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Research article

Identifying the Optimal Arm Priming Exercise Intensity to Improve Maximal Leg Sprint Cycling Performance

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Abstract

Priming exercises improve subsequent motor performance; however, their effectiveness may depend on the workload and involved body areas. The present study aimed to estimate the effects of leg and arm priming exercises performed at different intensities on maximal sprint cycling performance. Fourteen competitive male speed-skaters visited a lab eight times, where they underwent a body composition measurement, two $\dot{V}O_{2max}$ measurements (leg and arm ergometers), and five sprint cycling sessions after different priming exercise conditions. The five priming exercise conditions included 10-minute rest (Control); 10-minute arm ergometer exercise at 20% $\dot{V}O_{2max}$ (Arm 20%); 10-minute arm ergometer exercise at 70% $\dot{V}O_{2max}$ (Arm 70%); 1-min maximal arm ergometer exercise at 140% $\dot{V}O_{2max}$ (Arm 140%); and 10-min leg ergometer exercise at 70% $\dot{V}O_{2max}$ (Leg 70%). Power outputs of 60-s maximal sprint cycling, blood lactate concentration, heart rate, muscle and skin surface temperature, and rating of perceived exertion were compared between the priming conditions at different measurement points. Our results showed that the Leg 70% was the optimal priming exercise among our experimental conditions. Priming exercise with the Arm 70% also tended to improve subsequent motor performance, while Arm 20% and Arm 140% did not. Mild elevation in blood lactate concentration by arm priming exercise may improve the performance of high-intensity exercise.

Key words: Exercise, arm, heart rate, lactic acid.

Introduction

Motor performance can be modulated by providing conditioning stimuli prior to a main exercise, which is known as the priming effect. In the area of sports science, different types of prior exercise are used to increase the performance of interest and to reduce the risk of injury, such as warm-up and priming exercise.

Warm-up typically aims to elevate muscle and body temperature to improve the performance of subsequent exercise and to prevent injury, where it includes low to moderate exercise intensity, with relatively long exercise duration. Warm-up can also be passive, where subjects undergo passive interventions such as passive heating to elevate body temperature (Bishop, 2003a). The elevated muscle temperature was found to increase the ATP turnover and muscle fiber conduction velocity, improving the performance of vertical jump and power output of sprint cycling (Bergh and Ekblom, 1979; Gray et al., 2006). It is important to monitor the changes in body temperature to understand the effect of prior exercise on subsequent motor performance.

Priming typically aims to improve the performance of subsequent exercise by altering the $\dot{V}O_2$ kinetics, where it includes moderate to high intensity, with relatively short exercise duration. Increased performance after priming exercise may be achieved by increased oxygen dissociation from hemoglobin and myoglobin, accelerated metabolic reactions, increased nerve conduction velocity, increased blood volume in activated muscles, and reduced anaerobic contribution early after the beginning of the main exercise by elevated baseline oxygen uptake (Bishop, 2003b). Power output and aerobic contribution can be maximized by priming exercise, taking advantage of metabolic mechanisms to provide greater oxygen uptake and enhanced pulmonary gas exchange kinetics (Bohnert et al., 1998; Chorley and Lamb, 2019). Priming exercise is beneficial to optimize motor performance by elevated body temperature, metabolic, neural and psychological effects, including improved anaerobic metabolism, elevated oxygen uptake, and post-activation potentiation (Yaicharoen et al., 2012). Although warm-up and priming are not mutually exclusive since they share their benefits, priming is typically performed as an add-on to the warm-up procedure.

However, priming can have a negative influence on the performance of main exercise when its intensity is not optimal. It has been shown that subsequent motor performance is unchanged or even reduced when priming exercise intensity is too low or too high, or when the recovery period is too short (Bishop, 2003b). In order to overcome the negative effects of priming, several studies have investigated the effects of priming exercise using body areas that are not primarily involved in the main exercise. For example, arm exercise prior to sprint cycling has shown to enhance aerobic respiratory gas exchange kinetics and suppress lactate production during the main exercise (Bogdanis et al., 1994). Another study also reported that arm priming exercise produced lactate, which was consumed during lower limb exercise in elite cross-country skiers (Van Hall et al., 2003). Although there seems to be positive physiological effects of priming exercise using body areas that are not primarily involved in the main exercise, it should be noted there are several studies reporting no apparent benefit of such priming exercise on motor performance (Purge et al., 2017; Valiulin et al., 2022). These study results suggest that the suppressed anaerobic contribution and fatigue due to excessive intensity and insufficient resting after priming could have a negative influence on the main exercise performance. However, little evidence exists about the optimal intensity of priming exercise using body areas that are not primarily involved in the main

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exercise.

Therefore, the aim of this study was to estimate the effects of leg and arm priming exercises performed at different intensities on maximal sprint cycling performance. We compared blood lactate concentration (BLC), rating of perceived exertion, heart rate, and muscle temperature between different priming exercises, where intensity and body areas involved in the prime exercise were manipulated.

Methods

Participants

We included 14 competitive male speed-skaters in a university (median [interquartile range], age: 20.5 (3.0) years; height: 1.72 (0.05) m; body weight: 65.7 (6.0) kg; body mass index [BMI]: 22.5 ± 2.4 kg/m^2). All participants were categorized as Tier 3 (McKay et al., 2022), within the 8th rank in at least one of national competitions, and some participated in international competitions. We chose to include only male athletes to eliminate the bias associated with fluctuations of menstrual cycle hormones (Giacomoni et al., 2000; Yapıcı-Öksüzoğlu and Egesoy, 2021). Participants were excluded from the study if they reported musculoskeletal injuries that would limit their ability to perform cycling sessions using the upper and lower limbs. Participants were instructed to refrain from caffeinated food and drink, drugs, alcohol, tobacco, and any form of nicotine use within 24 hours prior to the experiment. Participants were also advised to refrain from taking anti-inflammatory or analgesic medications (Caritá et al., 2015). We did not have further restrictions on the nutrition intake. We reminded the participants that they cannot take above-mentioned substances 48 hours prior to the experiment, and made sure that participants followed the instructions by asking them on the day of the experiment. Participants were instructed not to train within 24 hours prior to the experiment. However, no specific control was made for exercise > 24 hour prior to the experiment since it was not possible to control training strictly in this population. After explaining the study procedures and risks involved in the study, written consent was obtained from all participants. The study was approved by the institutional review board (approval number: 2157).

