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EFFECTS OF **SPECIFIC CORE** RE-WARM-UPS ON CORE FUNCTION, LEG PERFUSION AND SECOND-HALF TEAM SPORT-SPECIFIC SPRINT PERFORMANCE: A RANDOMIZED CROSSOVER STUDY

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Running head: Inspiratory-loaded core muscle re-warm-ups

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Abstract

This study examined the effects of a specific core exercise program, as a re-warm-up regime during the half-time period, on inspiratory (IM) and core (CM) muscle functions, leg perfusion and team sport-specific sprint performance in the second half of a simulated exercise task. Nine team-sports players performed a simulated team-sport intermittent exercise protocol (IEP) in two phases, on a non-motorized treadmill, interspersed by a 15-min half-time break. During the half-time period subsequent to the 25-min Phase-1 IEP, the players either rested passively or performed 4-min CM exercise concomitant with inspiratory loaded breathing following 11-min passive recovery. The changes in IM and CM functions, leg perfusion and repeated-sprint ability mediated by the two recovery modes were compared. Following Phase-1 IEP, there was a significant decline in IM and CM functions respectively, revealed by the decreases in maximal inspiratory pressure (P_{Imax}: -8.1%) and performance of a sport-specific endurance plank test (SEPT: -29.7%, $p < 0.05$). With the 15-min passive recovery, the decline in IM and CM functions were not restored satisfactorily (-6.4%, -19.0%, $p < 0.05$). Moreover, repeated-sprint ability during the Phase-2 IEP tended to decrease (peak velocity: -2.3%, mean velocity: -2.1%) from the levels recorded in Phase-1. In contrast, following the re-warm-up exercises during half-time, the restoration of IM and CM function was accelerated (P_{Imax}: -0.9%, SEPT: -3.3%, $p < 0.05$). This was associated with enhanced repeated-sprint ability (peak velocity: +3.0%, mean velocity: +2.0%, $p < 0.05$) in Phase-2 IEP. Nevertheless, the changes in the anterior thigh muscle perfusion assessed by near-infrared spectroscopy following the re-warm-up exercises was not different from that of passive recovery ($p > 0.05$). The findings suggest that a brief inspiratory-loaded CM

exercise regime appears to be an effective re-warm-up strategy that optimizes second-half repeated-sprint performance and core function of players in team sports.

Keywords: repeated-sprint ability, high-intensity intermittent exercise, core stability, inspiratory muscle, fatigability

Introduction

Several intermittent-type team sports (e.g. soccer, handball) are played for between 60-90 min duration, with a half-time break of 10-20 min at the mid-way point (Russell et al., 2015). **Half-time strategies for optimizing second-half performances are essential as passive recovery has been associated with physiological changes, such as decreases in core and muscle temperature, and reduction in blood glucose levels, that may impair both the physical and cognitive performance of players (Mohr et al., 2004, Greig et al., 2007, Lovell et al., 2013a). In fact, the passive half time interval leads to a decrement in the high-intensity running performance and increase in the incidence of muscular injury in the initial 5-15 min of the second half of competitive match-play. This has been reported frequently in professional soccer players (Lovell et al., 2013b).** Currently, strategies associated with the maintenance of physical performance employed during a 15-min half-time break include injury treatment, hydro-nutritional practices and heat maintenance (Russell et al., 2015). **For initiating active recovery in working muscles** and attenuating body temperature loss due to transient drop-off in muscle activity and associated blood flow, actively engaging in specific physical activity, termed as “re-warm-up exercises”, has been suggested (Mohr et al., 2004). In fact, several re-warm-up regimes including a moderate-intensity run, whole-body **vibration** and lower-body resistance exercise have been demonstrated effectively to protect **against** the decrements

in functional ability of the lower limbs and subsequent sprint ability observed under passive control conditions (Mohr et al., 2004, Lovell et al., 2013b, Zois et al., 2013). However, available time and space limit the implementation of such activities in real-game settings (Towlson et al., 2013).

In a sporting environment, core muscles (CM) are commonly referred to as all the muscles between the knee and sternum with a focus on the abdominal region, low back and hip (Fig, 2005). During running exercise when the body is upright, the CM are actively involved in providing torso and lumbopelvic stiffness that helps to optimize running form and support the kinetic chains of the upper and lower extremities (Kibler et al., 2006, Borghuis et al., 2008). Apart from supporting core stability, a substantial portion of the CM, located in the torso, are inspiratory muscles (IM) concomitantly responsible for the breathing movement of the chest and abdomen in meeting the strenuous ventilatory demands (McConnell, 2009). It has been demonstrated that exhaustive high-intensity running exercise reduces the IM and CM function with fatigue, impairing exercise performance (Tong et al., 2014a, 2016). However, whether the re-warm-ups during the half-time break in team sports, observed in a game setting could facilitate the functional recovery of the potential fatigued IM and CM and associated maintenance of the second-half exercise performance have not been investigated.

