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The effect of warm-up on intermittent sprint performance and selected thermoregulatory parameters

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Abstract

Objectives: To investigate the effect of various warm-up intensities based upon individual lactate thresholds on subsequent intermittent sprint performance, as well as to determine which temperature (muscle; T_{mu}, rectal; T_{re} or body; T_b) best correlated with performance (total work, work and power output of the first sprint, and % work decrement).
Design: Nine male team-sport participants performed five 10-min warm-up protocols consisting of different exercise intensities on five separate occasions, separated by a week.
Methods: Each warm-up protocol was followed by a 6 × 4-s intermittent sprint test performed on a cycle ergometer with 21-s of recovery between sprints. T_{mu}, T_{re} and T_b were monitored throughout the test.
Results: There were no differences between warm-up conditions for total work (J kg^{-1}; $P = 0.442$), first sprint work (J kg^{-1}; $P = 0.769$), power output of the first sprint (W kg^{-1}; $P = 0.189$), or % work decrement ($P = 0.136$), respectively. Moderate to large effect sizes (>0.5; Cohen's *d*) suggested a tendency for improvement in every performance variable assessed following a warm-up performed at an intensity midway between lactate inflection and lactate threshold. While T_{mu}, T_{re}, T_b, heart rate, ratings of perceived exertion and plasma lactate increased significantly during the exercise protocols ($P < 0.05$), there were no significant correlations between T_{mu}, T_{re}, and T_b assessed immediately after each warm-up condition and any performance variable assessed.
Conclusions: Warm-up performed at an intensity midway between lactate inflection and lactate threshold resulted in optimal intermittent sprint performance. Significant increases in T_{mu}, T_{re} and T_b during the sprint test did not affect exercise performance between warm-up conditions.

Keywords: Muscle temperature; Lactate threshold; Lactate inflection

1. Introduction

Warm-up (WUP) is a well-accepted practice that is considered by many athletes and coaches to be an essential precursor to training sessions and competition, as well as a means to minimise sport-related injuries.[1] An active WUP is proposed to improve subsequent exercise performance through numerous temperature and non-temperature related benefits, which overall, prime the body for the ensuing exercise task.[2] Examples of these proposed benefits (described in detail in a review by Bishop[2]), are: increased nerve conduction rates, decreased joint and muscle resistance, speeding of metabolic reactions, increased blood flow to muscles, greater unloading of oxygen to working muscles, postactivation potentiation, as well as psychological effects.

While many researchers have reported improved exercise performance following an active WUP,[3,4] other researchers have found no benefit.[5,6] Lack of consensus regarding the effects of WUP on exercise performance may be due to heterogeneity of different exercise protocols, the lack of well-controlled studies, the recruitment of small cohorts, or the use of $\dot{V}O_{2max}$ to determine WUP intensity. Of relevance, Bishop et al.[7] noted that a WUP intensity of 80% $\dot{V}O_{2max}$

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was likely to be above the lactate threshold (LT: also known as 'anaerobic threshold') in some individuals (particularly if untrained) but below the LT in others (i.e. well trained athletes). Importantly, a WUP intensity that is greater than LT has been shown to result in high-energy phosphocreatine depletion (and the subsequent accumulation of phosphate), as well as an increase in metabolic acidemia, which can impair subsequent exercise performance.[7,8] While the role of intracellular acidosis on skeletal muscle fatigue has been challenged in recent years,[9] scientific opinion in this area is still equivocal. Overall, this suggests that WUP intensity should be based on lactate levels, rather than $\%\dot{V}O_{2max}$, with the ideal WUP intensity being able to raise body temperature to a point where benefits associated with WUP are achieved, without a concomitant detrimental increase in metabolic acidemia, the depletion of high-energy substrates, or the accumulation of phosphate.

Additionally, while a number of studies have investigated the effect of WUP intensity on single-sprint performance,[4,7,10] there is no published research to the authors' knowledge, describing the effects of WUP on intermittent sprint ability, where WUP intensity was based on lactate thresholds. This lack of research is surprising, as in many countries the most popular sports, are team sports, which require athletes to sprint repeatedly throughout the match.

