**Manuscript Title**: The influence of warm-up duration on simulated rugby league interchange match performance.

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## Abstract

**Objective:** The study was conducted to understand the effects of a short (10-minute) and a long (30-minute) duration warm-up on subsequent readiness to exercise and movement during simulated rugby league match play. **Methods:** Using a randomised cross-over design, 13 male rugby players (age: 23.6 ± 4.1 y) completed a 10- or 30-minute warm-up immediately before 2 x 23 min rugby league movement simulation protocol. Comparisons of the responses to the warm-up and during the simulation were made between each trial. **Results:** Total distance, high- and low speed running and tympanic temperature (ES = 0.56 to 20.8) were all higher in the 30 min warm-up, with differences in relative distance and heart rate unclear (ES = -0.36 to 0.06). Differences in participants' readiness to exercise after the warm-ups were unclear (ES = 0.25). Differences between trials for movement characteristics (ES = -0.13 to -0.32), RPE (ES = -0.13 to 0.04) and B[La] after the simulation were mostly unclear, with only trivial changes in high-speed running (ES = 0.08) and a lower heart rate (ES = -0.26) between the two playing bouts after the 30 min warm-up trial. **Conclusion:** Practitioners can use warm-ups between 10 or 30 minutes for rugby league interchange players without any implications for subsequent match running performance.

Key words: Pre-conditioning, intermittent running, collision sport

## Introduction

Intermittent high-speed running, sprinting and tackling together with low speed movements over two 40-minute halves characterise the movements of rugby league (Gabbett, 2005). To manage fatigue-related changes in player performance, teams employ interchange substitutions, who are typically forwards and used twice throughout the match for short periods each of ~20 minutes (Waldron, Highton & Twist, 2013b). The movement characteristics of rugby league interchange forwards show they cover greater distances in relation to time spent playing compared to backs (95 ± 7 $m \cdot min^{-1}$ vs. 89 ± 4 $m \cdot min^{-1}$, respectively; Waldron, Twist, Highton, Worsfold & Daniels, 2011) and they complete a higher number of tackles (20.1 ± 11.3 vs. 10.7 ± 8.0, respectively; McLellan, Lovell & Gass, 2011). Therefore, interchange substitutes experience greater physical demands during their playing time compared to whole-match players.

A warm-up is conducted before most sporting activities to prepare the athlete to perform optimally (Fradkin, Zazryn, & Smoliga, 2010; van den Tillaar & von Heimburg, 2016; Kilduff, Finn, Baker, Cook & West, 2013a). Physiological outcomes of a warm-up include increased body temperature, increased muscle temperature ($T_m$), muscle fibre conduction velocity, muscle activation and positive changes in metabolism such as increased oxygen uptake kinetics (Bishop, 2003; McGowan et al., 2015; Silva, Neiva, Marques, Izquierdo, & Marinho, 2018). For example, increases in body temperature have been shown to result in faster sprints and repeated sprints in team sport athletes (Kilduff, West, Williams & Cook, 2013b; Yanci, Iturri, Castillo, Pardeiro & Nakamura, 2019). Similarly, high intensity warm-ups can alter oxygen uptake kinetics that leads to greater initial oxygen use, reduced anaerobic contribution and a 1-2% improvement during 800 m running time (Ingham et al., 2008). The warm-up might also offer various psychological adaptations, such as an improved readiness to exercise (van den Tillaar & von Heimburg, 2016; Romaratezabala, Nakamura, Castillo, Gorostegi-Anduaga &

Yanci, 2018) and a lower perception of effort during subsequent exercise (van den Tillaar, Vatten & von Heimburg, 2017).

The duration of a warm-up before match play is important and in team sports has been reported to range between 15-45 minutes, with a mean time of ~30 minutes (Towlson et al., 2013; Kilduff et al., 2013b). The warm up time of ~30 minutes is surprising given muscle temperature after a moderate intensity warm-up (80-100% of lactate threshold) is sufficiently increased and at a steady state by ~10 minutes (Bishop, 2003). Overly long warm-ups could unnecessarily prolong the total exercise duration and exacerbate fatigue in subsequent exercise (Mujika, Gonzalez de Txabarri, Maldonado-Martin & Pyne, 2012; Zois et al., 2015). Indeed, given glycogen depletion impairs performance in the latter stages of rugby match play (Bradley et al., 2016; Bradley et al., 2017), starting a match after a longer warm-up could negatively affect running performance towards the end. Studying warm-ups that employ the minimum beneficial duration compared to currently used longer durations of ~30 minutes would offer valuable practical insight to those responsible for pre-match preparation strategies.