Experimental procedures

The experimental procedures are summarized in Figure 1. Each participant visited the lab for a total of eight times, with an interval of ≥ 24 hours between sessions. The first visit included body composition measurement. Body composition was measured based on the bioelectrical impedance method (InBody 720, InBody Japan, Tokyo, Japan) to estimate body weight, skeletal muscle and body fat mass, body fat percentage, BMI, right and left arm muscle mass, and right and left leg muscle mass. The measurements were performed in a static standing position with palms and soles touching the electrodes of the device.

In the second and third visits, an incremental exercise test was performed separately for arm and leg exercises, using arm (SCIFITpro1, Life Fitness, Rosemont, IL) and leg (Powermax-V3, Konami, Tokyo, Japan) ergometers, respectively. We measured the lactate threshold (LT) during the $\dot{V}O_{2max}$ measurement.

On the subsequent five visits, participants performed maximal sprint cycling after different priming exercises (Figure 1). The order of the priming exercises was randomized to minimize confounding effects. After completing the priming exercises, participants sat for 5 minutes on a leg ergometer. After the 5-minute rest, the main exercise was performed, where participants performed maximal sprint cycling for 60 s. Measurements of BLC, heart rate, muscle and skin surface temperature, and rating of perceived exertion (RPE) were performed at four time points during the main experiment: before priming

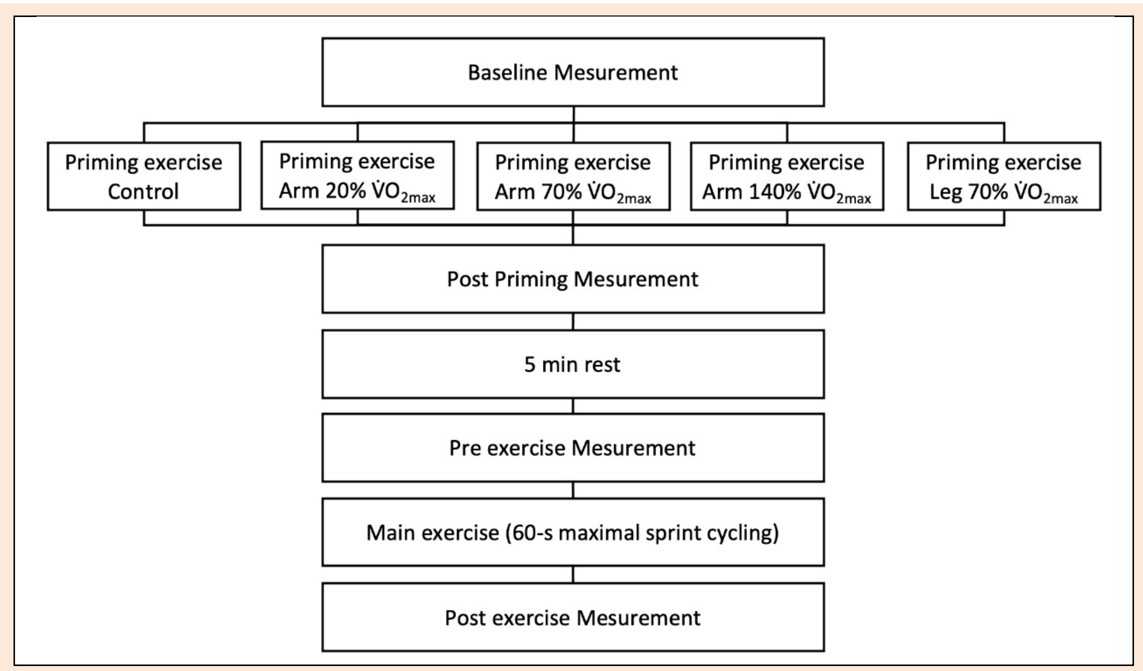

Figure 1. Experimental procedures.

exercise (baseline), after priming exercise (post-priming), before the main exercise (pre-exercise), and after the main exercise (post-exercise). Blood lactate concentration was measured using a lactate analyzer (Lactate Pro 2, Arkray, Kyoto, Japan). Arterial blood samples of 0.3 µL were obtained from the ear. The first blood drop was removed to avoid contamination of the blood sample. Heart rate was measured using a heart rate monitor (Polar h10, Polar, Kempele, Finland). Muscle and skin surface temperatures were measured using a temperature monitoring device based on the zero-heat-flow method (core temp CTM-205, Termo, Tokyo, Japan). Measurement sensors (deep temperature sensor PD7, Termo, Tokyo, Japan: surface temperature sensor: PD-K161, Termo, Tokyo, Japan) were tightly attached to the skin over the midpoint of the right vastus lateralis using double-sided tape. The measurement of muscle and skin surface temperatures was performed continuously during the main experiments. RPE was measured separately for shortness of breath, arm fatigue, and leg fatigue, using the Borg scale (Borg, 1982). All measurements were performed in a room where temperature was maintained at 25 °C and humidity at 50%.

