**Title page**

**Regular Article**

**Title:** Effects of acute oral lactate supplementation on energy metabolism in humans

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**Running title:** Effects of lactate supplementation in humans

**Abstract**

Lactate administration has been suggested to affect energy metabolism by acting as an energy fuel and/or exhibiting various physiological responses. Although some previous studies have found that the intravenous infusion of lactate might increase energy expenditure, the effect of oral supplementation is unknown. In this study, we investigated the effects of acute oral lactate supplementation on energy metabolism during rest and exercise. Twelve healthy subjects (ten men and two women, average age of 21.2 ± 0.8 years) participated in this single-blind, placebo-controlled, randomized crossover study. All subjects received two different supplements: supplements containing 1115 mg of lactate (LAC) and placebo supplements consisting of the same mass of glucose as the supplements in LAC (PLA). 1 hour after ingesting the supplements, they performed cycling exercise (unloaded, 70 rpm, 30 min). Measurements taken included oxygen consumption, blood lactate and glucose concentrations, heart rate, rating of perceived exertion, and gastric discomfort level. The results showed that the area under the curve for oxygen consumption during rest was significantly higher with LAC than with PLA treatment (LAC: 41.3 ± 3.7 ml/kg vs. PLA: 37.2 ± 5.5 ml/kg, $p < 0.01$). By contrast, no significant differences were observed between LAC and PLA treatments in any of the measurements during exercise. In

conclusion, acute oral lactate supplementation increased oxygen consumption during rest.

**Keywords**

lactate supplementation, oxygen consumption, energy metabolism

**タイトル**

単回の乳酸の経口摂取がヒトのエネルギー代謝に与える影響

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**要旨**

乳酸の投与はエネルギー源としての作用や様々な生理的反応を示すことによって、エネルギー代謝に影響を及ぼす可能性があることが示唆されている。いくつかの先行研究において乳酸の静脈投与がエネルギー消費量を増加させる可能性が示唆されているが、経口摂取による影響は分かっていない。本研究ではヒトを対象に、単回の乳酸の経口摂取が安静時および運動時のエネルギー代謝に与える影響を調べた。健常な 12 名（男性 10 名と女性 2 名、平均年齢 21.2 ± 0.8 歳）を対象にしたランダム化交差試験（単盲検）とした。乳酸（1115mg）を含有するサプリメントを摂取する条件（乳酸条件）および、乳酸条件のサプリメントと同重量のブドウ糖であるプラセボサプリメントを摂取する条件（プラセボ条件）の 2 試行を行った。サプリメントの摂取から 1 時間後に、被験者は自転車運動（無負荷、70rpm、30 分間）を開始した。測定項目は酸素消費量、血中乳酸濃度、血中グルコース濃

度、心拍数、主観的運動強度、胃部不快感とした。その結果、安静時の酸素消費量の曲線化面積については、プラセボ条件と比べて乳酸条件で有意に高値を示した（乳酸条件: 41.3 ± 3.7 ml/kg vs.プラセボ条件: 37.2 ± 5.5 ml/kg, $p < 0.01$）。一方で、運動時にはいずれの項目においても両条件間で有意差は認められなかった。結論として、単回の乳酸の経口摂取は安静時の酸素消費量を増加させた。

**キーワード**

乳酸摂取、酸素消費、エネルギー代謝

## Introduction

Lactate has classically been considered a product of glycolysis that causes fatigue, but its interpretation has been changing in recent years [1-3]. Rather, lactate is a readily available fuel as an oxidative substrate and is even preferred over glucose [1, 4-6]. In addition, it has been shown that lactate induces various physiological responses in the whole body [7]. For example, studies have reported that lactate administration enhances the metabolic buffering capacity, such as increasing blood bicarbonate [8, 9], and increases pulmonary ventilation and cardiac output [7, 10, 11]. These roles of lactate as an energy fuel and in exerting physiological actions suggest the potential benefit of lactate supplementation. When lactate is consumed orally, it is rapidly absorbed primarily in the upper intestine through sodium-coupled intestinal lactate transporters [1], and after reaching the bloodstream, it is either oxidized primarily in skeletal muscle or converted into glucose in the liver [12]. Especially during exercise, most intravenously infused lactate is metabolized in skeletal muscle [12, 13]. Given the possibility of glycogen sparing [14-16] and the metabolic buffering capacity [8] associated with lactate administration, earlier researchers have investigated whether the ingestion of polylactate, which is an easily ingestible form of lactate, enhances athletic performance [8, 17-19]. Recently, some studies have also investigated the effects of commercially available supplements containing low-

dose lactate on athletic performance [20-23]. However, fundamental knowledge about the effects of lactate supplementation on energy metabolism is lacking.