While several studies have examined the effects of short compared to long warm-up durations on sport-specific movements (Romaratezabala et al., 2018; van den Tillaar & von Heimburg, 2016; van den Tillaar et al., 2017; Mujika et al., 2012), a limitation of these studies is the use of proxy measures of performance (e.g. jumps, sprints or repeated sprints). The effect of warm-up duration on extended periods of intermittent activity that replicate the movements of match play is unclear (Silva et al., 2018). Therefore, in an attempt to understand the effect of warm-up duration on a rugby league interchange player's subsequent readiness, movement and internal responses to match play, the aim of this study was to investigate the effect of a short (10-minute) and a long (30-minute) duration warm-up performed before a simulated rugby league match.

## Methods

### Participants and study design

With institutional ethics approval from the University of Chester's Department of Sport and Exercise Sciences (SES18-19/24), 13 male trained amateur rugby league players (age: 23.6 ± 4.1 y, stature: 180.4 ± 6.5 cm, body mass: 92.4 ± 15.7 kg, Prone Yo-Yo IR1: 551 ± 148 m) volunteered to take part in the study. All participants provided written informed consent before completing three visits with 7-10 days between each visit. After performing the Prone Yo-Yo Intermittent Recovery Test, participants were habituated with the warm-up protocols, the modified Rugby League Movement-Simulation Protocol for Interchange Players (RLMSP-i; Norris, Highton, & Twist, 2018), measures of counter movement jump (CMJ), blood lactate concentration (BLa), tympanic temperature, subjective ratings of readiness to exercise (RTE) and rating of perceived exertion (RPE). The second visit was 7-14 days afterwards and comprised either the short (10-minute) or long (30-minute) warm-up, depending on the randomisation, and was performed on an outdoor 3G pitch. Environmental conditions were recorded (Oregon Scientific, All Weather 3.0, Oregon, United States) and similar between trials (18.0 ± 5.4 cf. 17.5 ± 6.2°C; humidity 56 ± 9 cf. 48 ± 9%). Participants were asked to arrive in a fed and rested state by avoiding heavy exercise in the 24 hours before each visit, maintain the same diet 24 hours before each trial, to refrain from consuming alcohol 24 hours before testing and not to use any performance enhancing supplements during the entirety of the study. After measures of CMJ and tympanic temperature, participants completed the respective warm-up after which RTE, B[La], tympanic temperature and CMJ jump height was recorded. Participants then completed the RLMSP-i with CMJ and B[La] taken on completion. Visit three occurred 7-14 days after the second visit, where participants completed the alternative warm-up from the second visit using a randomized cross-over design and the same procedures.

## Procedures

*Prone Yo-Yo Intermittent Recovery Test Level 1*

The prone Yo-Yo Intermittent Recovery Test Level 1 (Dobbin, Highton, Moss, Hunwicks & Twist, 2018) required the participant to complete as many 2 x 20 m shuttles in the required time (starting speed 10 $km \cdot h^{-1}$) with speed increased by 0.5 $km \cdot h^{-1}$ every 60 s, until exhaustion. Between shuttles, there was a 10 s recovery where participants walked for 10 m. At the start of each shuttle, the participant assumed a prone position with their head behind the start line and with straight legs. After two failed attempts to reach the start/finish line in the time, the test was terminated, and the participant's total distance was recorded.

*Warm-up and re-warm-up protocols*

The 10-minute warm-up, adapted from Kilduff et al. (2013b), comprised two cycles of jogging, skipping and lateral bounds over a 20 m distance with a walk back to the start/finish line between each exercise. Participants then completed two cycles of high knees, heel flicks, and lunges with a shoulder twist over a 10 m distance with a walk between each exercise, followed by a maximal sprint over 20 m. For the following 2 minutes, participants played a 2 vs. 1 in a 10 x 10 m grid comprising 2 attacking players (participants) with a ball completing as many passes as possible and 1 defender (researcher) with a bump pad trying to inhibit the attackers' progress. This was then followed by 2 minutes of the RLMSP-i (see below) which included two sprints over 20.5 m. For the 30-minute warm-up, the 10-minute procedure was repeated three times. The warm-up was delivered by the same researcher for all participants.

The re-warm-up, taken in the last 4 minutes of the half-time interval of the RLMSP-i, consisted of jogging, skipping and alternate lateral bounds over a 20 m distance, with a walk between each exercise back to the start/finish line, for a period of 2 minutes. For the remaining 2 minutes participants completed high knees, heel flicks and high knee strides with a walk between each exercise back to the start/finish line over a 10 m distance.

