**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 [V\textsubscript{O\textsuperscript{2}max}]; [60% RW]), and 3 minutes of low-intensity RW (cycling at 30% of V\textsubscript{O\textsuperscript{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 V\textsubscript{O\textsuperscript{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** intermittent 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\textsubscript{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\degree 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...
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 Tm (1,15). In fact, a previous study has demonstrated that a low-intensity warm-up (i.e., 39% of maximal oxygen uptake [VO2max]) before competitions increased the subsequent cycling sprint performance compared with a moderate-intensity (i.e., 56% of VO2max) or high-intensity (i.e., 74% and 80% of VO2max) warm-up (23). Witterkind 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 after half-time has been addressed in previous studies (23,29), 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 VO2max 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 VO2max: 52.6 ± 6.2 ml·kg⁻¹·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 VO2max and maximum heart rate (HRmax) 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
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 \( \text{VO}_2\text{max} \)), and ended with 70 seconds of moderate-intensity cycling (i.e., 60% of \( \text{VO}_2\text{max} \)). 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 \( \text{VO}_2\text{max} \) for 3 minutes (60% RW), or rested on the cycle ergometer for 11 minutes followed by cycling at 30% of \( \text{VO}_2\text{max} \) 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 \( \text{VO}_2\text{max} \)). 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.
The muscle temperature was estimated from the skin temperature as follows: $T_m = 1.02 \times \text{skin temperature} + 0.89$ (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 $V_O_2$, carbon dioxide production ($V_CO_2$), and respiratory exchange ratio (RER) were calculated.

Muscle oxygenation was measured using a light-emitting diode sensor for near-infrared spatial resolved spectroscopy (NIRSRS; Hb14; ASTEM, Kanagawa, Japan) at 2 wave lengths (770 and 830 nm) and a sampling frequency of 5 Hz, with the diode located on the right vastus lateralis at 30% of the length (26). The NIRSRS diode sensor for near-infrared spatial resolved spectroscopy were calculated.

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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 1.1°C; 30% RW: $p = 0.08$, 95% CI: −0.1 to 1.1°C; Figure 3).

Gas Analysis and NIRS
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.
Changes in the mean values of NIRsRS variables at 54–65 minutes are provided in Figure 5. There was a main effect of trial for \( \Delta \text{oxy-Hb} \) and \( \Delta \text{total-Hb} \) (\( \Delta \text{oxy-Hb}: p < 0.05, \text{partial } \eta^2 = 0.292, \Delta \text{total-Hb}: p < 0.05, \text{partial } \eta^2 = 0.350 \)). There was no significant difference among the 3 trials regarding \( \Delta \text{oxy-Hb} \). \( \Delta \text{total-Hb} \) was higher in the 60% RW trial than in the control trial (\( p < 0.05, 95\% \text{ CI: } 0.4–9.7 \text{ mmol} \cdot \text{L}^{-1} \)).

There was a trial \( \times \) time interaction for the mean \( \Delta \text{oxy-Hb} \) during the 105 seconds of active recovery (\( p < 0.05, \text{partial } \eta^2 = 0.389 \)). At 55–65 minutes, it tended to be higher in both RW trials than in the control trial (control: \( -2.0 \pm 3.9 \text{ mmol} \cdot \text{L}^{-1} \); 60% RW: \( 1.8 \pm 2.0 \text{ mmol} \cdot \text{L}^{-1} \), \( p = 0.06, 95\% \text{ CI: } -0.2 \text{ to } 7.7 \text{ mmol} \cdot \text{L}^{-1} \); 30% RW: \( 1.0 \pm 4.3 \text{ mmol} \cdot \text{L}^{-1} \), \( p = 0.06, 95\% \text{ CI: } -0.1 \text{ to } 6.1 \text{ mmol} \cdot \text{L}^{-1} \)). 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 (\( p < 0.05, \text{partial } \eta^2 = 0.575 \)), time (\( p < 0.05, \text{partial } \eta^2 = 0.979 \)), and trial \( \times \) time interaction (\( p < 0.05, \text{partial } \eta^2 = 0.815 \)) for the mean HR.
Half-Time Re-Warm Up and Exercise Performance

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 VO_{2max}) RW was as effective in increasing cycling sprint performance as moderate-intensity (i.e., 60% of VO_{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 VO_{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, VO_{2CO2} 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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