Therefore, the aim of this study was to investigate the impact of varying WUP intensities (based on individual lactate accumulation) on intermittent sprint ability so to determine which intensity results in better subsequent exercise performance. A second aim of this study was to investigate whether muscle, body and rectal temperature (T_{mu}, T_b or T_{re}, respectively) induced by the various WUP protocols, were correlated with exercise performance. It was hypothesised that a WUP intensity performed mid-way between lactate inflection (LI) and LT would result in better intermittent sprint performance, as this intensity would produce an increase in body temperatures, while at the same time avoid a large increase in metabolic acidemia.

2. Methods

Nine male participants (mean ± SD age: 26.1 ± 4.4 years, body mass: 86.9 ± 11.4 kg, $\dot{V}O_{2max}$: 49.6 ± 6.1 mL kg^{-1} min^{-1}) were recruited from The University of Western Australia (UWA). All participants played in team-sports (rugby, AFL football and soccer) and trained three days per week (7.6 ± 2.7 h week^{-1} per week) with competition occurring once a week. The Research Ethics committee of UWA granted approval for the study's procedures and all participants provided written informed consent.

Participants were required to complete three preliminary sessions and five experimental trials over a seven-week period. During the first visit, participants performed a familiarisation session of both the graded exercise test (GXT) and the intermittent sprint test. Height was also determined using a stadiometer, while body-mass was measured using Sauter scales (model ED3300, Ebingen, West Germany). The GXT was performed on the second visit to determine the participant's LI, LT and $\dot{V}O_{2max}$. On the third visit, participants performed a second familiarisation of the intermittent sprint test. Participants then performed each of the five experimental trials over a five week period. Participants were asked to maintain their normal diet and training throughout the study and were required to consume no food or beverages (other than water) during the 2-h period prior to testing. Participants were requested to keep a diary of their food and drink intake during the 48-h period prior to exercise and to replicate this intake prior to each exercise trial. Additionally, participants were asked not to consume alcohol or perform vigorous exercise in the 24-h prior to testing.

All exercise tests were performed on a calibrated, front-access, cycle ergometer (Model EX-10, Repco, Australia) that was interfaced with a computer system for data collection (Cyclemax, UWA, Australia). Before testing, the ergometer was calibrated on a mechanical rig (Western Australia Institute of Sport, Perth, Australia) across a range of power outputs (100–2000 W).

The GXT consisted of an intermittent protocol (1-min rest between stages) performed on the same cycle ergometer described earlier. The test commenced at 70 W, with intensity increased every 3 min by 30 W until the participant could no longer maintain the required power output (volitional exhaustion). Lactate thresholds and $\dot{V}O_{2max}$ were determined from data collected during the GXT. The sum of the four highest consecutive 15-s of oxygen values was recorded as the participant's $\dot{V}O_{2max}$, while the LT was calculated using the modified Dmax method.[11] This is determined by the point on the polynomial regression curve that yields the maximal perpendicular distance to the straight line connecting the first increase in lactate concentration of more than 0.4 mM above the resting level (lactate inflection[12]) and the final lactate point. During the GXT, expired air was continuously analysed for O_2 and CO_2 concentrations using Ametek gas analysers (Applied Electrochemistry, SOV S-3 A/1 and COV CD-3A, Pittsburgh, PA), while ventilation was recorded every 15-s using a turbine ventilometer (Morgan, 225A, Kent, England). The gas analysers were calibrated immediately before and verified after each test using three certified gravimetric gas mixtures (BOC Gases, Chatswood, Australia), while the ventilometer was calibrated pre-exercise and verified post-exercise using a 1 L syringe in accordance with the manufacturer's instructions. Capillary plasma lactate samples were taken at rest and immediately following each 3-min stage of the GXT. Plasma lactate concentrations were determined using a blood-gas analyser (ABL625, Radiometer, Copenhagen), which was regularly calibrated using precision standards.