Recently, a 6-wk functional IM training period, which was composed of four inspiratory-loaded CM exercises, was found to augment the global IM and CM functions in endurance runners, and enhance their running performance (Tong et al., 2016). The performance of such CM exercises at mild intensity with simultaneous inspiratory load was likely to activate the two muscle groups for subsequent exercise readiness (Lin et al. 2007). Such activities might also facilitate the recovery of exercise-induced IM and CM

fatigue due to the previous notion that active recovery performed using the same muscle groups which were active during the preceded fatiguing exercise, compared with that which remained unaffected by fatigue, was more effective in restoring muscle function (Mika et al., 2016). Accordingly, it was reasonable to postulate that a single set of inspiratory-loaded CM exercises, which could be accomplished within a few minutes in a confined space, could be a potential alternative to current re-warm-up strategies to attenuate the possible decrements of IM and CM functions that might occur following the first half of intermittent-type team sports. This strategy may also help to improve blood perfusion in active muscles including the legs, and promote the sprinting ability of the players during the second half (Mohr et al., 2004). The purpose of this study therefore, was to investigate the effect of a single set of inspiratory-loaded CM exercises as a potential re-warm-up strategy in team sports.

Methods

Participants

Nine male college athletes (Table 1), who had received training in different intermittent-type team sports (soccer and handball) for 2-3 hrs·day⁻¹, 3-4 days·wk⁻¹, for at least two years, volunteered to participate in the study. The sample size was estimated based on the assumption that the minimum practical important difference of the repeated-sprint performance was 1.2 ± 1.1% (Buchheit et al., 2009), and the expected typical error (within-subject SD) was 0.8% (Impellizzeri et al., 2008). The use of the acceptable precision a priori in sample size estimation was the approach developed for magnitude-based inferences (Hopkins et al., 2006). A sample size of >7 participants in the present study would provide maximal chances of 0.5% and 20% of type I and type II errors,

respectively. After being fully informed of the experimental procedures and possible discomfort associated with the exercise test, participants gave their written informed consent. Ethical approval for this study was obtained from the Committee on the Use of Human and Animal Subjects in Teaching and Research of Hong Kong Baptist University. The study was conducted in accordance with the Declaration of Helsinki.

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|----------------|
| Insert Table 1 |
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Experimental Design

Participants performed a simulated team-sports intermittent exercise protocol (IEP) on a non-motorized treadmill in two phases [phase one (P1), phase two (P2)], interspersed by a 15-min half-time break, in separate experimental trials. During the 15-min half-time break, the participants performed either an entire 15-min passive recovery (CON) or 11-min passive recovery plus 4-min specific re-warm-up exercises (RWU). The IM and CM functions, leg perfusion and sprint performance at the onset of the P2-IEP following the RWU were compared correspondingly to those in the CON trial.

In the present study, CM function of participants was assessed using a sport-specific endurance plank test developed previously in our laboratory (Tong et al. 2014b). Since the plank test would lead to severe local muscle fatigue in CM that has been shown to impair subsequent running performance (Tong et al. 2014a), the assessments of Pre-P1, Post-P1 and Pre-P2 IM and CM functions in CON and RWU trials were arranged on separate days. For monitoring leg perfusion, near-infrared spectroscopy was adopted. Since cutaneous reflex vasoconstriction and a resultant fall in skin temperature that could potentially occur in the transition from rest to exercise, and might confound the accuracy of near-infrared readings on the target muscles (Torii et al., 1992, Buono et al., 2005),

skin temperature at selected body sites were measured subsequent to every near-infrared measurement for reference purposes.

Figure 1 shows the timeline of Pre-P1, Post-P1 and Pre-P2 measurements in each trial. The order in which the RWU and CON trials were performed was counterbalanced and the assignment of participants to testing protocols was done in a random fashion. In all trials, standardized whole-body warm-up exercises, which comprised of a 5-min motorized-treadmill run, a 10-min period of stretching, and five 6-s non-motorized treadmill runs with velocities ranging from moderate to maximum, were performed prior to the exercise tests. All trials were **completed** under controlled laboratory condition. The mean air temperature and relative humidity (20.0 ± 1.6 °C, $73.5 \pm 3.1\%$) in the laboratory in the CON trials did not differ from those, respectively, recorded in RWU trials (19.5 ± 1.5 °C, $72.8 \pm 1.6\%$, $p > 0.05$). Before each trial, the participants refrained from eating for at least two hours, and from participation in strenuous physical activity for at least one day. All trials were scheduled to occur at the same time of day **to control for diurnal variation effects** and were separated by a minimum of 3 days.