In some studies using intravenous infusion, lactate increased oxygen consumption or energy expenditure by 3%–11% during rest or exercise in humans [6, 24-28], termed by some as the thermic effect of lactate based on changes in the results of breath gas analysis [24-26]. However, no evidence shows that oral supplementation with lactate increases energy expenditure in humans. Unlike intravenous infusion, the effect on energy expenditure may not be reproduced because oral supplementation involves the process of absorption from the digestive tract. Ensuring energy expenditure through exercise is a typical prescription for preventing obesity [29, 30], but there are cases in which sufficient exercise sometimes cannot be executed, such as lack of time [31] and low physical capacity [32]. If oral lactate supplementation increases energy expenditure, it may contribute to helping ensure energy expenditure. In this study, we investigated the effects of acute oral lactate supplementation on energy metabolism during rest and exercise.

## Materials and Methods

### Subjects

The present study subjects comprised ten men and two women. The subjects had an

average age of 21.2 ± 0.8 years, body mass of 64.6 ± 8.1 kg, height of 171.3 ± 6.0 cm, and body fat of 17.2 ± 3.8%. The sample size calculation was performed using G*Power 3.1.9.7. We used previously published results [33] that determined a significant effect of ingestion of thermogenic supplement on oxygen consumption, where effect size delta distributed approximately 1.0 during rest and 0.6 during low-intensity exercise. Assuming a two-tailed paired t-test with a significance level of 5%, and a power of 80%, the required sample size was calculated to be 10 for a rest condition and 24 for an exercise condition. Subjects were informed about the risks and discomforts associated with participation and thereafter provided written informed consent. This study was approved by the ethics committee of Kyushu Kyoritsu University (2022-07).

Experimental design

A randomized, single-blind crossover study was conducted. The subjects visited the laboratory on two separate occasions. On the day of the experiment, the subjects started the exercise 1 hour after ingesting either the lactate supplement (LAC) or the placebo supplement (PLA). Those treatment orders were randomized, and subjects were blinded to the treatment order until the study ended. The average washout period was 8.0 ± 6.7 days.

The subjects were also asked to refrain from strenuous exercise and alcohol on the day before the experiment. Additionally, subjects were asked to share a photographic record of their dinner the day before the experiment. On the day of the experiment, the subjects were instructed to arrive at the laboratory without having consumed any food or drink except for water after waking up. Three hours prior to the exercise, the subjects consumed a prescribed breakfast upon arrival at the laboratory. The prescribed breakfast was 636 kcal (including 13% protein, 3% fat, and 84% carbohydrate) and consisted of white rice and canned tuna. After the meal, the subjects remained in the sitting position until the start of exercise. Exercise execution started between the hours of 10:00 am and 1:00 pm. Each subject completed both the LAC and PLA experiments on the same time schedule. To ensure the validity of investigations into the effects of exogenous lactate, in the present study, we chose low-intensity exercise since endogenous lactate production during exercise would be minimized. Regarding the exercise protocol, subjects performed low-intensity cycling exercise (unloaded, 70 rpm, 30 min) using a cycle ergometer (Corival V2; Lode BV, Groningen, Netherlands). It is common to set the same relative intensity based on the results of $\dot{V}O_2$max measurement. However, $\dot{V}O_2$max measurement requires rigorous effort, and it is difficult to obtain accurate values because it is affected by factors such as the subject's motivation [34]. Therefore, the intensity of the cycling exercise in the

present study was matched to be absolute intensity (unloaded). The position of the saddle was replicated for both experiments.

Measurements

The laboratory environment's temperature and humidity were recorded. The LAC and PLA environments were 21.5 ± 1.1 °C and 49.3 ± 5.5%, and 21.3 ± 1.4 °C and 45.7 ± 7.4%, respectively. On the first experimental day, anthropometric data were recorded, including height and body mass, as well as body composition using bioelectrical impedance (MC-780; TANITA, Tokyo, Japan).