Exercise protocols

Incremental exercise test ($\dot{V}O_{2max}$ and LT)

Leg and arm incremental exercise tests were separately performed to determine the workload of priming exercises with minor modifications of test protocol from previous studies (Alison et al., 1998; Fujii et al., 2018). Leg incremental exercise testing was performed using a leg ergometer with an electromagnetic brake system (Powermax-V3, Konami, Tokyo, Japan). After a 2-minute warm-up with no load, participants initiated the test from a work rate of 70 W, which was increased by 35 W every 2 minutes while pedaling cadence was maintained constant at 70 rpm. The test continued until the participants could no longer maintain a pedaling rate of 70 rpm for 5 seconds or reported fatigue (Fujii et al., 2018). Arm incremental exercise test was performed using an arm ergometer (SCIFITpro1, Life Fitness, Rosemont, IL). After a 2-minute warm-up with no load, participants initiated the test from a workload of 40W, which was increased by 5 W every 2 minutes while the pedaling cadence was maintained constant at 50 rpm (Alison et al., 1998). The measurement was performed in the standing position and the center of the crank was adjusted to the shoulder level. The participants wore a mask that covered nose and mouth, where a flow sensor and gas-sampling tube were connected. Expired volume and gases were continuously analyzed using an electric gas flow meter (AE100i, Minato Medical Science, Osaka, Japan). We verified that at least one of following three criteria were met at $\dot{V}O_{2max}$: 1) exceeding 90% of age-predicted maximum heart rate; 2) reaching a plateau of oxygen uptake (i.e., difference of oxygen uptake at last 2 stages < 150 ml/min); and 3) respiratory quotient (ratio of VCO_2 and VO_2) > 1.1. Verbal encouragement was provided during the tests. At the end of each workload stage, BLC was measured using a lactate analyzer (Lactate Pro 2, Arkray, Kyoto, Japan). We identified two lactate thresholds (LTs) and ventilatory thresholds (VTs) during the incremental exercise tests based on the three-phase model (Binder et al., 2008). The first and second LTs (LT1 and LT2*)* were defined as the workload where BLC exceeded 2 mmol/L and 4 mmol/L, respectively. The first and second VTs (VT1 and VT2) were identified by comprehensive judgment using $\dot{V}CO_2$ versus $\dot{V}O_2$ graph, $\dot{V}E/\dot{V}O_2$ versus workload graph, $\dot{V}O_2$ versus $\dot{V}CO_2$ graph, $\dot{V}E/\dot{V}CO_2$ versus workload graph, $P_{ET}O_2$, and $P_{ET}CO_2$. All analyses were performed by two independent examiners (TM & YT), and the third examiner was also involved when any discrepancies were found (Coyle, 1995).

Priming exercise

The workload of each priming exercise condition was adjusted based on the $\dot{V}O_{2max}$ measured during the incremental exercise test, separately for leg and arm cycling (Table 1). The five priming exercise conditions included 10-minute rest (Control), 10-minute arm ergometer exercise at 20% $\dot{V}O_{2max}$ (Arm 20%), 10-minute arm ergometer exercise at 70% $\dot{V}O_{2max}$ (Arm 70%), 1-minute arm ergometer exercise at 140% $\dot{V}O_{2max}$ (Arm 140%), and 10-minute leg ergometer exercise at 70% $\dot{V}O_{2max}$ (Leg 70%). Both Arm 70% and Leg 70% conditions were around the LT2 intensity (Table 2). The Arm 20% condition was set as a condition where aerobic contribution is the primary source for energy production. Performance of the intermediate exercise performance (i.e., 10 sec < exercise duration < 5 min) can be effectively improved by priming exercise at around 70% $\dot{V}O_{2max}$ (Bishop, 2003b). Similarly, in our preliminary experiment, we confirmed that the BLC exceeded 5 mmol/L at 70% $\dot{V}O_{2max}$ for both leg and arm priming exercises, suggesting that it is the optimal workload to evoke both aerobic and anaerobic contributions. We also verified that BLC only showed a small change from its baseline level in the Arm 20% condition, suggesting that anaerobic contribution during the priming exercise was minimal. The Arm 140% condition was set as the short-term high-intensity exercise reaching all-out, where participants performed a maximal arm sprint cycling for 60 s. In both leg and arm priming exercises, a 2-minute warm-up with no load was performed before starting the priming exercise at each condition. In the Control condition, participants sat on a stool for 10 minutes.

Table 1. Descriptive measures of the study participants.

Characteristics	Median (IQR)
Age (years)	20.5 (3.0)
Height (m)	1.72 (0.05)
Weight (kg)	65.7 (6.0)
BMI (kg/m^2)	22.5 (2.4)
Fat mass (kg)	9.4 (5.2)
% Body Fat (%)	15.4 (5.0)
Muscle mass (kg)	
Total skeletal muscle mass	32.1 (4.9)
Right arm	3.0 (0.7)
Left arm	2.8 (0.6)
Right leg	9.1 (1.0)
Left leg	9.0 (0.9)
Trunk	23.9 (3.7)

BMI: body mass index; IQR: interquartile range

Main exercise

Participants performed maximal sprint cycling for 60 s using a leg ergometer (Powermax-V3, Konami, Tokyo, JAPAN). Each foot was attached to the pedal using a binding strap. The workload of the exercise was set at 7.5% of body weight (Gastin et al., 1991). The height of the handle and saddle were adjusted to a comfortable level prior to the experiment. All participants performed the main exercise with standing cycling. Verbal encouragement was provided during the exercise.

Table 2. Results of incremental exercise test and workload settings.

