Manuscript title: Passive heat maintenance after an initial warm-up improves high intensity activity during an interchange rugby league match simulation protocol.

ABSTRACT

This study examined using passive heat maintenance to maintain core temperature after a warm-up and its effect on first half running performance in rugby players. Thirteen male rugby players completed this randomized crossover study. Tympanic temperature was taken before a warm-up and then after a further 15 minutes passive recovery either with (PHM) or without (CON) a passive heat maintenance garment. Participants then completed 23 min of the rugby league match simulation protocol (RLMSP-i). Differences in tympanic temperature were unclear between CON and PHM before (35.7 ± 1.3 cf. 36.0 ± 1.1°C; ES = 0.20) and during exercise (34.5 ± 0.1 cf. 35.2 ± 0.1°C; ES = 0.26-0.35). High-intensity running (ES = 0.27) and peak sprint speed were higher (ES = 0.46-0.56) during the PHM compared to the CON trial. Time spent above 20 $W{\cdot}kg^{-1}$ also increased in the first quartile of PHM compared to CON trial (ES = 0.18). All other between trial comparisons of performance were unclear. HR_{mean} (ES = 0.38) was higher in PHM compared to CON, while differences in RPE_{mean} (ES = -0.19) were unclear. There are small to large increases in high intensity work performed during a playing bout when rugby players wear a PHM garment after a warm-up. Rugby players should consider PHM during extended periods of time between a warm-up and starting a match.

Key words: Temperature, intermittent activity, running

INTRODUCTION

Rugby league coaches use interchange players to provide 'impact', whereby these individuals start or are introduced at specific time points to increase the intensity of the match. Interchange players typically perform short bouts (~20 minutes) of exercise that start with a high initial running intensity followed by a rapid decline as an individual fatigues (28). It follows that interchange players must be physiologically prepared before taking the field to meet the physical requirements expected of them, with the musculature of both the upper and lower body fundamental to the running and collision activities associated with rugby league (11).

A 'warm-up' is a series of events typically employed by athletes in preparation for performance. These activities are believed to contribute to improvements in physical performance by initiating several physiological responses, such as an increased intramuscular temperature, an improved capacity for ATP re-synthesis, faster pulmonary and muscle oxygen (O_2) uptake kinetics, an increased blood flow and O_2 delivery to active muscles, and an increase in nerve conduction velocity (for reviews see 1,2,15). Such practices are deemed necessary to ensure an athlete takes to the field physiologically ready to meet the movement demands of competition.

During a professional rugby league match, players are required to re-enter the dressing room after the warm-up, before the start of the match. This period enables coaches to communicate important information relating to tactics and also returns the player's body to a state of homeostasis (3,8). However, after a warm-up, muscle and core temperature can decline rapidly and return to near resting values within 15–20 min (9,10,16,19,31). The rate of decline in muscle and core temperature is influenced by the surrounding environment and can be exacerbated depending on the ambient conditions. Colder ambient conditions result in a faster decline in T_m, due to the steeper temperature gradient owing to the difference between the muscle, skin and ambient air (9,15). A 1°C reduction in muscle temperature is likely to have detrimental effects of ~2-4% on muscle performance (19,25). Therefore, it is important to maintain body temperature in the period between the warm-up and start of exercise.

Several studies have used passive heat maintenance (PHM) strategies to reduce the losses in muscle and core temperature gained after an initial warm-up (9, 10,16,23,30). PHM has also been used to preserve T_c in rugby union players during a 15 min period simulating half time, which attenuated any subsequent temperature-related loss in repeated sprint performance (24). PHM involves the athlete applying an item of clothing designed to maintain elevated temperatures from a prior warm up whilst remaining stationary during recovery. While several studies have observed a positive influence of PHM on maintaining body temperature and performance (16,29,23), a major limitation of these and many warm-up studies is the use of short duration, isolated movements, such as knee extension and repeated sprints, to assess performance. Such movements do not replicate the specific movement characteristics or durations associated with team sports (26), and thus the efficacy of PHM to improve such activities remains unknown.

