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Effect of Low-Dose Sodium Bicarbonate Supplementation on Intermittent Endurance Performance

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Abstract

In this study, we investigated the effect of sodium bicarbonate ($NaHCO_3$) supplementation at a dose of 0.2 g·kg^{-1} 40 min before an exercise on intermittent endurance performance and gastrointestinal distress. The participants were six healthy male students of a university. The Yo-Yo intermittent recovery test level 2 (Yo-Yo IR2) was used for the evaluation of intermittent endurance. The participants ingested water (Cont) or $NaHCO_3$ independently at three timings. After drinking water, the Yo-Yo IR1 was performed for 2 min as warm-up. After resting for 5 min, the Yo-Yo IR2 was initiated. The measurement items were exercise distance, nutrition intake, biochemical test results, and blood gas analysis findings. The participants who ingested $NaHCO_3$ had a 14% extended distance than those who ingested Cont, and 2/3 of those who took $NaHCO_3$ showed a better motor performance. No significant difference was observed between the participants who took Cont and $NaHCO_3$ in terms of pH level at baseline, and the $NaHCO_3$ level was significantly higher during pre- and post-exercise ($p < 0.05$). No significant difference was observed between the participants who took Cont and $NaHCO_3$ in terms of bicarbonate ion level at baseline, and the $NaHCO_3$ level was significantly higher during pre- and post-exercise ($p < 0.05$). In conclusion, even when the participants ingested $NaHCO_3$ at a low dose (0.2 g·kg^{-1}), their exercise ability during an intermittent endurance test has improved. Furthermore, when digestive absorption is considered, eating a meal in advance may be able to suppress the onset of gastrointestinal distress.

Keywords

Sodium Bicarbonate, Yo-Yo IR2, Blood pH, High-Intensity Intermittent Endurance, Alkalosis

1. Introduction

Since body fluids have a buffering capacity, the pH levels inside and outside the cells are maintained. When exercising, the pH level in the muscles and blood becomes acidic. This phenomenon is attributed to the production of lactic acid when glucose is converted into adenosine triphosphate (ATP) during exercise, and hydrogen ions (H^+) that decompose from lactic acid accumulate in the body. It is a phenomenon that remarkably decreases the shrinkage and relaxation rates [1]. The intake of sodium bicarbonate ($NaHCO_3$) increases the pH level in the blood, and it regulates the speed in which the body becomes acidic during exercise. This phenomenon is attributed to the increase in bicarbonate ion (HCO_3^-) levels in the body owing to the outflow of H^+ to the outside of the cell and the buffering capacity that promotes neutralization. Moreover, recent studies have shown that HCO_3^- may reduce the stimulation of sensory nerves by H^+. Therefore, it may have a positive influence on the nervous and peripheral systems [2]. In relation to these facts, the intake of $NaHCO_3$ increases the pH level in the blood to alkalinity and reduces fatigue. Bishop [3] has reported that female athletes who ingested $NaHCO_3$ had a significantly high $NaHCO_3$ level, which was measured using an ergometer, after an intermittent sprint test and that the intake of $NaHCO_3$ improves intermittent sprint performance. In addition, the ingestion of $NaHCO_3$ and intermittent exercise for 30 min resulted in an improved sprint performance in the early stage [4]. The improvements in performance occurred within 15 min of exercise, which is consistent with the time in which the pH of the blood rapidly changes. Several studies on the ergogenic effect of $NaHCO_3$ uptake have been conducted. However, its intake dose and timing are not consistent. A dose of 0.3 $g \cdot kg^{-1}$ is frequently used [5]. This was obtained from several dose-response relationship studies. However, because $NaHCO_3$ is 27% sodium, a dose of 0.3 $g \cdot kg^{-1}$ is significantly higher than the upper limit of 2300 mg/day [6]. Therefore, substantial gastrointestinal distress, such as stomach pain and diarrhea, may highly occur [2] [7]. When using $NaHCO_3$ in actual sports, it is important to take doses that do not cause gastrointestinal distress at ingestion timings that can maximize the effect. Siegler *et al.* [8] have reported that the timing of ingestion varies depending on its dose. When ingesting a dose of 0.3 $g \cdot kg^{-1}$, the blood HCO_3^- concentration peaks at approximately 60 min after ingestion and peaks at around 40 min when ingesting a dose of 0.2 $g \cdot kg^{-1}$. It is preferred to start exercise when the HCO_3^- concentration in the blood peaks because HCO_3^- slows the speed in which the body becomes acidic. In this study, we investigated the effect of $NaHCO_3$ intake (0.2 $g \cdot kg^{-1}$) 40 min before an exercise on intermittent endurance performance and gastrointestinal distress.

