



**High-intensity cycling re-warm up within a very short time-frame increases the subsequent intermittent sprint performance**

Journal:	<i>European Journal of Sports Science</i>
Manuscript ID	TEJS-2019-0870.R2
Manuscript Type:	Original Paper
Keywords:	Performance, Recovery, Team Sport, Metabolism

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**1 High-intensity cycling re-warm up within a very short time-frame increases the**  
**2 subsequent intermittent sprint performance**

3 This study investigated the effect of high-intensity cycling re-warm up  
4 (RW) within a very short time-frame on the subsequent intermittent sprint  
5 performance. Twelve active males completed three trials in random order:  
6 control (CON); 3-min RW at 30% of maximal oxygen uptake ( $VO_{2max}$ )  
7 (RW30); and 1-min RW at 90% of  $VO_{2max}$  (RW90). During the  
8 experimental trials, participants performed 40 min of intermittent cycling  
9 exercise followed by 15 min of rest. During the rest period, participants  
10 completed CON, RW30, or RW90. After the rest period, participants  
11 performed the Cycling Intermittent-Sprint Protocol (CISP), which  
12 consisted of 10 seconds of rest, 5 seconds of maximal sprint, and 105  
13 seconds of active recovery with the cycles repeated over 10 min. The  
14 mean work during sprint for the CISP was significantly higher in both RW  
15 trials than in the CON trial (mean  $\pm$  standard deviation; CON:  $3539 \pm 698$   
16 J; RW30:  $3724 \pm 720$  J; RW90:  $3739 \pm 736$  J;  $p < 0.05$ ). The mean  
17 electromyogram amplitude during the sprint for the CISP was higher in the  
18 RW30 trial than in the CON trial; however, there was no significant  
19 difference between the two trials ( $p = 0.06$ ). The mean median frequency  
20 during sprint for the CISP was significantly higher in the RW90 trial than  
21 in the CON and RW30 trials ( $p < 0.05$ ). Rectal temperature did not differ  
22 between trials. Oxygenated haemoglobin during the initial 30 s of the  
23 CISP was significantly higher in the RW90 trial than in the CON trial ( $p <$   
24  $0.05$ ). Compared with seated rest, RW, irrespective of whether it  
25 comprised 1 min at 90% of  $VO_{2max}$  or 3 min at 30% of  $VO_{2max}$ , increased  
26 the subsequent intermittent sprint performance.

27 Keywords: intermittent team sport; cycling sprint; muscle activation; body  
28 temperature; gas analysis; muscle oxygenation

**29 Introduction**

30 The ability to perform high-intensity exercise is important for intermittent sports players.

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3 31 However, this ability decreases after half-time during intermittent team sports, including  
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5 32 football and rugby (Bradley et al., 2009; Lovell, Barrett, Portas, & Weston, 2013). The  
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7 33 distance covered while running at high-speed during a football match was reduced by  
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9 34 8.4% during the initial part of the second half compared with the initial part of the first  
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11 35 half (Weston et al., 2011). Furthermore, the sprint performance was reduced by 2.4% at  
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13 36 the onset of the second half compared with at the onset of the first half (Mohr, Krustup,  
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15 37 Nybo, Nielsen, & Bangsbo, 2004). These reductions resulted from the passive recovery  
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17 38 during half-time and have been associated with physiological changes, including loss of  
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19 39 muscle ( $T_m$ ) and core temperatures ( $T_c$ ), decrement of muscle activation and reduction  
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21 40 of oxygen availability in the muscle (Russell, West, Harper, Cook, & Kilduff, 2015;  
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23 41 Silva, Neiva, Marques, Izquierdo, & Marinho, 2018; Yanaoka, Hamada, et al., 2018).

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29 42 The efficacy of a re-warm up (RW) at half-time has been recently reviewed  
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31 43 (Hammami, Zois, Slimani, Russel, & Bouhlel, 2018; Russell et al., 2015; Silva et al.,  
32  
33 44 2018). RW is important to avoid a decrease in the ability to perform sprinting, jumping  
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35 45 and endurance exercise because it helps to maintain or increase  $T_m$ ,  $T_c$ , muscle  
36  
37 46 activation and oxygen availability in muscle (Russell et al., 2015; Silva et al., 2018;  
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39 47 Yanaoka, Hamada, et al., 2018; Yanaoka, Kashiwabara, et al., 2018). Although recent  
40  
41 48 reviews have recommended RW at moderate-intensity for 5 to 7 min to avoid reductions  
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43 49 in exercise performance immediately after a rest period (Hammami et al., 2018; Russell  
44  
45 50 et al., 2015; Silva et al., 2018), the RW protocol may not be suitable for competitions  
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47 51 because of time limits that restrict the implementation of RW in real-world settings  
48  
49 52 (Towson, Midgley, & Lovell, 2013). However, no studies have addressed an effective  
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51 53 RW protocol that can be performed within a very short time-frame. This issue is  
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53 54 important to address since fitness coaches and sports scientists are challenged to provide  
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55 55 evidence-based recommendations for an RW protocol that could increase the

subsequent high-intensity exercise performance during intermittent team sports.

Increases in exercise performance after a warm-up depend on the net balance between fatigue and potentiation (Bishop, 2003; Seitz & Haff, 2016). A high-intensity warm-up has greater influences on body temperature, muscle activation, anaerobic metabolism, aerobic metabolism and acute fatigue compared with a low-intensity warm-up (Bishop, 2003; McGowan, Pyne, Thompson, & Rattray, 2015). Particularly, a high-intensity warm-up may impair subsequent sprint performance due to acute fatigue compared with a low-intensity warm-up when the matched for warm-up durations (McGowan et al., 2015). For example, maximal sprint performance decreases after a cycling warm-up at 110% of peak aerobic power compared with those at 40% and 80% of peak aerobic power (Wittekind, Cooper, Elwell, Leung, & Beneke, 2012). In contrast, a high-intensity warm-up may have a similar potentiation effect on exercise performance compared a low-intensity warm-up when matched for total volume during warm-up. A previous study has compared the effects of low-intensity, long-duration warm-ups and high-intensity, short-duration warm-ups on exercise performance when matched for total warm-up volume and suggested that similar positive effects on exercise performance were observed for these protocols (Shima, Maeda, & Nishizono, 2006). However, it is not known whether RW has similar, if any, benefits in increasing the subsequent exercise performance.