Insert Figure 1

Procedures

Preliminary tests and familiarization trials

Prior to the experimental trials, physical characteristics, including lung function and aerobic capacity were measured. **The details of the measurements of lung function and the aerobic capacity tests have been reported previously (Tong et al. 2001).** Following preliminary testing, participants were familiarized with the measurements of IM and CM functions, as well as the sprint test and the IEP. This familiarization period introduced,

the testing equipment and protocols, as well as providing the participants with the experience of exercising to the limits of tolerance.

Intermittent exercise protocol

The specific IEP performed on a non-motorized treadmill (Force 3, Woodway, USA) was modified from a protocol used for prolonged intermittent-type sport simulation adopted in previous studies (Sirotic and Coutts, 2008). Briefly, the modified protocol was interspersed with six activities including standing still, walking, jogging, running, dashing and sprinting on the treadmill with the brake force set at 2 kp. The velocities for each activity were 0%, 20%, 35%, 50%, 70% and 100% of individual maximal sprint velocity, respectively. The maximal sprint velocity of participants was measured in a preliminary testing trial. The participants performed three maximal 4-s sprints on the treadmill, each separated by 14 s of passive recovery (Zois et al., 2013). The highest velocity of the participants obtained in a single second from the three **sprint** trials was, on average, 5.37 ± 0.33 (range: 4.95-5.83) $\text{m}\cdot\text{s}^{-1}$. Figure 2 shows the IEP of a typical participant. **The duration of P1-IEP was 25.8 min, and included three sets of the repeated-sprint ability test. The order of activities and sprint tests in P2-IEP were identical to those of P1-IEP. The P2-IEP of 7.5 min was terminated following completion of three sets of the repeated-sprint ability test.** The velocity and work of the treadmill exercises during the IEP were recorded at 25 Hz using Force 3.0 software (Woodway, USA). The total work of P1-IEP were recorded in each trial for reliability purposes.

Insert Figure 2

Inspiratory-loaded core muscle re-warm-ups

During the 15-min passive recovery in the CON trial, participants were asked to sit on a bench in a relaxed manner. Water replacement *ad libitum* was administered voluntarily while nutritional supplementation was prohibited. In the RWU trial, the

activities in the first 11 minutes of the 15-min break were identical to those in the CON trial. The specific re-warm-up protocol was performed following the 11-min passive recovery period. Four inspiratory-loaded CM exercises, which are running-specific, have been shown as being effective to exert loading on the two muscle groups (Sander et al., 2013, Tong et al., 2016): These include, (a) Prone kneeling - With hands on the floor, lift the left hand and right knee from a kneeling position and extend the arm and leg until both are horizontal, then return; and (b) Forearm bridging - Maintain a plank position, with the body in a straight line. Brace the abdominal and hip muscles and raise alternately the straightened left and right legs; and (c) Bridge with one leg to lift the pelvis - Lie on the floor with knees bent. One foot is placed on the floor while the other is lifted with hip flexion. Raise up the hips and form a straight bodyline through the knee, then return; and (d) Lateral bridging with alternating leg flexion and extension - Maintain a side-bridge position by placing the feet together and balance on one hand. Brace the abdominal and hip muscles and perform leg flexion and extension alternatively. The four CM exercises outlined were performed for 8 repetitions per side. Related pictures of the exercise have been **provided** previously (Sander et al., 2013). During each CM exercise, inspiratory load was imposed simultaneously using a POWERbreathe IM trainer (Classic L3, POWERbreathe International, UK) at the mouth. The load on the pressure-threshold device was set at 40% of the maximum inspiratory pressure (P_Imax). Participants inhaled forcefully through the device as they initiated the required body actions from the starting position, and exhaled slowly when returning to the starting position.

Repeated-sprint ability test

Three sets of 3 x 4-s all-out sprints on the same Woodway treadmill (brake force = 2 kp), interspersed with 14-s passive recovery, were incorporated at the beginning, and

early stages of the IEP for assessing repeated-sprint ability (Figure 2). For the calculation of peak and mean velocity of each sprint, the start point was standardized to $1 \text{ m}\cdot\text{s}^{-1}$; from this point, a 4-s period was calculated. Acceleration was recorded as the rate of change in velocity in the 0.5 s immediately after reaching a velocity of $1 \text{ m}\cdot\text{s}^{-1}$ (Zois et al., 2013). The average performance of the three sets of repeated sprints were used for analysis. In addition, the sprint decrement score was used to quantify fatigability during the test (Hughes et al., 2006).

$$\text{Sprint decrement score} = 100 - [\text{sum of mean velocity} / (\text{highest mean velocity} \times \text{number of sprints}) \times 100]$$

Inspiratory muscle and core muscle function tests

Global IM function was measured by performing maximal inspiratory efforts at residual volume against a **semi-occluded** rubber-scuba-type mouthpiece with a 1 mm orifice. The maximum inspiratory mouth pressure at quasi-zero flow (P_{Imax} in cmH_2O) provided a surrogate measure of IM strength (Green et al., 2002). The maximal inspiratory efforts were repeated at least 5 times until the results were stable (vary by $<10\%$ in consecutive three maneuvers), and the highest value was recorded for analysis.

