ORIGINAL ARTICLE

# The response of reaction time and fatigability to exhaustive exercise in young male

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## ABSTRACT

The post-exercise effect on cognitive function is associated with exercise intensity, duration, and psychological and physiological factors. The present study aimed to investigate the impact of exhaustive exercise on cognitive function and the differences in psychological and physiological parameters between positive and negative responders to exercise. Seventeen young males performed an exhaustive incremental submaximal exercise task. Reaction time in the incongruent Stroop task, salivary cortisol and immunoglobulin A (SIgA) levels, and visual analogue scale scores for fatigue were evaluated. Participants were divided into 2 groups: slower group, which exhibited an increase in reaction time; and faster group, which exhibited a decrease in reaction time after the exercise. There were no differences in changes in the salivary cortisol and SIgA level between the slower and faster groups. The slower group exhibited a greater increase in fatigue than the faster group. The increase in fatigue score was positively correlated with the changes in reaction time. Results of this study demonstrated that the excessive increase in fatigue after exhaustive exercise delays cognitive response time. Findings suggest that the individual differences in perceived fatigability, rather than physiological responses, may be modulated to alter cognitive performance after exhaustive exercise.

**Keywords**: Performance analysis, Fatigue, Executive function, Exercise.

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## INTRODUCTION

Cognitive function is believed to be critical for functional mobility in various decision-making and problem-solving processes, helping athletes and elderly to maintain sports performance and health-related quality of life (Williams et al., 2010). Recent studies have examined the responses of cognitive function to exercise (Basso & Suzuki, 2017, Chang et al., 2012). In general, moderate-intensity exercise has positively affects cognitive function (McMorris & Hale, 2012). In contrast to moderate exercise, the impact of high-intensity or exhaustive exercise cannot be confirmed because consistent results have not been obtained. Some studies have shown that high-intensity exercise that induces the accumulation of lactate decreases attention and lowers working memory score (Coco et al., 2019; Perciavalle et al., 2015). Another study reported that exhaustive exercise until exhaustion did not alter accuracy or reaction time in the Go/No-go test (Sudo et al., 2017). A study focusing on athletes reported that exhaustive exercise increased arousal status and shortened reaction time in the Flanker task (Vrijkotte et al., 2018). These discrepancies may be the results of differences in exercise intensity and duration, and individual differences in physiological response and psychological perspective(s) (Tomporowski & Norman, 1986).

Accumulation of physical and emotional fatigue is believed to lead to the deterioration of cognitive function (Barnes & Van Dyne, 2009). The degree of fatigue is modulated by the interaction between performance fatigability and perceived fatigability-related central, peripheral, psychological, and homeostatic factors (Enoka & Duchateau, 2016). Interestingly, Jager et al. (2014) reported a positive effect of exercise on the cognitive function evaluated by the conflict Flanker task only in cortisol responders who exhibited an increase in cortisol levels after the exercise game, whereas no changes were observed in non-responders who exhibited no increase or a decrease in cortisol levels after the exercise. This study suggests that the individual differences in homeostatic responses to exercise likely involved in enhancing of cognitive function. Furthermore, most previous studies investigating maximal exercise were conducted using incremental exercise protocols, which are confounded by the effect of high intensity or cumulative fatigue, and little is known about the exhaustion under submaximal exercise (Schmit et al., 2015). Recently, Hou et al. (2016) demonstrated that submaximal exercise until exhaustion induces central fatigue and alters brain activation patterns during hand movement. However, the effects of exhaustive exercise at submaximal intensity on cognitive function have not been investigated.

As such, the current study aimed to investigate the impact of exhaustive exercise on cognitive function along with homeostatic factors, such as stress and immune function, and the self-reported subjective response to exhaustive exercise in young males. We hypothesized that changes in cortisol or immunoglobulin A (SIgA) and perceived fatigability after exercise are higher in negative effects of exercise than in positive effects on cognitive function. Accordingly, we evaluated salivary cortisol and SIgA levels, visual analogue scale (VAS) score for fatigue, arousal, and sleepiness, and reaction time in the incongruent Stroop task before and after prolonged exhaustive exercise at submaximal intensity. We compared these parameters between positive responders, who exhibited faster reaction time, and negative responders, who exhibited slower reaction time after exercise.