Therefore, the purposes of the present study were 1) to investigate the effect of high-intensity RW within a very short time-frame on the subsequent intermittent cycling sprint performance and 2) to compare the effects of high-intensity RW within a very short time-frame and an established lower-intensity RW with a longer duration (Yanaoka, Hamada, et al., 2018) on intermittent cycling sprint performance. Based on a

previous study, the present study defined an intermittent sprint as a short-duration sprint interspersed with recovery periods long enough to allow nearly complete recovery of sprint performance (Girard, Mendez-Villanueva, & Bishop, 2011). We hypothesized that high-intensity RW within a very short time-frame and lower-intensity RW with a longer duration would have similar beneficial effects on the intermittent cycling sprint performance. In the present study, a 3-min RW at 30% of maximal oxygen uptake ( $\text{VO}_{2\text{max}}$ ) was chosen since it has been established as the lowest-volume RW that increased intermittent sprint performance (Yanaoka, Hamada, et al., 2018)

## METHODS

### Materials and Methods

#### *Participants*

Twelve active males who habitually exercised for more than 2 days per week participated in this study. Participants were included in the study if they had no recent history of illness, injury, or rehabilitation during the testing schedule. The physical characteristics of the participants were as follows: age,  $23 \pm 2$  years; height,  $1.71 \pm 0.05$  m; body mass,  $68.5 \pm 8.7$  kg; and  $\text{VO}_{2\text{max}}$ ,  $47.7 \pm 6.6$  mL/kg/min (mean  $\pm$  standard deviation [SD]). This study was approved by the Ethics Review Committee on Research with Human Subjects of Waseda University (approval number: 2017-286), and all participants provided written informed consent before participating in this study.

Participants were asked to not alter their regular lifestyle habits, exercise and diet throughout the study. They recorded all the food and drinks consumed for 24 h prior to each experimental trial, and they replicated their dietary intake during subsequent trials to ensure that they were standardised across trials. Participants

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103 refrained from consuming alcohol and caffeine for 24 h prior to each experimental trial.  
104 Furthermore, they fasted for 3 h before each experimental trial and were only allowed to  
105 consume water during that time period.

106 ***Experimental Design***

107 Participants completed three trials in randomised, counterbalanced order after one  
108 practice trial to familiarise themselves with the experiment at least 3 days before the  
109 first experimental trial. All trials were separated by 3 to 13 days. During the  
110 experimental trials, two consecutive intermittent cycling exercises separated by a 15-  
111 min rest period were performed on a cycle ergometer (Monark 894E, Monark, Varberg,  
112 Sweden). Interventions during the 15-min rest period were as follows: seated rest  
113 (control: CON); 3-min RW at 30% of  $VO_{2max}$  (RW30); and 1-min RW at 90% of  
114  $VO_{2max}$  (RW90). The RW30 was previously reported as the lowest work during RW  
115 (Yanaoka, Hamada, et al., 2018). The mean temperature and humidity during the  
116 experimental trials were  $20.6 \pm 0.5^{\circ}C$  and  $50.8 \pm 1.4\%$  (mean  $\pm$  SD), respectively. All  
117 three experimental trials were performed at the same time of day to avoid any circadian  
118 rhythm-related variations in the obtained results.

119 ***Graded Exercise Test***

120 Participants initially underwent a graded exercise test to determine their  $VO_{2max}$  and  
121 maximum heart rate ( $HR_{max}$ ) on a cycle ergometer (Monark 894E, Monark, Varberg,  
122 Sweden). The test started at 40 W, with a target cadence of 80 rpm, and increased by 40  
123 W every 2 min until volitional exhaustion. A breath-by-breath gas analysis was  
124 performed using an automatic gas analyser (Quark CPET, COSMED, Rome, Italy).  
125 Linear regression for  $VO_2$  against exercise intensity was calculated and used to predict

the relative exercise intensity during the experimental trials (i.e., 60% and 130% of  $\text{VO}_{2\text{max}}$ ).

### ***Exercise Protocol***

The exercise protocol used in the present study was the same as that of a previous study (Yanaoka, Hamada, et al., 2018). In the experimental trials, participants performed 40 min of intermittent cycling exercise followed by 15 min of rest and 10 min of the Cycling Intermittent-Sprint Protocol (CISP) on a cycle ergometer (Monark 894E, Monark, Varberg, Sweden) (Figure 1). First, participants rested on a chair for 5 min, followed by a standardised warm-up (i.e., 5 min of cycling at 95 W and 30 s of cycling at 120 W). Then, they performed 40 min of intermittent cycling exercise that consisted of 20 repetitions that lasted 2 min each. Each 2-min period started with 15 s of passive rest, followed by 25 s of unloaded cycling, 10 s of cycling at 130% of  $\text{VO}_{2\text{max}}$  and 70 s of cycling at 60% of  $\text{VO}_{2\text{max}}$ . After the 15-min rest period, they performed the CISP, which consisted of 5 repetitions that lasted 2 min each. Each 2-min period started with 10 s of passive rest, followed by 5 s of maximal sprint against a resistance of 7.5% of body mass and 105 s of cycling at 50% of  $\text{VO}_{2\text{max}}$ . Each sprint was initiated from a stationary start, with the right pedal crank at approximately 90° to the horizontal plane. Pedal cadence throughout the trial was 80 rpm, except during the 5-s maximal sprint. The CISP that was described previously was used to assess the intermittent sprint performance of athletes (Hayes et al., 2013).

FIGURE 1 ABOUT HERE

### ***RW Intervention***

During the 15-min rest period, participants rested on the cycle ergometer for 15 min

(CON), rested on the cycle ergometer for 11 min followed by cycling at 30% of  $VO_{2max}$  for 3 min (RW30), or rested on the cycle ergometer for 13 min followed by cycling at 90% of  $VO_{2max}$  for 1 min (RW90). The intensity of the RW90 was chosen to equalise the exercise volume (i.e., energy expenditure), which is estimated using oxygen uptake values and exercise duration according to the formula of the American College of Sports Medicine (American College of Sports Medicine, 2010) during RW, with the RW30. Each RW trial was completed 1 min prior to the commencement of the CISP.

**Measurements**

*Sprint performance*

Power during 5 s of sprinting of the CISP was calculated using a Monark Anaerobic Test software (Monark, Varberg, Sweden), which accounted for both the load on the flywheel and crank kinematics. Work was defined as the mean power multiplied by the duration of the sprint (i.e., 5 s). High reliability of the work during sprints for the CISP has been previously reported (i.e., intra-class correlation = 0.9) (Hayes et al., 2013).