Given the scope for losses in body temperature after a warm-up and the potential implications for performance, the purpose of this study was to assess the extended effects of wearing a PHM garment after a warm-up on interchange players' movement characteristics during a simulated rugby match.

METHODS

Experimental approach to the problem

Using a randomized crossover design, participants completed a standardised outdoor warm-up after which they immediately entered a temperature controlled changing room adjacent to the warm-up area where the heating cycle was controlled. Participants wore either a passive heat maintenance garment (PHM) or their own playing kit (CON) for 15 minutes before returning outdoors to complete the first half of a simulation protocol designed to replicate the movement demands imposed on interchanged rugby league players (RLMSP-i). Individual testing took place over a 12-day period with three days' rest after baseline measurements and 7-10 days' rest between the CON and PHM trials. All testing was performed at the same time of day (± 1 h) to minimise any effect of diurnal variation and for participants to be in the changing room at the same time of the building's heating cycle. Environmental conditions were recorded throughout the protocol (Digitec, Digitec Corporation, New Holland, PA, USA), with similar environmental conditions in the CON and PHM trials for temperature (12.6 ± 3.8°C cf. 11.5 ± 4.4°C) and relative humidity (54.8 ± 11.4 % cf. 53.5 ± 14.9 %), respectively. Temperature (19.9 ± 1.6°C and 19.8 ±2.6°C) and relative humidity (44.2 ± 7.0% and 46.9 ± 14.6%) were also similar in the changing room for CON and PHM trials, respectively.

Subjects

With institutional ethics approval, 13 male rugby players familiar with the movement demands of rugby league forwards (mean ± SD, age: 19.2 ± 0.8 y, stature: 181.6 ± 64 cm, body mass: 81.3 ± 7.8 kg) volunteered to participate in the study. The participants were asked to refrain from strenuous activity 24 h before each trial and to abstain from wearing any item of clothing that might influence heat loss (e.g. thermal leggings, jumpers and tracksuits). Players consumed their normal pre-match diet before trial one and were asked to repeat this for the second trial.

Procedures

Baseline measurements and habituation

Participants performed the 20 m multi-stage fitness test (MSFT) in an indoor sports hall to ensure they possessed the requisite physical qualities to perform the RLMSP-i. Using the criteria outlined by Waldron et al. (26), participants were required to possess an estimated VO_{2max} >45 $ml \cdot kg^{-1} \cdot min^{-1}$ (Level 9 MSFT). During this visit participants were also habituated to the procedure used for measuring tympanic temperature and completed the standardised warm-up and one cycle of the RLMSP-i.

Passive heat maintenance garment

Participants wore a long sleeved, below knee length jacket with a heavy weight nylon and polyester design (Optimum Sub-Suit jacket, Optimum Ltd, Lancashire, UK), similar to the jacket used previously (16). The quilted design enabled the trapping of warm, still air between the jacket and the participant providing a thermal insulation layer. The garment's outer layer was also waterproof, thus reducing heat loss via latent heat.

Standardised warm-up

The warm-up replicated that adopted by Kilduff *et al.* (16), comprising: jogging, skipping and lateral bounding (each 5 x 35 m), dynamic stretches (high knees, heal flicks, walking leg swings, walking lunges, mountain climbers [each 4 x 30 m]), striding into maximal sprinting (2 x 40 m), and a rolling start maximal sprint (2 x 40 m). The warm-up was performed on a 3G artificial turf surface and was lead by the same researcher on each occasion.

Tympanic temperature

Tympanic temperature was used to estimate core body temperature (Braun IRT6020 ThermoScan 5, Braun, UK), with measures taken before, 15 min after the warm-up (both while seated in the changing room) and at the end of each quartile during the simulation protocol. Tympanic temperature has been used in similar studies (6) to allow participant compliance and is known to be reliable (22), as well as sharing a strong relationship with rectal temperature during exercise (5).