Incremental exercise test results	Median (IQR)
Leg $\dot{V}O2max$ test	
Workload at $\dot{V}O_{2max}$ (W)	343.0 (68.6)
$\dot{V}O_{2max}$ (ml/kg/min)	58.9 (10.3)
Heart rate max (bpm)	199.0 (2.8)
BLC max (mmol/L)	17.2 (3.8)
Exercise time at $\dot{V}O_{2max}$ (sec)	1181.1 (195.0)
Arm $\dot{V}O_{2max}$ test	
Workload at $\dot{V}O_{2max}$ (W)	95.0 (27.5)
$\dot{V}O_{2max}$ (ml/kg/min)	35.4 (15.6)
Heart rate max (bpm)	185.5 (13.0)
BLC max (mmol/L)	8.8 (3.3)
Exercise time at $\dot{V}O_{2max}$ (sec)	791.4 (480.0)
Workload at LT1 and VT1	
Leg LT1 power (W)	120.1 (102.9)
Leg VT1 power (W)	171.5 (51.5)
Leg LT1 heart rate (bpm)	131.5 (9.8)
Arm LT1 power (W)	45.0 (5.0)
Arm VT1 power (W)	60.0 (23.8)
Arm LT1 heart rate (bpm)	126.5 (39.5)
Workload at LT2 and VT2	
Leg LT2 power (W)	205.8 (145.8)
Leg VT2 power (W)	274.4 (145.8)
Leg LT2 heart rate (bpm)	164.5 (14.8)
Arm LT2 power (W)	57.5 (12.5)
Arm VT2 power (W)	72.5 (26.3)
Arm LT2 heart rate (bpm)	136.5 (45.0)
Workload of priming exercise (W)	
Arm 20%	19.0 (5.5)
Arm 70%	66.5 (19.3)
Arm 140%	133.0 (38.5)
Leg 70%	240.1 (48)
Workload of main exercise (kp)	4.9 (0.5)

Outcome measures

Primary outcome

Power outputs, including the peak power, mean power, and fatigue index (FI) during main exercise were used as the primary outcomes. The FI was calculated using the following formula:

$$\text{fatigue index } (\%) = \frac{(\text{peak power (W)} - \text{minimum power (W)})}{\textit{peak power (W)}} \times 100$$

Secondary outcomes

Blood lactate concentration, heart rate, muscle and skin surface temperature, and RPE at pre- and post-exercise were compared between priming conditions. We also calculated changes in BLC (ΔBLC), using the following formula:

$$\Delta BLC = BLC_{Post\ exercise} - BLC_{Pre\ exercise}$$

Statistical procedures

The results of the Shapiro-Wilk test showed that outcomes did not have normal distribution. Therefore, nonparametric tests were used in this study. Descriptive statistics were summarized using median and interquartile range. Outcome measures were compared between conditions using the Friedman test. Wilcoxon signed-rank test using Bonferroni correction was used for post-hoc analysis. The effect size (ES) of the Friedman test and Wilcoxon signed-rank test was estimated using the Kendall's W value. All analyses were performed using SPSS v. 25.0 (IBM Corp., Armonk, NY). A two-tailed p-value <0.05 was considered statistically significant.

Results

Demographics

Demographic characteristics of the 14 participants are presented in Table 1. The results of the incremental exercise tests and exercise workload are summarized in Table 2. The exercise duration of the incremental exercise test was significantly longer in the leg test than in the arm test (Z = 2.867, p = 0.004, ES = 0.445). The workload of priming exercises (Arm 20%, Leg 20%, Arm 70%, Leg 70%, and Arm 140%) and its relationship with LT2 in each participant is shown in Figure 2. The workload in Leg 70% was similar to the LT2 (median LT2: 70% $\dot{V}O_{2max}$), while that in Arm 70% was slightly higher than the LT2 (median LT2: 56.7% $\dot{V}O_{2max}$).

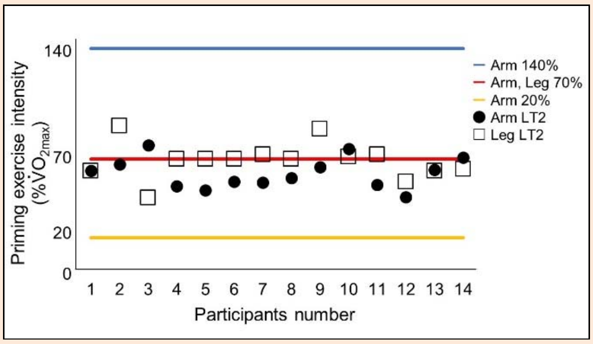

Figure 2. The workload of priming exercise and LT in arm (black circles) and leg (white square) ergometer (%$\dot{V}O_{2max}$).

Power output

Peak power was highest in the Leg 70% condition and significantly greater than in the Control, Arm 20%, and Arm 140% conditions; conversely, it did not significantly differ from the Arm 70% condition ($\chi^2 = 18.296$, p = 0.001, ES = 0.327; Table 3). Mean power tended to be high in the Leg 70% condition, and it was significantly greater than that in the 140% condition ($\chi^2 = 20.553$, p < 0.001, ES = 0.367). The FI did not differ between experimental conditions ($\chi^2 = 4.975$, p = 0.290).

Blood lactate concentration

BLC showed significant differences between experimental conditions at post-priming and pre-exercise (post-priming: $\chi^2 = 37.799$, p < 0.001, ES = 0.675; pre-exercise: $\chi^2 = 40.390$, p < 0.001, ES = 0.721; Table 4), while no significant differences were seen at baseline and post-exercise. BLC was significantly elevated at post-priming and pre-exercise in the Arm 70%, Arm 140%, and Leg 70%

conditions relatively to the Control and Arm 20% conditions. The BLC was similar between Arm 70% and Leg 70% at all measurement points. The ΔBLC did not differ between conditions and its median did not exceed 10 mmol/L in Arm 70%, Arm 140%, and Leg 70% conditions ($\chi^2 = 3.254$, p = 0.516).