Figure 1 shows a schematic representation of the experiment. From 10 min before exercise until the end of the 30-min exercise session, the subjects wore a facemask, and their exhaled gases were analyzed for oxygen consumption averaged over 60 s, using indirect calorimetry (AR-1; ARCO SYSTEM, Chiba, Japan). The blood lactate and glucose concentrations, heart rate, rating of perceived exertion (RPE), and gastric discomfort level were measured at rest before exercise (at 0 min) and during exercise (at 10, 20, and 30 min). Blood lactate and glucose concentrations were measured using equipment (Lactate pro 2; ARKRAY, Kyoto, Japan, and GLUCOCARD PlusCare; ARKRAY, Kyoto, Japan, respectively) that measures their blood concentrations from a

small blood sample from a fingertip capillary. Heart rate was measured using a heart rate sensor with a chest strap (Polar H10; Polar Electro, Kempele, Finland). RPE was recorded using the Borg scale. The gastric discomfort level was recorded using a visual analog scale. The subjects indicated the severity of symptoms on a scale from 0 mm to 100 mm, with 0 mm being “no symptom” and 100 mm being “severe symptom”.

Supplementation

As in previous studies [20-23], subjects received powdered supplements containing 1115 mg of lactate from a combination of calcium lactate monohydrate and magnesium lactate dihydrate (Sportlegs; Sport Specifics, Longmont, USA) in accordance with the manufacturer’s recommended dosage in the LAC treatment. In the PLA treatment, subjects received a placebo supplement consisting of the same mass of glucose (about 1860 mg) as the supplements in the LAC treatment. The lactate and placebo supplements were indistinguishable via visual sensation and gustation because both were packaged in the same-sized gelatin capsules. On the basis of previous studies [12, 21-23, 35, 36], it was decided that the supplements would be ingested 1 hour before the exercise.

Statistical analysis

All data are expressed as the mean ± standard deviation (SD). We used BellCurve for Excel (Social Survey Research Information, Tokyo, Japan) for the analysis.

Significant differences in values over time and treatments were determined using a two-way repeated measures analysis of variance (ANOVA). When differences were found to be significant for the main effect or interaction, comparisons were made using a Bonferroni test. The area under the curve (AUC) was calculated for each subject using the trapezoidal method. A paired t-test was used to determine AUC differences between the two treatments. Statistical significance was defined as $p < 0.05$.

## Results

Oxygen consumption

Figure 2-a shows the oxygen consumption averaged every 10 min. There was no main effect of treatment or interaction on oxygen consumption, but there was a significant main effect of time (time: $p < 0.01$, Fig. 2-a). The values at each point during exercise were significantly higher than the value during rest in both treatments (all $p < 0.01$). The AUC for oxygen consumption during rest was significantly higher in the LAC treatment than in the PLA treatment ($p < 0.01$, Fig. 2-b). By contrast, no significant difference was found between treatments in the AUC for oxygen consumption during exercise (Fig. 2-c).

127

128 Blood lactate concentration

129 Figure 3-a shows the results for the blood lactate concentration. There was no main
130 effect of treatment or interaction on blood lactate concentration, but there was a
131 significant main effect of time ($p < 0.05$, Fig. 3-a). The blood lactate concentrations in the
132 LAC treatment were significantly lower at 20 and 30 min than the value at 0 min (both $p$
133 $< 0.01$). Similarly, the blood lactate concentrations with the PLA treatment were
134 significantly lower at 10 min ($p < 0.05$) and 30 min ($p < 0.01$) than the value at 0 min.
135 There was also no significant difference between treatments on the AUC for blood lactate
136 concentration (Fig. 3-b).

137 Given the insufficiency of previous studies on blood lactate concentrations after oral
138 lactate supplementation, we conducted an additional experiment to examine the time
139 course in more detail with resting subjects ($n = 5$) using the same lactate supplements.
140 The results of the one-way ANOVA revealed no significant changes (Fig. 3-c).