*The Rugby League Movement-Simulation Protocol for Interchanged Players*

The RLMSP-i (Norris et al., 2018; Figure 1) comprises two bouts of 23-minute activity, separated by a 15-minute recovery period, to simulate the mean playing time of elite interchanged rugby league players. The simulation consists of sprints, jogging, walking, standing and tackling, designed to reproduce total relative running demands of ~100 $m \cdot min^{-1}$, ~1 physical contact per minute and mean heart rate of 85-90 $\%HR_{max}$ (Waldron et al., 2011). The contact element involved a collision between two participants that were matched for body mass. The contact element comprised one participant performing a defensive tackle on their opponent holding a tackle shield after an 8 m sprint towards the opponent. At point of contact the participant was instructed to wrap their arms around the tackle shield and their opponent and attempt to gain dominance whilst their opponent resisted. After three seconds the researcher called "held" and both participants were instructed to perform a 'flapjack' exercise to replicate the change of orientation associated with completed tackles. The 'flapjack' exercise involved dropping to the prone position on the ground before rolling 360$^o$ to one side and back to the original position before returning to their feet. In the next contact during the cycle, participants alternated roles from offensive (holding the tackle shield) to defensive (performing the tackle). Participants performed 24 offensive and 24 defensive efforts over the duration of the simulation.

***** Insert Fig 1 here *****

*Assessment of external measures*

Movement during the warm-up and RLMSP-i was recorded using a 10 Hz GPS device fitted with a 100 Hz accelerometer (Catapult, Optimeye S5, Melbourne, Australia). Participants were fitted with a vest, holding a GPS unit placed between the scapulae, with the participants using the same GPS monitor for each visit. For the warm-up and RLMSP-i measures of total distance (m), speed ($m \cdot min^{-1}$), low- (<14.0 $km \cdot h^{-1}$), and high-speed (≥14.0 $km \cdot h^{-1}$) distance were recorded. Peak speed ($km \cdot h^{-1}$), taken from the 20.5 m sprint, and speed to contact, taken from the 8 m sprint into the collision, were also measured during every cycle of the RLMSP-i. Heart rate (HR) was recorded throughout the warm-up and RLMSP-i via a HR monitor (Polar Electro, Oy, Finland) integrated with the GPS device. Using the Borg (6-20) RPE scale (Borg, 1970), participants were asked to rate their perceived exertion after the warm-up and after each quartile (i.e. every sixth sprint) of both halves during the RLMSP-i. At the end of both the warm-up and RLMSP-i, a capillary blood sample was taken from each participant and analysed for blood lactate concentration (B[La]) using a portable analyser (Lactate Pro 2 analyser, Arkray. Kyoto, Japan).

*Tympanic temperature*

Tympanic temperature was taken immediately after the warm-up by placing the thermometer (Riester, Rudolf Riester GmbH, Jungingen, Germany) in the right ear of each participant. Tympanic temperature was used to estimate core body temperature and has been previously used in similar studies assessing sport performance (Cook, Holdcroft, Drawer & Kilduff, 2013; Fairbank, Highton & Twist, 2019) as it is known to be both valid (Casa et al., 2007) and reliable (Purssell, While & Coomber, 2009).

*Readiness to exercise*

To assess participants' perceived readiness to exercise (RTE), they were asked to provide a rating between 0-10 (0 = not at all ready and 10 = perfect for playing) on a Likert scale in the 5 minutes after the warm-up before starting the RLMSP-i. This scale has been used previously to assess readiness to exercise before exercise (Romaratezabala et al., 2018).

*Countermovement jump*

Participants performed a maximal vertical jump, after a countermovement, (CMJ) which was recorded using a jump mat (Just Jump, Probotics Inc, Alabama, USA). Participants stood up straight with hands on hips, then with flexed knees to approximately 90 degrees, they extended into a jump. The best jump height (cm) from two trials was used for analysis.

*Statistical analysis*

All comparisons between trials of movement characteristics, muscle function, blood lactate concentration and perceived response during the warm-up and rugby simulation are reported as effect sizes (Cohen's d) and 95% confidence intervals (ES ± 95% CI), with threshold values of 0.0-0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; 1.2-2.0, large; >2.0, very large (Hopkins, Marshall, Batterham & Hanin, 2009). Effects with confidence intervals that crossed a small positive or negative change were classified as unclear. For those wishing to interpret the analysis using a more traditional approach, we provide *p*-values based on appropriate null hypothesis tests, although any ES confidence interval that includes zero can be considered as $p > 0.05$.

## Results

There were very large differences in total distance covered (ES = 20.8 ± 10.49, $p < 0.001$), high-speed running (ES = 8.93 ± 4.57, $p < 0.001$) and low-speed running (ES = 19.2 ± 9.71, $p < 0.001$), all of which were higher in the 30-minute compared to 10-minute warm-up protocol. Small differences in B[La] (ES = -0.58 ± 0.56, $p = 0.33$) and tympanic temperature (ES = 0.56 ± 0.68, $p = 0.08$) were also observed for which values were higher in the 10-minute and 30-minute warm-up protocols, respectively. Differences in speed (ES = -0.36 ± 0.74, $p = 0.30$), HR (ES = 0.06 ± 0.43, $p = 0.762$), and jump height (ES = -0.20 ± 0.75, $p = 0.434$) between warm-up protocols were unclear. All data are shown in Table 1.

