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Very-Short-Duration, Low-Intensity Half-Time Re–warm up Increases Subsequent Intermittent Sprint Performance

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Abstract

Yanaoka, T, Hamada, Y, Kashiwabara, K, Kurata, K, Yamamoto, R, Miyashita, M, and Hirose, N. Very-short-duration, low-intensity half-time re–warm up increases subsequent intermittent sprint performance. *J Strength Cond Res* 32(11): 3258–3266, 2018—This study investigated the effect of very-short-duration, low-intensity half-time re–warm up (RW) on subsequent intermittent sprint performance. Using a randomized cross-over design, 11 healthy men performed 3 trials. In the experimental trials, participants performed the first 40-minute intermittent exercise followed by a 15-minute half-time. The interventions at half-time were 15 minutes of seated rest (control), 3 minutes of moderate-intensity RW (cycling at 60% of maximal oxygen uptake [$\dot{V}O_2$max]; [60% RW]), and 3 minutes of low-intensity RW (cycling at 30% of $\dot{V}O_2$max; [30% RW]). After half-time, participants performed the Cycling Intermittent-Sprint Protocol (CISP), which consisted of 10 seconds of rest, 5 seconds of maximal sprint, and 105 seconds of active recovery at 50% of $\dot{V}O_2$max, with the cycles repeated over the 20-minute duration. The mean work and electromyogram amplitude during the sprint in the CISP were higher in both RW trials than in the control trial ($p < 0.05$). Muscle temperature, estimated from the skin temperature, at 60 minutes was higher in the 60% RW trial than in the control and 30% RW trials ($p < 0.05$). The mean change in oxygenated hemoglobin concentration during active recovery at 55–65 minutes tended to be higher in both RW trials than in the control trial (60% RW trial: $p = 0.06$, 30% RW trial: $p = 0.06$). In conclusion, very-short-duration, low-intensity RW increased intermittent sprint performance after the half-time, in comparison with a traditional passive half-time practice, and was as effective as a moderate-intensity RW when matched for total duration.

Key Words intremittent team sport, cycling sprint, muscle activation, electromyogram, muscle oxygenation

Introduction

Many intermittent team sports, such as football and rugby, are played over 2 consecutive periods separated by a break at half-time. During the half-time, players are typically passive, and they engage in tactical debriefing and video analyses, receive medical attention, if needed, and ensure adequate nutritional replenishment (22). However, numerous studies have reported declines in the amounts of the high-intensity running and sprinting, which are important indicators of performance in players of intermittent team sports (17), after traditional passive half-time practices in thermoneutral environments (3).

In previous studies, a re–warm up (RW) of short duration at half-time involving approximately 7 minutes of moderate-intensity exercise has been shown to attenuate the losses in core and muscle temperatures (T_m) during half-time and avoid reductions in performance of sprint, vertical countermovement jump, and Yo-Yo intermittent recovery test immediately after half-time (12,13,19,21,31). For example, Russell et al. have suggested that RW attenuated the loss in core temperature by 0.5° C and increased repeated shuttle sprint ability and peak power output during countermovement jumps immediately after half-time (21). However, a recent review highlighted that the players may not be able to complete the RW of 7 minutes used in previous studies since they typically have approximately 3 minutes available for an RW in actual matches (22). Indeed, only 58% of the fitness coaches and sport scientists in the Premier League and Championship divisions of professional football instructed players to engage

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in RW either on the pitch or within the facilities of the venue, and 63% of them reported that one of the major situational limiting factors was a lack of time (28). Therefore, it is necessary to evaluate the effectiveness of very-short-duration RW (i.e., 3 minutes) during half-time in increasing the intermittent exercise performance after half-time.

A recent review regarding warm-up for precompetition preparation indicated that the efficacy of a warm-up is determined by its intensity and duration, as well as the time between the completion of the warm-up and start of the competition (15). Regarding intensity, a low- and moderate-intensity warm-up performed with no recovery time can be effective in improving the sprint and intermittent sprint performance as it results in little depletion in phosphocreatine and increases T_m (1,15). In fact, a previous study has demonstrated that a low-intensity warm-up (i.e., 39% of maximal oxygen uptake [$\dot{V}O_2max$]) before competitions increased the subsequent cycling sprint performance compared with a moderate-intensity (i.e., 56% of $\dot{V}O_2max$) or high-intensity (i.e., 74% and 80% of $\dot{V}O_2max$) warm-up (23). Wittekind et al. similarly reported that a low-intensity (i.e., 40% of peak aerobic power) warm-up was more effective in increasing the cycling sprint performance than was a high-intensity (i.e., 110% of peak aerobic power) warm-up (29). However, it is not known whether RW has similar, if any, benefits in increasing the subsequent exercise performance (23,29). In addition, although the effectiveness of moderate-intensity RW in preventing a decrement in exercise performance has been addressed in previous studies (12,13,19,21,31), to the best knowledge of the authors, there has been no study that investigated the effects of low-intensity RW on subsequent exercise performance.