2. Methods

2.1. Participants

The participants were six healthy male students of a university (age: 21.8 ± 0.75 years, height: 170.5 ± 4.68 cm, and weight: 68.0 ± 9.25 kg). After explaining to each participant the purpose and procedure of the research and the risks associated with the experiment, a written informed consent was obtained. This research was approved by the Ethics Review Committee of Nippon Sports Science University (no. 017 H 025).

2.2. Method of Measurement

The experiments were conducted twice at 1-week interval. In terms of food and drinks, caffeine and alcoholic beverages were banned on the day before and the day of the experiment, and the participants consumed the prescribed breakfast (200 g of white rice, 1 pack of natto, and miso soup) 3 h before the start of the trial. During the trial, we practiced twice on another day using the Yo-Yo intermittent recoverytest level2 (Yo-Yo IR2) to avoid differences in the proficiency of the participants. On the day of the experiment, they were visited 2 h before the start of the Yo-Yo IR2, and a blood sample was drawn (baseline information) while the participants were in supine position. While the participants were at rest in sitting position, they ingested water (Cont) or $NaHCO_3$ independently at three timings. After drinking water, the Yo-Yo IR1 was performed for 2 min as warm-up. After resting for 5 min after warming-up, a blood sample was drawn (pre-exercise information), and the Yo-Yo IR2 test was initiated. Immediately after the end of the Yo-Yo IR2, blood was collected again (post-exercise information, **Figure 1**). Heart rate was measured continuously from the start of the Yo-Yo IR2 until 5 min after the end of the test exercise. The blood lactic concentration was set just before the Yo-Yo IR2 (160 m, 280 m, and 440 m), immediately after termination, 1 min after completion, and 3, 5, and 10 min after.

2.3. Yo-Yo IR2

The Yo-Yo IR2 is based on the shuttle run test in which a marker is placed 5 m behind the start/goal line, and a participant jogs around this 5-m section and returns to the line (**Figure 2**). The jogging time is 10 s. If it is recorded every roundtrip (40 m) and the participant cannot return to the start/goal line within the time, warning is provided during the first occurrence, and the lap was recorded at the stage when a participant could not return to the second time. In addition, level 2 focuses on high-intensity intermittent motion combined with anaerobic and aerobic exercise [9].

2.4. Intake Conditions

In total, 200 mL of Cont or $NaHCO_3$ was consumed per intake. The ingestion timing was 3 times in total (1 h, 40 min, and 20 min before starting the exercise). The participants ingested $NaHCO_3$ 40 min before the exercise. The amount of ingested $NaHCO_3$ was 0.2 $g \cdot kg^{-1}$ body weight, and 200 ml of Cont was ingested.

2.5. Nutrition Intake Survey

A survey on food intake was conducted the day before the experiment using both self-recorded food intake and visual records obtained using the provided

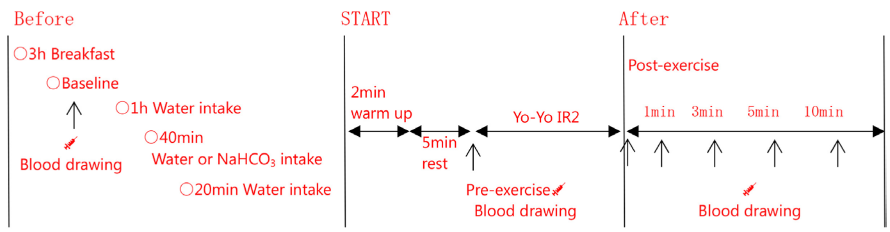

Figure 1. Experiment protocol.