*Surface electromyogram*

An electromyogram (EMG) of the muscle bellies of the right vastus lateralis was recorded during the 5-s sprint using a surface electrode (SX230-1000, Biometrics, Newport, United Kingdom), with the ground electrode placed on the left wrist (sampling frequency: 1000 Hz, band pass filter: 10–500 Hz). Electrode placement was defined by 30% of the length between the patella and greater trochanter (Takagi et al., 2014). To reduce impedance ( $< 2\text{ k}\Omega$ ), the skin was abraded and washed before electrode placement. The root mean square (RMS) and median frequency (MDF) as the mean values between the onset and the end of the burst were calculated for each sprint.



The RMS values were normalised to the 100% maximum voluntary isometric contraction (MVC) value obtained from 3-s MVC against manual resistance before each experimental trial. The 100% MVC value was obtained from a 1-s window during the 3-s MVC. Onset of the burst was defined by using an electric threshold of  $\pm 0.2$  mV (Racinais et al., 2007).

#### *Body temperature*

Rectal temperature ( $T_r$ ) was measured using a thermistor (401J, Nikkiso-therm, Tokyo, Japan) from a depth of 10 cm past the anal sphincter at 1-min intervals. Skin temperature ( $T_s$ ) was measured using a button-type data logger (Thermochron SL, KN Laboratories, Osaka, Japan) at 1-min intervals, and the logger was attached to four sites (i.e., chest, forearm, thigh and calf). The mean  $T_s$  was calculated as follows:  $T_s = 0.3 \times (\text{chest} + \text{forearm}) + 0.2 \times (\text{thigh} + \text{calf})$  (Ramanathan, 1964). The  $T_m$  at the thigh was estimated from the  $T_s$  using the following equation:  $T_m = 1.02 \times T_s \text{ at the thigh} + 0.89$  (de Ruiter, Jones, Sargeant, & de Haan, 1999).

#### *Gas analysis*

A breath-by-breath gas analysis was continuously performed using an automatic gas analyser (Quark CPET, COSMED, Rome, Italy) during the experimental trial. The analysers were calibrated before each graded exercise test with gases of known concentrations ( $O_2$ : 16%,  $CO_2$ : 5%), and the tube flowmeter was calibrated using a 3-L syringe. The mean  $VO_2$ , carbon dioxide production ( $VCO_2$ ) and respiratory exchange ratio (RER) were calculated.

### 193 *Muscle oxygenation measurements*

194 Two-wavelength (770 and 830 nm) light-emitting diode near-infrared spatial-resolved  
195 spectroscopy (NIR<sub>SRS</sub>: Hb14, ASTEM, Kanagawa, Japan) was used to measure muscle  
196 oxygenation of the right vastus lateralis, which was defined as 30% of the length  
197 between the patella and the greater trochanter above the patella at 5 Hz (Yanaoka,  
198 Hamada, et al., 2018). The NIR<sub>SRS</sub> probe consisted of one light source and two  
199 photodiode detectors, and the optode distances were 20 and 30 mm. The NIR<sub>SRS</sub>  
200 technique provided continuous, non-invasive monitoring of changes in oxygenated  
201 ( $\Delta$ oxy-Hb), deoxygenated ( $\Delta$ deoxy-Hb) and total haemoglobin ( $\Delta$ total-Hb)  
202 concentrations from rest before a standardised warm-up, and muscle oxygen saturation  
203 ( $SmO_2$ ). The  $\Delta$ total-Hb and  $SmO_2$  were calculated with the following equations:  $\Delta$ total-  
204 Hb =  $\Delta$ oxy-Hb +  $\Delta$ deoxy-Hb;  $SmO_2$  = oxy-Hb / total-Hb. The NIR<sub>SRS</sub> variables were  
205 affected by the thickness of the fat layer (Niwayama, Lin, Shao, Kudo, & Yamamoto,  
206 2000). However, the NIR<sub>SRS</sub> data can be corrected by using the fat layer thickness  
207 (Niwayama, Suzuki, Yamashita, & Yasuda, 2012). Therefore, the fat layer thickness at  
208 the measurement site was assessed using an ultrasound device (LogiQ3, GE Healthcare,  
209 Tokyo, Japan) before each trial, and the NIR<sub>SRS</sub> variables were calculated using fat-  
210 correction software (Hb14, ASTEM, Kanagawa, Japan). The within-subject coefficient  
211 of variation for the fat layer thickness was  $3.6 \pm 1.5\%$ .

### 212 *HR and the Rating of Perceived Exertion*

213 HR was measured using a wireless HR monitor at 5-s intervals during the experimental  
214 trials (Polar RCX3, Polar Electro, Kempele, Finland). The rating of perceived exertion  
215 (RPE) was assessed before and after 40 min of cycling intermittent exercise, after the  
216 rest period and after the CISP (i.e., at 0, 40, 55 and 65 min) (Borg, 1982).

## 217 ***Statistical Analyses***

218 The sample size was estimated using G\*Power 3 (Faul, Erdfelder, Lang, & Buchner,  
219 2007), using the data from a previous study that investigated the warm-up effects on  
220 exercise performance when the total work during a warm-up was matched (Shima et al.,  
221 2006). To detect improvements in exercise performance with a power of 80% and an  
222 alpha level of 5%, a sample size of  $\geq 7$  participants was required. Statistics were  
223 computed using SPSS computer software (version 25.0, SPSS Japan Inc., Tokyo,  
224 Japan). All values are shown as mean  $\pm$  SD. The Shapiro–Wilk test was used to check  
225 for normality of distribution. All measurements were found to be normally distributed.  
226 A repeated-measures two-factor analysis of variance was used to examine differences  
227 among the three trials for all measurements. Mauchly’s test was consulted and  
228 Greenhouse–Geisser correction was applied if sphericity was violated. When significant  
229 interactions and trial effects were detected, post-hoc multiple comparisons were made  
230 using the Bonferroni method. Statistical significance was set at  $p < 0.05$ . Unfortunately,  
231 some data were missing;  $T_r$  data are presented for 11 participants,  $T_s$  and estimated  $T_m$   
232 data are presented for 10 participants and  $NIR_{SRS}$  data are presented for 9 participants.

## 233 **Results**

### 234 ***Sprint Performance***

235 The mean work during sprint for the CISP was significantly higher in both RW trials  
236 than in the CON trial (RW30:  $p = 0.038$ , RW90:  $p = 0.021$ , Figure 2a).