***** Insert Table 1 here *****

Differences in participants' readiness to exercise (RTE) after the warm up were unclear between the 10-minute (6.9 ± 1.3 AU) and 30-minute (7.3 ± 2.3 AU) protocols (ES = 0.25 ± 0.88, $p = 0.551$). Data are shown in Figure 2.

***** Insert Fig 2 here *****

Differences between trials were unclear for total distance (ES = 0.11 ± 0.34, $p = 0.607$), speed (ES = 0.11 ± 0.34, $p = 0.603$) and low-speed running (ES = 0.30 ± 0.45, $p = 0.306$), but trivial for high-speed running (ES = -0.07 ± 0.18, $p = 0.492$) and heart rate (ES = 0.24 ± 0.25, $p = 0.175$). There were small and trivial differences between halves for high-speed running (ES = -0.35 ± 0.18, $p = 0.004$) and heart rate (ES = -0.26 ± 0.40, $p = 0.581$), respectively. Differences in total distance (ES = -0.23 ± 0.24, $p = 0.059$), speed (ES = -0.24 ± 0.24, $p = 0.058$), low-speed running (ES = -0.07 ± 0.28, $p = 0.593$) were unclear. Changes between halves by trial in total distance (ES = -0.13 ± 0.54, $p = 0.362$), speed (ES = -0.13 ± 0.54, $p = 0.364$), low-speed running (ES = -0.32 ± 0.68, $p$ = 0.324) were all unclear, while high-speed running (ES = 0.08 ± 0.25, $p$ = 0.365) and heart rate (ES = -0.26 ± 0.40, $p$ = 0.699) were trivial. All data are shown in Table 2.

***** Insert Table 2 here *****

There were trivial to moderate reductions in peak speed (ES = -0.11 to -1.12, $p < 0.001$; Figure 3C) and speed to contact (ES = -0.14 to -0.65, $p$ = 0.157, Figure 3D) during the match simulation. Examining the effect of warm-up on the first quartile of sprint activity revealed differences between the trials were unclear for peak speed (ES = -0.01 ± 30, $p$ = 0.958; Figure 3A) and sprint to contact (ES = -0.17 ± 47, $p$ = 0.456; Figure 3B). Similarly, differences in peak speed (ES = -0.28 to 0.20, $p$ = 0.642; Figure 3C) and speed to contact throughout the simulation (ES = -0.32 to 0.04, $p$ = 0.310; Figure 3D) were unclear between the 30-minute and 10-minute trials. Differences in RPE between trials were unclear at all time points (ES = -0.13 to 0.04, $p$ = 0.689; Figure 4) as were the differences in B[La] after the simulation (3.9 ± 1.8 cf. 3.9 ± 2.5 $mmol \cdot L^{-1}$ for 10- and 30-minute trials, respectively; ES = 0.01 ± 0.52, $p$ = 0.953). Differences in CMJ after the 10-minute (49.1 ± 9.4 cm) and 30-minute (47.3 ± 9.4 cm) trials were trivial (ES = 0.16 ± 0.2, $p$ = 0.116).

***** Insert Fig 3A-D here *****

***** Insert Fig 4 here *****

## Discussion

This is the first study reporting the effect of warm-up duration on readiness to exercise and simulated rugby league match running performance. Despite a greater volume of running performed at the same relative intensity in a 10-minute compared to 30-minute warm-up, subsequent prolonged intermittent running performance and perceived exertion were similar during 2 x 23-minute bouts replicating the movement characteristics of interchange rugby league players. It appears warm-ups of either 10- or 30-minutes duration have a similar impact on subsequent intermittent running performance.

As anticipated, absolute activity and tympanic temperature was higher in the 30- compared to 10-minute warm-up, while the speed (~87 $m \cdot min^{-1}$) and heart rate (~76% maximum heart rate) were similar between trials. These data confirm that the main difference between the trials was the volume of activity performed in the warm-up because of a different duration while the intensity of preparatory activity remained similar. Blood lactate concentration was higher after the shorter warm up (3.2 ± 1.1 cf. 2.0 ± 1.3 $mmol \cdot L^{-1}$), which, although unexpected, was probably influenced by the activity performed immediately before sampling (Impellizeri et al., 2005; Waldron et al., 2013b). Jump height (cm) after the warm-up was similar between trials and suggests that the neuromuscular performance in a single maximal effort jump is not compromised when a warm-up of the same relative intensity is extended from 10 to 30 minutes. During exercise of the same intensity, muscle temperature is likely to have stabilised after ~10 minutes and remained so up to 30 minutes (Bishop, 2003). Therefore, it is unlikely muscle temperature after warm-up exercise of 10 and 30 minutes would be different, hence the similarities in jump performance. This is in contrast to core temperature, which would have likely risen more gradually (Bishop, 2003) and perhaps explains the difference ~0.6°C in tympanic temperature between the warm-ups. Collectively, these data are in contrast to a previous study that report a higher physiological strain on participants after longer compared to shorter warm-ups (Mujika et al., 2012). However, the longer duration warm-up used by Mujika and colleagues was 60 min, twice that of this study’s longer warm-up.