141

142 Other measurements (Table 1)

143 There was no main effect of treatment or an interaction on the heart rate, RPE, and blood
144 glucose concentration, but there was a significant main effect of time. Heart rate and RPE

145 at each point during exercise were significantly higher than the values at rest in both
146 treatments (all $p < 0.01$). The blood glucose concentrations at each point during exercise
147 were significantly lower than the values at rest with only the PLA treatment (all $p < 0.01$).
148 No significant changes were found in the gastric discomfort level.
149
150 **Discussion**
151 The effect of lactate supplementation on oxygen consumption
152 We used glucose as a placebo of lactate supplement because glucose is also an oxidative
153 substrate that competes with lactate [4,6]. Previous studies have shown that intravenous
154 infusion of lactate increased energy expenditure, whereas glucose as a control had no
155 effect [24]. As a result of the oral supplementation in this study, the AUC for oxygen
156 consumption during rest was significantly higher in the LAC treatment than in the PLA
157 treatment (Fig. 2-b). To our knowledge, this is the first study to suggest that oral lactate
158 supplementation increases oxygen consumption. However, no significant effects of oral
159 lactate supplementation were observed on oxygen consumption during exercise (Fig. 2-
160 c). RPE and heart rate during exercise were also similar in both the LAC and PLA
161 treatments (Table 1), suggesting that well-matched physiological loads were exerted
162 during exercise.

163 Considering the findings of previous studies, we present some possible mechanisms for
164 the increase in resting oxygen consumption in this study. First, the administered lactate
165 may increase resting energy expenditure via the sympathetic nervous system. Ettinger et
166 al. (1991) reported that the administration of dichloroacetate, which suppresses lactate
167 production during exercise, inhibits sympathetic nervous activity [37]. Furthermore,
168 Haesler et al. (1995) reported that the intravenous infusion of lactate increased energy
169 expenditure, but the increase was partially negated by propranolol (β-adrenergic receptor
170 blockade) [26]. Although taste stimuli can also induce sympathetic nervous system
171 activation [38], action via gustatory sensation was probably not involved in the present
172 study because the ingested lactate was packaged in a gelatin capsule. Thus, the ingested
173 lactate may circulate throughout the body and partially contribute to the increase in
174 oxygen consumption via the sympathetic nervous system. However, the role of lactate
175 itself on sympathetic activation is under discussion [39] and requires further investigation.
176 During exercise, the body is regulated by various physiological systems including the
177 nervous and the cardiorespiratory system, to respond to physiological stress. The
178 acceleration of cardiorespiratory responses in the low-intensity exercise is affected
179 primarily by a withdrawal of parasympathetic restraint [40,41]. Although the exercise in this
180 study was low-intensity, the effects of exercise on heart rate and oxygen consumption

were clearly greater than that of lactate ingestion (Fig. 2-a, Table 1). It is therefore possible that the effect of lactate ingestion was not detectable during exercise.

Second, there may also have been an effect of ATP consumption because of gluconeogenesis from lactate [24]. During rest, a portion of the exogenous lactate is oxidized while the remainder is used as a substrate for numerous metabolic processes, especially gluconeogenesis [12]. It is believed that the energetic cost of gluconeogenesis from lactate results in an increase in oxygen consumption [27]. Although no significant difference in blood glucose concentrations were observed in this study (Table 1), this is likely due to mechanisms maintaining glucose homeostasis [42] and the small amount of lactate used in this study. During exercise, most of the lactate administered is rapidly oxidized in exercising skeletal muscles [1, 12, 13]. Therefore, the effect of lactate supplementation on oxygen consumption may not have been observed during exercise in this study.

As described above, the increase in resting oxygen consumption by ingesting lactate supplements may be expressed through some mechanisms. Further studies are needed to reveal the details of the mechanism. Note that previous study, it has reported that intravenous infusion of lactate increased oxygen consumption during moderate-intensity exercise but not during rest [27]. The inconsistency of findings between studies may be due

199 to differences in administration and exercise methods. There is little evidence regarding
200 the effect of lactate administration on oxygen consumption, so the accumulation of
201 knowledge is needed in the future.

202 The increase in oxygen consumption during rest with LAC administration was
203 approximately 10% compared with PLA administration (Fig. 2-a). Moreover, the oxygen
204 consumption during exercise increased approximately two-fold compared with that at rest
205 in both treatments (Fig. 2-a). The accumulation of slight effects by lactate
206 supplementation could lead to obesity prevention. However, a higher dosage of lactate
207 may be more effective at increasing energy expenditure because some studies have
208 confirmed the dose-dependent effects of lactate administration [43-45]. The low dosage of
209 lactate supplements in our present study and previous investigations [20-23] was used
210 following the manufacturer's guidelines. No gastric discomfort was observed in this study
211 (Table 1), likely because of the low dose. By contrast, some attempts at large quantities
212 of lactate ingestion were unsuccessful because they were found to result in
213 gastrointestinal side effects [19, 36, 46]. If the dosage of lactate could be increased without
214 causing gastrointestinal side effects, a greater increase in energy expenditure could be
215 obtained. Future studies are needed to explore safe and effective doses of lactate
216 supplements on energy expenditure.