Table 3. Power outputs for the 60-s maximal sprint cycling.

	Control	Arm 20%	Arm 70%	Arm 140%	Leg 70%	p value
Peak Power (W)	827.0 (196.0)	848.5 (164.0)	878.5 (159.0)	861.0 (151.0)	919.0 (170) [a, b, d]	0.001
Mean Power (W)	560.0 (85.0)	558.0 (72.0)	563.0 (75.0)	537.0 (89.0)	593.0 (100.0) [d]	<0.001
Fatigue index (%)	48.8 (10.4)	48.4 (8.9)	48.8 (8.5)	48.8 (6.9)	46.6 (7.6)	0.29

p value: p value for the Friedman test; Control: No priming; Arm: priming with arm ergometer; Leg: priming with leg ergometer; a: vs. Control; b: vs. Arm 20%; c: vs. Arm 70%; d: vs. Arm 140%; e: vs. Leg 70%.

Table 4. Exertion measures evaluated at each measurement point. Values presented as median (IQR)

		Control	Arm 20%	Arm 70%	Arm 140%	Leg 70%	p value
BLC (mmol/L)	Baseline	1.6 (0.4)	1.9 (0.9)	1.5 (1.0)	1.8 (0.6)	1.5 (0.6)	0.345
	Post-priming	1.5 (0.9)	1.7 (1.2)	4.2 (2.7) [a, b]	6.2 (2.1) [a, b]	5.6 (4.1) [a, b]	<0.001
	Pre-exercise	1.7 (0.6)	1.8 (1.4)	3.8 (2.1) [a, b]	7.1 (3.7) [a, b]	3.5 (5.1) [a, b]	<0.001
	Post-exercise	12 (7.9)	12.8 (6.1)	12.9 (2.8)	15.2 (3.8)	13.5 (4.9)	0.248
ΔBLC (mmol/L)	Post minus pre exercise	10.3 (8.6)	11.0 (5.5)	9.3 (4.6)	9.0 (6.1)	9.6 (5.8)	0.516
HR (bpm)	Baseline	77.0 (19.0)	81.5 (11.0)	83.5 (12.0)	88.0 (20.0) [a]	82.0 (9.0)	0.05
	Post-priming	77.0 (16.0)	107.5 (26.0)	157.5 (35.0) [a]	167.0 (16.0) [a, b]	169.5 (24.0) [a, b]	<0.001
	Pre-exercise	86.5 (13.0)	90.5 (24.0)	107.5 (21.0)	120.0 (22.0) [a, b]	117.0 (21.0) [a, b]	<0.001
	Post-exercise	176.0 (9.0)	178.5 (11.0)	184.0 (8.0) [a, b]	180.0 (10.0)	195.0 (13.0) [a, b, d]	<0.001
Ts (°C)	Baseline	30.7 (1.2)	30.9 (2.7)	31.3 (2.2)	30.8 (1.9)	30.5 (1.8)	0.558
	Post-priming	31.1 (1.6)	31.2 (2.6)	31.3 (2.6)	30.6 (1.9)	31.7 (1.8)	0.215
	Pre-exercise	31.0 (1.4)	31.2 (2)	31.4 (1.6)	30.7 (2.2)	33.1 (0.9) [a, b, c, d]	<0.001
	Post-exercise	30.7 (1.8)	30.8 (1.6)	31.0 (1.6)	30.3(1.9)	31.5(1.6)	0.081
Tm (°C)	Baseline	33.6 (1.8)	34.4 (1.3)	34.0 (1.9)	33.7 (1.6)	33.4 (2.2)	0.459
	Post-priming	34.9 (2.1)	35.0 (1.0)	35.0 (0.9)	34.3 (1.7)	37.0 (2.3) [a, b, c, d]	<0.001
	Pre-exercise	34.9 (2.4)	34.8 (1.2)	35.0 (0.8)	34.4 (2.1)	37.4 (1.7) [a, b, c, d]	<0.001
	Post-exercise	35.1 (2.1)	34.9 (1.3)	35.1 (0.7)	34.8 (2.0)	37.0 (1.8) [a, b, c, d]	<0.001
RPE-Breath	Baseline	6.0 (1.0)	6.0 (1.0)	6.0 (0.0)	6.0 (1.0)	6.0 (1.0)	0.367
	Post-priming	6.0 (1.0)	7.5 (4.0)	12.0 (4.0) [a]	15.0 (4.0) [a, b]	20.0 (2.0) [a, b]	<0.001
	Pre-exercise	6.0 (1.0)	7.0 (2.0)	9.0 (4.0)	11.5 (3.0) [a, b]	11.0 (2.0) [a, b]	<0.001
	Post-exercise	18.5 (3.0)	18.5 (3.0)	18.0 (3.0)	19.0 (2.0)	20.0 (2.0)	0.264
RPE-Leg	Baseline	6.0 (1.0)	6.0 (1.0)	6.0 (0.0)	6.0 (2.0)	6.0 (1.0)	0.225
	Post-priming	6.0 (0.0)	7.5 (3.0)	9.0 (3.0)	13.0 (5.0) [a, b]	15.0 (3.0) [a, b, c]	<0.001
	Pre-exercise	6.0 (1.0)	7.0 (2.0)	8.0 (2.0)	11.5(4.0) [a, b]	11.0 (2.0) [a, b, c]	<0.001
	Post-exercise	20.0 (2.0)	20.0 (2.0)	19.0 (3.0)	20.0 (1.0)	19.5 (1.0)	0.271
RPE-Arm	Baseline	6.0 (1.0)	6.0 (1.0)	6.0 (0.0)	6.0 (1.0)	6.0 (0.0)	0.339
	Post-priming	6.0 (1.0)	9.0 (4.0)	15.5(4.0) [a]	19.0 (3.0) [a, b, e]	10.0 (2.0) [a]	<0.001
	Pre-exercise	6.0 (1.0)	7.0 (2.0)	12.5 (5.0) [a, b]	15.0 (3.0) [a, b, e]	9.0 (3.0)	<0.001
	Post-exercise	14.5 (3.0)	15.0 (5.0)	15.0 (2.0)	17.0 (3.0)	14.0 (3.0)	0.034