Rugby League Match Simulation Protocol

Participants performed the RLMSP-i on an artificial 3G grass pitch according to the procedures described previously by Waldron *et al.* (27). To avoid the influence of others on an individual's pacing, participants ran alone. Participants' movement speeds were controlled using an audio signal as they moved between coloured cones positioned over a 28.5 m linear track. The audio signal controlling movements are based on the mean speeds and activities of interchange players recognised during elite senior rugby league matches (28,29). The RLMSP-i bout lasted ~22 min, replicating the mean time that an interchange forward spends on the pitch during his first playing bout (28).

Each participant was given specific instructions on how to complete the contact during the RLMSP-i, which was accompanied with demonstrations performed by the researcher during habituation. Contact was simulated with participants tackling a soft, cylindrical shaped tackle bag (Gilbert Rugby, East Sussex, England; mass = 23 kg; dimensions = 138 x 45 cm) at match intensity. The contact began with an 8 m sprint and tackling the bag with the shoulder at around hip height. At the point of contact, the participant was instructed to flex the hips, knees and ankles, whilst keeping both arms wrapped around the tackle bag. The bag was driven to the floor and the participant landed in a prone position, still grasping the bag. Once landed, the participant was instructed to roll 360º laterally one way whilst still holding the bag, touching it on the floor, before rolling laterally 360º back to the original position. The contact was performed once per cycle. Players also performed a 'flapjack' movement once per cycle, requiring the participant to sprint 8 m drop from a standing to a prone position, and roll laterally 360º, before rolling back 360º to the original position and standing up. Each cycle of the RLMSP-i consists of two parts; the first (ball in play) lasting 60.32 s is performed twice and the second (ball out of play) lasting 48.25 s. The order of activity is as follows: 20.5 m sprint, 8 m jog (decelerate), 8 m sprint to contact, 7.0 s simulated contact, 20.5 m jog (ball in play), and 13.5 m walk x 2,13.5 m jog, 13.5 m walk (ball out of play).

Movement demands, heart rate, and RPE during the RLMSP-i

Participants wore the same portable micro-technology device (Optimeye S5, Catapult Innovations, Melbourne, Australia) between the scapulae in an appropriately sized vest. The unit comprised a 10 Hz GPS device integrated with a 6-g tri-axial accelerometer sampling at 100 Hz. Heart rate was collected continuously using a coded HR monitor (Polar Electro Oy, Kempele, Finland), fitted to the chest of the participant, with the mean value (HR_{mean}) used for analysis. Both movement and HR data were downloaded using manufacturer's software (Sprint, Version 5.1, Catapult Sports, VIC, Australia). Data were analyzed for the total bout (21.43 min) and per playing quartile of the RLMSP-i, included: total relative distance ($m \cdot min^{-1}$), relative distance at high- (>14 $km \cdot h^{-1}$), moderate- (7-14 $km \cdot h^{-1}$), low-intensity (< 7 $km \cdot h^{-1}$) and peak running speed ($km \cdot h^{-1}$). To ascertain the effect of the intervention on accelerated running metrics distance at high metabolic power (>20 $W \cdot kg^{-1}$) was also calculated. Rating of perceived exertion (RPE; 4) was taken towards the end of each quartile, during the walking phase and before tympanic temperature was measured. The mean value (RPE_{mean}) was used for analysis.

Statistical Analyses

All data were analysed using the effect size (ES) statistic with 90% confidence intervals (CI) and % change to determine the magnitude of effects using a custom spreadsheet (13). Thresholds for the magnitude of the observed change for each variable was determined as the within-participant standard deviation (SD) in that variable x 0.2, 0.6 and 1.2 for a small, moderate and large effect, respectively (13). Threshold probabilities for a meaningful effect based on the 90% CI were: <0.5% most unlikely, 0.5–5% very unlikely, 5–25% unlikely, 25–75% possibly, 75–95% likely, 95–99.5% very likely, >99.5% most likely. Effects with 90% CI across a likely small positive or negative change were classified as unclear.