Participants were then allocated to one of five groups, with each group performing a different experimental trial each week (in a randomised manner), at approximately the same time of day, over a five-week period (Latin-square design). The WUP intensities were either:

(1) WUP 1 – half the difference between LI and LT below the LI level;
(2) WUP 2 – at LI;
(3) WUP 3 – midway between LI and LT level;
(4) WUP 4 – LT;
(5) WUP 5 – half the difference between LI and LT above the LT level.

Warm-up 1 represented a very low-intensity WUP that was expected to result in minimal plasma lactate levels, while WUP 5 represented a very high-intensity WUP that was expected to result in high levels of plasma lactate level, with various intensities selected between these two points. A control group was not included due to ethical considerations based on the risk of injury performing all-out sprints without a prior WUP.[13]

Following a 10-min WUP and a passive 2-min rest period, participants performed the intermittent sprint test. The intermittent sprint test involved 6 × 4-s sprints, separated by 21-s of active recovery performed at an intensity that equated to WUP 1. While this test was performed on a cycle ergometer due to the ease in assessing power and work, a strong correlation has been reported between intermittent-sprint cycling and running performance.[14] Further, cycle sprint tests have previously been used in other studies to simulate intermittent sprints performed during a team-sport game.[15–17] During the test, participants were requested to sprint as fast as they could during each sprint. Total work for the six sprints ($\mathrm{J\,kg^{-1}}$), work done ($\mathrm{J\,kg^{-1}}$) and power output ($\mathrm{W\,kg^{-1}}$) for the first sprint and % work decrement were calculated. Percent work decrement was determined using the method described by Fitzsimmons et al.,[18] i.e. 100 − [(total time/[best time × 6]) × 100]. Heart rate (HR: Polar Electro Oy, Kempele, Finland), plasma lactate concentrations and ratings of perceived exertion (RPE), based upon the Borg scale (6–20),[19] were assessed pre-WUP, immediately post-WUP, as well as pre and post sprint-bouts.

Rectal temperature (T_{re}) was measured using a thermistor (Model RET-1, Physitemp Instruments Inc., NJ, USA) from a site 10 cm beyond the external anal sphincter. Skin thermistors (Model SST-2, Physitemp Instruments Inc., Clifton, NJ, USA) were attached to four sites (sternum, mid-forearm, upper thigh and calf). Mean skin temperature (T_{sk}) was calculated using the formula $T_{sk} = 0.3(T_1 + T_2) + 0.2{\cdot}(T_3 + T_4)$, where T_1 is chest, T_2 is upper arm, T_3 is thigh and T_4 is calf temperature.[20] Mean body temperature (T_b) was calculated as $0.87\ T_{re} + 0.13{\cdot}T_{sk}$.[21]

Muscle temperature was monitored via a needle thermistor probe (Model T-204A, Physitemp Instruments Inc., NJ, USA) inserted 4 cm into an anaesthetised area of the vastus lateralis, half-way between the anterior superior iliac spine and the superior border of the patella by a medical doctor. Temperature measurements were taken to the nearest 0.1 °C from all thermistor sites. Rectal temperature (T_{re}) and muscle temperature (T_{mu}) were measured continuously throughout the experimental trials.

Table 1
Total work (W_{tot}), first sprint work (W_{1st}), power output of first sprint (P_{1st}) and % work decrement (W_{dec}) recorded during a 6 × 4 s intermittent sprint test (mean ± SD). $N = 9$.

	W_{tot} ($\mathrm{J\,kg^{-1}}$)	W_{1st} ($\mathrm{J\,kg^{-1}}$)	P_{1st} ($\mathrm{W\,kg^{-1}}$)	W_{dec} (%)
WUP 1	261.1 ± 38.3	44.9 ± 6.3	15.9 ± 2.1	10.6 ± 5.3
WUP 2	257.5 ± 26.0	46.3 ± 4.9	16.0 ± 1.7	10.7 ± 3.9
WUP 3	272.4 ± 22.6	47.5 ± 5.5	16.6 ± 1.5	6.5 ± 4.2
WUP 4	258.8 ± 38.9	47.0 ± 8.6	16.6 ± 1.5	7.7 ± 2.8
WUP 5	260.8 ± 28.9	45.1 ± 5.1	15.6 ± 1.7	8.6 ± 1.8

