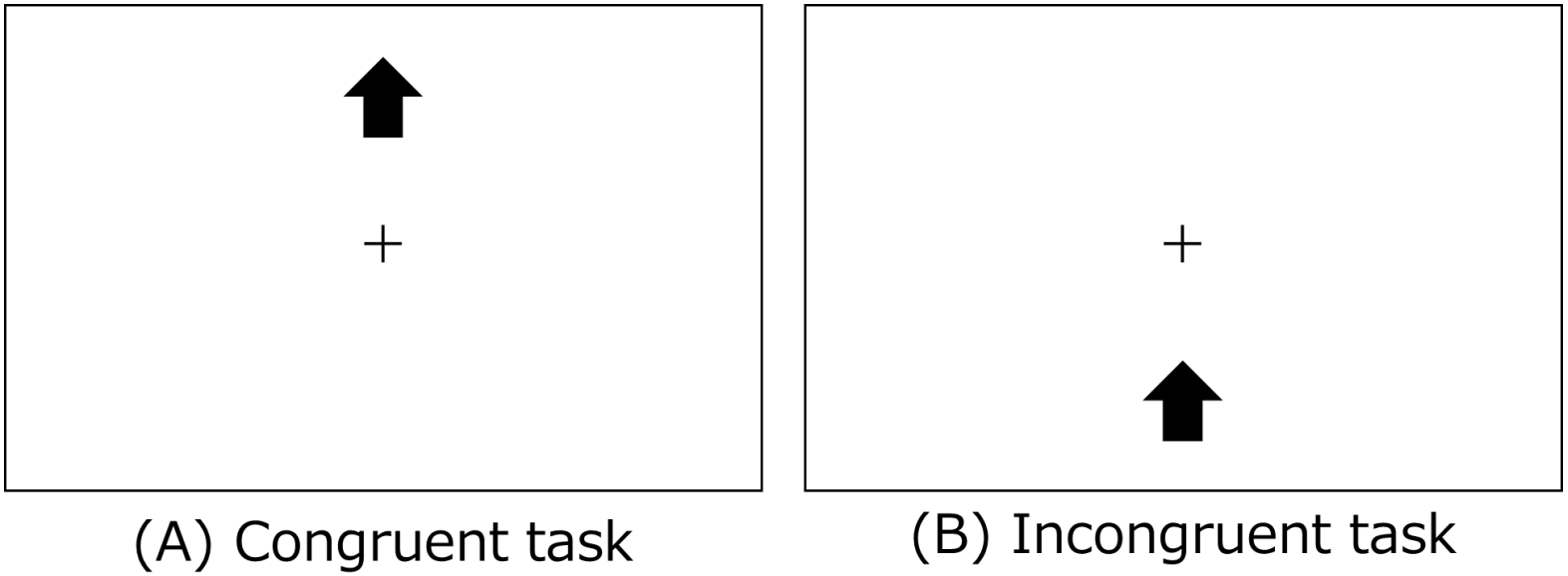

Figure 2. This is an example of Schneider's spatial Stroop task. In the Congruent task, the displayed position and the direction of the arrow match as shown in A. On the other hand, in the Incongruent task, the position displayed on the screen and the direction of the arrow are mismatched, as shown in B.