## MATERIALS AND METHODS

### *Subjects*

Seventeen healthy young males (mean [±SD] age, 29 ± 3 years; height, 172 ± 7 cm; weight, 69 ± 8 kg) participated in this study. The subjects were medication-free and had no history of neurological or cardiovascular disease(s) or physical injuries. All participants were informed of the purpose and methods as well as the risks of the study, and each provided informed consent for participation. This study was performed in accordance with the principles of the Declaration of Helsinki and approved by the ethics committees of the Japan Institute of Sports Sciences (030).

### *Study protocol*

Participants performed a cognitive task before and after exhaustive exercise in the afternoon. They were at least 3 h postprandial, abstained from caffeine and alcohol for 12 h, and strenuous exercise for 24 h. They underwent a graded exercise test using a cycle ergometer (Fujin-Raijin, O.C. Labo, Tokyo, Japan) until exhaustion based on a previous study that affects to brain function (Hou et al., 2016). The exercise started at 50 W as a warm-up for 5min; the workload was increased by 50 W every 8 min up to 250 W at the final stage, and they were encouraged to pedal until reaching an exhaustion state that could not maintain a cadence of 50 revolution per min. During the exercise test, heart rate was measured using a commercially available monitor (V800; Polar Electro Inc., Kemple, Finland) and oxygen uptake was measured using a spirometer (AE300S; Minato Medical Sciences, Osaka, Japan). These physiological parameters were averaged every 30 s, and the peak heart rate and maximal oxygen uptake were calculated. The present study recorded ratings of perceived exertion (RPE) using the Borg scale. Before and after exhaustive exercise, VAS score was measured, and salivary samples were collected to evaluate cortisol levels and SIgA secretion rate before and after exhaustive exercise.

### *Measurement*

*Cognitive function*

Subjects performed the Stroop task, which is widely used to measure the ability to properly control attention and behaviour during executive tasks. The Stroop task involved incongruent condition as previously described in our laboratory (Akazawa et al., 2019). In the incongruent Stroop task, a colour word was displayed in incongruent colours (e.g., the word "*RED*" was presented in blue colour) at the top of the monitor and incongruent colour word on the right and left side of the monitor. Subjects were asked to identify the corresponding colours by pressing a button. This task included 2 sets of 10 trials, each set with a length of 30 s. Three practice sessions (1 week, 1 day and immediately before the experiment) were performed. The reaction time for correct answers were evaluated.

*Psychological and physiological parameters*

Before and after the exhaustive exercise, subjects were asked to report their subjective perceptions of fatigue, arousal, and sleepiness based on a VAS score, and saliva samples were collected. Each VAS item was scored from 0 mm (do not feel at all) to 100 mm (completely feel fatigue, arousal, or sleepiness) on a horizontal line. Saliva was collected using an oral cotton swab and a storage tube (Salimetrics oral swab; Salimetrics, Carlsbad, CA, USA). The subject sat, rinsed their mouth 3 times, and rested for at least 5 min. Saliva production was stimulated by chewing on cotton for 1 min. The obtained saliva was centrifuged (1500 ×*g*) and frozen at –80°C until analysis. Cortisol and SIgA concentration were determined using a commercially available enzyme immunoassay kit (Salimetrics, Carlsbad, CA, USA). The SIgA secretion rate was normalized to the saliva flow rate.

### *Statistical analysis*

All data are expressed as mean ± standard deviation (SD). To assess the difference in response to the exhaustive exercise test, subjects were divided into the 2 groups: negative responders, who increased (slower group): and positive responders, who decreased (faster group) in reaction time in the incongruent Stroop task. Physiological and behavioural data analyses were performed using SPSS version 24 (IBM Corporation, Armonk, NY, USA), and differences with $p < .05$ were considered to be statistically significant.

Repeated measure analysis of variance was used to determine the effect of exhaustive exercise on reaction time. When a significant interaction effect was observed, a post-hoc Bonferroni test was used to identify significant differences between the mean values and independent t-test was used to evaluate group differences in physiological parameters during exercise and changes in psychological parameters before and after the exercise. Pearson correlation coefficient was used to determine the association between changes in reaction time in the incongruent Stroop task and VAS score.