The effect of lactate supplementation on the blood lactate concentration

The blood lactate concentration is considered to be an indicator for determining whether administered lactate has reached the whole body. In normal physiological conditions in humans, the range of the blood lactate concentration is 0.5–2 mmol/L [1]. In the present study, the ingestion of lactate supplements did not lead to detectable changes in blood lactate concentrations (Fig. 3-a). Furthermore, additional experiments examining a more detailed time course in resting conditions also showed no changes in blood lactate concentrations (Fig. 3-c). Similarly, many studies have also reported no change in circulating lactate following lactate ingestion [4, 8, 9, 19-21, 36, 47-49]. Neither van Montfoort et al. (2004) nor Morris et al. (2011) reported significant increases in blood lactate concentrations despite the ingestion of larger quantities of lactate (320 and 120 mg/kg, respectively) [9, 35]. Importantly, the effects on physiological variables or athletic performance following lactate ingestion were observed even without an increase in the blood lactate concentration [4, 8, 9, 20, 36, 45, 48]. Therefore, it seems that the effects of lactate ingestion could be expected even if a significant increase in blood lactate levels did not occur. Exogenous lactate is a readily available substrate in that it is rapidly transported and oxidized [4, 18, 50]. For example, $^{13}CO_2$ in breath from a lactate tracer taken orally

235 immediately prior to exercise peaked 15 minutes after exercise began, whereas $^{13}CO_2$
236 after taking the glucose tracer peaked at 45 min [4]. This property of lactate potentially may
237 explain why no increase in blood lactate levels is observed after lactate ingestion.
238 The blood lactate concentrations were lower during exercise than during rest in both
239 treatments (Fig. 3-a). Basically, blood lactate concentration represents a balance between
240 the release of lactate into blood from working muscle and the uptake of lactate by mainly
241 the liver and muscle [1, 51]. Decrease in blood lactate concentrations are often observed
242 during low-intensity exercise, presumably due to enhanced lactate uptake into muscles [52].
243 The same phenomenon may have occurred in this study.
244
245 Limitations
246 The present study has some limitations. Firstly, the effects of the timing of lactate
247 ingestion were not examined in detail. In addition, it is necessary to examine the effects
248 of lactate supplements during rest over a longer period. Unlike the research using
249 continuous administration via intravenous infusion [6, 24-28], the appropriate timing of oral
250 lactate supplementation is difficult to determine [48]. Based on manufacturer's instructions
251 [21-23] and the previous studies that have examined the blood bicarbonate level peaked at
252 80 min following the ingestion of the calcium lactate [12,35], it is common to take lactate

253 60-80 minutes before exercise [21-23, 36]. In the present study, therefore, the supplements
254 were ingested 1 hour before the exercise, and the experimental data were measured from
255 10 min before exercise (i.e., 50 min after the ingestion) until the end of a 30-min exercise
256 session (Fig. 1). Depending on the timing of ingestion, oxygen consumption may also
257 increase during exercise. Moreover, a greater effect might be observed at an earlier stage
258 after lactate ingestion because lactate is metabolized rapidly [4, 18, 50]. Recently, it was
259 reported that the same supplement used in our study elicited an ergogenic effect when
260 taken 30 min before the short-duration time trial [20], suggesting that the necessity to
261 examine the effects at earlier stages after lactate ingestion. Future research should focus
262 on the effects of the timing of lactate ingestion. Secondly, we did not assess the lactate
263 oxidation rate throughout the experiment via isotope tracers and therefore could not assess
264 the metabolism of the ingested lactate in detail. In this study, the possibility exists that
265 lactate was absorbed in the upper intestine and then was mainly oxidized in the liver,
266 rather than circulating throughout the whole body. Moreover, the ingested lactate may
267 indirectly affect the sympathetic nervous system and/or energy expenditure through
268 specific receptors (hydroxycarboxylic acid receptor 1) in the stomach and gastrointestinal
269 tract [7, 53]. New technologies such as fluorescent indicators of lactate [54] will aid in
270 developing an understanding of the role of lactate metabolism. Finally, there was a

limitation of the sample size for data during exercise. As mentioned above in the Materials and Methods, the statistical power analysis indicated that the sample size needed to detect differences in oxygen consumption during exercise was 24. If sufficient subjects had been recruited, it may have been possible to detect differences in oxygen consumption during exercise. Moreover, there was a gender imbalance in this study (ten men and two women). Therefore, it is difficult to generalize the results of this study in terms of gender. To our knowledge, there are no studies that have investigated the effect of lactate administration with a focus on gender differences.