p-value: p-value for the Friedman test; BLC: blood lactate concentration; IQR: interquartile range; Ts: skin surface temperature; Tm: muscle temperature; RPE: rating of perceived exertion; [a]: vs. Control; [b]: vs. Arm 20%; [c]: vs. Arm 70%; [d]: vs. Arm 140%; [e]: vs. Leg 70%

Heart rate

Heart rate significantly differed between conditions at post-priming, pre-exercise, and post-exercise (post-priming: $\chi^2 = 47.269$, p < 0.001, ES = 0.844; pre-exercise: $\chi^2 = 34.816$, p < 0.001, ES = 0.622; post-exercise: $\chi^2 = 42.755$, p < 0.001, ES = 0.763; Table 4). Heart rate at the post-priming and pre-exercise were significantly elevated in the Arm 70%, Arm 140%, and Leg 70% conditions, compared with the Control and Arm 20% conditions. Heart rate at post-exercise was significantly elevated in the Arm 70% and Leg 70% condition, compared with the Control and Arm 20% conditions.

Muscle and skin surface temperature

Muscle temperature significantly differed between conditions at post-priming, pre-exercise, and post-exercise (post-priming: $\chi^2 = 21.720$, p < 0.001, ES = 0.388; pre-exercise: $\chi^2 = 25.448$, p < 0.001, ES = 0.454; post-exercise: $\chi^2 = 23.209$, p < 0.001, ES = 0.414; Table 4). Muscle temperature at post-priming, pre-exercise, and post-exercise was significantly elevated in the 70% Leg condition compared with the other four conditions. Skin surface temperature at pre-exercise was significantly elevated in the 70% Leg condition compared with the other four conditions ($\chi^2 = 20.563$, p < 0.001, ES = 0.367).

Rating of perceived exertion (RPE)

Perceived shortness of breath

Perceived shortness of breath significantly differed between conditions at post-priming and pre-exercise (post-priming: $\chi^2 = 48.524$, p < 0.001, ES = 0.867; pre-exercise: $\chi^2 = 42.041$, p < 0.001, ES = 0.751; Table 4). Participants perceived greater shortness of breath at post-priming and pre-exercise in the Arm 140% and Leg 70% conditions compared with Control and Arm 20% conditions. Perceived shortness of breath at post-priming in the Arm 70% was significantly greater than in the Control condition.

Perceived leg fatigue

Perceived leg fatigue significantly differed between conditions at post-priming and pre-exercise (post-priming: χ^2 = 42.902, p < 0.001, ES = 0.766; pre-exercise: χ^2 = 40.285, p < 0.001, ES = 0.719; Table 4). Participants perceived significantly greater leg fatigue at post-priming and pre-exercise in the Leg 70% condition compared with Control, Arm 20%, and Arm 70% conditions. Perceived leg fatigue at post-priming and pre-exercise in the Arm 140% condition was significantly greater compared with the Control and Arm 20% conditions.

Perceived arm fatigue

Perceived arm fatigue significantly differed between conditions at post-priming and pre-exercise (post-priming: χ^2 = 51.385, p < 0.001, ES = 0.918; pre-exercise: χ^2 = 49.023, p < 0.001, ES = 0.875; Table 4). Participants perceived greater arm fatigue at post-priming in the Arm 140% condition, compared with the Control, Arm 20%, and Leg 70% conditions. At pre-exercise, perceived arm fatigue was greater in the Arm 70% and Arm 140% conditions compared with Control and Arm 20%, and Leg 70% conditions.

Discussion

The present study investigated the effects of leg and arm priming exercises at different intensities on sprint cycling performance. The primary finding of this study was that the Leg 70% led to the best maximal sprint cycling performance among all experimental conditions. Furthermore, the best performance of maximal sprint cycling was achieved after the Arm 70% priming exercise among three workloads for the arm priming, while the difference did not reach statistical significance. These study results demonstrate that the effectiveness of priming exercise on subsequent motor performance may depend on the workload and involved body areas.

Optimal range for prior elevation of blood lactate concentration

Previous studies demonstrated that an excessive increase in lactate concentration (≥6 mmol/L) leads to no or negative effects on exercise performance (Burnley et al., 2005; Ferguson et al., 2007; Koppo and Bouckaert, 2002; Wilkerson et al., 2004). However, previous studies also reported that mild increase in lactate concentration (≈3 mmol/L) improved subsequent exercise performance (Bailey et al., 2009; Jones et al., 2003; Palmer et al., 2009). In our study, the BLC level was similar between the Arm 70% and Leg 70% conditions at pre-exercise, as demonstrated by the BLC levels of 3.8 and 3.5 mmol/L, respectively (Table 4). In contrast, a high BLC level of 7.1 mmol/L was observed at pre-exercise after the Arm 140% condition. Mean power and peak power in the Arm 140% did not change from the Control, while it was significantly lower than these in the Leg 70% condition.