All values are reported as mean ± SD. Differences in performance between conditions, including total work ($\mathrm{J\,kg^{-1}}$), power output ($\mathrm{W\,kg^{-1}}$) and work of the first sprint and % work decrement were analysed using a one-way ANOVA with repeated-measures. Plasma lactate concentrations, HR, RPE, T_{mu}, T_{re} and T_b were analysed using a two-way ANOVA with repeated-measures. A Newman–Keuls post hoc test was applied whenever significance was found. Statistical significance was accepted at the level of $P < 0.05$. Performance variables were also compared between WUP intensities using Cohen's d effect sizes (ES) and thresholds (≤0.49, small; 0.5–0.79 = moderate; >0.8, strong).[22] Only moderate to large effect sizes (≥0.5) are reported. Further, Pearson correlation coefficients were used in order to assess the relationship between T_{re}, T_{mu}, T_b, assessed immediately after each WUP, and performance variables. All statistical analyses were conducted using the SigmaStat statistical package (Version 3.1, SigmaStat, CA, USA).

3. Results

There were no statistical differences between each WUP condition for total work ($\mathrm{J\,kg^{-1}}$; $P = 0.442$), first sprint work ($\mathrm{J\,kg^{-1}}$; $P = 0.769$), power output of the first sprint ($\mathrm{W\,kg^{-1}}$; $P = 0.189$), or % work decrement ($P = 0.136$), respectively (Table 1). However, moderate to large effect sizes were evident between the WUP intensities for total work (WUP 3 vs 2, 3, 4 and 5, $d = 0.5$–0.6), first sprint work (WUP 3 vs 1, $d = 0.5$), power output of the first sprint (WUP 3 vs 5, $d = 0.7$; WUP 4 vs 5, $d = 0.6$) and percent work decrement (WUP 3 vs 1, $d = -0.8$; WUP 3 vs 2, $d = -1.0$; WUP 3 vs 5, $d = -0.6$; WUP 1 vs 4, $d = 0.7$; WUP 1 vs 5, $d = 0.5$; WUP 2 vs 4, $d = 0.9$; WUP 2 vs 5, $d = 0.7$).

Changes in plasma lactate concentration, HR and RPE, pre and post each WUP condition and pre and post each intermittent sprint bout, are displayed in Fig. 1(a–c). Changes in plasma lactate concentrations over time were significantly higher ($P < 0.05$) post-WUP compared to pre-WUP after WUP's 3, 4, and 5. Further, plasma lactate concentrations increased significantly between post WUP and post-bout in all conditions, except for WUP 5 ($P < 0.05$). Heart rate