Therefore, the purpose of this study was to investigate the effects of very-short-duration RW (i.e., 3 minutes) on subsequent intermittent sprint performance and compare the effects of low- and moderate-intensity RWs on subsequent intermittent sprint performance. We hypothesized that both low- and moderate-intensity RWs would increase the intermittent sprint performance, and that the low-intensity RW would have the same influence on intermittent sprint performance as moderate-intensity RW because previous studies have suggested that low- and moderate-intensity "warm-up" can increase intermittent sprint performance (1,15).

Methods

Experimental Approach to the Problem

Participants completed 3 trials in a randomized order. In the experimental trials, 2 consecutive intermittent exercises separated by a 15-minute half-time were performed on a cycle ergometer (Monark 894E; Monark, Varberg, Sweden). The interventions at half-time included 15 minutes of seated rest for the control trial and 3 minutes of cycling at 60 and 30% of $\dot{V}O_2max$ in others. Exercise performance after half-time was evaluated using a Cycling Intermittent-Sprint Protocol (CISP) that has been described previously to assess intermittent sprint performance in athletes of intermittent team sports (10). A high reliability of work during sprints in the CISP has previously been reported (i.e., intraclass correlation = 0.9) (10).

All trials were separated by at least 3 days. Participants performed 1 practice trial to familiarize themselves with the experiment at least 3 days before the first experimental trial. The mean temperature and humidity in the experimental trials were 20.6 ± 0.5° C and 50.8 ± 1.4% (mean ± *SD*), respectively.

Subjects

Eleven healthy men who trained (i.e., more than an hour per session) for more than 2 days per week (mean ± *SD*: age: 22.7 ± 2.4 [range, 20–28] years; height: 1.73 ± 0.06 m; body mass: 65.3 ± 10.0 kg; and $\dot{V}O_2max$: 52.6 ± 6.2 $ml \cdot kg^{-1} \cdot min^{-1}$) participated in this study. This study was approved by the Ethics Review Committee on Research with Human Subjects of Waseda University (Approval number: 2017-048), and all participants provided written informed consent to participate in this study.

Procedures

Participants were asked not to alter their regular lifestyle habits, exercise, and diet throughout the study. Participants recorded all the meals and drinks consumed for 24 hours before each experimental trial and replicated their dietary intake in subsequent trials, ensuring that they were standardized across trials. Participants refrained from intake of alcohol and caffeine for 24 hours before each experimental trial. Furthermore, participants fasted for 3 hours, except for consumption of water, before each experimental trial. All 3 experimental trials were performed at the same time of day to avoid any circadian rhythm-related variation in the obtained results.

Participants initially underwent a graded exercise test to determine their $\dot{V}O_2max$ and maximum heart rate (HR_{max}) on a cycle ergometer (Monark 894E; Monark). The test started at 40 W with a target cadence of 80 rpm and increased by 40 W every 2 minutes until volitional exhaustion. Breath-by-breath gas analysis was performed using an automatic gas analyzer (Quark CPET; COSMED, Rome, Italy). Heart rate was measured using a wireless HR monitor at 5-second intervals (Polar RCX3; Polar Electro, Kempele, Finland).

In the experimental trials, the participants performed 2 consecutive intermittent exercises separated by a 15-minute half-time on a cycle ergometer (Monark 894E; Monark) (Figure 1). First, the participants rested on a chair for 5 minutes followed by a standardized warm-up (i.e., 5 minutes of cycling at 95 W and a 30-second bout at 120 W with a cadence of 80 rpm and 30-second rest between both bouts). Then, they performed the first 40-minute intermittent exercise, which consisted of 20, 2-minute periods. Each