The main exercise (i.e., 60-second sprint cycling) involved both aerobic and anaerobic efforts. A previous study has shown that the peak oxygen uptake during the 60-second sprint cycling was about 90% oxygen uptake during the $\dot{V}O_{2max}$ test, suggesting that aerobic contribution was close to its maximum capacity (Carey and Richardson, 2003). Furthermore, the same study showed that the peak power during the 60-second sprint cycling was similar to that during the 30-second Wingate anaerobic test (30-second sprint cycling). The results of our study showed that the BLC level was substantially increased by the main sprint cycling (median of ΔBLC ranging from 9.0 to 11.0). These findings indicate that the 60-second sprint cycling required large aerobic and anaerobic contributions.

There are several possible mechanisms related to the improved peak power following mild elevation of lactate concentration level. It has been shown that when lactate is added to fatigued skeletal muscle, Na+ - K+ pumping was facilitated, improving muscle excitability and force (Nielsen et al., 2001). Furthermore, elevated blood lactate may be beneficial in terms of delivery of oxidative and gluconeogenic substrates as well as in cell signaling, as proposed by the lactate shuttle concept (Brooks, 2018). Specifically, BLC is influenced by lactate transporters such as MCT1 and MCT4, which exist in the Type I and II muscle fibers, respectively. MCT1 is primarily responsible for lactate uptake and MCT4 for lactate release. The extent of elevation in BLC following high-intensity exercise has been shown to be correlated with the volume of MCT4 protein in Thoroughbred horses (Kitaoka et al., 2014). It is possible that the mechanisms proposed in the lactate shuttle concept, where release and uptake of lactate respectively occur due to MCT4 in glycolytic muscle fibers and due to MCT1 in oxidative muscle fibers, play an important role in motor performance. These mechanisms may have provided benefits on the performance of maximal sprint cycling following mild elevation of BLC through arm exercise, which are not primarily involved in the sprint cycling in our study. In contrast to peak power, mean power during maximal sprint cycling after any type of priming exercise did not differ from the Control condition. This finding is consistent with previous studies that demonstrated that elevated BLC and associated changes in gas exchange kinetics after priming exercise did not necessarily improve exercise performance (Bishop et al., 2001; Bogdanis et al., 1994; Gerbino et al., 1996; Grant et al., 2014; Klausen et al., 1972; Purge et al., 2017; Valiulin et al., 2021; 2022; Wilkerson et al., 2004).

We confirmed that in the Arm 70%, Arm 140%, and Leg 70% conditions, the heart rate was elevated to around or above the LT2 heart rate at post-priming. A heart rate increase above the LT2 level reflects facilitation of sympathetic activity. It has been shown that elevated BLC was associated with increased blood catecholamine concentration, particularly norepinephrine (Lehmann et al., 1981). Therefore, it is likely that priming exercise at moderate to high intensity (i.e., ≥LT2 level) facilitated sympathetic activity.

Our results showed that the extent of BLC elevation at post-priming exercise was greater in the Leg 70% compared to the Arm 70% condition, while the difference did not reach statistical significance. This result is consistent with a previous study that compared the BLC after arm or leg exercise with matched workload (30%, 50%, and 80% $\dot{V}O_{2max}$) (Ahlborg and Jensen-Urstad, 1991). They found that the BLC level was significantly higher after the arm exercise than after the leg exercise when the workload was low (30 and 50% $\dot{V}O_{2max}$). However, it was slightly elevated after the leg exercise when the workload was moderate to high (80% $\dot{V}O_{2max}$). This may be explained by the fact that arterial adrenaline level was greater during leg exercise than during arm exercise both at 70% $\dot{V}O_{2max}$ (Savard et al., 1989).

Elevated muscle temperature

In our study, vastus lateralis temperature was significantly elevated in the Leg 70% at all time points after the priming exercise. The change of vastus lateralis temperature after the priming exercise did not differ between Arm 20%, 70%, and 140% priming (≈1°C increase). These results indicate that energy expenditure or exercise time of arm priming alone may not have a large influence on muscle temperature of the remote body area. However, vastus lateralis temperature was significantly elevated after the priming exercise with leg 70%. Therefore, it is the leg priming exercise that benefits most from the performance gain associated with elevated muscle temperature after priming exercise, while arm priming exercise may bring about little change of vastus lateralis temperature. Elevated muscle temperature in the Leg 70% condition is likely due to enhanced local metabolic heat production in the vastus lateralis, which was one of the primary muscles for the leg ergometer exercise. Increased muscle temperature provides multiple benefits, such as reduced muscle elastic resistance, increased oxygen supply to skeletal muscles, enhanced glycogenolysis, increased nerve conduction velocity (Bishop, 2003b), and increased recruitment of type II muscle contribution due to facilitated ATP turnover (Gray et al., 2006). These additional benefits related to elevated muscle temperature may explain the improved performance after the Leg 70% condition in our study.

Downside of excessive workload in priming exercise

A substantial increase in BLC was observed after the Arm 140% condition, while power outputs (i.e., peak power and mean power) of sprint cycling were significantly smaller than after the Leg 70% condition. The excessive increase in lactate concentration may have negatively affected the power output during sprint cycling. There are two possible mechanisms that may be involved in the negative impact of Arm 140% priming on the power outputs of sprint cycling. First, it has been shown that total anaerobic energy contribution is suppressed when baseline BLC level is substantially elevated by high-intensity priming exercise (Valiulin et al., 2021; Valiulin et al., 2022). Since the anaerobic energy contribution is large during high-intensity exercise, the reduced anaerobic contribution due to elevated BLC may have limited the performance of sprint cycling in our study (Hargreaves and Spriet, 2020). Second, perceived leg fatigue after the priming exercise in the Arm 140% condition was similar to the Leg 70% condition, which in turn were significantly greater than the Control and Arm 20% conditions. The observed leg fatigue after the intensive arm priming exercise may be due to central fatigue. One study reported that arm power output was substantially decreased after leg fatigue was induced (Sidhu et al., 2014). However, the same study showed that arm power output was not affected by leg fatigue when sensory input from the leg was inhibited by intrathecal fentanyl injection. These experimental findings suggest that central fatigue following the intense arm priming exercise was one of the primary sources of leg fatigue observed in our study. Unlike the Arm 140% condition, perceived leg fatigue at pre-exercise in the Arm 70% condition was significantly smaller than after the Leg 70% condition, suggesting that the exercise intensity at around LT2 had only limited influence on the perception of fatigue in remote unexercised body areas. Therefore, the Arm 70% condition may elevate BLC without inducing leg fatigue.