237 FIGURE 2 ABOUT HERE

### 238 ***Neuromuscular Activity***

239 The mean RMS during sprint for the CISP was higher in the RW30 trial than in the

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2  
3 240 CON trial; however, there was no significant difference between the two trials ( $p =$   
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5 241 0.056) (Figure 2b). The mean MDF during sprint for the CISP was significantly higher  
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7 242 in the RW90 trial than in the CON and RW30 trials (CON:  $p = 0.014$ , RW30:  $p =$   
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9 243 0.040) (Figure 2c).

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14 244 ***Body Temperature***

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16 245  $T_r$  did not differ among the three trials (Table 1). Mean  $T_s$  and estimated  $T_m$  at 65 min  
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18 246 was significantly higher in both RW trials than in the CON trial ( $T_s$ : RW30;  $p = 0.042$ ,  
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20 247 RW90;  $p = 0.037$ ,  $T_m$ : RW30;  $p = 0.003$ , RW90;  $p = 0.013$ ) (Table 1).

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24 248 TABLE 1 ABOUT HERE

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28 249 ***Gas Analysis and Muscle Oxygenation***

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31 250 Mean  $VO_2$ ,  $VCO_2$  and RER during the first 40-min intermittent exercise did not differ  
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33 251 among the three trials. The mean values of  $VO_2$ ,  $VCO_2$  and RER during the CISP are  
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35 252 provided in Figure 3. The mean  $VO_2$  during the initial 30 s of the CISP was  
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37 253 significantly higher in both RW trials than in the CON trial (RW30:  $p = 0.001$ , RW90:  $p$   
38  
39 254  $< 0.001$ ), and it was significantly higher in the RW90 trial than in the RW30 trial ( $p =$   
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41 255 0.005) (Figure 3a). The mean  $VCO_2$  for the CISP was significantly higher in the RW30  
42  
43 256 trial than in the CON trial ( $p = 0.02$ ) (Figure 3b). The mean RER for the CISP was  
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45 257 significantly higher in both RW trials than in the CON trial (RW30:  $p = 0.021$ , RW90:  $p$   
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47 258  $= 0.016$ ) (Figure 3c).

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52 259 All  $NIR_{SRS}$  variables during the first 40-min intermittent exercise did not differ  
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54 260 among the three trials. The mean values of all  $NIR_{SRS}$  variables during the CISP are  
55  
56 261 provided in Figure 4. The mean  $\Delta oxy-Hb$  during the initial 30 s of the CISP was  
57  
58 262 significantly higher in the RW90 trial than in the CON trial ( $p = 0.012$ ) (Figure 4a). The

mean  $\Delta$ deoxy-Hb in the initial 30 s of the CISP was higher in the RW30 trial than in the CON trial; however, there was no significant difference between the two trials ( $p = 0.061$ ) (Figure 4b). The mean  $\Delta$ total-Hb during the initial 30 s of the CISP was higher in both RW trials than in the CON trial; however, there were no significant differences between the trials (RW30:  $p = 0.099$ , RW90:  $p = 0.083$ ) (Figure 4c). The mean  $SmO_2$  during the CISP did not differ among the three trials.

FIGURES 3 and 4 ABOUT HERE

### ***HR and RPE***

There was a main effect of trial ( $p < 0.001$ ) and trial  $\times$  time interaction ( $p < 0.001$ ) for the HR. The HR before the commencement of the CISP was significantly higher in both RW trials than in the CON trial (CON:  $46 \pm 5\%$   $HR_{max}$ , RW30:  $49 \pm 5\%$   $HR_{max}$ ,  $p = 0.038$ , RW90:  $68 \pm 4\%$   $HR_{max}$ ,  $p < 0.001$ ), and significantly higher in the RW90 trial than in the RW30 trial ( $p < 0.001$ ). The HR during the CISP was significantly higher in the RW90 trial than in the other trials (CON:  $70 \pm 5\%$   $HR_{max}$ ,  $p = 0.015$ , RW30:  $71 \pm 4\%$   $HR_{max}$ ,  $p = 0.008$ , RW90:  $74 \pm 6\%$   $HR_{max}$ ).

There was a main effect of trial ( $p = 0.001$ ) and trial  $\times$  time interaction ( $p = 0.007$ ) for the RPE. The RPE at 55 min was significantly higher in the RW90 trial than in the other trials (CON:  $9.5 \pm 2.4$  arbitrary units [A.U.],  $p = 0.008$ , RW30:  $10.4 \pm 2.0$  A.U.,  $p = 0.023$ , RW90:  $11.8 \pm 2.1$  A.U.).

### **Discussion**

To our knowledge, the present study is the first to investigate the effect of 1-min high-intensity cycling RW on the subsequent intermittent sprint performance. The main findings of the present study were that 1) the RW90 trial showed that the subsequent

cycling intermittent sprint performance was increased by 5.7% compared with the CON trial and 2) the RW90 trial was as effective as the RW30 trial for increasing the cycling sprint performance. Moreover, the rates of increase of the cycling intermittent sprint performances were similar compared with those of RW protocols reported previously (i.e., 7-min RW at 70% of  $HR_{max}$ : 4.1% [Yanaoka, Kashiwabara, et al., 2018] and 3-min RW at 60% of  $VO_{2max}$ : 7.1% [Yanaoka, Hamada, et al., 2018]). Many fitness coaches believed that the major limitation of the implementation of RW is lack of time (Towilson et al., 2013). Therefore, the present findings may be of value for players and coaches who are generally busy with other ergogenic strategies during half-time.

Exercise performance improvements after a warm-up are generally attributed to increased body temperature, resulting in increases in adenosine triphosphate turnover and cross-bridge cycling rate, as well as improvements in muscle fibre functionality and muscle fibre conduction velocity (MFCV) (McGowan et al., 2015). Furthermore, sprint performance after RW for 7 min was increased because of maintained or increased  $T_r$  and  $T_m$  (Hammami et al., 2018; Russell et al., 2015; Silva et al., 2018). For example, Mohr et al. reported that a moderate-intensity RW for 7 min maintained  $T_m$  during half-time of actual soccer matches, and there was a correlation ( $r = 0.6$ ) between the change in  $T_m$  and sprint performance (Mohr et al., 2004). In the present study, both RW trials showed increased estimated  $T_m$  at 65 min. This increase in the estimated  $T_m$  during the CISP may contribute to the increased intermittent sprint performance because of the physiological changes that occur with increasing body temperature. However, since the  $T_m$  in the present study was estimated from the  $T_s$ , the  $T_m$  may be underestimated.  $T_s$  at the thigh might have decreased after commencement of a cycling exercise due to reflex vasoconstriction, and it is followed by an increase (Nakayama, Ohnuki, & Niwa, 1977). However, we have no direct  $T_m$  data. Therefore,  $T_m$ , which is measured directly,

311 requires further study.