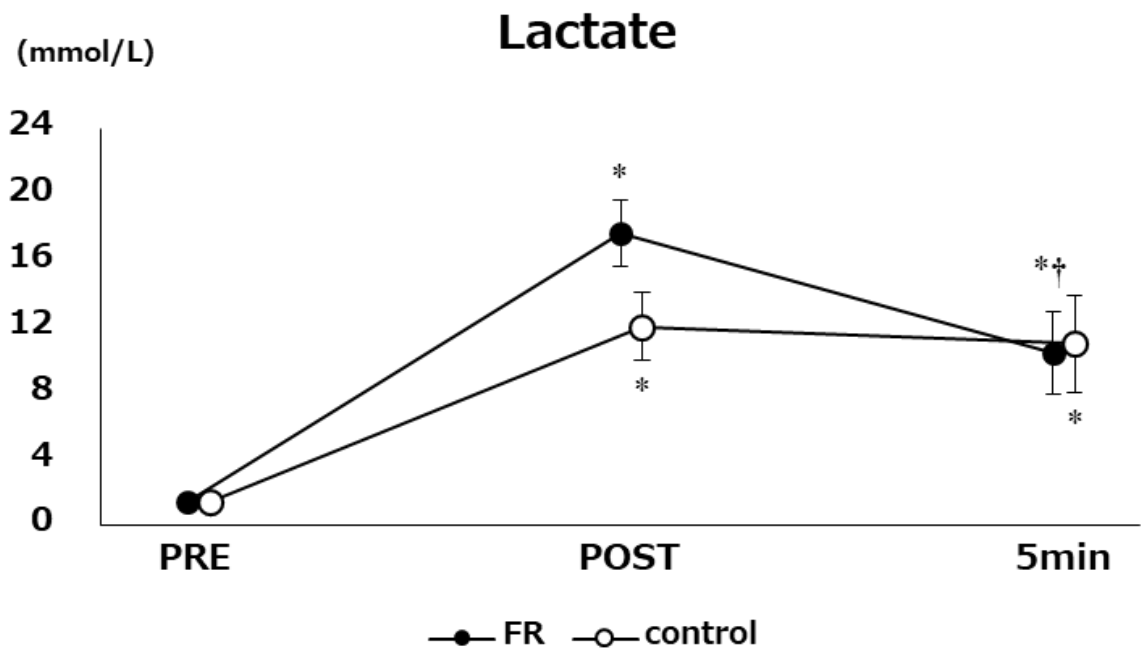

Figure 3. The changes in lactate at PRE, POST, and 5 min after each condition are shown.

*: significant difference with PRE ($P < .01$)

†:Significanct difference with POST ($P < .01$)

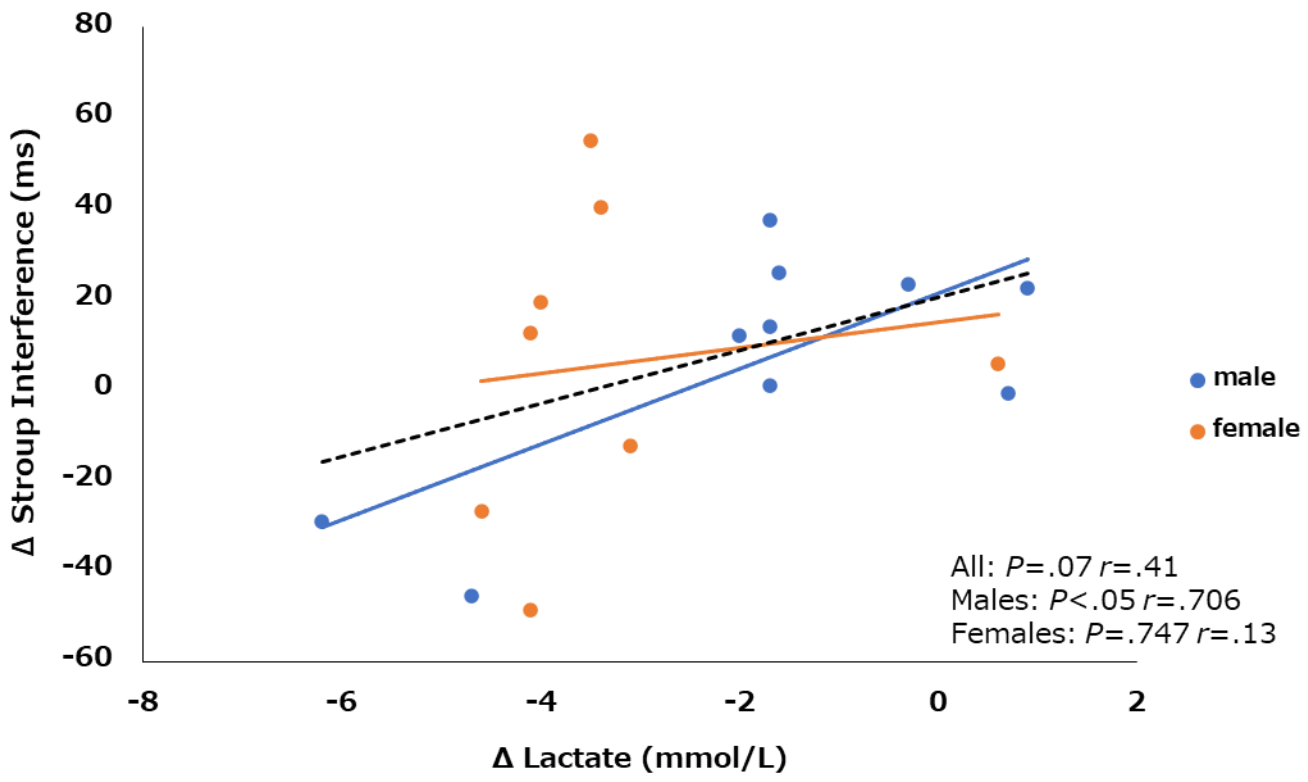

Figure 4. The correlation between the changes in lactate and Stroop interference in the FR condition are shown in the figure. The dotted lines indicate the regression lines for sexes, blue for males and orange for females.