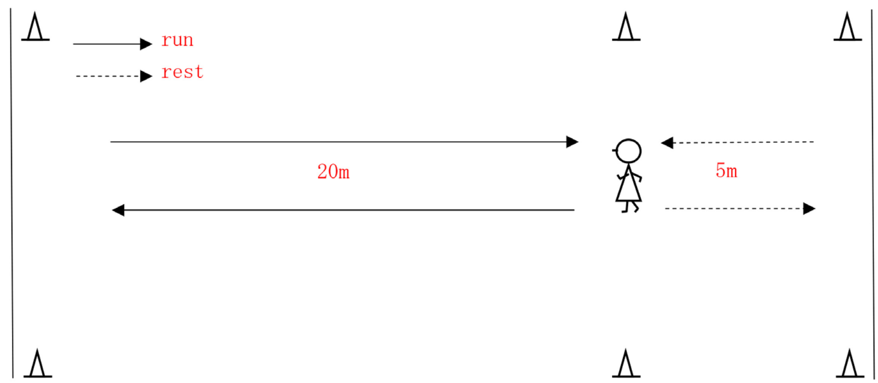

Figure 2. Yo-Yo IR2 protocol.

digital camera. The nutrient intake of the participants was calculated based on the diet record and photographs. All dietary records were used to determine total energy intake and amount of carbohydrate, protein, and lipid intake with a computerized nutrient analysis program (Excel Eiyokun version 8.0, Japan Food Composition Table version 5, Kenpakusya, Tokyo, Japan). Total energy intake and amount of carbohydrate, protein, and lipid in take from commercially prepared and restaurant food were calculated using information from the manufacturer's websites or by asking the manufacturer.

2.6. Biochemical Test and Blood Gas Analysis

Blood was collected from the cephalic vein. After standing for 2 h, the serum was collected by centrifugation at 3000 rpm for 5 min using a centrifugal separator. Analysis items included total protein (TP), albumin (Alb), creatine kinase (CK), triglyceride (TG), and blood urea nitrogen (BUN) levels. BML Co., Ltd. conducted the analysis (Tokyo, Japan).

For blood gas analysis, a blood gas analyzer (Rapid Labo 348 EX, Siemens) was used. The collected blood was quickly set in the instrument, and analysis was started. The analysis items were pH, sodium (Na^+), potassium (K^+), and bicarbonate ion (HCO_3^-) levels.

2.7. Analysis

The Statistical Package for the Social Sciences software version 22 (IBM Inc.) was used for analysis. All data were expressed as mean ± standard deviation (mean ± SD). A *t* test with correspondence between beverages was conducted, and one-way analysis of variance was carried out for the variation between beverages. The Tukey's HSD method was used, and significant differences were observed. The significance level was set at $p < 0.05$.

3. Results

A significant difference was observed in the $NaHCO_3$ level as well as total energy and carbohydrate intake ($p < 0.05$, **Table 1**). No significant differences were noted in the protein and lipid intake. Moreover, the distance of exercise between the participants who ingested Cont and $NaHCO_3$ did not significantly differ (**Figure 3**). However, the intake of $NaHCO_3$ resulted in 14% extended distance, and 2/3 of the participants who took $NaHCO_3$ had a better motor performance. Heart rate and blood lactate concentration are shown in **Table 2**. Heart rate gradually increased from the start of the Yo-Yo IR2. However, no significant difference was found in terms of Cont and $NaHCO_3$ intake. Moreover, the participants who ingested Cont and $NaHCO_3$ did not significantly differ in terms of blood lactate concentration at baseline and during pre- and post-exercise. However, the $NaHCO_3$ level was significantly elevated at 3 and 5 min after the end of the Yo-Yo IR2 ($p < 0.05$). Furthermore, the $NaHCO_3$ level was significantly higher in the peak blood lactic concentration ($p < 0.05$). Results of the biochemical tests are presented in **Table 3**. No significant difference was observed between the participants who took Cont and $NaHCO_3$ in the fluctuation of all items at baseline and during pre- and post-exercise. In addition, the participants who took Cont and $NaHCO_3$ did not significantly differ in terms of TP, Alb, CK, TG, and BUN levels. Results of the blood gas analysis are presented in **Figure 4** and **Table 4**. No significant difference was observed between the participants who took Cont and $NaHCO_3$ in terms of pH at baseline, and the $NaHCO_3$ level was significantly higher during pre-and post-exercise ($p < 0.05$). No significant difference was observed between the participants who took Cont and $NaHCO_3$ in terms of HCO_3^- level at baseline, and the $NaHCO_3$ level was significantly higher during pre-and post-exercise ($p < 0.05$). Na^+ level was significantly higher in participants who took $NaHCO_3$ than those who took Cont during pre- and post-exercise ($p < 0.05$). No significant difference was observed in the K^+ level of the participants who took Cont and $NaHCO_3$.