An often overlooked and under-reported evaluation of a warm-up was the participants' perceived readiness to exercise afterwards, that in this study was similar for both the short (6.9 ± 1.3 AU) and long warm-up (7.3 ± 2.3 AU). These findings are in contrast to a previous study using the same scale reporting a better readiness to exercise after a longer (34 minute) compared shorter (17 minute) warm-up (Romaratezabala et al., 2018). However, Romaratezabala and colleagues (2018) used an independent groups rather than the repeated measures study design, meaning our work is better positioned experimentally to examine the effect of warm-up duration. Examining the individual responses (Figure 2) also reveals participants were divided in their perceptions of whether a longer warm-up (54%) was better than the shorter warm-up (46%) in preparing them for the match simulation. That just over half of participants preferred the longer warm-up might be because many were already accustomed to longer warm-up routines in their own pre-match experiences, as those of many team sports, including rugby league, are known to last ~30 minutes (Kilduff et al., 2013b; Towlson et al., 2013). These data highlight the importance and individuality of an athlete's perceived readiness to perform as an outcome measure of a warm-up.

To the authors' knowledge, this is the first study to use a more practically meaningful model to examine the effects of warm-up duration on a rugby league simulation. There was no difference between a 10-minute and 30-minute warm-up for any of the movement, physiological or perceptual measures during the simulated match, reaffirming findings of previous studies using repeated sprint protocols (Taylor et al., 2013; van den Tillaar and Von Heimburg, 2016), sprint and agility tests (Romaratezabala et al., 2018; van den Tillaar et al., 2019), a 3-minute run (van den Tillaar et al., 2017) and repeated explosive tasks (Zois et al., 2011). Observing no differences in the peak speed and sprint to contact in the initial quartile

(~ 5 min) of the simulation (Figure 3A and 3B) enabled more direct comparisons with other studies that have considered the effect of warm-up duration on short-duration sprint activity (Taylor et al., 2013; van den Tillaar and Von Heimburg, 2016; Romaratezabala et al., 2018; van den Tillaar et al., 2019). On an individual level, it appeared that sprint performance in the initial period varied between participants depending on the warm-up duration. Individual data showed that 7 (54%) and 11 (85%) of the participants reported differences in peak speed and speed to contact, respectively, during the first ~ 5 min that were greater than the error in sprint performance (3.7%) for the simulation (Norris et al., 2019). Such data again suggest that the effects of a warm-up duration are individual specific.

Using a longer match simulation also enabled the effects of a longer and shorter duration warm-up on movement characteristics in the later stages of prolonged intermittent running to be examined. It was postulated that longer warm-ups might evoke greater substrate depletion than shorter duration practices manifesting as a reduction in high speed movements towards the latter stages of the simulation. While we observed reductions in high-speed running, peak sprint speed and sprint to contact as the simulation progressed, all of which are characteristics of cumulative fatigue within match play (Waldron et al., 2013a; Kempton et al., 2015), there were no differences in these measures between trials. A longer warm-up, covering greater distance and more high-speed running, therefore had no detrimental effect on subsequent prolonged intermittent running capability of interchange rugby league players when compared to a shorter preparatory period of similar intensity.

This study is not without limitations. Only the effects of warm-up duration on the movement characteristics of interchange players was studied. It is possible that a longer warm-up would have influenced running speed in the second half of match play for whole match players, and future studies should consider the effect of warm-up duration on those playing for 80 minutes, particularly given the importance of muscle glycogen for exercise of this duration (Hawley et al., 1997). Measures of muscle glycogen concentration were also not assessed, which would have enabled conformation of substrate availability before and after the warm up and changes after the simulation. The use of a simulated activity enables a reliable tool to study the effect of warm-up duration on match running performance (Norris et al., 2019) but did not permit examination of the influence on other fundamental elements of match play, such as skill and cognitive loads. Finally, the use of trained amateur rugby players means extrapolation of the findings to elite professional players, who possess better physical qualities, should be done cautiously.

*Practical implications*

Coaches should be mindful that shorter duration warm-ups (i.e. 10 minutes) can be used with interchange rugby players before a match without concern for players being underprepared for the running demands. Conversely, where players or coaches require a more extended warm-up to prepare for a match, durations of up to 30 minutes can be used without any concerns for deleterious effects on subsequent match running performance. Where coaches deliberately alter a player's typical warm-up duration, they might be mindful of the potential impact on the athlete's perceived readiness to perform.