312       Enhanced muscle activation is one of the factors for an acute increase in exercise  
313 performance after a warm-up or RW (McGowan et al., 2015; Yanaoka, Hamada, et al.,  
314 2018). For example, a previous study that used the same exercise protocol as the one  
315 described in the present study indicated that the 3-min low-intensity RW increased the  
316 subsequent intermittent cycling sprint performance and RMS during sprints (Yanaoka,  
317 Hamada, et al., 2018). It has been suggested that enhanced muscle activation, as  
318 evidenced by increased EMG activity during sprints, may be related to the acute  
319 increase in the intermittent cycling sprint performance after RW (Yanaoka, Hamada, et  
320 al., 2018) because a previous study reported that there is a linear relationship between  
321 RMS and power output during cycling (Hug & Dorel, 2009). Although there was no  
322 significant difference between the two trials for the mean RMS ( $p = 0.056$ ) (Figure 2b),  
323 the mean RMS during sprinting for the CISP was higher in the RW30 trial than in the  
324 CON trial. Moreover, the RW90 trial increased MDF during sprints for the CISP  
325 compared with the CON and RW30 trials. These findings suggested that the RW90 trial  
326 may increase the MFCV since a previous study reported that the MDF reflected the  
327 MFCV (Stewart, Macaluso, & De Vito, 2003). MFCV increases after active warm-up  
328 via increased core and muscle temperatures or a higher recruitment of type II muscle  
329 fibres (Kupa, Roy, Kandarian, & De Luca, 1995; Morimoto, Umazume, & Masuda,  
330 1980; Sadoyama, Masuda, Miyata, & Katsuta, 1988). In the present study, both RW  
331 trials did not influence the  $T_r$  or estimated  $T_m$  during the rest period. Therefore, it is a  
332 possible that the RW90 trial may increase the recruitment of type II muscle fibres.

333       A previous study reported that high-intensity voluntary contractions lead to  
334 enhancement in voluntary muscular performance in subsequent exercise, which is a



phenomenon called post-activation potentiation (PAP) (Blazevich & Babault, 2019). Increased intermittent cycling sprint performance after the RW90 (i.e., high-intensity RW) trial may be related to the PAP effect. The effect of high-intensity RW aimed at a PAP effect on sprint performance was investigated, and the results suggested that a five-repetition maximal leg press RW could improve subsequent sprint performance (Zois, Bishop, Fairweather, Ball, & Aughey, 2013). The potential mechanisms underlying the PAP effect are an increase in calcium ( $\text{Ca}^{2+}$ ) sensitivity of the acto-myosin complex caused by phosphorylation of the myosin regulatory light chain and an increase in higher-order motor neuron recruitment (Blazevich & Babault, 2019; Sale, 2002). A previous study suggested that the PAP effect is greater in type II muscle fibres than in type I muscle fibres since type II muscle fibres have lower basal  $\text{Ca}^{2+}$  sensitivity and type I muscle fibres already have higher  $\text{Ca}^{2+}$  sensitivity (Blazevich & Babault, 2019). Our speculation (i.e., increased recruitment of type II muscle fibres) may be consistent with these mechanisms of the PAP effect. However, further investigations of the high-intensity RW used in the present study and the PAP effect are needed since the intensity of the RW90 trial was lower than that in a previous study (i.e., 90% of  $\text{VO}_{2\text{max}}$  or a 5-repetition maximal leg press) (Zois et al., 2013).

Another potential mechanism contributing to the increased intermittent cycling sprint performance after both RW trials might be an enhancement of the primary  $\text{VO}_2$  response after commencement of the CISP. A previous study suggested that there is a close relationship between the ability to maintain intermittent sprint performance and faster  $\text{VO}_2$  kinetics (Dupont, McCall, Prieur, Millet, & Berthoin, 2010). A reasonable hypothesis (Edholm, Krstrup, & Randers, 2015) that RW may enhance the primary  $\text{VO}_2$  response to the subsequent exercise was suggested since soccer players started the second half with a higher HR, which is related to  $\text{VO}_2$  responses during varying non-



steady state exercises (Bot & Hollander, 2000), after RW. In the present study, higher  $\text{VO}_2$  and HR after both RWs were observed, suggesting that the present results supported a previously proposed hypothesis (Edholm et al., 2015), and that an enhanced primary  $\text{VO}_2$  response may contribute to increased intermittent sprint performance in both RW trials. Moreover, the RW90 trial increased  $\Delta\text{oxy-Hb}$  during the CISP, suggesting that oxygen availability in muscle increased after RW. Increased oxygen availability in muscle may accelerate the re-synthesis of phosphocreatine, which is directly related to the ability to perform high-intensity exercise after sprints (Girard et al., 2011; Spencer, Bishop, Dawson, & Goodman, 2005). Therefore, increased oxygen availability in muscle may contribute to the increased intermittent cycling sprint performance after the RW90.

The potential mechanism of oxygen availability in the muscle in the RW90 trial may increase the oxygen supply to the muscle. The  $\Delta\text{oxy-Hb}$  is an indicator of the balance between  $\text{O}_2$  supply and utilization (Takagi, 2016). No differences in the mean  $\Delta\text{deoxy-Hb}$ , which is an indicator of the balance between  $\text{O}_2$  unloading in the muscle and blood outflow from the muscle (Takagi, 2016), were observed among the three trials, thus suggesting the possibility of increased  $\text{O}_2$  supply but not decreased  $\text{O}_2$  utilization. Previous reviews have suggested that a warm-up increases the oxygen supply to the muscle via vasodilation of blood vessels and an increase in blood flow to the muscles during subsequent exercise (Bishop, 2003; Jones, Koppo, Burnley, & Carter, 2003). A previous study reported that relative changes in the oxy-Hb increased after a warm-up, and that this may occur due to the increased blood flow to the muscle (Takizawa & Ishii, 2006). Moreover, it has been suggested that a specific core RW may increase muscle blood flow, as evidenced by decreased mean  $T_{\text{sk}}$ , which was possibly a result of cutaneous reflex vasoconstriction with exercise (Tong, Baker, Zhang, Kong, &

Nie, 2019). The redistribution of blood flow from skin to active muscles to meet the augmented metabolic demand is a compensatory vasoregulation after the commencement of exercise (Nakayama et al., 1977). However, no studies have addressed the muscle and skin blood flow, measured directly following RW. Future research should be focused on muscle and skin blood flow.

