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The effectiveness of a practical half-time re-warm-up strategy on performance and the physical response to soccer-specific activity.

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Running head:

The physical response to a half-time re-warm-up strategy in soccer

Key Words:

Jump performance, intermittent activity, Sprint performance, active recovery

Abstract

The aim of this study was to assess the influence of a half-time (HT) re-warm up (RWU) strategy on measures of performance and the physical and perceptual response to soccer-specific activity. Ten male amateur soccer players completed a control (CON) and RWU trial, in which participants completed 60 minutes (4 x 15-minute periods with a 15-minute HT period interspersing the third and fourth periods) of a soccer-specific exercise protocol. The CON trial comprised a passive 15-minute HT period, whilst the RWU trial comprised a passive 12-minute period, followed by a 3-minute RWU. The RWU elicited an improvement in 20m sprint times (*d*=0.6; CON: 3.42 ± 0.20s; RWU: 3.32 ± 0.12s), and both squat (*d*=0.6; CON: 26.96 ± 5.00cm; RWU: 30.17 ± 5.13cm) and countermovement jump height (*d*=0.7; CON: 28.15 ± 4.72cm; RWU: 31.53 ± 5.43cm) immediately following the RWU and into the first 15-minutes of the second half. There were however no significant changes in 5m or 10m sprint performance, perceptions of muscle soreness, or PlayerLoad™. The player’s ratings of perceived exertion were however higher (~2 a.u) following the RWU. The current study supports the use of a HT RWU intervention to elicit acute changes in performance.

Introduction

Soccer matches are commonly divided into two 45-minute halves, separated by a 15-minute half-time (HT) period. Typically, this HT period is reserved for recovery, treatment, and tactical discussion, and is primarily passive in nature (Russell et al., 2015). However, research into elite-level match-play has shown that key performance markers are reduced during the first fifteen minutes of the second half, when compared to the first fifteen minutes of the first half (Bradley et al., 2009; Di Salvo et al., 2009; Lovell et al., 2013). Consequently, it has been suggested that a purely passive HT period may not prove to be beneficial to performance (Mugglestone et al., 2013; Edholm, Krustrup and Randers, 2015; Russell et al., 2015a; Russell at al., 2018). To overcome this issue, the implementation of HT re-warm-up strategies (RWU) have been proposed to offer a method of better preparing the players for the second half of match-play (Russell et al., 2015b).

It has been suggested that although 89% of practitioners acknowledge the potential benefits of a HT RWU strategy, only 58% actually instruct their players to complete one (Towlson, Midgley and Lovell, 2013). This disparity has been attributed to pressured time constraints and reluctance from the head coach/manager to willingly reduce time dedicated to tactical interventions (Towlson, Midgley and Lovell, 2013). Where studies have previously assessed the effectiveness of a HT RWU strategy, there has been no clear consensus on the most beneficial and practical methods. For example, previous studies have identified that both a 5- (Lovell et al., 2007, Lovell, et al., 2013) and 7-minute (Mohr et al., 2004) RWU strategy appear to elicit beneficial changes in performance when compared to a passive HT strategy. However, the duration of these RWU methods is far in excess of what has previously been suggested as a realistic time-frame to be able to implement a RWU strategy, with practioners suggesting the time available would be as little as 3-minutes (Towlson, Midgley and Lovell, 2013). Recently, a 3-minute cycling based RWU strategy was also shown to be as effective as a 7 minute RWU for improving intermittent sprint performance (Yanoaka et al., 2018).

Previous studies have also used methods to RWU players which may practically be difficult to deliver to a whole squad during this constrained time period. For example, previous studies have utilised whole body vibration methods (Lovell et al., 2007, Lovell, et al., 2013), leg press machinery (Zois et al., 2013), and heated garments (Russell et al., 2018). Although these methods are suported with regards to their potential benefits on subsequent performance, the feasability of these methods to be applied to a whole team of players is somewhat questionable. It has been suggested that observed benefits from a HT RWU can be atributed to the ability to elict post activation potentiation (PAP) within the lower limbs of players (Russell et al., 2015b). Heavy resistance exercise are often utilised to elict the most beneficial PAP effects; however, as previously suggested, these methods are not always practical for a HT RWU. Alternatively, both ballistic and plyometric exercises have been shown to elict PAP induced improvements in both sprint and jump performance (Turner et al., 2015), whilst also offering a method which can be adminstered to a whole team during a reduced time frame. In further support of this, a recent review article by Silva et al., (2018) advocates the use of 2-5 minutes of high intensity (> 90% of maximum heart rate) jump and sprint activity as an effective RWU strategy.