Future perspectives

In this study, acute oral lactate supplementation increased oxygen consumption during rest. However, the long-term effects of lactate supplementation on physical variables such as body weight and body fat percentage are unknown in humans. Previous animal studies have reported that long-term lactate administration without exercise alleviated the accumulation of fat mass [55] and that lactate-based compound treatment combined with voluntary exercise (low-intensity exercise) decreased fat mass [56]. These studies suggest that lactate administration could become a new therapeutic and interventional approach to obesity. Further human research into the effects of long-term lactate ingestion on

physical variables is warranted.

As described above, the increase in oxygen consumption owing to lactate supplementation was smaller than that owing to the exercise in this study. Considering that ingesting large amounts of lactate can cause gastrointestinal side effects [19, 36, 46], a combination of multiple energy substrates may be a feasible approach [19, 44]. An example of a promising nutritive substance is acetate, which is an easily available energy substrate with various physiological effects, as well as lactate [24, 57-59]. For example, the intravenous administration of acetate has also been reported to increase energy expenditure [24]. Further research is needed for application in clinical practice.

## Conclusion

In this study, we investigated the effects of acute oral lactate supplementation on energy metabolism using a lactate supplement and glucose as the placebo. As a result, acute oral lactate supplementation significantly increased oxygen consumption during rest compared with that with placebo.

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## Conflict of Interest

The authors declare no conflicts of interest.

## Author Contributions

Conceived and designed the study: KS.

Performed the study: KS.

Analyzed the data: KS.

Interpreted the data: KS, YT, and HH.

Wrote the paper: KS.

All authors approved the final version of the manuscript.

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**Fig. 1.** Schematic representation of the experiment.

**Fig. 2.** Changes in oxygen consumption during rest and exercise (a). AUC for oxygen consumption during rest (b). AUC for oxygen consumption during exercise (c).

††: $p < 0.01$ vs. the value during rest with PLA treatment.

‡‡: $p < 0.01$ vs. the value during rest with LAC treatment.

**: $p < 0.01$ vs. PLA treatment.

**Fig. 3.** Changes in blood lactate concentration during rest and exercise (a). AUC for blood lactate concentration during exercise (b). The additional experimental results detailing the changes in the blood lactate concentration after ingesting a lactate supplement (c).

†: $p < 0.05$ vs. the value at 0 min with PLA treatment.

††: $p < 0.01$ vs. the value at 0 min with PLA treatment.

‡: $p < 0.05$ vs. the value at 0 min with LAC treatment.

532 **Fig. 1**

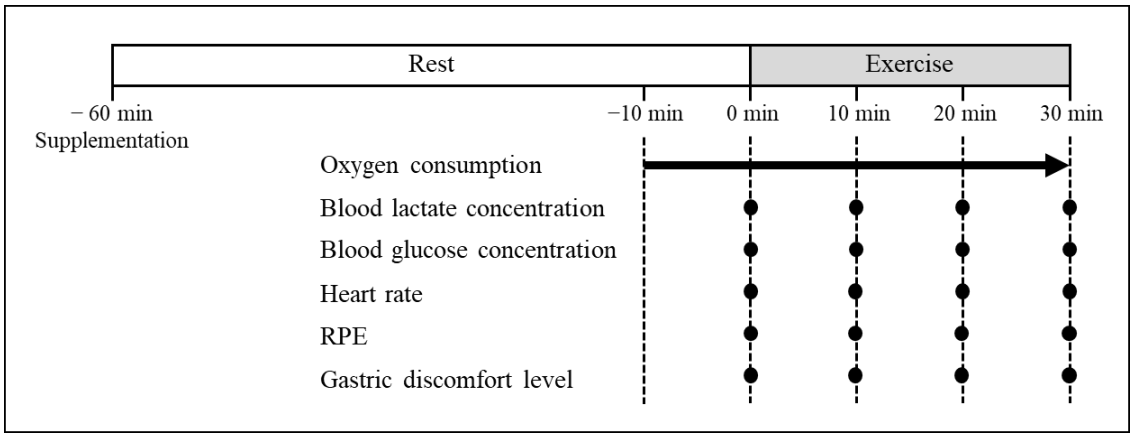


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Figure 1 (Seike et al.)