The present study did not observe decreased mean  $T_s$  at 55 min after both RW trials compared with the CON trial, which is not consistent with a previous study (Tong, Baker, Zhang, Kong, & Nie, 2019). This may be due to differences in the measuring method of  $T_s$  between the present and previous studies (Tong, Baker, Zhang, Kong, & Nie, 2019). Although the mean  $T_s$  was calculated from 4 sites in the present study, it was calculated from 12 sites (i.e., head, upper arm, forearm, finger, chest, upper back, lower back, anterior thigh, posterior thigh, anterior calf and posterior calf) in the previous study (Tong, Baker, Zhang, Kong, & Nie, 2019). The decrease in  $T_s$  after the commencement of exercise is greater in the extremities than in the trunk (Nakayama et al., 1977). Indeed, the previous study showed that the  $T_s$  at the finger most decreased after RW (Tong, Baker, Zhang, Kong, & Nie, 2019). Thus, because of differences in the assignment of regional proportions to calculate  $T_s$  between the present and previous studies, decrements of  $T_s$  after both RW trials may not be observed in the present study.

Although both RW trials had similar positive influences on the subsequent intermittent sprint performance, the present study reported that RPE at 55 min was significantly higher in the RW90 trial than in the RW30 trial. According to Towlson et al., another situational factors perceived as a major barrier to the implementation of RW was interference with the psychological preparation of the players (Towlson et al., 2013). However, the RPE at 55 min in the RW90 trial was  $11.8 \pm 2.1$  (i.e., between “light” and “somewhat hard”), suggesting that a 1-min RW at 90% of  $VO_{2max}$  may not

410 be considered more difficult exercise for the active, younger individuals who  
411 participated in this study.

412 This study had some limitations. First, there was a difference between the  
413 exercise mode and intensity used in the present study and that of actual intermittent  
414 team sports. This study used two consecutive intermittent cycling exercises. However,  
415 most intermittent team sports involve running, jumping and multidirectional running.  
416 Moreover, it was not possible to conclude whether the present results could be obtained  
417 using actual intermittent team sports. However, a previous study has suggested that  
418 there was a moderate correlation between repeated sprint performance performed on a  
419 cycle ergometer and during running on the ground (i.e., total work vs total run time)  
420 (Fitzsimons, Dawson, Ward, & Wilkinson, 1993). Therefore, intermittent sprint  
421 performance following a RW may be increased during actual intermittent team sports.  
422 Second, the type of participants involved in the present study did not allow us to make  
423 comparisons with professional athletes. Therefore, it is not possible to conclude whether  
424 the present results can be applied to these activities or actual intermittent team sports  
425 played by professional athletes.

426 In conclusion, the 1-min cycling RW at 90% of  $VO_{2max}$  increased the subsequent  
427 intermittent cycling sprint performance over 10 min after the 15-min rest period  
428 compared with seated rest, and it was as effective as the 3-min cycling RW at 30% of  
429  $VO_{2max}$ . These evidence-based findings may contribute to the implementation of RW  
430 within a very short time-frame.

### 431 **Acknowledgements**

432 This study was supported by a Grant-in-Aid for JSPS Research Fellow (number:  
433 17J02878) (to TY) and internal funding from the Waseda University (to MM and NH).

## 434 Declaration of Interest Statement

435 The authors have no conflicts of interest to disclose.

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## Figure captions

Figure 1. Schematic representation of the study protocol.

CON: 15 min of seated rest trial, RW30: 3-min RW at 30% of  $VO_{2max}$  trial, RW90: 1-min RW at 90% of  $VO_{2max}$  trial, CISP: The Cycling Intermittent-Sprint Protocol.

Figure 2. The mean work (a), RMS (b) and MDF (c) during sprint for the CISP among three trials.

CON: 15 min of seated rest trial, RW30: 3-min RW at 30% of  $VO_{2max}$  trial, RW90: 1-min RW at 90% of  $VO_{2max}$  trial, RMS: root mean square, MDF: median frequency, CISP: The Cycling Intermittent-Sprint Protocol. (n = 12, mean  $\pm$  SD)  
Means were compared by using a repeated-measures two-factor analysis of variance.  
Mean work: trial p = 0.002, RMS: trial p = 0.024, MDF: trial p = 0.004.

Figure 3.  $VO_2$  (a),  $VCO_2$  (b) and RER (c) of the mean values during the CISP.

CON: 15 min of seated rest trial, RW30: 3-min RW at 30% of  $VO_{2max}$  trial, RW90: 1-min RW at 90% of  $VO_{2max}$  trial,  $VO_2$ : oxygen uptake,  $VCO_2$ : carbon dioxide production, RER: respiratory exchange ratio. (n = 12, mean  $\pm$  SD)  
Data are displayed as 30-s averages. Means were compared by using a repeated-measures two-factor analysis of variance.  $VO_2$ : trial p = 0.298; interaction p < 0.001,  $VCO_2$ : trial p = 0.016; interaction p < 0.001, RER: trial p = 0.002; interaction p < 0.001.

\* Significant difference between the CON and RW30 trials (p < 0.05)

# Significant difference between the CON and RW90 trials (p < 0.05)

† Significant difference between the RW90 and RW30 trials (p < 0.05)

Figure 4. Changes in oxy-Hb (a), deoxy-Hb (b) and total-Hb (c) from the rest period before the standardised warm-up and  $SmO_2$  (d) of the mean values during the CISP.

CON: 15 min of seated rest trial, RW30: 3-min RW at 30% of  $VO_{2max}$  trial, RW90: 1-min RW at 90% of  $VO_{2max}$  trial, (n = 9, mean  $\pm$  SD)

Data are displayed as 30-s averages. Means were compared by using a repeated-measures two-factor analysis of variance.  $\Delta$ oxy-Hb: trial p = 0.051; interaction p =

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613 0.004,  $\Delta$ deoxy-Hb: trial  $p = 0.859$ ; interaction  $p = 0.004$ ,  $\Delta$ total-Hb: trial  $p = 0.318$ ;  
614 interaction  $p = 0.001$ ,  $SmO_2$ : trial  $p = 0.651$ ; interaction  $p = 0.447$ .  
615 # Significant difference between the CON and RW90 trials ( $p < 0.05$ )  
616

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1 Table 1. Rectal ( $T_r$ ), mean skin ( $T_s$ ) and estimated muscle ( $T_m$ ) temperatures at each measurement point among three trials.