Assessing the effectiveness of any within match strategy can present many issues. For example, although the use of actual match-play offers ecological validity, the contextual factors which exist during match play often makes it difficult to attribute changes in physical responses and performance to the application of any intervention

(Edholm, Krustrup and Randers, 2015). It is for this reason that previous studies have often utilised soccer-specific exercise protocols (SSEP) to provide a standardised yet valid response to soccer-specific activity whilst allowing for the assessment of controlled measures (Nicholas, Nuttall and Williams, 2000; Small, McNaughton, Greig and Lovell, 2009; Williams, Abt and Kilding, 2010; Bendiksen et al., 2012).

There is therefore a need to develop a HT RWU strategy that is both time efficient and practically applicable to contemporary soccer, and assess the response to the RWU using a standardised SSEP, and contemporary measures. The aim of this study was to assess the performance, physical, and perceptual responses associated with the completion of an ecologically valid 3 minute HT RWU strategy when compared to a passive HT period. It was hypothesised that the HT RWU would elicit beneifical responses during the intial stages of the second half of the protocol.

Method

Research Design

The experimental research design used in the current study was a within-participants cross-over design to assess changes in physical performance and both the perceptual and physical response to soccer-specific activity. Participants were required to attend for testing on three separate occasions, ensuring that a minimum of 72 hours separated each session (Ispirlidis et al., 2009). The three sessions included a familiarisation trial, and two experimental trials comprising 60 minutes of a SSEP (Lovell, Knapper, & Small, 2008). The experimental trials were completed with a counterbalanced measures design. The standardised activity of the current protocol thus allowed for a direct comparison of the performance, perceptual, and physical response to the completion of a passive HT period (CON trial) and a HT RWU strategy. The dependent variables were chosen to quantify response to the experimental trials by using contemporary measurements which are regularly used in an applied setting (Halson 2014). For example, perceptual measures and heart rate are often used in applied practice to monitor internal load, with modern developments in micro-electrical measurement systems (MEMS) offering methods to quantify external load. It has recently been advocated that MEMS derived accelerometry based metrics could offer reliable methods (Casamichana et al., 2013; Ehrmann et al., 2016) to assess changes in movement efficiency during soccer-specific activity (Page et al., 2015; 2016; 2017), thus providing a method to assess the effectiveness of contemporary interventions such as a HT RWU strategy.

Participants

Ten male amateur soccer players (mean ± SD: age 23 ± 4 yrs, height 182.0 ± 6.4 cm, mass 77.3 ± 7.2 kg) participated in the current study. The sample size selected was identified using an *a priori* calculation from pilot study data. This was identified as being sufficient to provide appropriate statistical power (0.8; p = 0.05) to evaluate the interactions for all independent variables. In addition to weekly matches, participants completed training volumes of ~3-4 hours·week^{-1}. Participants were apparently healthy and were injury-free for a minimum of 3 months prior to testing. All participants provided informed consent before commencing any trials.

A health screening procedure was completed prior to each trial, with this comprising a health and well-being questionnaire and the measurement of resting heart rate (HR) and blood pressure (BP) (Omron, MX3 Plus, Netherlands). Resting values of >90 beats·min^{-1} and >140/90 mm/hg for HR and BP respectively, were contraindications to exercise. The current study was ethically approved by an institutional ethics committee.

Experimental Procedures

All participants were required to complete three separate trials comprising one familiarisation trial, and two separate experimental trials. To remove surface interactions, all trials were conducted on the same indoor playing surface. All testing was completed between 12 and 5pm to mimic regular match-day routines, and to regulate any circadian rhythm variations (Teo, Newton and McGuigan, 2011). Participants were asked to repeat similar nutritional intake, before the second experimental trial, of that which was consumed in the preceding 48 hours of the first trial. Participants were instructed to abstain from the consumption of alcohol (Barnes, 2014), and from performing exhaustive exercise in the preceding 72 hours before a trial.