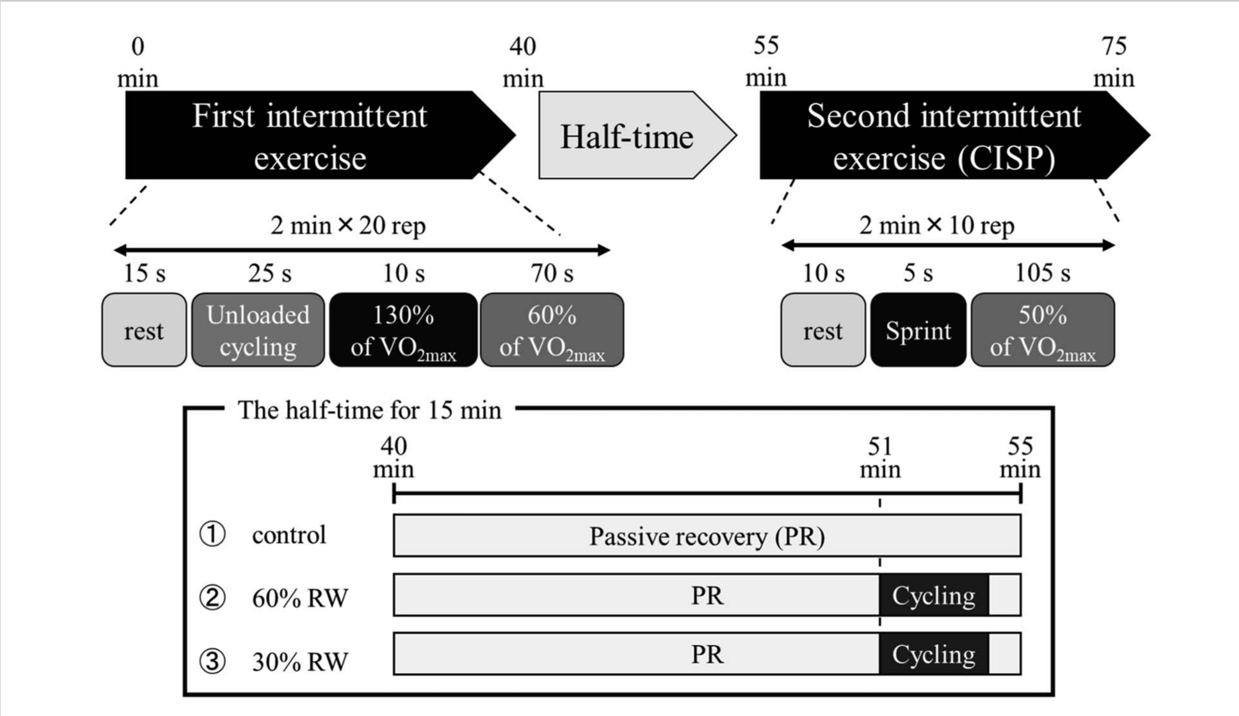

Figure 1. Schematic representation of the study protocol. Control: 15 minutes of seated rest trial, 60% RW: moderate-intensity (60% of $\dot{V}O_2max$) RW trial, 30% RW: low-intensity (30% of $\dot{V}O_2max$) RW trial. CISP = the Cycling Intermittent-Sprint Protocol; RW = re–warm up.

2-minute period started with 15 seconds of passive rest followed by 25 seconds of unloaded cycling, 10 seconds of high-intensity cycling (i.e., 130% of $\dot{V}O_2max$), and ended with 70 seconds of moderate-intensity cycling (i.e., 60% of $\dot{V}O_2max$). The 40-minute intermittent exercise was based on a pilot work to determine that all participants could finish the required workload, and the proportions of rest and unloaded, high-intensity, and moderate-intensity cycling in this exercise reflect those of the time spent in a soccer match (17). During the half-time, participants either rested on the cycle ergometer for 15 minutes (control), rested on the cycle ergometer for 11 minutes followed by cycling at 60% of $\dot{V}O_2max$ for 3 minutes (60% RW), or rested on the cycle ergometer for 11 minutes followed by cycling at 30% of $\dot{V}O_2max$ for 3 minutes (30% RW). Each RW protocol was completed 1 minute before the start of the second intermittent exercise, using the CISP, performed for 20 minutes (10). The CISP consisted of 10, 2-minute periods. Each 2-minute period started with 10 seconds of passive rest followed by a 5-second maximal sprint against a resistance of 7.5% of body mass, followed by 105 seconds of active recovery (i.e., 50% of $\dot{V}O_2max$). Each sprint was initiated from a stationary start, with the right pedal crank at approximately 90° to the horizontal. The pedal cadence throughout the trial was 80 rpm, except during the 5-second maximal sprint.

Measurements. Work was calculated as the mean power output multiplied by the duration of the sprint (5 seconds), using the Anaerobic Test Software (Monark ATS Software; Monark).

The electromyograms (EMG) from the muscle bellies of the right vastus lateralis were recorded during the maximal sprint using a surface electrode (SX230-1000; Biometrics, Newport, United Kingdom) at a sampling frequency of 1,000 Hz, with the ground electrode placed on the left wrist. To reduce impedance (<2 kΩ), the skin was abraded and washed before electrode placement. The root mean square (RMS) as the mean value between the onset and end of the burst were calculated per sprint, and then averaged at 55–65 and 65–75 minutes for simplicity and statistical analyses. Onsets of the bursts were defined by an electric threshold of ± 0.2 mV (20). Three-second maximum voluntary isometric contraction against manual resistance was recorded to obtain the 100% EMG signal for normalization before each experimental trial. The 100% RMS value was obtained from 1-second window between 3-second maximum voluntary isometric contraction. The hip and knee joints were flexed at 90° during the maximum voluntary isometric contraction.

Skin temperature over the right vastus lateralis was measured using a thermistor thermometer (ITP082-24; Nikkiso-therm, Tokyo, Japan) during each experimental trial.