Global CM function was assessed by complying with the protocol of the sport-specific endurance plank test (SEPT) reported previously (Tong et al., 2014b). This test requires participants to maintain the prone bridge in good form throughout the following stages with no rest in between: **(a) hold the basic plank position for 60 s; (b) lift the right arm off the ground and hold for 15 s; (c) return the right arm to the ground and lift the left arm for 15 s; (d) return the left arm to the ground and lift the right leg for 15 s; (e) return the right leg to the ground and lift the left leg for 15 s; (f) lift both the left leg and right arm from the ground and hold for 15 s; (g) return the left leg and right arm to the**

ground, and lift both the right leg and left arm off the ground for 15 s; (h) return to the basic plank position for 30 s; (i) repeat the steps from (a) to (i) until the maintenance of the prone bridge failed.

The conditions of the SEPT were standardized by using identical body posture. The distances between the left and right elbows (medial epicondyle), the left and right feet (1st metatarsal), and the elbow and feet on the left and right sides of the body were measured during the familiarization trial while the participants were comfortably performing the prone bridge on a bench. Further, two elastic strings of ~80 cm length which were attached horizontally to a pair of vertical scales were placed beside the bench during the test. The two strings maintained at a distance of 10 cm and were adjusted up and down until a height was reached that was at the same level as the participants' hip (the iliac crest was evenly in between the two strings). This setting acted as a reference for the objective monitoring of hip displacement during the test. The measured distances between the elbows and feet, as well as the hip height, remained constant in subsequent experimental trials. During the assessment, the test administrator sat one meter away from the bench with the seat height adjusted to a level so that the hip displacement of the participants could be monitored horizontally. The participants were then asked to maintain the prone bridge throughout the test with maximum effort. For each time that the hip was beyond either of the reference lines, a verbal warning was given. The test was terminated when the hip failed to be maintained at the required level after receiving two consecutive warnings. The measured time to the limit of tolerance was used as the index of global CM function.

Measurements

Regional oxygen saturation in the leg measured by near-infrared spectroscopy (NIRS, NIRO 200, Hamamatsu Photonics K.K., Japan) was used to monitor leg perfusion at the time points of Pre-P1, Post-P1, Pre-P2. Details of the measurement have been reported previously (Tong et al., 2012). Briefly, the emitting and receiving optodes were positioned on the vastus lateralis of the left leg, at the mid-point of the muscle, along the vertical axis of the thigh. The interoptode space of 4 cm allows measurement to a depth of 2 cm. Skinfold thickness of the participants at the measuring site were 7.7 ± 3.1 mm. The absolute changes (Δ) in tissue oxygenated (HbO_2) and deoxygenated (HHb) haemoglobin concentrations were recorded continuously during the intervention, with respect to an initial value set equal at zero for every 500 ms. The sum of the ΔHbO_2 and ΔHHb , represents the blood-volume index (tHb), and was expressed as percentage of the measured maximum value.

During the IEP at the time points of Pre-P1, Post-P1 and Pre-P2, blood lactate ([La]) and whole-body mean skin temperature (T_{skin}) were measured using YSI 1500 Sport Analyzer (YSI, OH), and Cole-Parmer Scientific Thermistor Thermometer (IL, USA), respectively. The area-weighted T_{skin} was calculated by assigning the following regional percentages: 6% head, 9% upper arm, 6% forearm, 2% finger, 9.5% chest, 9.5% abdomen, 9.5% upper back, 9.5% lower back, 10% anterior thigh, 10% posterior thigh, 9.5% anterior calf, and 9.5% posterior calf (Kenny et al., 2003). Heart rate (HR, Polar HR monitor, Finland), ratings of perceived breathlessness (RPB, Borg scale 0-10) and exertion (RPE, Borg scale 6-20) were also recorded at the same time points, and immediately following each set of repeated-sprint ability tests in each IEP.