Variables	Trials	Time (min)				p values
		Pre (before first intermittent exercise)	40 (after first intermittent exercise)	55 (before the CISP)	65 (after the CISP)	
$T_r$ (°C)	CON	$37.2 \pm 0.2$	$38.0 \pm 0.2$	$37.8 \pm 0.3$	$37.8 \pm 0.3$	Trial: $p > 0.05$ Interaction: $p > 0.05$
	RW30	$37.2 \pm 0.3$	$37.9 \pm 0.3$	$37.7 \pm 0.3$	$37.9 \pm 0.2$	
	RW90	$37.2 \pm 0.2$	$38.0 \pm 0.2$	$37.8 \pm 0.2$	$38.0 \pm 0.2$	
Mean $T_s$ (°C)	CON	$33.0 \pm 0.9$	$35.3 \pm 0.7$	$33.1 \pm 1.0$	$33.3 \pm 1.2$	Trial: $p > 0.05$ Interaction: $p < 0.05$
	RW30	$33.1 \pm 0.6$	$35.4 \pm 0.6$	$33.5 \pm 0.9$	$34.2 \pm 1.0^*$	
	RW90	$33.1 \pm 0.7$	$35.4 \pm 0.7$	$33.4 \pm 1.0$	$34.2 \pm 1.2^*$	
Estimated $T_m$ (°C)	CON	$34.0 \pm 1.0$	$37.0 \pm 0.9$	$35.9 \pm 0.8$	$35.5 \pm 1.0$	Trial: $p > 0.05$ Interaction: $p < 0.05$
	RW30	$34.3 \pm 1.1$	$37.3 \pm 0.8$	$36.0 \pm 1.1$	$36.3 \pm 1.1^*$	
	RW90	$34.3 \pm 0.8$	$37.3 \pm 0.7$	$36.2 \pm 0.8$	$36.5 \pm 1.0^*$	

2 Means were compared by using a repeated-measures two-factor analysis of variance. CON: 15 min of seated rest trial, RW30: 3-min RW at 30%  
 3 of  $VO_{2max}$  trial, RW90: 1-min RW at 90% of  $VO_{2max}$  trial, CISP: The Cycling Intermittent-Sprint Protocol. ( $T_r$ :  $n = 11$ , mean  $T_s$  and estimated  $T_m$ :  
 4  $n = 10$ , mean  $\pm$  SD)

5 \* Significantly different from the CON trial ( $p < 0.05$ )