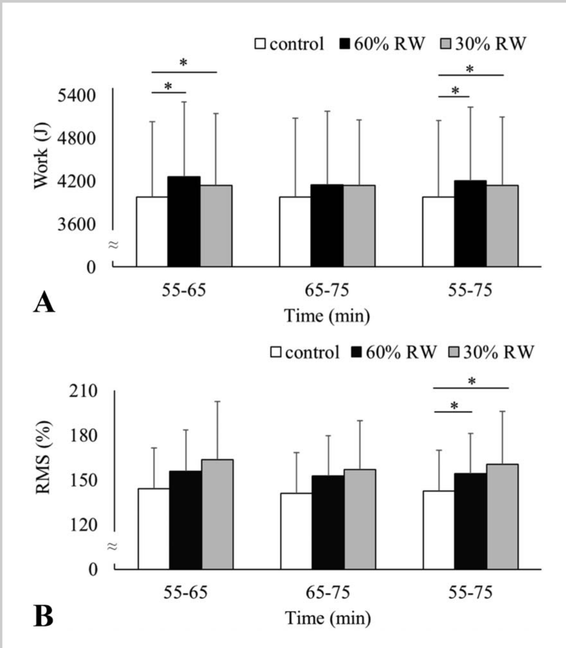

Figure 2. The mean work (A) and RMS (B) at each measurement point among 3 trials. Control: 15 minutes of seated rest trial, 60% RW: moderate-intensity (60% of $\dot{V}O_2max$) RW trial, 30% RW: low-intensity (30% of $\dot{V}O_2max$) RW trial. ([A]: $n = 11$, [B]: $n = 10$, mean ± *SD*). Work: a main effect of trial; $p < 0.05$, a main effect of time; $p > 0.05$, interaction; $p < 0.05$. RMS: a main effect of trial; $p < 0.05$, a main effect of time; $p < 0.05$, interaction; $p > 0.05$. *Significantly different from the control trial ($p < 0.05$). RMS = root mean square; RW = re–warm up.

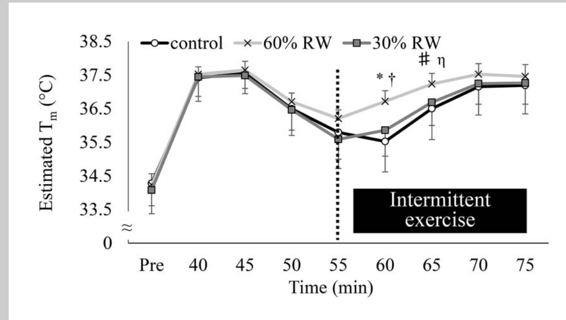

Figure 3. The estimated muscle temperature at each measurement point among 3 trials. Control: 15 minutes of seated rest trial, 60% RW: moderate-intensity (60% of $\dot{V}O_2max$) RW trial, 30% RW: low-intensity (30% of $\dot{V}O_2max$) RW trial, estimated T_m: the estimated muscle temperature. ($n = 11$, mean ± *SD*). A main effect of trial; $p > 0.05$, a main effect of time; $p > 0.05$, interaction; $p < 0.05$. *Significantly different from the control trial ($p < 0.05$). †Significantly different from the 30% RW trial ($p < 0.05$). #Tendency different from the control trial ($0.05 < p < 0.1$). ηTendency different from the 30% RW trial ($0.05 < p < 0.1$). RW = re–warm up.

The muscle temperature was estimated from the skin temperature as follows: $T_m = 1.02 \times$ skin temperature $+0.89$ (correlation between muscle and skin temperatures $r^2 = 0.98$), as per previously described methods (4).

Breath-by-breath gas analysis was continuously performed using an automatic gas analyzer (Quark CPET; COSMED) during the experimental trial. The mean $\dot{V}O_2$, carbon dioxide production ($\dot{V}CO_2$), and respiratory exchange ratio (RER) were calculated.

Muscle oxygenation was measured using a light-emitting diode sensor for near-infrared spatial resolved spectroscopy (NIR_{SRS}: Hb14; ASTEM, Kanagawa, Japan) at 2 wave lengths (770 and 830 mm) and a sampling frequency of 5 Hz, with the diode located on the right vastus lateralis at 30% of the length between the patella and greater trochanter (26). The NIR_{SRS} technique provides continuous, noninvasive monitoring of changes in oxygenated, deoxygenated, and total hemoglobin (Δoxy-Hb, Δdeoxy-Hb, and Δtotal-Hb, respectively) concentrations in comparison with those at rest before the standardized warm-up and muscle oxygen saturation (SmO_2). The probe consisted of 1 light source and 2 photodiode detectors, and the optode distances were 20 and 30 mm (26). In this study, Δoxy-Hb, Δdeoxy-Hb, Δtotal-Hb, and SmO_2 were calculated using fat-correction software (Hb11; ASTEM, Kanagawa, Japan) (26), with the thickness of the fat layer measured using ultrasonography (LogiQ3; GE Healthcare, Tokyo, Japan) before each experimental trial.

Heart rate was measured using a wireless HR monitor at 5-second intervals during the experimental trials (Polar RCX3; Polar Electro).

The rating of perceived exertion (RPE) (2) was assessed before and after the first intermittent exercise, after half-time, and at 10-minute intervals during the CISP (i.e., 0, 40, 55, 65, and 75 minutes).

Statistical Analyses

The sample size was estimated using G*Power 3 (6), using the date from a previous study that investigated the effects of RW on repeated shuttle sprint ability (21). To detect improvements in exercise performance with a power of 80% and an alpha level of 5%, a sample size of ≥6 participants was required. All values are shown as mean ± *SD*. Statistics were computed using SPSS computer software (Version 24.0; SPSS Japan, Inc., Japan). The mean work, RMS, estimated T_m, $\dot{V}O_2$, $\dot{V}CO_2$, RER, Δoxy-Hb, Δdeoxy-Hb, Δtotal-Hb, SmO_2, HR, and RPE were compared using repeated-measures 2-factor (trial × time) analysis of variance. Where significant interaction and trial effect were found, the values were subsequently analyzed using a Bonferroni multiple comparison test. Partial η^2 values are provided as an estimate of the effect size. The 95% confidence intervals (95% CI) for the mean absolute pairwise differences between the trials were calculated using the t-distribution and degrees of freedom ($n-1$). Root mean square, Δoxy-Hb, Δdeoxy-Hb, Δtotal-Hb, and SmO_2 data are represented for 10 participants because they were missing for 1 participant. Statistical significance was set at $p \leq 0.05$.