RESULTS

Differences in tympanic temperature after the 15 min passive recovery between CON (35.7 ± 1.3°C) and PHM (36.0 ± 1.1°C) trials were *unclear* (ES = 0.20 ± 0.52). Similarly, differences between CON and PHM at quartiles one (34.6 ± 1.2 cf. 35.3 ± 1.9°C, ES = 0.26 ± 0.56), two (34.4 ± 1.8 cf. 35.1 ± 1.9°C, ES = 0.35 ± 0.57), three (34.6 ± 1.8 cf. 35.2 ± 1.4°C, ES = 0.31 ± 0.58) and four (34.6 ± 2.0 cf. 35.1 ± 1.8°C, ES = 0.23 ± 0.47) during the RLMSP-i were *unclear*. All data are shown in Figure 1.

***** Insert Figure 1 here*****

Differences in movement characteristics and physiological responses after the PHM and CON trials are shown in Table 1. Overall high-intensity running was *possibly* higher in the PHM compared to the CON condition (ES = 0.27 ± 0.27). Peak sprint speed was *likely* higher during bouts one (ES = 0.46 ± 0.57), three (ES = 0.47 ± 0.32) and four (ES = 0.56 ± 0.47) during the PHM compared to the CON trial. Time spent above 20 W·kg^{-1} also showed a *possible* increase in the PHM compared to CON trial (ES = 0.18 ± 0.20), with *likely* higher values during bout one (ES=0.50 ± 0.55) of the RLMSP-i (Figure 2). All other between trial movement comparisons were *unclear*.

HR_{mean} (ES = 0.38 ± 0.25) was *possibly* higher in PHM compared to CON, while differences in RPE_{mean} (ES = -0.19 ± 0.41) were *unclear* (Table 1)

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

***** Insert Figure 2 here*****

DISCUSSION

For the first time, we present data on using a passive heat maintenance garment (PHM) between the warm-up and starting prolonged intermittent activity that replicates the movement characteristics of an entire playing bout for an interchange rugby league player. This extends previous studies that have examined the effect of a PHM garment on only a repeated sprint assessment (RSA) (16,23,24). Compared to wearing just playing kit (i.e. control), the use of PHM after a warm up resulted in only small increases in the distance covered at high intensity (>14 km/h), time above high metabolic power (>20 $W{\cdot}kg^{-1}$) and faster peak sprint speeds during simulated match activities for a rugby league interchange player.

Differences in tympanic temperature between the PHM and CON period were unclear. However, tympanic temperature after PHM was higher and the mean magnitude of the difference from the CON trial before exercise commenced (~0.3°C) was similar to values reported previously for team sport players using passive heat maintenance after a warm up (16,23). The measurement of only tympanic temperature might explain the variability in temperature observed between trials. Despite being able to track changes in core temperature over time, tympanic temperature typically underestimates criterion (i.e. rectal temperature) values and is susceptible to variations in air temperature within the ear canal (5). Tympanic temperature was chosen as an estimate of core temperature because of its low invasiveness and ease of use in the field.

While relative distances were expectedly similar between trials, the PHM trial resulted in a small increase in high intensity running. The sprint is the only self-paced element of the rugby simulation protocol, so an increase in sprint speed is likely to have contributed to more running performed above 14 $km \cdot h^{-1}$ during the PHM trial. Indeed, peak sprint speeds were greater during the PHM (7.30 ± 0.2 $m \cdot s^{-1}$) compared to the CON trial (7.20 ± 0.2 $m \cdot s^{-1}$). Temperature-related mechanisms such as the increase in nerve conduction- and transition-rate (18), and an increased capacity for ATP re-synthesis (1,17) have previously been used to explain the improved sprint performance after passive heat maintenance. Given we only measured tympanic temperature, that was not different between trials, measurements of muscle temperature (e.g. 19) would be required to further establish the potential for PHM to influence prolonged intermittent running performance. Given participants were not blinded to the wearing of a passive heat maintenance jacket, we cannot therefore discount the possibility of a placebo effect and that the higher peak sprint speeds during the PHM trial were partly attributed to players knowing they had worn the jacket beforehand (6,26). While isolating the placebo effect is prudent in terms of experimental design and understanding how an intervention works, harnessing the athlete's belief to improve performance might be acceptable in the context of the real world (12).