*Conclusion*

This study illustrates no differences in match running performance for interchange rugby league players having completed either 10 or 30-min moderate intensity, match specific warm-up beforehand. Coaches can therefore use similar warm-ups for rugby league interchange players of durations between 10 and 30 minutes without concerns for altered running performance during a subsequent match. Careful consideration of players' individual preferences for warm-up duration should be considered.

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**Table legends**

**Table 1.** Movement characteristics and physiological responses to 10- and 30-minute warm-up protocols. Values are mean ± SD.

**Table 2**. Movement characteristics and physiological responses during the RLMSP-i after 10- and 30-minute warm-up protocols.

**Figure legends**

**Figure 1.** Schematic of the RLMSP-i (not to scale), including the chronological ordering of audio cues. Y = yellow cone; R = red cone; B = blue cone; W = white cone. Taken from Norris et al. (2018).

**Figure 2**. Individual post warm-up readiness to exercise responses for 10- and 30-minute warm-up.

**Figure 3**. Peak speed (A) and speed to contact (B) during the first quartile (T1) of the RLMSP-i. Peak speed (C) and speed to contact (D) for each quartile during 2 x 23 min bouts of the RLMSP-i performed after 10-minute (●) and 30-minute (■) warm-up. T1-T4 and T6-T8 represent quartiles for 1st and 2nd bout, respectively.

**Figure 4**. Rating of perceived exertion (RPE, 6-20) for each quartile during 2 x 23 min bouts of the RLMSP-i performed after 10-minute (●) and 30-minute (■) warm-up. T1-T4 and T6-T8 represent quartiles for 1st and 2nd bout, respectively.

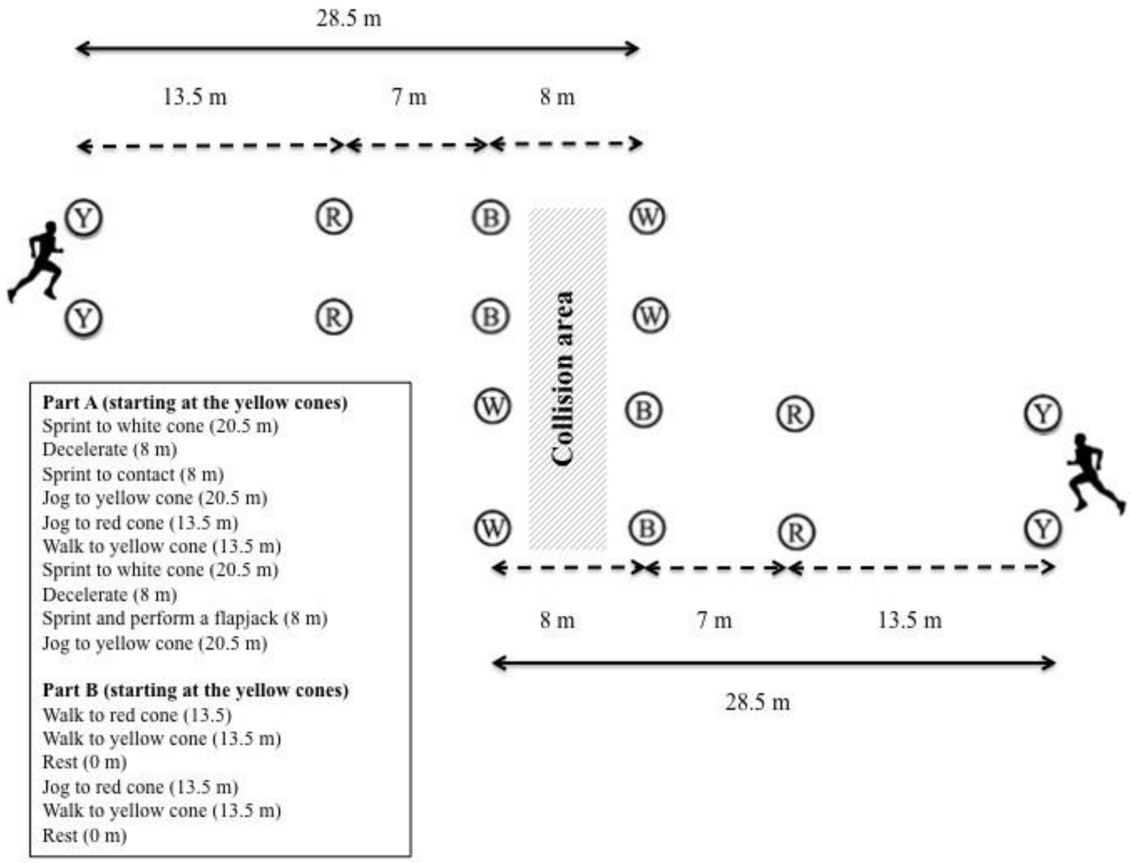
28.5 m
13.5 m
7 m
8 m
Y
R
B
W
Collision area
Part A (starting at the yellow cones)
Sprint to white cone (20.5 m)
Decelerate (8 m)
Sprint to contact (8 m)
Jog to yellow cone (20.5 m)
Jog to red cone (13.5 m)
Walk to yellow cone (13.5 m)
Sprint to white cone (20.5 m)
Decelerate (8 m)
Sprint and perform a flapjack (8 m)
Jog to yellow cone (20.5 m)
Part B (starting at the yellow cones)
Walk to red cone (13.5)
Walk to yellow cone (13.5 m)
Rest (0 m)
Jog to red cone (13.5 m)
Walk to yellow cone (13.5 m)
Rest (0 m)
8 m
7 m
13.5 m
28.5 m