The familiarisation trial consisted of a 15-minute soccer-specific warm-up routine using the Raise, Activate, Mobilise, and Potentiate (RAMP) method (Jeffreys, 2007), and the completion of a 30-minute bout of a SSEP (Lovell et al. 2007). During the familiarisation trial, the participants were also instructed on the correct use of all testing equipment.

The two experimental trials comprised a CON trial and a RWU trial, the order of which was randomised. Before each trial, a 15-minute RAMP warm-up was conducted, to prepare for the following exercise bout. In an attempt to best replicate typical pre-match practices, a 15 minute period interspersed the completion of the warm up period and the start of each trial. During the CON trial, participants completed the first 45 minutes of the SSEP, followed by a passive 15-minute HT interval. During the HT period participants were instructed to remain seated and consume water *ad libitum*. Total fluid consumption in the first experimental trial was recorded (403 ± 198 ml), and was replicated in the subsequent trial. The RWU trial comprised the same warm-up and first half routine; however, the initial 12 minutes of the HT interval were passive, followed by a 3-minute re-warm-up strategy.

The RWU protocol included a combination of body weight exercises, as well as ballistic and plyometric movements (Russell et al., 2018). The RWU protocol was performed over a 20 m circuit utilising a RAMP method (Jeffreys 2007). The participants were instructed to perform two sets of jogging (40 m) and skipping (40 m), followed by one set (20 m) of each dynamic stretch exercise (knee raises; heel flicks; lateral side lunges; front lunges; high kicks; tuck jumps; and reactive sprints). The movements were performed in tandem with an example being provided by the lead researcher. Following the completion of the aforementioned dynamic stretches, participants completed two sets each of straight sprinting, tuck jump into sprints and reaction sprints (facing opposite way and then turning and sprinting). For both experimental trials, a further 15 minutes of the soccer simulation was then completed following the HT interval. Figure 1 provides a schematic representation of the experimental design and measures.

Soccer Simulation

The SSEP utilised in the current study was the Soccer Aerobic Field Test ($SAFT^{90}$) (Lovell, Knapper, & Small, 2008). The protocol comprised a 20-m agility-based course with slalom training poles positioned at the 2-m, 9-m, 10-m, and 11-m marks. Participants were required to either run backwards or side-step around the 2-m pole, before running forwards and slaloming between the 9-m, 10-m, and 11-m poles at varied intensities. When the participants reached the 20-m marker they were instructed to return to the start at the set intensity whilst bypassing the poles. The locomotive activity associated with the protocol is based on time-motion analysis data obtained from professional match-play, and is controlled through verbal cues on an audio CD. The entire protocol consists of a 15-minute activity profile which can be repeated six times to create a full 90-minute simulation. The current study only repeated the activity profile four times, as performance measures were only assessed in the opening 15 minutes of the first and second half. Comparisons between these two periods can indicate decrements in performance following the HT period (Mohr et al., 2004; Lovell et al., 2007).

Experimental Measures

A tri-axial accelerometer (Kionix KX94; Kionix, Ithaca, NY, USA) recording at 100 Hz was contained within an inertial measurement unit (MinimaxX, S4; Catapult Innovations, Scoresby, Australia), and was housed within a standardised neoprene pouch at the cervical region of the participants spine. Triaxial accelerometry data was continuously recorded during each experimental trial to quantify tri-axial (PL_{total}) and uniaxial PlayerLoad™ in the medial-lateral (PL_{ML}), anterior-posterior (PL_{AP}), and vertical (PL_{V}) movement planes. All PlayerLoad™ measures were calculated using Catapult Sprint software v5.0.9.2 (Catapult Innovations) for the 0-5, 5-10, 10-15, 45-50, 50-55, and 55-60-minute periods of the experimental trials (Figure 1). The PlayerLoad™ metrics and associated calculations have previously been defined in a number of research studies (Boyd et al., 2011; Page et al., 2015; 2016; 2017). Heart rate values were recorded as point readings immediately pre-trial (0 minutes), every 5 minutes in the first 15 minute period of the first half, immediately pre HT, immediately pre second half, and every 5 minutes in the first 15 minute period of the second half.