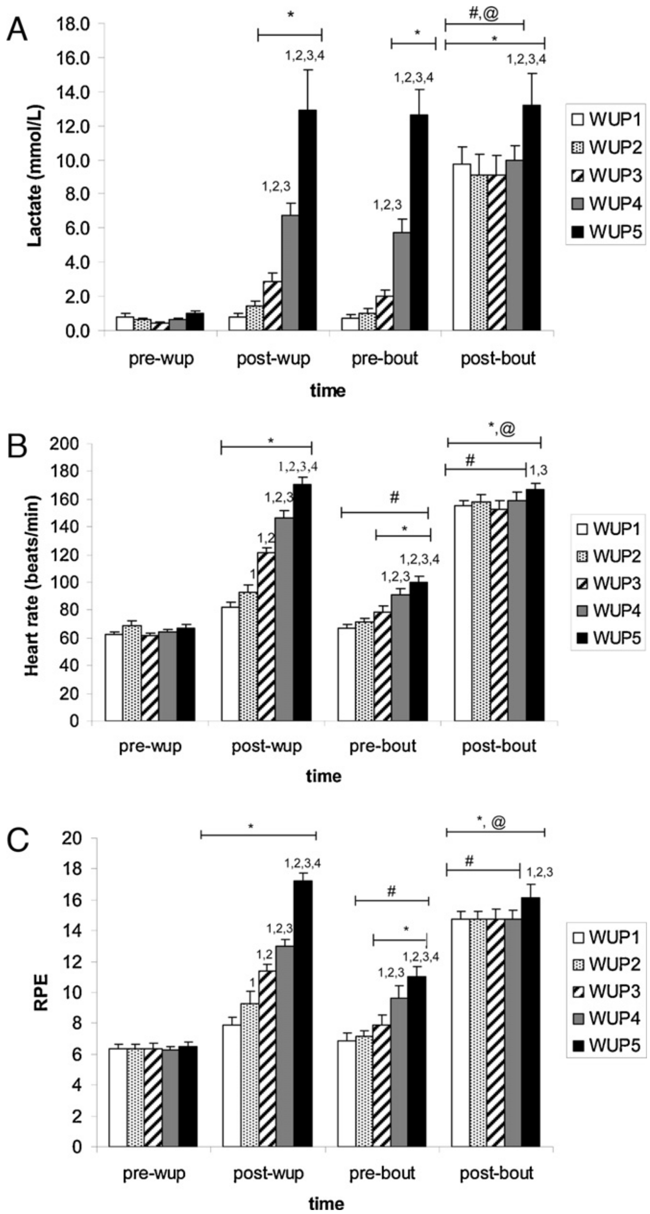

Fig. 1. Plasma lactate concentration (a), heart rate (b), and rating of perceived exertion (RPE) values (c) for each WUP intensity. *Significantly different from pre-WUP ($P < 0.05$), #significantly different from post-WUP, @significantly different ($P < 0.05$) from before intermittent sprint performance (pre-bout), 1 (2, 3, 4, 5) = significantly different ($P < 0.05$) from WUP 1 (2, 3, 4, 5).

increased significantly post-WUP compared with pre-WUP in every WUP condition ($P < 0.05$), except for WUP 1 ($P > 0.05$). At post WUP, there were significant differences in HR between every WUP condition ($P < 0.05$), while HR values for all WUP conditions were significantly higher post-bout compared to pre-bout values ($P < 0.01$), with significant differences resulting between WUP 5 and WUP's 1 and 3 ($P < 0.05$). Finally, changes in RPE values over time were similar between WUP conditions ($P > 0.05$), except after the rest period (pre-bout), where RPE was significantly lower than post-WUP in all WUP conditions ($P < 0.001$), apart from WUP 1 ($P > 0.05$). Following the intermittent sprint test (post-bout), RPE values for all WUP conditions were significantly higher than pre-bout values ($P < 0.001$), with significant differences ($P < 0.05$) resulting between WUP 5 compared with WUP's 1, 2 and 3.

No significant differences were found between WUP conditions for T_{mu}, T_{re} or T_b at pre-WUP ($P > 0.05$; Table 2). At post-WUP, T_{mu} for WUPs 2, 3, 4, and 5 was significantly higher ($P < 0.05$) than T_{mu} for WUP 1, while T_{mu} for WUP 5 was also significantly higher ($P < 0.05$) than those recorded for WUP's 2, 3, and 4. Both T_{re} and T_b were also significantly higher ($P < 0.05$) post-WUP for WUP 5 compared to WUPs 1 and 2. Similar differences for all temperature variables were observed immediately prior to performing the intermittent sprint bout. Finally, post-bout T_{mu} was significantly higher in WUPs 2, 4 and 5 compared to WUP 1 ($P < 0.05$), while both T_{re} and T_b were significantly higher ($P < 0.05$) in WUP 5 compared to all other WUP conditions.