Statistical analyses

Data were analyzed using a one-way repeated-measures ANOVA to examine the differences in P_Imax and SEPT between selected time points of different trials, and two-way repeated-measures ANOVA to examine the difference in other variables between selected time points, and across trials. Post hoc analyses for ANOVA using the Bonferroni test for identifying simple main effects were performed when a significant interaction was detected. Intraclass reliability coefficient (ICC) was calculated to examine the reliability of total work between trials. Relationships between variables were determined using Pearson correlation (*r*) test. All results were expressed as the mean \pm SD, and the level of statistical significance was set at $p \leq 0.05$. In addition to this null hypothesis testing, the changes in the variables of IM and CM functions, repeated-sprint ability, blood volume index and skin temperature were also assessed for practical significance using the approach based on the magnitudes of change - magnitude-based inference (MBI) (Hopkins 2009). The probability of the changes being *beneficial (better)* [i.e. greater than the smallest worthwhile change (0.2 of the pooled between-subject SD, based on Cohen's *d* principle)], *trivial (similar)* or *detrimental (poorer)* in variables were calculated. The uncertainty of the changes was expressed as 90% confidence limits (CL). Quantitative chances (QC) for reaching the *beneficial (better)* / *trivial (similar)* / *detrimental (poorer)* effects were assessed qualitatively as follows: <1%, *Almost certainly not*; 1–5%, *Very unlikely*; 5–25%, *Unlikely*; 25–75%, *Possibly*; 75–95%, *Likely*; 95–99%, *Very likely*; >99%, *Almost certainly*. Differences were described as substantial if the probability of a difference was Likely or higher and non-trivial in size. If the 90% CL of a difference spanned the thresholds for the smallest worthwhile beneficial and detrimental effects, the outcome was deemed *Unclear*.

Results

In experimental trials, the total work performed in the P1-IEP were not significantly different (CON_2: 243.9 ±27.6 KJ, RWU_1: 256.1 ±31.9 KJ, CON_3: 255.4 ±30.4 KJ, RWU_2: 251.6 ±33.9 KJ, CON_4: 256.0 ±30.0 KJ, $p>0.05$). The ICC of the total work among the five trials was 0.93 (95% confidence interval: 0.83 - 0.98), suggesting that the performance of the P1-IEP in different trials were highly repeatable.

Table 2 shows the changes in PImax and SEPT among Pre-P1, Post-P1, CON_Pre-P2, RWU_Pre-P2. The interactions of the PImax ($F_{(3,24)} = 9.20, p<0.05$) and SEPT ($F_{(3,24)} = 14.5, p<0.05$) among the four time points were significant. Following the P1-IEP, both PImax and SEPT decreased significantly from the Pre-P1 level ($p<0.05$), and did not recover well within the 15-min passive recovery in the CON trials ($p<0.05$). However, the decreased Post-P1 PImax and SEPT returned to the Pre-P1 level subsequent to the specific re-warm-up exercise in the RWU_1 ($p>0.05$). Such changes in the PImax and SEPT among the different time points were in agreement with the qualitative outcomes of MBI (Table 2), suggesting *Very likely* to *Almost certainly* true changes. Further, the captioned changes in PImax and SEPT at the different time points, expressed as a percentage of Pre-P1 value, were positively correlated ($r=0.66, p<0.05$) in participants.

Table 3 shows the performance of the repeated-sprint variables and the practical significance of the changes in the variables between P1-IEP and P2-IEP in the CON_4 and RWU_2. Significant interactions between the time points and across trials were found in peak ($F_{(1,8)} = 17.3, p<0.05$) and mean ($F_{(1,8)} = 13.9, p<0.05$) velocity, but not in acceleration ($F_{(1,8)} = 1.15, p>0.05$) and sprint decrement scores ($F_{(1,8)} = 0.01, p>0.05$).

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During the P1-IEP, all variables were not significantly different between the CON_4 and RWU_2 ($p>0.05$). During the P2-IEP, the peak and mean velocities in the CON_4 were likely to reduce from the corresponding P1-IEP values but did not achieve significance ($p>0.05$). In contrast, the peak and mean velocities in the RWU_2 increased significantly from that of P1-IEP ($p<0.05$) following the re-warm-up exercise. There was no significant change in the acceleration and sprint decrement score between the two phases in both the CON_4 and RWU_2. Such changes in the repeated-sprint variables were also evident by the MBI qualitative outcomes, suggesting *Likely* to *Almost certainly* true changes. Moreover, when the changes in peak and mean velocities in P2-IEP, were expressed as a percentage of the P1-IEP value, the increase in the peak and mean velocities in RWU_2 were much greater than that in CON_4 (Figure 3). Further, when the relative changes in peak and mean velocities in the CON_4 and RWU_2 were plotted against the Δ SEPT performance and Δ PI_{max} in Pre-P2 relative to Post-P1 values in the corresponding trials (Figure 4), significant inter-individual correlations ($r\geq 0.53$, $p<0.05$) were found.