Table 1. Nutritional intake a day before the experiment.

	Cont		$NaHCO_3$	
	Mean	SD	Mean	SD
Total energy intake (kcal)	1884.8	661.6	1013.2*	413.9*
Carbohydrate (g)	276.5	106.3	133.3*	86.6*
Protein (g)	67.4	28.9	37.7	18.1
Lipid (g)	49.2	24.5	33.1	19.7

Values were presented as mean ± SD. *p < 0.05 vs. Cont. Cont: water.

Table 2. Yo-Yo IR2. Variations in heart rate and blood lactate concentrations during post-exercise.

	Cont		$NaHCO_3$	
	Mean	SD	Mean	SD
Heart rate (bpm)	179.8	9.8	177.3	13.0
Blood lactic concentration (mmol/L)				
Pre-exercise	1.3	0.3	1.5	0.4
Post-exercise	9.9	3.4	11.4	3.0
After 1 minute	10.6	0.7	11.4	2.3
After 3 minutes	10.8	1.9	13.4*	2.5
After 5 minutes	11.0	1.4	14.4*	2.6
After 10 minutes	10.9	1.9	12.8	2.4

Values were presented as mean ± SD. *p < 0.05 vs. Cont.

Table 3. Biochemical test results.

	Cont			$NaHCO_3$		
	Baseline	Pre-exercise	Post-exercise	Baseline	Pre-exercise	Post-exercise
TP (g/dL)	7.2 ± 0.5	7.2 ± 0.4	7.9 ± 0.3	7.0 ± 0.8	7.1 ± 0.2	7.7 ± 8.2
Alb (g/dL)	4.4 ± 0.3	4.3 ± 0.2	4.7 ± 0.2	4.2 ± 0.2	4.3 ± 0.2	4.8 ± 0.3
CK (U/L)	198.1 ± 110.3	202.8 ± 118.6	225.0 ± 122.1	228.1 ± 109.5	232.1 ± 107.7	252.5 ± 111.7
TG (mg/dL)	101.6 ± 66.7	102.6 ± 69.5	116.5 ± 83.4	105.3 ± 54.9	100.0 ± 70.7	113.0 ± 83.2
BUN (mg/dL)	13.9 ± 3.8	13.6 ± 3.4	13.6 ± 3.5	12.8 ± 1.8	12.7 ± 1.8	12.8 ± 1.9

Values were presented as mean ± SD. *p < 0.05 vs. Con.

Table 4. Na^+ and K^+ levels.

	Cont			$NaHCO_3$		
	Baseline	Pre-exercise	Post-exercise	Baseline	Pre-exercise	Post-exercise
Na^+ (mmol/L)	142.3 ± 1.2	143.2 ± 1.0	148.1 ± 1.7	142.8 ± 1.2	144.8 ± 1.3*	149.3 ± 1.2*
K^+ (mmol/L)	4.3 ± 0.7	5.9 ± 1.4	6.7 ± 1.4	3.9 ± 0.1	4.7 ± 1.3	5.3 ± 0.9

Values were presented as mean ± SD. *p < 0.05 vs. Cont.

4. Discussion

In the Yo-Yo IR2, the intake of $NaHCO_3$ compared with Context ended the exercise distance by 14%. Krustrup *et al.* [10] have shown that the ingestion of 0.4 $g \cdot kg^{-1}$ of $NaHCO_3$ extended the distance by 14% when the same exercise was performed. In addition, Jason [11] *et al.* have presented that a distance extension of 12.4% was observed when 0.3 g of $NaHCO_3$ was ingested prior to the same exercise. These previous studies have shown the ergogenic effect of $NaHCO_3$ on high-intensity exercise state, which allows the performance of short-term, intermittent and anaerobic Yo-Yo IR2 under metabolic stress. One of the reasons for improving the capacity of intermittent exercise is the increase in pH due to