Three single beam timing gates (Smartspeed, Fusion Sport, Australia), set at a standing torso height were used to assess speed of 5m, 10m, and 20m sprints. Participants were required to perform 3 maximal sprints from a standing position with the front foot placed in line with the first timing gate (Ishøi et al., 2017). Timing started when the participants passed the first timing gate at 0-m and was recorded when they passed each of the subsequent gates. Only the best attempt (least time taken to complete the required distance) was considered for analysis. As illustrated in figure 1, sprint performance was recorded at rest, at 5 minute sections throughout the first 15 minute period of the SSEP, immediately pre- and post HT, and for each 5 minute section of the first 15 minutes of the second half.

Immediately following each of the aforementioned sprint performance assessments, the participants were also required to complete 6 maximal effort jumps (3 x SJ and 3 x CMJ) using a jump mat (Smart Jump, Fusion Sport, Australia). All jumps were standardised by giving participants the same verbal instructions. For the SJ, the participants were initially instructed to move into a squat position with a 90-degree bend at the knee. They were then told to hold this position for a 2 second period, before then performing a maximal vertical jump. The same instructions were provided for the CMJ; however, for these jumps, the participants were told to not hold the squat position and instead instantly initiate the vertical jump. For both types of jumps, the participants were instructed to keep their hands on their hips, and once airborne keep their legs straight until they contact the ground (Arnason et al., 2004; Stølen et al., 2005). For each jumping assessment, only the best attempt (highest jump height) was considered for analysis. A 20 second rest period was allocated between each sprint and jump effort (Russell et al., 2018), thus resulting in a 3-minute testing period for each performance assessment (illustrated in figure 1).

As identified in figure 1, perceptual measures were also recorded as point readings throughout the experimental trials. The perceptual measures comprised the assessment of the participants muscle soreness (MS) and rating of perceived exertion (RPE). The RPE data was recorded using the Borg 6-20 point scale (Borg, 1982) immediately prior to the SSEP, at 5 minute increments throughout the first 15 minute period, immediately prior to HT, and at each 5 minute increment in the first 15 minute period of the second half. To quantify lower limb MS, participants were instructed to perform a single squat down to a position of 90-degrees of knee flexion, before using a marker to draw a straight vertical line on a visual analogue scale (VAS) (Chen and Nosaka, 2006). The VAS scale comprised a 0-10 cm horizontal line, with the words 'not sore at all' at the 0-cm mark and 'very, very sore' at the 10-cm mark. The MS measures were completed at the same time periods as the RPE data, with an additional recording being made immediately prior to the start of the second half.

**Insert figure 1 about here **

Statistical Analyses

The assumptions of the general linear model (GLM) were initially assessed to ensure model adequacy. A 2-way repeated-measures GLM was chosen as an appropriate parametric test to compare differences between trials and measurement points. Where significant main effects and interactions were identified, post hoc pairwise comparisons with a Bonferroni correction were completed. For all significant main effects and interactions, 95% confidence intervals for difference (CI diff) are reported. Partial eta squared values are also reported for all main effects and interactions, with these classified as small (0.01–0.059), moderate (0.06–0.137), and large (>0.138) (Richardson 2011). Additionally, Cohens d effect sizes and 95% confidence intervals (CI) have been calculated to compare all measures recorded between trials. Cohen's d (*d*) effect sizes were calculated using pooled SD data and were classified as trivial (< 0.20 – 0.49), moderate (0.50–0.79) and large (> 0.80) (Cohen, 1992). All statistical analyses were conducted using PASW Statistics Editor 24.0 for Mac (SPSS, Inc, Chicago, IL, USA), with statistical significance set at $p \leq 0.05$. All data are reported as mean ± SD, unless otherwise stated. Except for the PL data (calculated from an average of the first 15-minute measures), between session reliability was assessed using intraclass correlation coefficients (ICC) from the pre-HT measures. The ICC values were then used to calculate the minimal detectable difference (MDD) via the calculation of the standard error of measurement (SEM). SEM was calculated using the formula: $SD\ Pooled\ \times \sqrt{(1 - ICC)}$ (Thomas, Nelson & Silverman, 2005), whilst MDD was calculated using the formula: $MDD = SEM\ \times 1.96\ \times \sqrt{2}$ (Weir, 2005).