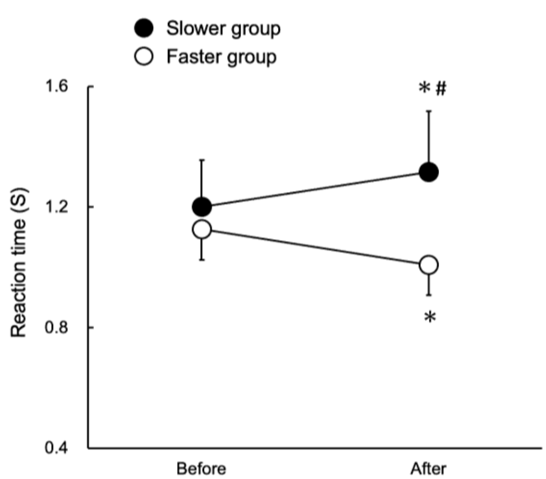
## RESULTS

Six subjects exhibited an increase in reaction time, whereas 11 exhibited a decrease the reaction time; these subjects were divided into slower and faster groups. Regarding cognitive performance, the reaction time significantly decreased in the faster group after exhaustive exercise, whereas it increased in the slower group (Figure 1). The salivary cortisol and SIgA levels and VAS scores in the slower and the faster groups did not differ at baseline. The change in fatigue-VAS score was significantly different between the slower and faster groups ($p < .05$) (Table 1). There were no significant differences in time to exhaustion, peak oxygen uptake, peak heart rate, peak RPE during exercise, or changes in salivary cortisol level and SIgA flow rate and arousal- and sleepiness-VAS score between the groups. A significant correlation was observed between the increase in the fatigue-VAS score and the changes in reaction time (Figure 2; r = 0.539, $p < .05$).

Table 1. The physiological parameters during exercise, the changes in salivary cortisol level and secretary immunoglobulin A flow rate and subjective condition visual analogue scale in the slower and faster groups.

| | **Slower** | **Faster** |
|---|---|---|
| Time to exhaustion (s) | 1789 ± 168 | 1887 ± 438 |
| Peak oxygen uptake (ml/min/kg) | 48 ± 3 | 52 ± 7 |
| Peak heart rate (bpm) | 193 ± 11 | 186 ± 13 |
| Peak RPE | 20 ± 0.4 | 19 ± 1.0 |
| Change in cortisol (µg/dL) | 4 ± 14 | 15 ± 11 |
| Change in SIgA (µg/min) | 23 ± 177 | 141 ± 145 |
| Change in fatigue-VAS (mm) | 78 ± 17* | 55 ± 22 |
| Change in arousal-VAS (mm) | 6 ± 29 | 18 ± 28 |
| Change in sleepiness-VAS (mm) | -10 ± 40 | -20 ± 22 |

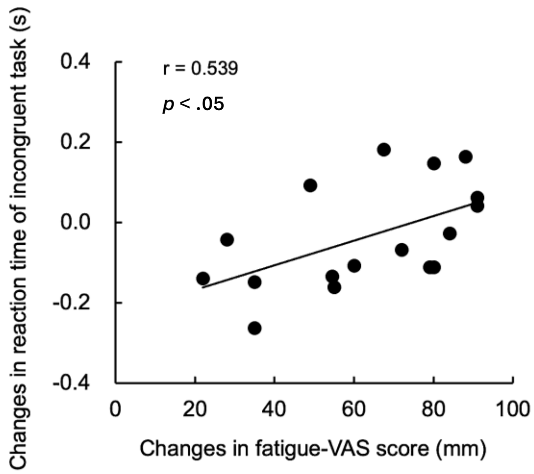
*Note. RPE: rating of perceived exertion, SIgA: secretary immunoglobulin A. * p < .05 vs. Faster group.*




*Note. * p < .05 vs. Before, # p < .05 vs. Faster group.*

Figure 1. The reaction time before and after exhaustive exercise test in the slower and faster groups.




*Note. VAS: visual analogue scale.*

Figure 2. The relationship between the changes in fatigue-VAS score and reaction time in incongruent Stroop task.

## DISCUSSION

This study investigated the effects of exhaustive exercise on the cognitive function using psychological and physiological parameters. The main finding was that the slower response group exhibited a greater increase in the fatigue-VAS score. The increase in the fatigue-VAS score was significantly correlated with the changes in reaction time in the incongruent Stroop task. These results suggest that the differences in cognitive functional responses to exhaustive exercise are associated with perceived fatigability.