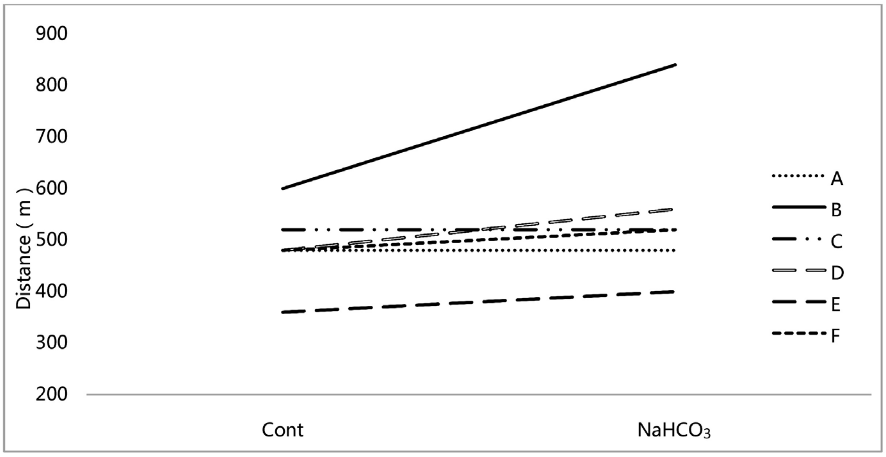

Figure 3. Distance of exercise in Yo-Yo IR2.

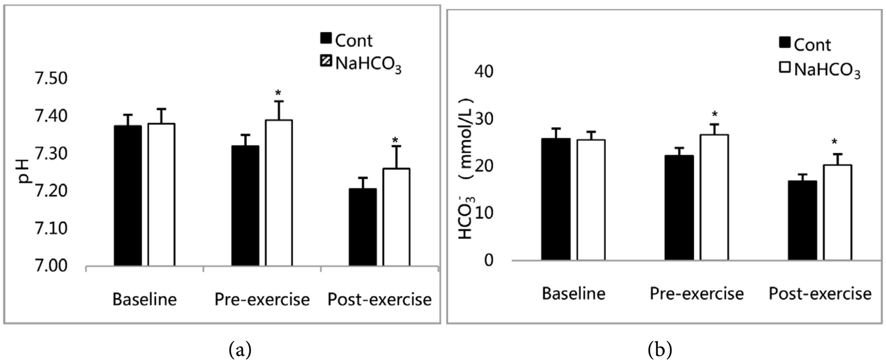

Figure 4. pH (a)and HCO_3^- (b) *p < 0.05 vs. Cont.

an elevated buffering capacity in the blood by HCO_3^-, and the H^+ value and lactate gradient of the muscle and blood are increased [12]. In this study, the HCO_3^- level was significantly elevated by 20% during pre-exercise when $NaHCO_3$ was ingested. In addition, at baseline, the pH levels of the participants were 7.37 ± 0.03 after ingesting Cont and 7.38 ± 0.05 after ingesting $NaHCO_3$. However, 1 h after the intake of Cont and $NaHCO_3$, the pH levels were 7.32 ± 0.03 and 7.39 ± 0.05, respectively. Only $NaHCO_3$ was likely to increase pH level to alkalinity. Despite the fact that the blood collection timing during pre-exercise was after warm-up, the pH level of the participants who took $NaHCO_3$ was more alkaline than the baseline. In addition, despite the increased exercise distance after ingesting $NaHCO_3$ compared to Cont, $NaHCO_3$ significantly increases the pH and HCO_3^- levels during post-exercise. These may have increased the movement distance by activating the buffering capacity in the blood. Significantly higher Na^+ values were observed during pre- and post-exercise after the ingestion of $NaHCO_3$. No significant difference was observed in K^+ level. However, it was more likely lower during pre- and post-exercise after the ingestion of $NaHCO_3$. The pH level during pre-exercise was significantly higher in participants who ingested $NaHCO_3$ than in those who ingested Cont. In terms of K^+ level, no significant difference was observed, and a decrease may be observed.