There were no significant correlations between T_{mu} recorded immediately after each WUP and any of the performance variables assessed (i.e. total work, $r = -0.46$ to 0.65; first sprint work, $r = -0.49$ to 0.68; first sprint power output, $r = -0.44$ to 0.75; and % work decrement, $r = -0.49$ to 0.32). Similarly, no significant correlations were found between T_{re} assessed immediately after each WUP and any of the performance variables (i.e. total work, $r = -0.499$ to 0.490; first sprint work, $r = -0.234$ to 0.685; first sprint power output, $r = -0.663$ to 0.775; and % work decrement, $r = -0.524$ to 0.717). Finally, no significant correlations were found between T_b assessed immediately after each WUP and any of the performance variables (i.e. total work, $r = -0.274$ to 0.664; first sprint work, $r = 0.118$ to 0.492; first sprint power output, $r = -0.609$ to 0.658; and % work decrement, $r = -0.597$ to 0.250).

4. Discussion

This study employed WUP intensities based around each individual's LT in an effort to standardise the metabolic strain experienced by all participants during the various WUP conditions. This is an important consideration, as it has previously been shown that HR and plasma lactate differed between participants of different fitness levels when exercise was performed at a $\%\dot{V}O_{2max}$, but were similar during exercise performed at a %LT.[23] Consequently, the current study is the first to assess the effect of WUP based on lactate accumulation on intermittent sprint performance.

Despite the use of five different WUP intensities, which resulted in distinctive changes in HR, plasma lactate and RPE, there were no significant differences between any trials for any performance measures assessed. Nonetheless, results for total work were highest after WUP 3 (4.3%, 5.8%, 5.2% and 4.4% higher than WUP's 1, 2, 4 and 5, respectively), whilst percent work decrement values were lowest (4.0%, 4.2%, 1.2% and 2.1% lower than WUPs 1, 2, 4 and 5, respectively),

Table 2
Muscle, rectal and body temperatures (T_{mu}, T_{re}, T_b) before warm-up (pre-WUP), after warm-up (post-WUP), after a 5-min rest period (pre-bout), and after the intermittent sprint test (post-bout).

	WUP 1	WUP 2	WUP 3	WUP 4	WUP 5
T_{mu} (°C)					
Pre-WUP	36.3 ± 0.4	36.4 ± 0.5	36.2 ± 0.6	35.9 ± 0.7	36.4 ± 0.6
Post-WUP	37.1 ± 0.6*	37.9 ± 0.5$^{*(1)}$	37.9 ± 0.4$^{*(1)}$	38.1 ± 1.1$^{*(1)}$	39.2 ± 0.7$^{*(1,2,3,4)}$
Pre-bout	37.1 ± 0.5*	37.6 ± 0.6$^{*(1)}$	37.5 ± 0.3$^{*(1)}$	37.7 ± 0.8$^{*(1)}$	38.4 ± 0.4$^{*,\#(1,3)}$
Post-bout	37.5 ± 0.4*	38.1 ± 0.4$^{*(1)}$	37.9 ± 0.4*	37.9 ± 0.8$^{*(1)}$	38.6 ± 0.5$^{*,\#(1)}$
T_{re} (°C)					
Pre-WUP	37.3 ± 0.3	37.2 ± 0.2	37.3 ± 0.4	37.3 ± 0.3	37.4 ± 0.2
Post-WUP	37.4 ± 0.3	37.4 ± 0.2*	37.5 ± 0.3*	37.6 ± 0.3*	37.8 ± 0.2$^{*(1,2)}$
Pre-bout	37.5 ± 0.3	37.4 ± 0.2*	37.5 ± 0.2*	37.6 ± 0.3$^{*(2)}$	38.0 ± 0.3$^{*,\#(1,2,3)}$
Post-bout	37.5 ± 0.3*	37.4 ± 0.2*	37.5 ± 0.2*	37.6 ± 0.3*	38.0 ± 0.3$^{*,\#(1,2,3,4)}$
T_b (°C)					
Pre-WUP	36.9 ± 0.3	36.6 ± 0.3	36.8 ± 0.3	36.8 ± 0.3	36.9 ± 0.3
Post-WUP	37.0 ± 0.3*	36.9 ± 0.2*	37.0 ± 0.4*	37.2 ± 0.3$^{*(1,2)}$	37.5 ± 0.4$^{*(1,2)}$
Pre-bout	37.0 ± 0.3	36.0 ± 0.2*	37.0 ± 0.3*	37.3 ± 0.3$^{*(1,2)}$	37.7 ± 0.4$^{*,\#(1,2,3,4)}$
Post-bout	37.0 ± 0.3	36.86 ± 0.3*	37.0 ± 0.3*	37.2 ± 0.3$^{*(1,2)}$	37.7 ± 0.4$^{*,\#(1,2,3,4)}$