**Fig. 2-a**

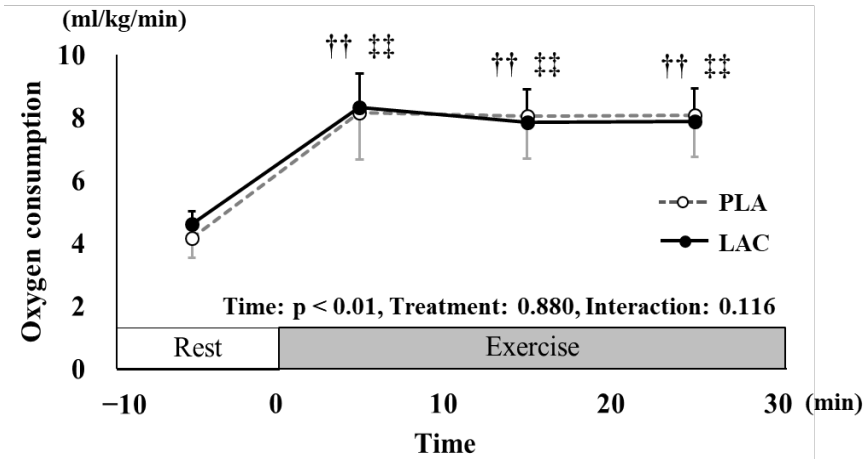


**Fig. 2-b**

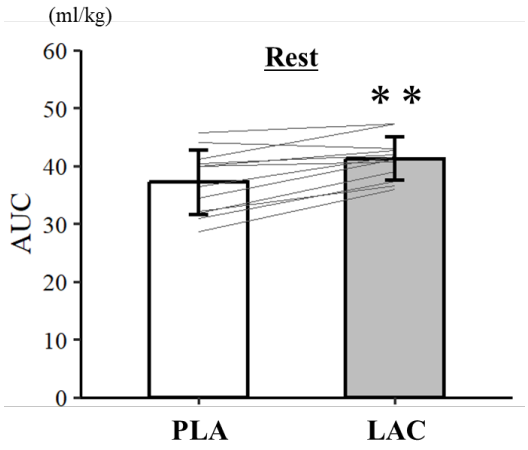


**Fig. 2-c**

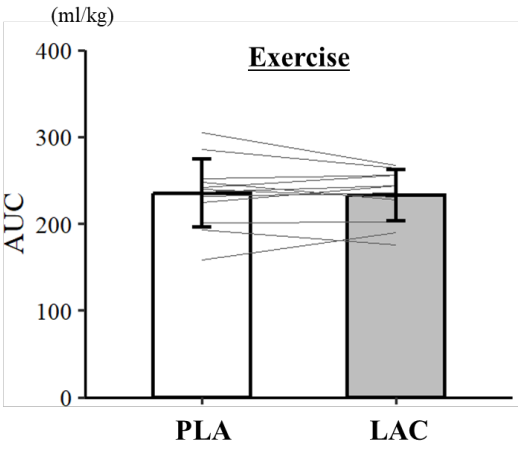


Figure 2 (Seike et al.)