Thus, the patients were already in an alkalosis state before warming-up. During fatigue after performing the Yo-Yo IR2, the pH and HCO_3^- levels increased. The onset of fatigue during high-intensity intermittent exercise can be caused by the intricate interactions between intracellular and extracellular concentrations and ion gradients, such as K^+, Na^+, and H^+ [13] [14]. A high Na^+ level may increase the possibility of H^+ outflow from inside the muscle during exercise. However, the potential fatigue effects of homeostatic imbalances on these ions are exerted in the muscle stroma compared to the intracellular environment. In this study, blood gas measurements are not performed during the Yo-Yo IR2. However, the interactions with ion gradients may have appeared after performing the Yo-Yo IR2. Sostaric *et al.* [15] have shown an improved exercise capacity after $NaHCO_3$ supplementation. The intake of $NaHCO_3$ inhibits the increase in K^+ level in the muscle stroma that occurs during the intense contractile activity of the muscles, and it may attenuate the degree of K^+-induced inactivation of myocytes during this activity [16] [17]. Furthermore, the increase in blood pH improves high-intensity intermittent endurance [18]. This phenomenon is attributed to the re-synthesis of creatine phosphate (ATP) that depends on the transport of H^+ from the cell and intramuscular pH, and as a result, the re-synthesis of ATP improves when the pH level is alkaline. Therefore, the production of more energy is possible. We believe that the same phenomenon was observed in this research and the performance of the participants may be affected.

Bangsbo *et al.* [9] have shown that blood lactate after the performance of the Yo-Yo IR2 test reached its peak during the recovery period of 5 - 8 min. The intake of $NaHCO_3$ promotes metabolite translocation. $NaHCO_3$ is divided into Na^+ and HCO_3^- in the blood, and HCO_3^- is bound to H^+ to adjust the pH of the blood. By contrast, Na^+ binds to the remaining constituents dissociated from H^+ and simultaneously produces sodium lactate. When improving the performance of lactic acid produced in large quantities via exercise, the recovery of lactic acid in the blood is essential. In this study, the peak of blood lactic acid was reached after 5 min of recovery. Moreover, Marriott *et al.* [12] have shown that $NaHCO_3$ resulted in a higher glycolytic contribution and undesirable intramuscular lactate production compared to caffeine and placebo. In this study, it was predicted that anaerobic energy metabolism was actively carried out at the time of $NaHCO_3$ intake, which may also be related to longer exercise distance. In this study, although the total energy and carbohydrate intakes significantly increased than the $NaHCO_3$ and Cont intakes on the previous day, the distance of exercise was increased after $NaHCO_3$ supplementation. This result suggests that the use of carbohydrate as energy during glycolysis is more effective than ingesting $NaHCO_3$.

Several previous studies have shown that metabolic alkalosis was caused by ingesting high doses of $NaHCO_3$ (0.3 - 0.4 $g \cdot kg^{-1}$ body weight) after fasting. However, the high capacity intake of $NaHCO_3$ causes gastrointestinal distress, such as diarrhea due to osmotic pressure. Naughton [19] has shown that the performance does not improve further even if the dose of bicarbonate exceeds 0.3 g·kg^{-1}. However, it causes serious side effects. In addition, Carr [7] has reported that the optimal intake of $NaHCO_3$ is less likely to cause gastrointestinal distress when meals are also taken [20]. In the present study, by feeding meals 3 h before the start of the Yo-Yo IR2 test, gastrointestinal pain was prevented, and based on the self-reports of the participants, they did not develop stomach pain. Furthermore, according to the study by Siegler [8] *et al.*, the minimum capacity causing metabolic alkalosis is 0.2 g·kg^{-1}. Bishop *et al.* [3] have reported that a significant improvement was observed in the intermittent endurance test compared with the placebo with an ingestion of 0.2 g·kg^{-1} of $NaHCO_3$. In the present study, similar results were obtained, indicating that the intake of 0.2 g·kg^{-1} of $NaHCO_3$ has effects on intermittent endurance test. In addition, the risk of developing gastrointestinal distress can be alleviated by taking a meal in advance. In this study, $NaHCO_3$ was difficult to ingest in capsules. Thus, it was dissolved in water and ingested. In relation to this, it differed in taste; thus, we did not use the placebo. Because the difference in taste was obvious, the placebo was not used. Therefore, the effect of the placebo may have affected the outcome.

5. Conclusion

In this study, we investigated the influence of $NaHCO_3$ uptake (0.2 g·kg^{-1}) 40 min before an intermittent exercise on endurance performance and gastrointestinal distress. In conclusion, even at a low dose of 0.2 g·kg^{-1}, the exercise ability of the participants during an intermittent endurance test has improved. Furthermore, when digestive absorption is considered, eating a meal in advance may be able to suppress the onset of gastrointestinal distress.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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