(1, 2, 3, 4) = significantly different from WUP (1, 2, 3, 4) ($P < 0.05$). $N = 9$.
* Significantly different from pre-WUP ($P < 0.05$).
$^{\#}$ Significantly different from post-WUP ($P < 0.05$).

with these differences supported by moderate to large effect sizes. Further, there was a tendency (ES > 0.5) for improved work and greater power output for the first sprint following WUP 3 compared to the other WUP conditions. These results suggest that an intensity performed midway between LI and LT may be the most appropriate for eliciting optimal 6 × 4-s (separated by 21-s) intermittent sprint performance. Interestingly, WUP 3 was of similar intensity (∼55% $\dot{V}O_{2max}$) to the WUP protocols used in other studies that have resulted in improved single sprint performance.[4,10]

While T_b, T_{mu}, and T_{re} all increased significantly post-WUP in all WUP conditions, there were no significant correlations between these temperatures and any of the performance variables assessed. According to Saltin et al.,[24] T_{mu} and T_{re} are directly proportional to the relative workload performed. Further, T_{mu} has been reported to increase rapidly within 5–10 min of the initiation of exercise, while T_{re} increases gradually over a longer period.[24] This temperature pattern was demonstrated in the current study, where T_{mu} and T_{re} increased significantly immediately following WUP's 2–5, with T_{mu} rising at a higher rate compared to T_{re}. While T_{mu} was also significantly higher after WUP 1, it remained below T_{re} reflecting the lower workload employed. Consistent with the previously reported relationship between exercise intensity and temperature, the greater the WUP intensity employed in the present study the higher the T_b, T_{mu} and T_{re} values. Interestingly, lack of significant increases in T_{mu}, T_{re} and T_b in all WUP conditions (specifically WUP 1), coupled with similar performance results between all WUP conditions demonstrates that these temperature increases did not play a significant role in exercise performance outcomes.

In respect to the effect of a specific temperature measurements (T_{mu}, T_{re} and T_b) on exercise performance, it had been previously reported that an increase in T_{mu} (as compared to core temperature), improved sprint cycling performance.[25] Sargeant[26] also described T_{mu} as one of the most important factors influencing the performance of short-term dynamic exercise, with an almost linear relationship observed between T_{mu} and peak power during a 20-s all out effort. Interestingly, this current study found no significant correlations between T_{mu}, T_{re} or T_b and any of the exercise performance variables assessed. Reasons for this outcome are speculative and may relate to the short duration of the intermittent sprint protocol that may have concluded before any significant correlations were achieved. Of further consideration is that any beneficial effect associated with increasing T_{mu} on exercise performance may have been consequently offset by the effects of high intensity exercise, such as the high pre-existing levels of metabolic acidemia, as evident after WUP 5 in this study.

5. Conclusion

Improved intermittent sprint performance, as supported by moderate to large effect sizes, suggests that a WUP performed at an intensity midway between LI and LT (i.e., WUP 3), as indicated by an RPE of ∼11 and a HR of ∼55% of HR_{max}, may represent the best intensity for improving subsequent short-term intermittent sprint performance. This tendency for improvement in intermittent sprint performance following WUP 3 may be important in team-sport games where faster sprint performance can be the difference between a successful or non-successful sporting manoeuvre.

Practical implications

- Performance of a WUP performed midway between LI and LT, as indicated by an RPE of ∼11 and a HR of

~55% of HR_{max} may improve subsequent first-sprint and intermittent sprint performance in team-sport athletes.
- Significant changes in muscle, body and rectal temperatures assessed after various WUP intensities had no effect on subsequent exercise performance.
- Significant differences in post-WUP HR and plasma lactate levels between various WUP intensities did not significantly affect subsequent exercise performance.

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