Results

Sprint Times

The GLM identified no significant trial*time interaction for 5m ($p= 0.299$; $\eta^2= 0.120$) or 10m sprint performance ($p= 0.293$; $\eta^2= 0.126$); however large η^2 values were observed. As illustrated in table 1, moderate *d* values were observed at 55 minutes into the protocol, with faster 10 and 5m sprint times recorded in in the RWU trial. Likewise, a similar observation was identified at 60 minutes with faster 10m sprint times in the RWU trial. In support of the observed improvements in 5 and 10m sprint performance observed at 55 minutes into the protocol, a significant trial*time interaction for 20 m sprint performance ($p = 0.042$; $\eta^2 = 0.192$) was also identified. The aforementioned differences were all within the range associated with the MDD. The GLM did not however identify a significant main effect for trial (5 m: $p= 0.416$, $\eta^2= 0.075$; 10 m: $p= 0.223$, $\eta^2= 0.160$; 20 m: $p = 0.252$, $\eta^2 = 0.143$) nor time (5 m: $p= 0.751$, $\eta^2= 0.065$; 10 m: $p= 0.741$, $\eta^2= 0.066$; 20 m: $p= 0.086$, $\eta^2 = 0.169$).

** Insert table 1 about here **

Jump Height

As identified in table 2, the GLM identified a significant trial*time interaction for SJ performance ($p= 0.034$; $\eta^2= 0.289$), with significantly higher values recorded at 5 minutes and post-HT in the RWU condition, with moderate *d* values also being identified. These observed differences were however less than the MDD and associated range at 5 minutes but were within the range associated with the MDD post-HT. Moderate *d* values were also recorded at 55 minutes with lower values recorded in the RWU trial when compared to the corresponding measurement point in the other trial; however, again this difference was less than both the MDD and associated range. The GLM did not however identify a significant main effect for trial ($p = 0.250$; $\eta^2 = 0.144$) or time ($p = 0.320$; $\eta^2 = 0.116$).

As identified in table 2, the GLM identified a significant trial*time interaction for CMJ performance ($p = 0.024$; η2 = 0.280), with data recorded Post HT in the RWU trial being significantly higher than the CON trial. This difference elicited a moderate

Cohen's *d* effect size and a difference greater than the MDD. The GLM also identified a significant main effect for trial ($p = 0.040$; $\eta^2 = 0.389$), but not for time ($p = 0.053$; $\eta^2 = 0.226$).

** Insert table 2 about here **

Heart Rate

As identified in table 3, the GLM identified a significant trial*time interaction for average HR ($p < 0.001$; $\eta^2 = 0.824$), with data recorded at Post HT in the RWU trial being significantly higher than the corresponding time point in the CON trial (*d*= 5.8). When comparing between trials, there were some moderate and large *d* values observed pre-intervention; however, the differences were lower than the MDD and associated range. The GLM did not identify a significant main effect for trial ($p= 0.453$; $\eta^2= 0.064$); however, as identified in table 3, there was a significant main effect for time ($p< 0.001$; $\eta^2= 0.581$).

Perceived muscle soreness

As identified in table 3, the GLM identified no significant trial*time interaction ($p = 0.668$; η2 = 0.075) recorded between trials; however, at post HT, a moderate *d* value was observed, with higher values recorded post-HT in the RWU trial. This difference was however less than the MDD and associated range. The GLM did not however identify a main effect for trial ($p = 0.191$; $\eta^2 = 0.182$), but there was a significant main effect for time ($p = < 0.01$; $\eta^2 = 0.688$) with the MS data increasing across each trial.

** Insert table 3 about here **

Rating of Perceived Exertion

As identified in table 3, the GLM identified a significant trial*time interaction for RPE ($p= 0.035$; $\eta^2= 0.301$), with data recorded at 50 minutes, 55 minutes, and 60 minutes in the RWU trial being significantly higher than the corresponding time points in the CON trial. These differences also elicited moderate and large *d* values, with the differences also being greater than the MDD. The GLM did not identify a significant main effect for trial ($p= 0.105$; $\eta^2= 0.265$); however, there was a significant main effect for time ($p< 0.001$; $\eta^2= 0.786$), with values increasing across measurement points.