Metabolic power has recently emerged as an important metric for analysing the movement characteristics of team sport players where multiple changes of direction contribute to an increased metabolic cost of activity (14,20,21). For the first time this study reports the effects of PHM on accelerated running during rugby league specific activity, with small increases in high metabolic power accompanying the increase in high speed running and peak sprint speed. However, improvements in high-metabolic power after PHM were localised to the first quartile of the simulation (Fig 2), which reaffirms previous observations that PHM only benefits the initial bouts of high intensity exercise (16,23). A greater high metabolic power also reflects the increased physiological load as shown with the higher mean heart rate. Regardless, these findings suggest that use of PHM facilitates players investing a greater energy output during a rugby league interchange bout. That the effect only seems beneficial at the outset of exercise is practically useful given these individuals are used by coaches as impact players.

PRACTICAL APPLICATIONS

Rugby players should consider wearing a passive heat maintenance garment in addition to playing kit in the 15 minutes between finishing the warm-up and starting the match, particularly when environmental temperature is low. This cheap and minimally disruptive method will ensure the athlete can complete pre-match routines and receive coach’s tactical briefings while minimising any losses of temperature gained from the warm-up.

CONCLUSION

Compared to wearing just playing kit, the addition of a passive heat maintenance garment in the period between the warm-up and start of exercise offered small improvements in high intensity running performance during a simulated playing bout for an interchange rugby league player. While these changes are small and the mechanisms to explain the improvements in running after passive heat maintenance remain unclear, this preconditioning method has no detrimental effect on players' interchange running performance. A passive heat maintenance strategy should ensure interchange players start the match in a state that allows them to perform more high intensity running activity and higher peak running speed throughout the playing bout. Future studies might further examine the impact of passive heat maintenance on important offensive and defensive skills performed during rugby matches.

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Figure legends

Figure 1. Tympanic temperature (°C) in PHM condition (black circles, dotted line) and CON trials (black triangles, solid line) before and 15 min after the warm up, and during the RLMSP-i. * denotes a small difference. Values expressed as Mean ± SD.

Figure 2. (A) Peak sprint speed ($m \cdot s^{-1}$) and (B) time at high metabolic power (s) in PHM (black circles, dotted line) and CON condition (black triangles, solid line) during stages of the RLMSP-i. * denotes a small difference. Values expressed as Mean ± SD.

Table 1. Movement characteristics and physiological responses to simulated rugby league match play after control (CON) and passive heat maintenance (PHM). Data are mean ± SD for CON vs PHM with % difference ± 90% CI and qualitative descriptor between trials.

	CON	PHM	% Difference ±90% CI	Qualitative interpretation
Relative distance ($m \cdot min^{-1}$)	100.6 ± 5.4	100.2 ± 4.6	-0.4 ± 2.9	*Unclear*
Low-intensity distance (m)	947.5 ± 92.8	920.4 ± 70.5	-2.6 ± 5.2	*Unclear*
Moderate-intensity distance (m)	870.5 ± 118.6	840.5 ± 84.5	-3.1 ± 3.6	*Unclear*
High-intensity distance (m)	618.1 ± 72.8	648.4 ± 88.6	4.7 ± 4.8	*Possibly higher*
High metabolic power >20 $W \cdot kg^{-1}$ (s)	190.4 ± 27.9	196.6 ± 27.2	3.4 ± 3.9	*Possibly higher*
HR_{mean} ($b \cdot min^{-1}$)	169 ± 8	171 ± 8	1.3 ± 2.0	*Possibly higher*
RPE_{mean}	13.0 ± 0.8	12.8 ± 1.2	-2.0 ± 4.4	*Unclear*

Low intensity distance (< 7 $km \cdot h^{-1}$); moderate intensity distance (7-14 $km \cdot h^{-1}$); high intensity distance (> 14 $km \cdot h^{-1}$)