**Fig. 3-a**

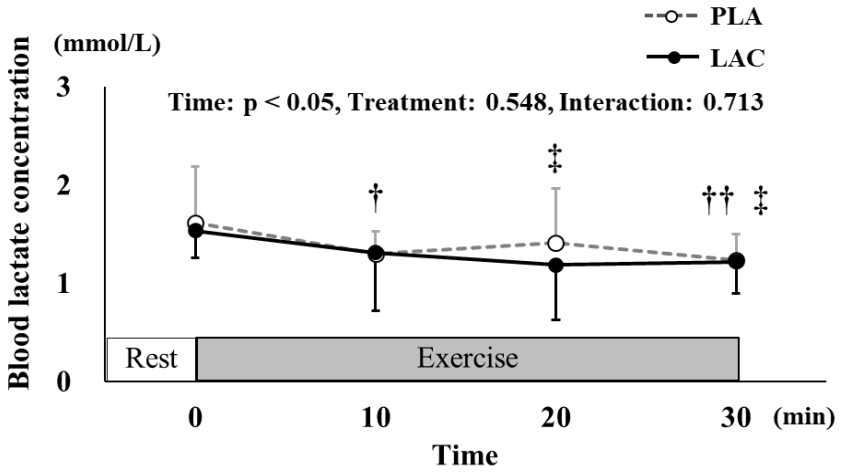


**Fig. 3-b**

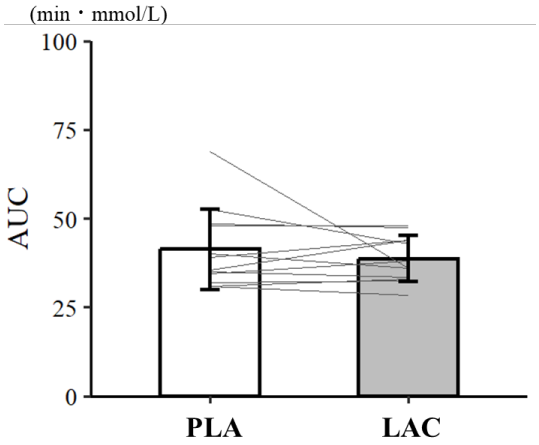


**Fig. 3-c**

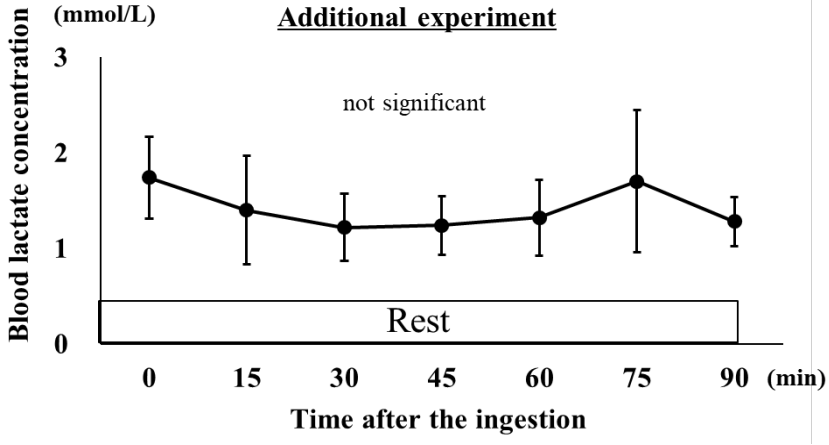


Figure 3 (Seike et al.)

546 **Table 1.** Other measurements. The data shown were measured during rest before exercise

547 (at 0 min) and during exercise (at 10, 20, and 30 min).

| | | Rest | Exercise | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 min | 10 min | 20 min | 30 min | Treatment | Time | Interaction |
| Heart rate (beats/min) | PLA | 65 ± 8 | 77 ± 7 ** | 75 ± 8.6 ** | 78 ± 9 ** | NS | $p < 0.01$ | NS |
| | LAC | 65 ± 8 | 75 ± 10 ** | 76 ± 10 ** | 76 ± 10 ** | | | |
| RPE | PLA | 6 ± 0 | 8.4 ± 1.8 ** | 8.9 ± 2.0 ** | 9. 8± 2.2 ** | NS | $p < 0.01$ | NS |
| | LAC | 6 ± 0 | 8.4 ± 1.8 ** | 9.1 ± 2.0 ** | 9.8 ± 2.1 ** | | | |
| Blood glucose concentration (mg/dL) | PLA | 111 ± 16 | 98 ± 13 ** | 101 ± 14 ** | 100 ± 13 ** | NS | $p < 0.05$ | NS |
| | LAC | 108 ± 16 | 104 ± 18 | 103 ± 17 | 107 ±16 | | | |
| Gastric discomfort level (mm) | PLA | 1 ± 4 | 1 ± 4 | 2 ± 5 | 2 ± 5 | NS | NS | NS |
| | LAC | 2 ± 8 | 2 ± 6 | 2 ± 6 | 2 ± 7 | | | |

548

549 NS: not significant.

550 **: $p < 0.01$ vs. at 0 min.