Figure 1

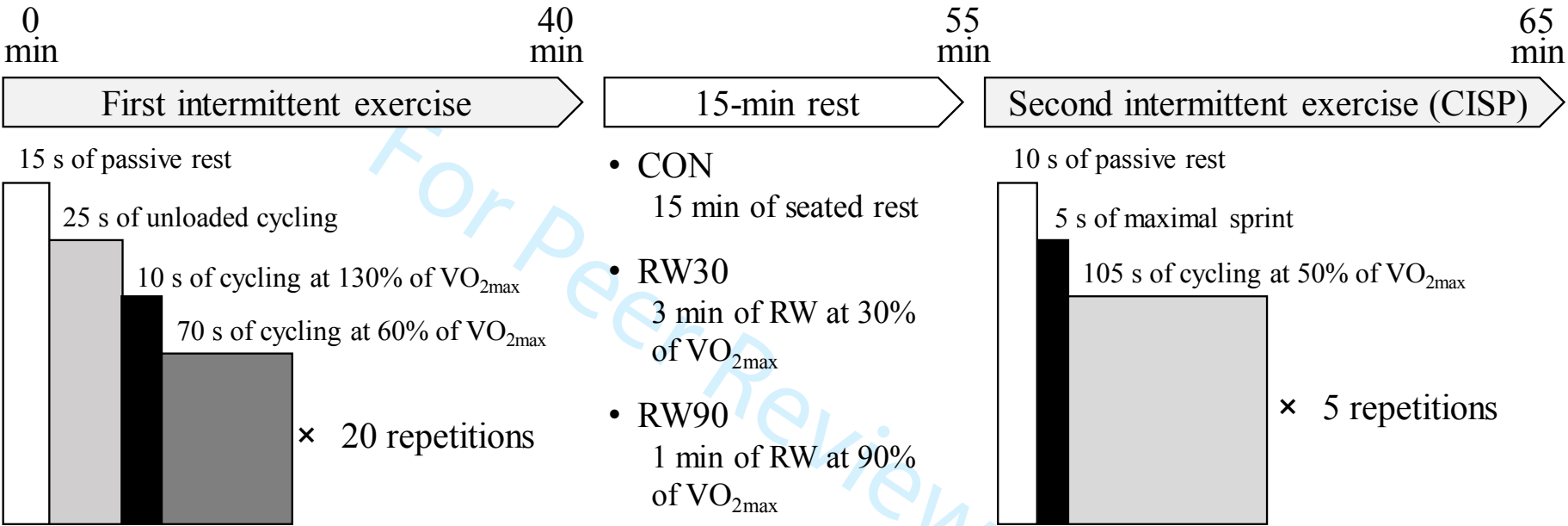


Figure 2

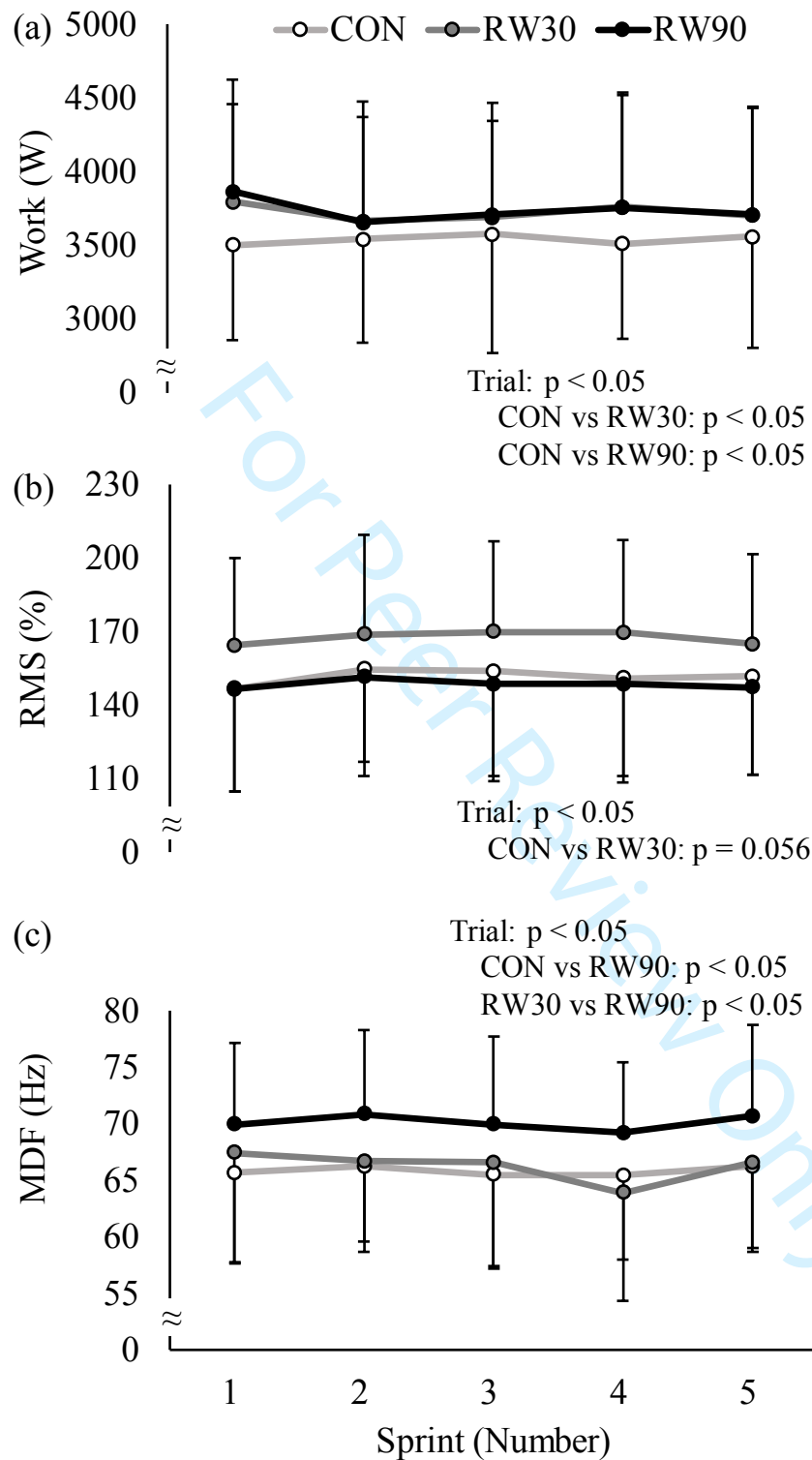


Figure 3

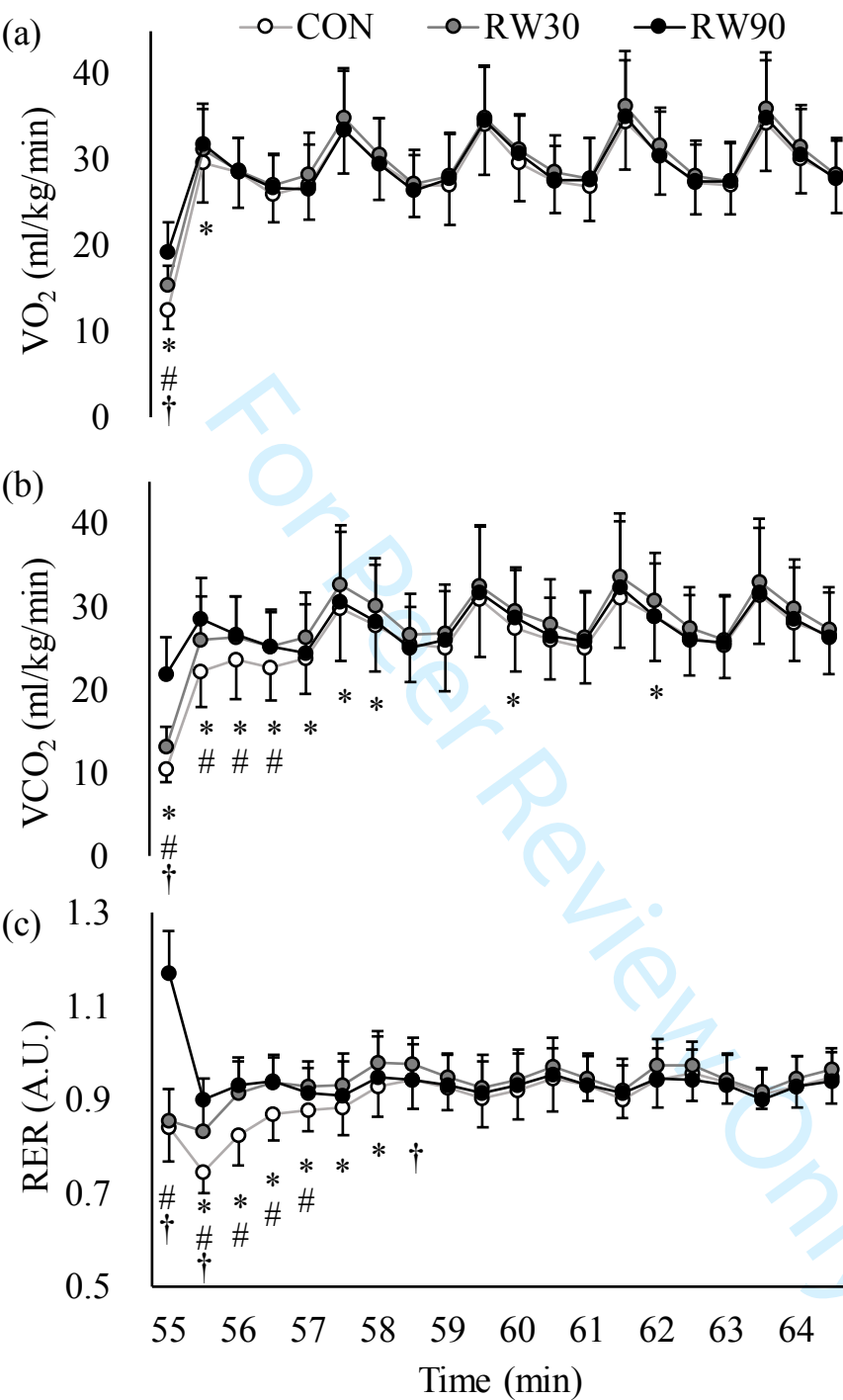




Figure 4