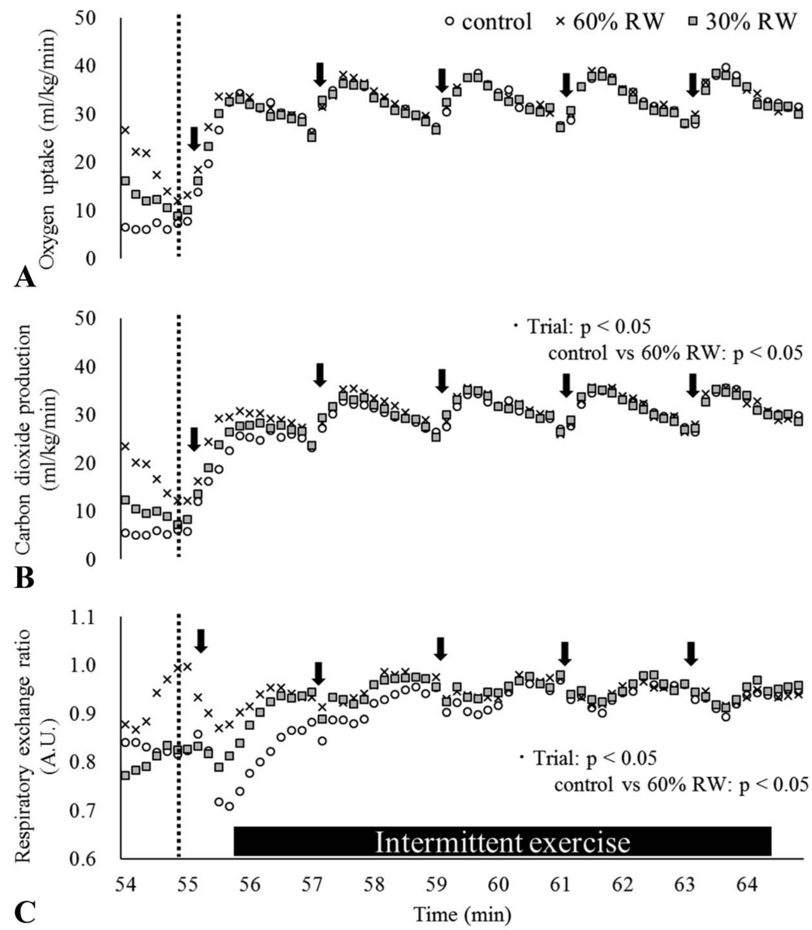

Figure 4. Oxygen uptake (A), carbon dioxide production (B), and respiratory exchange ratio (C) of the mean values at 54–65 minutes. Data are displayed as 10-second averages. Error bars is omitted for clarity. Arrow represents 5-second sprints of the second intermittent exercise. Control: 15 minutes of seated rest trial, 60% RW: moderate-intensity (60% of $\dot{V}O_2max$) RW trial, 30% RW: low-intensity (30% of $\dot{V}O_2max$) RW trial. ($n = 11$, mean). RW = re–warm up.

Results

Sprint Performance and Neuromuscular Activity

There were a main effect of trial ($p < 0.05$, partial $\eta^2 = 0.384$) and trial × time interaction ($p < 0.05$, partial $\eta^2 = 0.041$) for the mean work. The mean work was higher in both RW trials than in the control trial (60% RW: $p < 0.05$, 95% CI: 26–428 J; 30% RW: $p < 0.05$, 95% CI: 1–331 J; Figure 2A). The mean work at 55–65 minutes was higher in both RW trials than in the control trial (60% RW: $p < 0.05$, 95% CI: 73–490 J; 30% RW: $p < 0.05$, 95% CI: 8–325 J; Figure 2A).

There were a main effect of trial ($p < 0.05$, partial $\eta^2 = 0.336$) and time ($p < 0.05$, partial $\eta^2 = 0.384$) for the mean RMS. The mean RMS was higher in both RW trials than in the control trial (60% RW: $p < 0.05$, 95% CI: 0.2–23.2%; 30% RW: $p < 0.05$, 95% CI: 0.5–35.0%; Figure 2B).

Estimated Muscle Temperature

There was a trial × time interaction ($p < 0.05$, partial $\eta^2 = 0.437$) for the estimated T_m.

The estimated T_m at 60 minutes was higher in the 60% RW trial than in the control and 30% RW trials (control: $p < 0.05$, 95% CI: 0.4–2.0° C; 30% RW: $p < 0.05$, 95% CI: 0.2–1.5° C; Figure 3). The estimated T_m at 65 minutes tended to be higher in the 60% RW trial than in the control and 30% RW trials (control: $p = 0.08$, 95% CI: −0.1 to 1.5° C; 30% RW: $p = 0.08$, 95% CI: −0.1 to 1.1° C; Figure 3).