Figure 1

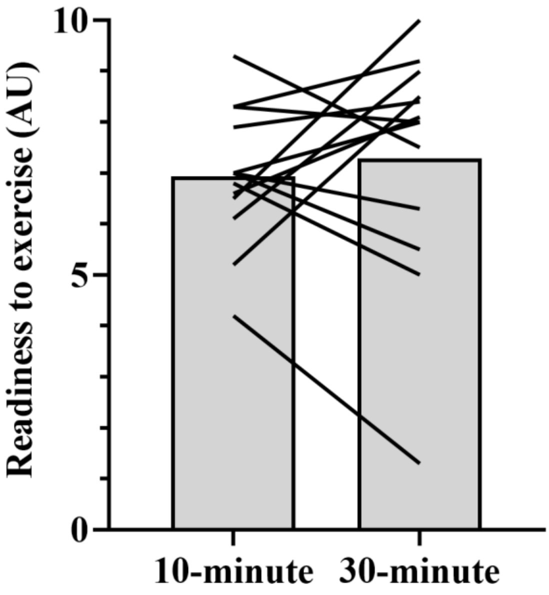


Figure 2

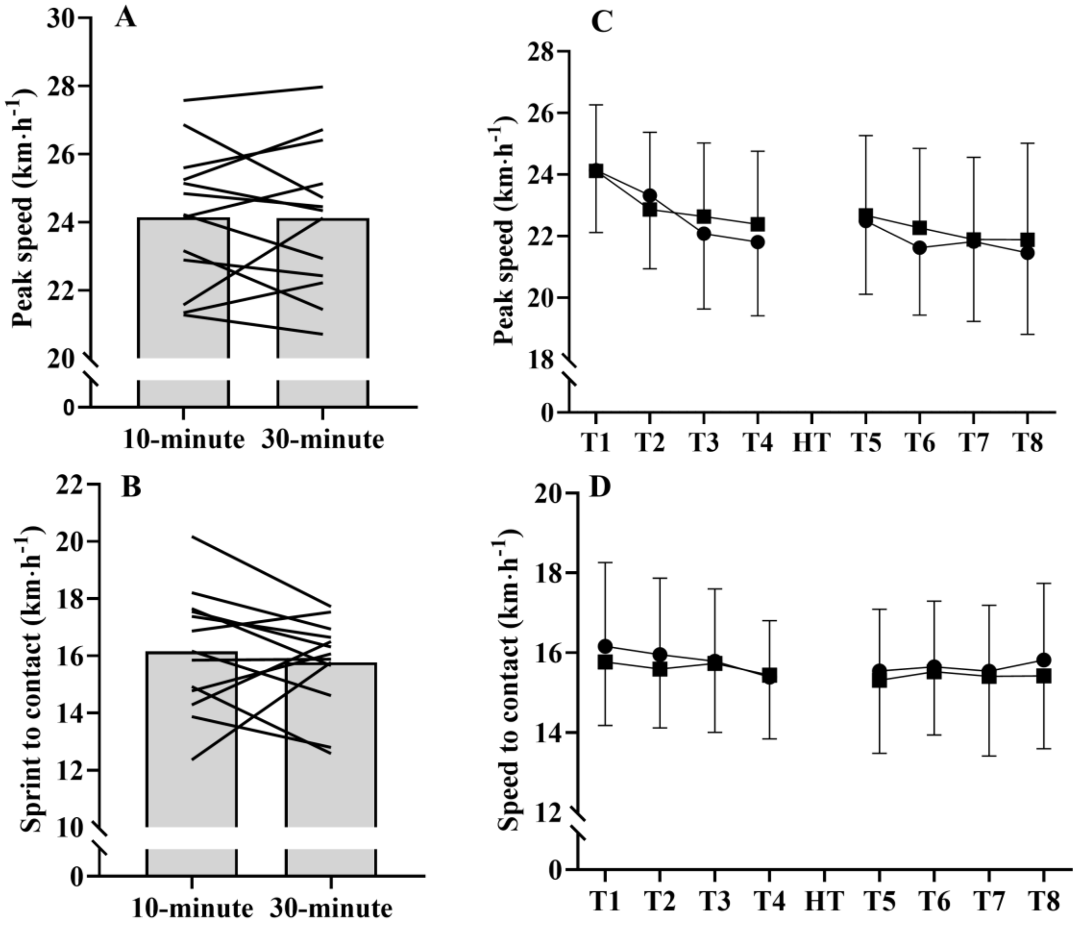
A
Peak speed (km·h-1)
30
28
26
24
22
20
0
10-minute
30-minute
C
28
26
24
22
20
18
0
T1
T2
T3
T4
HT
T5
T6
T7
T8
B
Sprint to contact (km·h-1)
22
20
18
16
14
12
10
0
D
Speed to contact (km·h-1)