Interval duration after priming exercise

We set the interval duration being 5 min since a previous study reported that the blood lactate level was most elevated at around 5 min after the high-intensity exercise (Gupta et al., 2021). The 5 min rest period was relatively short compared to the previous studies about priming exercise (Purge et al., 2017; Valiulin et al., 2021). The perceived fatigue (RPE) of breath and leg at pre-exercise (i.e., just before the main exercise after the recovery from priming) in the Leg 70% and Arm 140% were similar (RPE >11.0), showing that participants had mild fatigue before the main exercise. Our results showed that despite the perceived fatigue, the performance of the main exercise was the highest in the priming Leg 70% condition, suggesting that the benefit of the priming exercise with the Leg 70% exceeded the effect of perceived fatigue prior to the exercise. It is likely that the performance of the main exercise after 5 min rest in our study was lower than the performance after a longer or self-selected rest duration (Purge et al., 2017; Valiulin et al., 2021). Further study is needed to explore the optimal rest duration to maximize the benefit of priming exercise.

Study limitation

The present study has several limitations. First, the generalizability of our findings is limited since we only included competitive male speed skaters. Further study in female and novice participants is needed. Second, we did not collect gas exchange kinetics using the expiration gas analyzer during the experiment due to limited access to the device during the Covid-19 pandemic. This limited our discussion about the respiratory mechanisms of our findings. Future studies should clarify gas exchange kinetics such as $\dot{V}O_2$ uptake and its velocity during the priming and main exercises. Third, we did not have hemodynamic measurements in the study; it is known that blood flow regulation is different between arm and leg during exercise (Calbet et al., 2007; Secher and Volianitis, 2006). Future studies including regional blood flow measurement are needed to clarify changes associated with different exercise intensities and body parts involved in the priming exercise. Fourth, our study was conducted during the training period of active speed skaters. The results of the incremental exercise test showed that the exercise time at leg $\dot{V}O_{2max}$ was greater than that at arm $\dot{V}O_{2max}$. This is partly because speed skaters extensively train their lower limbs by cycling and weight training, while less focus is given to training their upper extremities. However, we believe that the different exercise duration between the arm and leg incremental tests had little influence on our study results since in our study, it was important to identify accurate lactate thresholds and workload at $\dot{V}O_{2max}$ for arm and leg exercises using incremental exercise tests. Specifically, it was not possible for the participants to undergo an arm exercise protocol with a longer duration since they perceived a high level of arm and hand fatigue from the low exercise intensity. Longer arm exercise duration may have resulted in a lower workload at $\dot{V}O_{2max}$ due to arm and hand fatigue. Furthermore, a previous study has shown that the anaerobic threshold was not affected by the duration of incremental exercise test, suggesting that shorter exercise duration had little influence on the accuracy of lactate thresholds identified in our study (Buchfuhrer et al., 1983). Therefore, we believe that the short exercise duration of arm exercise resulted in a more valid identification of workload at $\dot{V}O_{2max}$ than the protocol with a longer exercise duration. Indeed, the influence of incremental exercise test duration on the $\dot{V}O_{2max}$ needs to be clarified in a future study. Furthermore, the bias related to the type of training performed before the experiment may have influenced our data, even if we tried our best to control the bias by randomizing the order of experimental conditions. Fifth, the leg priming condition in our study was limited to 70% $\dot{V}O_{2max}$ only since the main focus of our study was to compare the effects of the workload of the priming using different body areas on sprint cycling performance. Future study needs to compare the effects of body parts involved in the priming exercise on the subsequent motor performance, by having matched workload between body parts (e.g., arm vs. leg priming). Lastly, our study used a short recovery duration of 5 min between priming exercise and main exercise. Studies have shown that the effects of priming exercise can be different depending on the recovery duration before the main exercise (Bailey et al., 2009; Ferguson et al., 2007; Vanhatalo and Jones, 2009; Wilkerson et al., 2004). Future studies need to address the effects of different recovery duration on performance.

Conclusion

In conclusion, performance of maximal sprint cycling after priming exercise using the arm ergometer at 70% $\dot{V}O_{2max}$ was similar to the performance after priming exercise using the leg ergometer at 70% $\dot{V}O_{2max}$, while arm ergometer priming exercise at 20% and 140% $\dot{V}O_{2max}$ did not change the performance. A mild elevation in BLC by priming exercise at around LT2 may improve the performance of high-intensity exercise.

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We thank all participants who volunteered for our study. The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The datasets generated and analyzed during the current study are not publicly available, but are available from the corresponding author who was an organizer of the study.

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Key points

- Maximal sprint cycling performance was comparable between the Arm 70% condition and the Leg 70% condition
- A mild elevation in BLC by arm priming exercise may improve the performance of high-intensity exercise
- Low (i.e., Arm 20%) and high (i.e., Arm 140%) workloads did not provide any performance benefits

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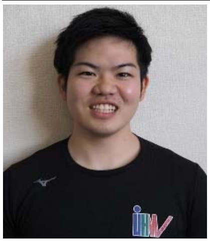

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