In general, moderate-intensity aerobic exercise acutely enhances cognitive function; however, the response depends largely on exercise intensity (Cheng et al., 2012). In this regard, cognitive functions such as working memory and attention, decrease immediately after the cessation of exhaustive maximum exercise (Coco et al., 2009; Hill et al., 2019). Sudo et al. (2017) reported that reaction time in the Go/No-go test did not change significantly before and after exhaustive exercise. In contrast, Vrijikotte et al. (2018) reported that the reaction time in the Flanker test was faster after exhaustive exercise than at baseline. Collectively, the results regarding the cognitive function response to the exhaustive exercise do not reach a general consensus. In this study, the overall average cognitive function evaluated by the reaction time in the Stroop incongruent task did not change after exhaustive exercise because we observed the extent of both slower responders and faster responders. Therefore, the response of cognitive function to the exhaustive exercise may depend on some individual differences.

In this study, we focused on the differences between negative (slower) and positive (faster) responders and further measured VAS as a subjective condition and saliva stress and immune parameters as objective conditions. No differences in physiological parameters were observed during the exhaustive exercise (Table 1). On the other hand, the magnitude of changes in the fatigue-VAS score from baseline was higher in the slower group than in the faster group (Table 1). A previous study demonstrated that 2 consecutive days of high-intensity sprint interval exercise increased the rating of physical and mental fatigue sensation and decreased cognitive function evaluated by simple and choice reaction time, visuospatial working, inhibition task, and incongruent Stroop response (Costello et al., 2022). This study revealed that cognitive performance was impaired when physical and emotional fatigue was increased by heavy exercise. In the present study, there is a significantly correlated between the changes in fatigue score and cognitive function. Furthermore, we found no differences in physiological measurements during exercise, including time to exhaustion, oxygen uptake, or heart rate, which indicated that the participants performed exercises of similar intensity and workload in the slower and faster groups. Collectively, the degree of increase in the perception of fatigue after exercise may be important for cognitive performance.

To monitor homeostatic responses to exercise leading to cumulative fatigue and overtraining, many researchers have investigated not only changes in psychological measures but also responses reflected by biochemical, hormonal, and immunological parameters (Mujika, 2017). Chronic heavy training load decreases SIgA and increases cortisol levels (Saw et al., 2016). SIgA is a psychoneuroimmunological marker, and its responses vary with individual stress level(s) (Okamura et al., 2010). Furthermore, cortisol plays a role in regulating the neuropeptide and neurotransmitter systems, affecting cognitive functions including attention, perception, memory, and emotional processing (Erickson et al., 2003). Jagar et al. (2014) reported that moderate-intensity exercise increases salivary cortisol levels and shortened the reaction time in the Franker task. They also demonstrated that high cortisol responders after exercise exhibited enhanced Franker task performance, whereas improvement in the Franker task was not observed in non-responders. However, there were no differences in changes in salivary cortisol or SIgA levels between the groups, whereas perceived fatigue score was significantly higher in the slower group than in the faster group in the present study. It is possible that the cognitive function response to exhaustive function is associated with psychological fatigue rather than a physiological homeostatic response.

The present study has limitations. First, this study was conducted using a relatively small sample size and non-athlete general population. Exercise-induced fatigue would cause deterioration in cognitive function including reaction time, visual perception, and concentration in athlete, which affects athletic performance or strategic decision making in the game (Zwierko et al., 2022). Therefore, the results of the present study may limit our generalizing our findings to athletes. Another limitation is the reliance on a simple self-reported visual analogue scale to assess the psychological parameters such as perceived fatigability. Further studies are necessary to evaluate comprehensively nature of fatigue and investigate its relation to cognitive function and athletic performance.

In conclusion, using an exhaustive exercise under submaximal intensity, the present study compared cognitive function responses to exercise between slower and faster reaction time groups. Results revealed that the slower group exhibited a larger increased in fatigue-VAS scores. These results suggest that the cognitive function response to exhaustive exercise may be associated with the perception of exercise fatigability.

## AUTHOR CONTRIBUTIONS

Nobuhiko Akazawa: design of the study, data analysis and interpretation, and writing the manuscript. Mana Otomo: data analysis and interpretation, and review and editing the manuscript. Mariko Nakamura: data analysis and interpretation, and review and editing the manuscript. All authors have approved the final version of the manuscript.

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## DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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