Gas Analysis and NIR_S

The mean values of $\dot{V}O_2$, $\dot{V}CO_2$, and RER at 54–65 minutes are provided in Figure 4. There was a main effect of trial for the mean $\dot{V}CO_2$ and RER ($\dot{V}CO_2$: $p < 0.05$, partial $\eta^2 = 0.298$, RER: $p < 0.05$, partial $\eta^2 = 0.368$). The mean $\dot{V}CO_2$ and RER were higher in the 60% RW trial than in the control trial

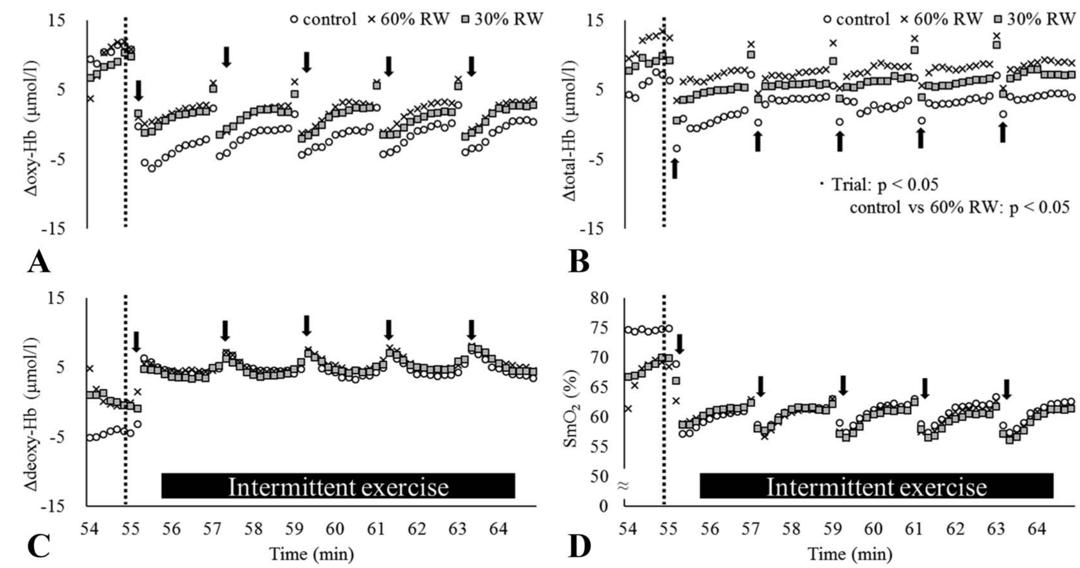

Figure 5. The changes in oxy-Hb (A), deoxy-Hb (B), total-Hb (C) from the rest before the standardized warm-up, and SmO_2 (D) of the mean values at 54–65 minutes. Data are displayed as 10-second averages. Error bars is omitted for clarity. Arrow represents 5-second sprints of the second intermittent exercise. Control: 15 minutes of seated rest trial, 60% RW: moderate-intensity (60% of $\dot{V}O_2max$) RW trial, 30% RW: low-intensity (30% of $\dot{V}O_2max$) RW trial. ($n = 10$, mean). RW = re–warm up.

($\dot{V}CO_2$: $p < 0.05$, 95% CI: 0.1–5.0 $ml \cdot kg^{-1} \cdot min^{-1}$, RER: $p < 0.05$, 95% CI: 0.01–0.08).

Changes in the mean values of NIR_{SRS} variables at 54–65 minutes are provided in Figure 5. There was a main effect of trial for Δoxy-Hb and Δtotal-Hb (Δoxy-Hb: $p < 0.05$, partial $\eta^2 = 0.292$, Δtotal-Hb: $p < 0.05$, partial $\eta^2 = 0.350$). There was no significant difference among the 3 trials regarding Δoxy-Hb. Δtotal-Hb was higher in the 60% RW trial than in the control trial ($p < 0.05$, 95% CI: 0.4–9.7 $\mu mol \cdot L^{-1}$). There was a trial × time interaction for the mean Δoxy-Hb during the 105 seconds of active recovery ($p < 0.05$, partial $\eta^2 = 0.389$). At 55–65 minutes, it tended to be higher in both RW trials than in the control trial (control: -2.0 ± 3.9 $\mu mol \cdot L^{-1}$; 60% RW: 1.8 ± 2.0 $\mu mol \cdot L^{-1}$, $p = 0.06$, 95% CI: −0.2 to 7.7 $\mu mol \cdot L^{-1}$; 30% RW: 1.0 ± 4.3 $\mu mol \cdot L^{-1}$, $p = 0.06$, 95% CI: −0.1 to 6.1 $\mu mol \cdot L^{-1}$). There was no significant difference in it at 65–75 minutes among the 3 trials.

Heart Rate and Rating of Perceived Exertion

There were a main effect of trial ($p < 0.05$, partial $\eta^2 = 0.575$), time ($p < 0.05$, partial $\eta^2 = 0.979$), and trial × time interaction ($p < 0.05$, partial $\eta^2 = 0.815$) for the mean HR

Table 1. Heart rate and the rating of perceived exertion at each measurement point among 3 trials.