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| Insert Table 3 |
| Insert Figure 3 & 4 |

The NIRS data shows that the interaction of the changes in tHb was not significant among the time points and across trials ($F_{(2,16)} = 0.18$, $p>0.05$). The tHb at the measuring site of the anterior thigh increased during the P1-IEP ($p<0.05$) and did not change significantly after the 15-min passive recovery in CON_3, as well as after re-warm-up exercise in RWU_1 ($p>0.05$). For the T_{skin} , there was a significant interaction among the time points and across trials ($F_{(2,16)} = 18.6$, $p<0.05$). Pre-P1 T_{skin} decreased significantly after P1-IEP in both trials ($p<0.05$). The decreased T_{skin} returned to the Pre-P1 level in CON_3, but not in RWU_1, after the half-time break. Figure 5 further shows that the skin temperature of all the selected measuring sites at Post-P1 in RWU_1 were significantly lower than the corresponding CON_3 values ($p<0.05$). Such changes in the tHb and T_{skin}

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| Insert Table 4 |
| Insert Figure 5 |

among the different time points were further supported by the qualitative outcomes of MBI, suggesting *Almost certainly* true changes (Table 4).

For the [La], HR, RPB and RPE, the interactions among the selected time points and across trials were not significant ($p>0.05$). The [La], HR, and the perceptual variables increased progressively in the P1-IEP and were restored partially during the 15-min half-time break with either passive recovery or re-warm-up exercise (Table 5). Nevertheless, all the variables at the Pre-P2 in the two trials were a little higher than the corresponding values of Pre-P1, and increased progressively during the P2-IEP.

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Discussion

The major findings of this study were that re-warm ups by performing a 4-min inspiratory-loaded CM exercise during the half-time break of an IEP could accelerate the restoration of the declined global IM and CM functions and enhance subsequent repeated-sprint ability in team-sport players. A brief discussion follows.

In the present study, the IEP performed on a non-motorized treadmill complied with a previous protocol that was designed to simulate the work demands of team sports during participation in field games (Sirotic and Coutts, 2008). The HR of the participants recorded at Post-P1 was ~90% of their maximum HR, and the corresponding RPE and RPB were recorded as being at a 'Very hard' level. Both the physiological and perceptual responses revealed that the IEP was intense to the participants, and the associated rigorous physical demands were somewhat equivalent to those resulting from the original protocol in the previous study (Sirotic and Coutts, 2008), and corresponded to the demands of field games in soccer (Edholm et al., 2015). Regarding the consistency of the P1-IEP of the RWU and CON trials performed on different days, the work done during the P1-IEP

recorded in the separated trials were found to be highly repeatable, suggesting that the six non-motorized treadmill activities interspersed in the IEP were performed by strictly complying with the corresponding preset speed. Further, the HR, LA, and perceptual responses of the participants recorded at Post-P1-IEP were comparable between the RWU and CON trials (Table 2). Accordingly, it is reasonable to presume that the alterations in the targeted muscle functions and perfusion of the participants, as well as their sprint ability, following the P1-IEP were similar across the RWU and CON trials.

It was noted that the IM and CM functions of the participants following the P1-IEP declined markedly by fatigue. The decline in muscle function was restored partially during the subsequent 15-min break. The alterations of the global IM and CM functions were correlated ($r^2=0.44$), and the moderate degree of relationship between the two variables are in line with our previous findings in high-intensity running exercise to exhaustion ($r^2=0.45$) (Tong et al., 2014a), and in specific IM training ($r^2=0.44$) (Tong et al., 2016). Such findings underpin the previous notion of the dual role of the IM in breathing and core stabilization in many daily activities, especially those associated with sports (McConnell, 2009). The current findings suggest that the two musculatures had worked synergistically during the P1-IEP, sharing the intense work load for breathing, and for stabilizing the core that presumably helped to optimize exercise economy (Borghuis et al., 2008). It has been shown that the IM fatigue-induced metaboreflex and resultant mediated sympathetic vasoconstriction in the legs during high-intensity intermittent running is associated with impairment of running performance (Tong et al., 2008, Archiza et al., 2018). In addition, the impaired core function with fatigue during running exercise might result in an unstable proximal base that may compromise the functional movements and loads of the lower extremity, deteriorating running

performance (Tong et al., 2014a). Although the present study did not measure running performance during the later stage of P1-IEP, it is reasonable to presume that decrements in running ability, especially those running events at high velocity, might have occurred in the participants following the P1-IEP.