** Insert figure 4 about here **

PlayerLoad^{TM} Metrics

As identified in table 4, the GLM identified no significant trial*time interaction for PL_{AP} ($p= 0.199$; $\eta^2= 0.207$), PL_{ML} ($p= 0.210$; $\eta^2= 0.222$), PL_V ($p= 0.976$; $\eta^2= 0.026$), and PL_{Total} ($p= 0.497$; $\eta^2= 0.130$). There was also no significant main effect for trial observed for PL_{AP} ($p= 0.477$; $\eta^2= 0.088$), PL_{ML} ($p= 0.526$; $\eta^2= 0.070$), PL_V ($p= 0.615$; $\eta^2= 0.045$), and PL_{Total} ($p= 0.811$; $\eta^2= 0.010$). With the exception of the PL_V ($p= 0.015$; $\eta^2= 0.361$) data, there was also no significant main effect for time observed for the other PL metrics (PL_{AP}: $p= 0.312$; $\eta^2= 0.172$; PL_{ML}: $p= 0.177$; $\eta^2= 0.264$; PL_{Total}: $p= 0.171$; $\eta^2= 0.218$). For all PL metrics, small *d* values were observed at all between trial measurement points.

** Insert table 4 about here **

Discussion

The aim of the current study was to investigate the influence of a 3-minute HT RWU strategy, when compared to a passive HT period in relation to both physical performance and the perceptual and physical response to soccer-specific activity. In support of the study hypotheses, the HT RWU strategy did elicit significant improvements in 20 m sprint, SJ height, and CMJ height performance. Improvements in both 5m and 10m sprint performance were also observed following the HT RWU, with moderate effect sizes being identified. Both HR and RPE ratings were found to be significantly higher immediately following the completion of the HT RWU protocol, with the RPE measures also being remaining significantly elevated throughout the first 15-minute period of the second half. There were however, no significant differences in MS ratings and PlayerLoad^{TM} following the HT RWU.

The current study was novel in its design by including performance, physical, and perceptual response measures at 5-minute periods across the first 15 minute period of each half. The use of a SSEP allows for additional measures to be recorded whilst maintaining methodological rigour. A previous study by Lovell et al., (2013b) utilised the same SSEP to assess the effectiveness of different HT RWU strategies; however, the authors only considered performance effects over 15 minute epochs, thus potentially missing performance benefits that occur over shorter periods. In contrast with the study by Lovell et al., (2013b), the current study identified improvements in sprint performance following the HT RWU. Significantly faster 20m sprint times were identified at 55 minutes, likewise, although not statistically significant, moderate *d* values were observed for both 5 and 10m sprint time at 55 minutes and for 10m and 20m sprint times at 60 minutes. These data therefore suggest that the HT RWU strategy utilised in the current study was therefore beneficial for sprint performance;

however, these differences were not evident immediately following the RWU and, with the exception of the 10m sprint times, were not evident 15 minute post HT. Acknowledging differences in methods between studies, the current data is in support of previous studies which have identified improved sprint performance following a HT re-warm-up intervention (Mohr, Krustrup, Nybo, Nielson, and Bangsbo, 2004; Towlson, Midgley and Lovell, 2013; Edholm, Krustrup and Randers, 2015; Yanoaka et al., 2018). The lack of observed improvement in sprint performance at 50 minutes may be due to the mechanisms associated with the observed performance benefit at 55 and 60 minutes. For example, it has previously been suggested that a prior bout of high intensity activity and plyometric type movements may elicit a post activation potentiation (PAP) effect on sprint performance; however, this response takes ~7 minutes to materialise (Healey and Cormyns 2017). This could therefore explain the observed response 10-15 minutes post RWU intervention.

Sprint performance has previously been acknowledged as having large implications for match-performance, with Faude, Koch, and Meyer (2012) identifying that 45% of goals scored in the German first division were preceded with straight line sprints. The observed improvements in sprint performance identified in the current study could therefore have potential implications for improved performance during actual match-play. Likewise, when considering that the initial stages of the second half of match play have been associated with reductions in locomotive activity (Towlson, Midgley and Lovell, 2013); the observed improvements in sprint performance could have potential performance benefits. The mechanisms behind the observed responses have not however been considered in the current study. For example, previous studies have examined core muscle temperature as a potential mechanism to explain observed changes in performance (Mohr et al., 2004; Lovell, Midgley, et al., 2013). Likewise, alterations in oxygen uptake, blood flow, and neuromuscular function have also been proposed as other possible mechanisms (Hodgson, Docherty and Robbins 2005).