Variables	Trials	Time (min) pre	0–40	54–55	55–65	65–75	p values
$\%HR_{max}$	Control	35 ± 4	71 ± 3	46 ± 5	72 ± 4	79 ± 6	Trial: $p < 0.05$
	60% RW	35 ± 3	72 ± 4	63 ± 7†	77 ± 5†	82 ± 5	Time: $p < 0.05$
	30% RW	36 ± 3	72 ± 4	52 ± 3†‡	75 ± 4	80 ± 4	Interaction: $p < 0.05$
RPE (A.U.)	Control	6.5 ± 1.0	12.0 ± 2.5	8.9 ± 2.5	12.2 ± 2.2	13.4 ± 2.5	Time: $p < 0.05$
	60% RW	6.5 ± 1.2	11.9 ± 2.6	10.8 ± 2.1	12.3 ± 2.6	13.3 ± 3.6	Interaction: $p < 0.05$
	30% RW	6.5 ± 1.5	11.9 ± 2.4	9.2 ± 1.7‡	11.8 ± 2.4	13.5 ± 2.3	

Control = 15 minutes of seated rest trial; RW = re–warm up; 60% RW = moderate-intensity (60% of $\dot{V}O_2max$) RW trial; 30% RW = low-intensity (30% of $\dot{V}O_2max$) RW trial; HR = heart rate; RPE = the rating of perceived exertion. ($n = 11$, mean ± *SD*).
†Significantly different from the control trial ($p < 0.05$).
‡Significantly different from the 60% RW trial ($p < 0.05$).

(Table 1). The mean HR at 54–55 minutes was higher in both RW trials than in the control trial (60% RW; $p < 0.05$, 95% CI: 12–22 $b \cdot min^{-1}$; 30% RW: $p < 0.05$, 95% CI: 2–10 $b \cdot min^{-1}$). It was also higher in the 60% RW trial than in the 30% RW trial ($p < 0.05$, 95% CI: 6–16 $b \cdot min^{-1}$). The mean HR at 55–65 minutes was higher in the 60% RW trial than in the control trial ($p < 0.05$, 95% CI: 2–8 $b \cdot min^{-1}$).

There were a main effect of time ($p < 0.05$, partial $\eta^2 = 0.787$) and trial × time interaction ($p < 0.05$, partial $\eta^2 = 0.204$) for RPE. Rating of perceived exertion at 55 minutes was higher in the 60% RW trial than in the 30% RW trial ($p < 0.05$, 95% CI: 0.3–2.9) (Table 1).

Discussion

The major findings of this study were that a very-short-duration (i.e., 3 minutes) RW increased the intermittent cycling sprint performance over the subsequent 10 minutes compared with a traditional passive half-time practice, and that low-intensity (i.e., 30% of $\dot{V}O_2max$) RW was as effective in increasing cycling sprint performance as moderate-intensity (i.e., 60% of $\dot{V}O_2max$) RW when matched for the total RW duration. The magnitude of increase in cycling sprint performance after the 30% RW trial was similar to that in 10- and 30-m sprint performance reported in previous studies (present study: 4.2%, Lovell et al. (12): 5.0%, and Mohr et al. (19): 4.0%). These findings may have practical implications for players and coaches who are generally busy with other tasks during half-time.

A recent review has reported the effectiveness of a short-duration, moderate-intensity RW protocol (i.e., 7 minutes × 70% of HR_{max}) in increasing running-based sprint performance (22). Notably, in this study, we investigated the effectiveness of a very-short-duration, low-intensity RW protocol (i.e., 3 minutes × 30% of $\dot{V}O_2max$) on intermittent cycling sprint performance after the half-time. Our very-short-duration, low-intensity RW protocol has 2 strengths. First, the RW protocol is easier to implement in practice. Russell et al. discussed the importance of considering the duration of RW for practical applications (22). The short-duration (i.e., 7 minutes) of RW used in previous studies (12,13,19,21,31) may be too time-consuming to implement in practice. Indeed, Towlson et al. have addressed that many fitness coaches and sport scientists felt that approximately 2.6 minutes was available for RW activities during half-time in intermittent team sports (28). Therefore, a very-short-duration (i.e., 3 minutes) RW would be easily implemented in practice compared with the short-duration (i.e., 7 minutes) RW reported previously (12,13,19,21,31). Second, physiological load was lower in low-intensity RW than in moderate-intensity RW. The physiological load of any half-time RW is also important to consider. In this study, $\dot{V}CO_2$ and RER were higher in the 60% RW trial than in the control trial, with values being comparable for the 30% RW trial and control trial. These results have suggested that the increases in intermittent cycling sprint performance were comparable between the 30% and 60% RW trials with the former requiring less anaerobic energy. In intermittent team sports, the anaerobic energy stores, such as carbohydrates, decrease in the last part of the second half (18). Therefore, the restriction of anaerobic energy consumption is important for players. In addition, this study has demonstrated that RPE at 55 minutes (i.e., at the end of the half-time) was lower in the 30% RW trial than the 60% RW trial, indicating that participants perceived less exertion when performing the 30% RW trial compared with the 60% RW trial. These results are important in supporting the implementation of a very-short-duration, low-intensity RW protocol in practice for intermittent team sports.