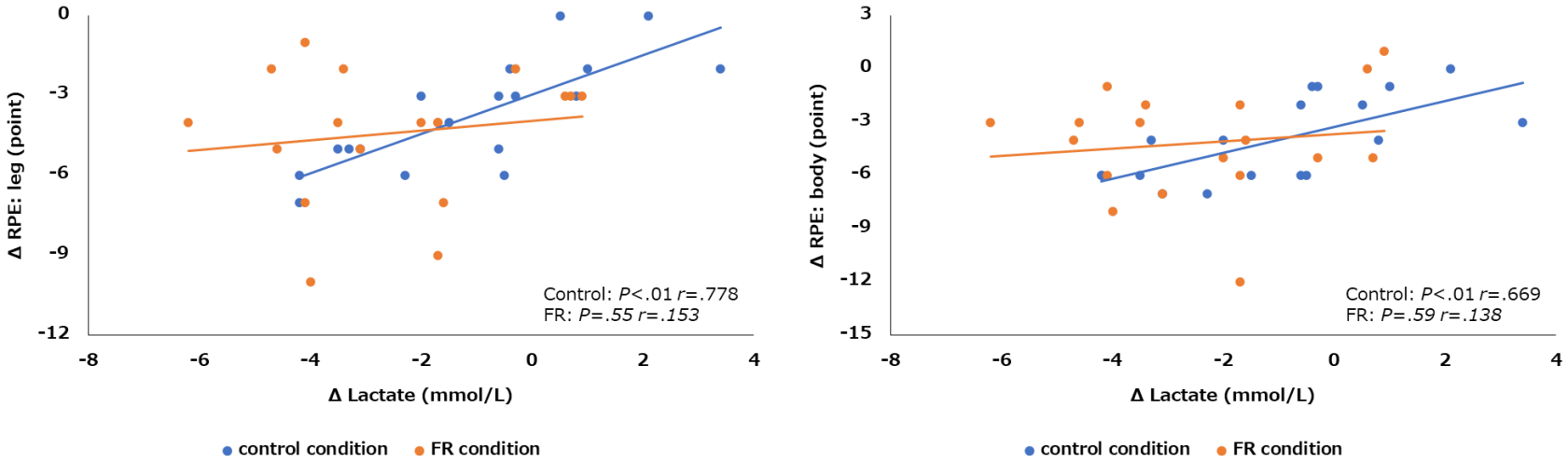

Figure 5. The correlations between the change in lactate and RPE leg and whole body in FR and control conditions are shown separately.

329 Table 1.

330 The following table shows the characteristics of the 18 participants (10 males and 8 females) in this

331 study (mean±SD).

Characteristic	Males (N=10)	Females (N=8)
Height (cm)	172.1±5.0	158.4±5.0*
Weight (kg)	67.1±8.4	48.1±5.3*
Age (years)	22.4±1.3	21.0±2.0
Thigh circumference (Right) (cm)	53.1±4.9	46.7±6.0†
Thigh circumference (Left) (cm)	53.2±4.3	47.1±5.9†

332

333 *: Significant difference with males ($P < .01$)

334 †: Significant difference with males ($P < .05$)

Table 2.

Physiological parameters of each condition before (PRE), immediately after exercise (POST), and after intervention (5min) are shown for each sex (mean±SD).

Conditions and variables		males	females
Control			
	HR[a] pre (bpm)	76.9±10.4	75.5±6.4
	HR[a] post (bpm)	181.3±11.9*	174.4±12.8*
	RPE[b] pre: leg / body (point)	6.4±0.7 / 6.5±0.7	7.9±2.2 / 8.1±2.3
	RPE[b] post: leg / body (point)	18.3±1.5*/ 16.8±2.1*	16.4±1.8*/ 15.8±1.6*
	RPE[b] 5min: leg / body (point)	14.7±2.9*† / 13.0±3.4*†	12.5±2.2*† / 11.5±2.7*†
	Total exercise time (sec)	651.0±87.0	405±92.5**
	kp max (a.u.)	3.4±0.4	2.3±0.4**
Foam Rolling			
	HR[a] pre (bpm)	77.1±12.2	81.6±6.6
	HR[a] post (bpm)	181.6±16.2*	170.9±25.2*
	RPE[b] pre: leg / body (point)	6.5±1.0 / 6.6±1.0	7.8±2.2 / 8.4±2.3
	RPE[b] post: leg / body (point)	18.6±1.4*/ 17.2±2.6*	16.5±2.0*/ 15.1±2.7*
	RPE[b] 5min: leg / body (point)	14.4±2.4*† / 12.7±3.2*†	11.9±2.0*†/ 11.4±2.1*†
	Total exercise time (sec)	615.5±138.5	396.6±91.7**
	kp max (a.u.)	3.2±0.6	2.3±0.4**

[a]HR: heart rate

[b]RPE: Rating of Perceived Exertion

*: Significant difference with PRE ($P < .01$)

†: Significant difference with POST ($P < .01$)

**: Significant difference with males ($P < .01$)