Figure 3

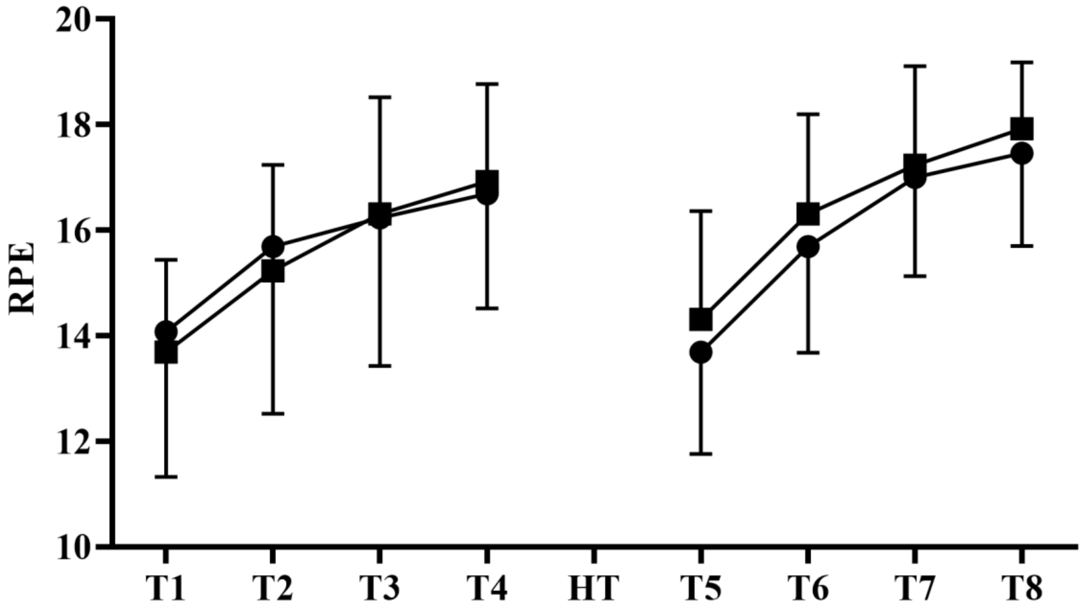


Figure 4

Table 1

| | 10-minute warm-up | 30-minute warm-up |
|---|---|---|
| Total distance (m) | 882 ± 74* | 2561 ± 172 |
| Speed ($m{\cdot}min^{-1}$) | 88 ± 7 | 85 ± 6 |
| High-speed running (m) | 112 ± 20* | 300 ± 52 |
| Low-speed running (m) | 764 ± 70* | 2216 ± 180 |
| Mean heart rate ($b{\cdot}min^{-1}$) | 150 ± 9 | 150 ± 8 |
| Blood lactate ($mmol{\cdot}L^{-1}$) | 3.3 ± 1.6* | 2.3 ± 1.2 |
| Jump height (cm) | 47.9 ± 12.4 | 47.9 ± 9.5 |
| Tympanic temperature (ºC) | 34.4 ± 1.0* | 35.0 ± 1.2 |

*indicates different to 30-minute warm-up

**Table 2**.

| | 10-min warm-up | | 30-min warm-up | |
|---|---|---|---|---|
| | 1st bout | 2nd bout | 1st bout | 2nd bout |
| Total distance (m) | 2440 ± 114 | 2388 ± 113 | 2408 ± 103 | 2388 ± 132 |
| Speed ($m \cdot min^{-1}$) | 106 ± 5 | 104 ± 5 | 105 ± 5 | 104 ± 6 |
| High-speed running (m) | 557 ± 74 | 521 ± 61 | 556 ± 65 | 533 ± 72 |
| Low-speed running (m) | 1883 ± 81 | 1861 ± 90 | 1838 ± 58 | 1846 ± 76 |
| Mean heart rate ($b \cdot min^{-1}$) | 167 ± 10 | 165 ± 9 | 164 ± 9 | 163 ± 7 |