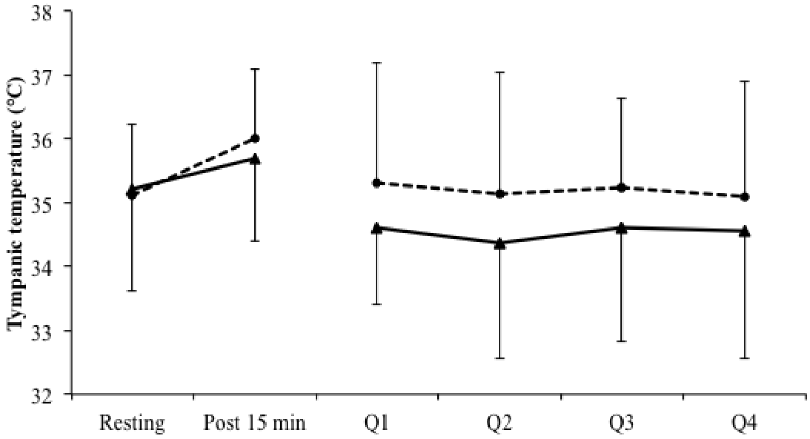
Tympanic temperature (°C)
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Figure 1

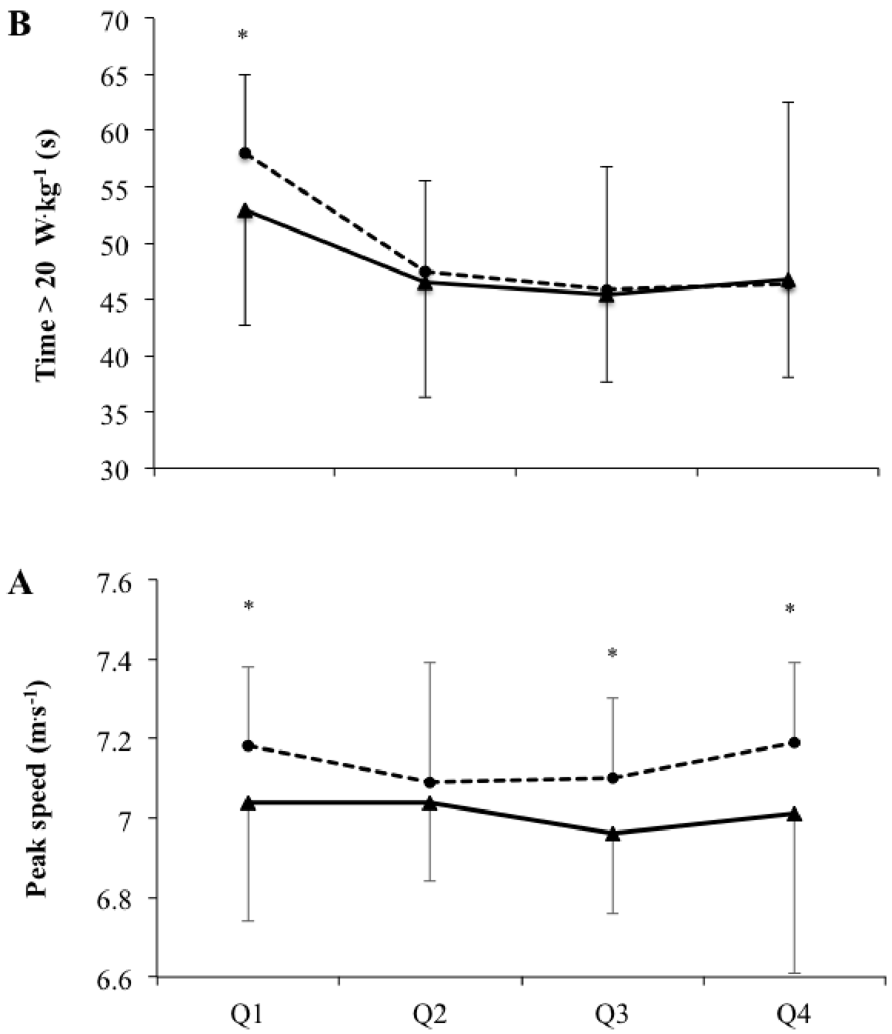

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Figure 2