One of the mechanisms for the acute increase in intermittent exercise performance after the 60% RW may be an increase in T_m, which is a major factor for increased exercise performance after RW (19). Mohr et al. have suggested that the mechanism of increased 30-m sprint performance after RW includes increased T_m because there is a correlation ($r = 0.6$) between the change in T_m and sprint performance during half-time, and the decrement of T_m during half-time was not observed after performing a moderate-intensity RW of 7 minutes (19). In this study, the estimated T_m, which was not directly measured from the muscle, increased after the 60% RW trial, but not 30% RW trial. A previous study reported the relationship between warm-up intensity and temperature (30). Therefore, 60% RW may be enough to increase T_m compared with 30% RW. Interestingly, despite a lack of significant increases in T_m in the 30% RW trial, a similar intermittent cycling sprint performance was observed between both RW trials. Thus, there might be another potential mechanism for the acute increase in intermittent cycling sprint performance after the 30% RW trial.

This study has demonstrated that the mean RMS was higher in the 30% RW trial than in the control trial. The result has suggested that enhanced muscle activation as evidenced by increased EMG activity during sprints may be related to the acute increase in intermittent cycling sprint performance after the 30% RW because there is a linear relationship between RMS and power output during cycling (11). Furthermore, a previous study has suggested that a low-intensity warm-up, such as half-squat exercise performed at 25 and 35% of 1 repetition maximum, enhanced muscle activation as evidenced by increased EMG activity of vastus lateralis and enhanced countermovement jump performance (24). Therefore, 30% RW may result in increased intermittent cycling sprint performance through enhanced muscle activation as evidenced by increased EMG activity. However, the mechanisms for enhanced muscle activation in this study are not clear. Increase in EMG activity is caused by increased motor unit recruitment and firing frequency (11). Future research should consider the effects of low-intensity RW on motor unit recruitment and firing frequency.

The mean Δoxy-Hb at 105 seconds of active recovery at 55–65 minutes tended to be higher in both RW trials than in the control trial. Increased oxygen availability after maximal exercise accelerates the resynthesis of phosphocreatine (8,9,14). Thus, the present results have suggested that both RWs may increase the oxygen availability in the muscle and contribute to the resynthesis of phosphocreatine during active recovery at 55–65 minutes. In this study, the mean work and RMS during maximum cycling sprint were also higher in both RW trials than in the control trial. It is possible to assume that adenosine triphosphate utilization was higher in both RW trials than in the control trial, and an increase in adenosine triphosphate resynthesis may be required in both RW trials. To restore phosphocreatine, the mean Δoxy-Hb at 105 seconds of active recovery at 55–65 minutes may have increased in both RW trials. We have, however, no direct data to support these speculations and thus such speculations require further study.

The mechanism of increased mean Δoxy-Hb, which is an indicator of the balance between oxygen supply and utilization (25), may be related to an increase in the oxygen supply to the muscles (1). A previous study has reported that oxygen utilization in muscles was strongly correlated with the activity of the muscle (16). In this study, the mean RMS was higher in both RW trials than in the control trial, and therefore, oxygen utilization may also be higher in both RW trials than in the control trial, thus, suggesting an increase in oxygen supply, which is greater than oxygen utilization, in both RW trials. Indeed, a previous study has suggested that oxy-Hb relatively increased by warm-up, and this may result from an increase in the oxygen supply to the muscles due to the increased blood flow to the muscle and shifted the oxygen dissociation curve to the right (27). Although oxygen supply to the muscles was not measured in this study, HR was higher after both RW trials than after the control trial. Heart rate has been used as an indicator of presumable oxygen supply to the muscles with an inherent limitation (5). Therefore, the present results have suggested that oxygen supply may be elevated after both RWs. By contrast, there was no significant difference in the mean Δoxy-Hb during the 105 seconds of active recovery at 65–75 minutes among the 3 trials. This finding may relate to the finding that there was no significant difference in the mean HR at 65–75 minutes among the 3 trials.

The limitations of this study need to be acknowledged in the interpretation of results. The mode and intensity of 2 intermittent exercises (i.e., simulated each half) we used in this study has limited practical applications in many intermittent team sports. This study evaluated the effectiveness of very-short-duration, low-intensity RW protocol using a cycling exercise, whereas most intermittent team sports use overground running and activities such as jumping and multidirectional running. It is not possible to conclude whether the present results can be applied in these activities. Moreover, the type of the participants we employed in this study (i.e., healthy men who trained for more than 2 days per week) does not allow to make a comparison with professional athletes. Nonetheless, it would be interesting to determine whether the RW used in this study would have similar effects in professional athletes when other modes of repeated exercises are performed for an extended period after half-time because the work during cycling sprint is proportional to sprint performance in over-ground running (7).

In conclusion, both very-short-duration RW at low and moderate intensities were equally effective in improving intermittent cycling sprint performance over 10 minutes after half-time, in comparison with a traditional passive half-time practice. These findings challenge the half-time practice and indicate that a very-short-duration low-intensity RW is beneficial in improving exercise performance after half-time.

Practical Applications

This study revealed that players of intermittent team sports may be able to increase their intermittent sprint performance using very-short-duration RW at low and moderate intensities. These findings would support its use in the field of athletics because very-short-duration RW may allow to accommodate with other specific ergogenic strategies during half-time. Moreover, this study have suggested that a low-intensity RW has same increase rate for exercise performance and less anaerobic energy compared with moderate-intensity RW. Therefore, very-short-duration, low-intensity RW may be recommended for players of intermittent team sports.

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