During the half-time phase of the IEP in the CON trial, the 15-min passive recovery following the P1-IEP appeared inefficient in restoring the IM and CM functions of the participants. Nevertheless, when the participants in the RWU trial performed the brief inspiratory-loaded CM exercises following the 11-min passive recovery with activities including rehydration that were similar to that of CON, accelerated restoration of the IM and CM functions occurred. The accelerated recovery of the fatigued IM and CM following the inspiratory-loaded CM exercises are in line with recent findings that the post-exercise active recovery of working muscles that were already fatigued by preceding exercise, was more effective in fatigue reduction than by working the muscles that were not involved (Mika et al., 2016). However, our current data could not clearly explain the underlying mechanism for the acceleration of functional recovery in the IM and CM. Potentially this endeavor might harness the benefit of a faster clearance of lactate accumulated in active muscles (Taoutaou et al., 1996).

Although the influences of the IM and CM functions on sprint ability have never been studied rigorously, we noted that the rate of restoration of the IM and CM functions during the 15-min break was positively correlated ($r^2=0.28-0.53$, Figure 4) to the increase in sprint ability between the P1-IEP and P2-IEP. It is known that running involves continuous alternate unilateral hip flexion and extension that creates corresponding trunk rotation in individuals in reaction to their leg movement (Schache et al., 1999). The work of CM during running is to stabilize the trunk by absorption of the disruptive torques, and

thus minimizing the diversion of leg force exertion, maintaining a stable and efficient running form (Behm et al., 2009). In this study, it is reasonable to postulate that the accelerated IM and CM function restoration through the specific re-warm-up protocol might have facilitated the creation of a solid base in the lumbopelvic-hip region for working in the P2-IEP. This might optimize energy transfer in relation to the kinetic chains from torso to extremities for subsequent sprints, and allow the sprints to be performed in a more linear manner, improving sprint performance (Kibler et al., 2006, Behm et al., 2009).

Increase in blood flow and associated temperature in leg muscles resulting from the re-warm-up protocol have been shown to be a factor contributing to augmented sprint ability (Russell et al., 2015). However, the current NIRS data did not reveal significant changes in muscle perfusion occurring at the site of measurement of the anterior thigh (Table 4) following the inspiratory-loaded CM exercises in RWU trial. Nevertheless, we noted that the T_{skin} following the re-warm-up protocol in the RWU trial was relatively lower in comparison to the corresponding CON T_{skin} (Table 4). Although the re-warm-up exercises were core specific, skin temperature was relatively lower at all the measuring sites including the core regions and leg muscles (Figure 5). Such response in skin temperature of unloaded body parts are in agreement with a previous finding in a 10-min cycling warm-up exercise (Fröhlich et al., 2015), and was possibly a result of cutaneous reflex vasoconstriction with muscular work (Torii et al., 1992). The resultant redistribution of blood flow from skin to underlying active muscles to meet augmented metabolic demand is a compensatory vasoregulation that occurs immediately in individuals when starting intense dynamic activity (Johnson, 1992). It has been demonstrated that the vasoconstrictor response in the skin vasculature *per se* could lead

to underestimation of the NIRS-measured total hemoglobin concentration, and associated oxygenation of the underlying muscle (Buono et al., 2005). The likely cutaneous vasoconstriction induced by the inspiratory-loaded CM exercises might have confounded the interpretation of the NIRS-derived signal in revealing the potential concomitant changes in the hemodynamics of the active muscles (Ferrari et al., 2011). Whether the specific re-warm-up protocol increases leg muscle blood flow and temperature, which may in part explain the improved sprint ability in the P2-IEP by means of associated enhancements of neuromuscular transmission and contractile function that are crucial during sprint performance (Davies and Young, 1983), awaits further investigation. Nevertheless, there were explicit findings that the sprint decrement score in the P2-IEP was not changed, revealing that RWU did not improve repeated-sprint performance fatigability. The transient RWU effect on sprint performance appeared at the beginning of the P2-IEP were not surprising as the single set of inspiratory-loaded core exercise was not likely to induce any promotion of oxidative phenotype in skeletal muscles that have been identified as crucial adaptive factors for improved repeated-sprint ability (Faiss et al., 2013).

Conclusion

In conclusion, IM and CM functions in team-sport players subsequent to the first half of a simulated team-sport IEP were reduced with fatigue. Passive recovery during the 15-min half-time break did not restore the declined muscle functions, and this was associated with the debilitated sprint performance during the initial stage of second half. Nevertheless, when a re-warm-up protocol by completing four running-specific inspiratory-loaded CM exercises was implemented in the players after passive recovery

for eleven minutes during the half-time break, accelerated restoration of the global IM and CM functions, and associated enhancement of sprint ability in the second half were observed. However, these changes were not concomitant with alterations of leg perfusion revealed by the NIRS-measured tHb.

The present study supports previous notions that passive recovery during the half-time break impairs repeated-sprint ability in the initial stage of the second half during team-sport competition (Russell et al., 2015). The sub-optimal preparation of players for explosive activities in the second half reduce the game tempo that is crucial in determining their competitive edge in game situations (Mohr et al., 2005). However, performing a brief inspiratory-loaded CM exercise during the last four minutes of the half-time break could accelerate the functional recovery and capacity of the global IM and CM, and it is associated with the enhancement of repeated-sprint ability in the second half of the game. While limited time and space are currently seen as the major barriers for the adoption of half-time re-warm-ups as a maintenance strategy of repeated-sprint ability in team sports, the brief inspiratory-loaded CM exercise regime, which could be accomplished within a few minutes in a small space, is a potential alternative to current re-warm-up strategies to optimize the second-half performance in team-sport players.

Key points

- **IM and CM functions of team-sport players were declined after the first half of a simulated team-sport IEP. Passive recovery during the subsequent 15-min half-time break did not restore the declined muscle functions, and this was associated with the debilitated sprint performance during the initial stage of second half.**
- A re-warm-up protocol composed of four running-specific inspiratory-loaded CM exercises carried out in the players after passive recovery for eleven minutes during the half-time break could accelerate the restoration of their IM and CM functions, and retain their sprint performance in the second half.

- The brief inspiratory-loaded CM exercise regime, which could be accomplished within a few minutes in a small space, is a potential alternative to current re-warm-up strategies to optimize second-half performance in team sport.

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Figure legends

Figure 1. The timeline of Pre-P1, Post-P1, and Pre-P2 measurements in the six experimental trials. Pre-P1, Pre-phase one; Post-P1, Post-phase one; Pre-P2, Pre-phase two; P_Imax, maximum inspiratory pressure; SEPT, sport-specific endurance plank test; T_{skin}, whole-body mean skin temperature; tHb, blood volume index; HR, heart rate; [La], blood lactate; RPB, rating of perceived breathlessness; RPE, rating of perceived exertion.

Figure 2. The P1-IEP and P2-IEP of a typical participant. P1, Phase one; P2, Phase 2; IEP, intermittent exercise protocol; P1-IEP activities (duration, frequency, percentage of total time designated to the activity); 1st S, 2nd S, and 3rd S, the three sets of 3 x 4-s repeated sprint ability test.

Figure 3. The changes in peak velocity, mean velocity, and acceleration of the repeated-sprint ability tests between the P1-IEP and P2-IEP in RWU in comparison to that of CON. Error bars indicate uncertainty in the true mean changes with 90% confidence intervals. Trivial areas were calculated from the smallest worthwhile changes. (Peak velocity: mean difference = 5.31%, $\pm 90\%$ CL = $\pm 0.11\%$, QC = 99.9 / 0.0 / 0.1.; Mean velocity: 4.03%, $\pm 0.2\%$, 99.7 / 0.1 / 0.2%; Acceleration: 2.60%, $\pm 9.0\%$, 74.4 / 14.2 / 11.3%)

Figure 4. The percentage change (Δ) in (A) peak velocity, and (B) mean velocity between P1-IEP and P2-IEP plotted against the Δ P_Imax (circle symbols) and Δ SEPT performance (rhombus symbols) between Post-P1 and Pre-P2. \blacklozenge and \bullet are data in RWU trial. \diamond and \circ are data in CON trial. Solid lines are the lines of regression.

Figure 5. The skin temperature of the 12 selected sites measured at the time point of Pre-P2. All the temperature measured in RWU trial were significantly lower than the corresponding values in CON trial ($p < 0.05$).

Table legends

Table 1. Physical characteristics of the participants ($n=9$).

Table 2. Changes in inspiratory muscle (P_Imax) and core muscle (SEPT) functions following P1-IEP (Post-P1), and before P2-IEP in CON (CON_Pre-P2) and RWU (RWU_Pre-P2) trials by comparing with baseline value (Pre-P1) ($n=9$).

Table 3. Changes in repeated-sprint ability between P1-IEP and P2-IEP in CON and RWU trials ($n=9$).

Table 4. Changes in blood volume index (tHb) and whole-body mean skin temperature (T_{skin}) following P1-IEP (Post-P1), and before P2-IEP (Pre-P2) in CON and RWU trials by comparing with baseline value (Pre-P1) ($n=9$).

TABLE 5. The physiological and perceptual responses at Pre-P1, Post-P1, and Pre-P2, and immediate following the three sets of repeated-sprint ability tests (1st S, 2nd S, 3rd S) in each IEP in the CON and RWU trials ($n=9$).

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