In support of the performance benefit observed in the sprint data, both the SJ and CMJ performance was improved during the Post HT assessments. Significantly higher jump height was also identified at 5 minutes during the RWU trial; however, these differences were less than the range associated with the MDD. This observed difference in the first half may be a result of slight differences in pre-trial practices between trials; however, these observed differences in the first half were not evident at HT, with the protocol seemingly reducing performance to the same absolute thresholds. The immediate improvement in jump performance was not however maintained throughout the first 15-minute period of the second half, with SJ performance in the RWU trial actually being reduced with moderate effect sizes at 55 minutes when compared to the control trial. The observed immediate improvements in jump performance may be attributable to the warm up having a beneficial effect when compared to passive rest; however, the lack of maintenance associated with this performance improvement may be due to the body weight plyometric elements of the RWU eliciting a limited PAP effect on jump performance (Tillin and Bishop, 2009). Likewise, although not supported by the sprint data, the observed response with the jump data may be due to a potential fatigue response as a result of the RWU.

It has previously been suggested that when compared to body weight exercises, heavy resistance exercises may result in an increased PAP effect (Edholm, Krustrup and Randers 2015). As such, further improvements in jump performance could potentially be achieved via the manipulation of the current RWU protocol. It should however be acknowledged that the current RWU method was developed to incorporate limited equipment, thus increasing potential practical application. The performance level of the current participants may also be a factor, with previous literature identifying that more elite players possess increase fatigue resistance and the ability to better elicit a PAP effect in performance (Tillin and Bishop, 2009). As such, future research should consider these and other RWU methods with alternative populations. Adaptations of the current protocol to include exercises which provide greater muscular stimulation, or with the addition of resistance, such as, but not limited to, weighted vests or sand bags, could increase the chances of inducing additional performance benefits. However, practitioners should always be conscious of the practical application of any intervention.

In relation to the HR data, not surprisingly, the current study identified significantly higher HR data immediately following the HT RWU. This response was however not apparent during the first 15 minute of the second half, with higher HR values actually being recorded in the CON trial at all second half measurement points, with moderate effect sizes observed at 60 minutes. These data therefore suggest a lower physiological response following the RWU; however, this should be considered with caution when considering large and moderate effect sizes were also observed in the first half between trials. With the exception of the post-HT measures all other differences were lower than the MDD and associated range. In support of the elevated HR response observed following the HT RWU, the current study identified an elevated RPE response across the first 15 minutes of the second half of the RWU trial. In support of previous literature (Yanoaka et al., 2018), these data therefore suggest that even with improvements in selected performance measures, the perceived exertion of the players is increased, thus suggesting an offset in the perceived fatigue and preparedness at the beginning of the second half. This response could in turn have a negative influence on performance through potential pacing strategies and subconscious down regulation

(Noakes, St. Clair Gibson and Lambert, 2004; St Clair Gibson et al., 2006; Sampson, Fullagar and Gabbett, 2015). These data also suggest that the observed performance benefits may not be a result of the player's perceptual benefit of the HT RWU. It could however be suggested that any further improvements or maintenance of performance may have been subsequently hindered by the participants increased perception of effort. The observed increase in RPE may be attributable to the non-familiar nature of the HT RWU strategy.

The PlayerLoad™ data was not significantly different between conditions, thus suggesting that although the total work load is increased with the inclusion of a HT RWU, movement efficiency is not altered following the HT period. A potential factor that has been previously stated as a reason not to implement a RWU, is to avoid unnecessary player fatigue (Towlson, Midgley and Lovell, 2013). The data provided from this study may help to overcome these perceptions. For example, although the participant's RPE was elevated following the HT RWU, performance, movement efficiency, HR, and perceived muscle soreness were either improved, or were not significantly different in the initial stages of the second half.

Although the authors have tried to conduct a study utilising measures and methods which could easily be utilised in applied practice, a potential limitation of the current study is that the mechanisms behind the observed responses have not been considered. An additional limitation is that the observed response is potentially specific to the current methods utilised in this study. As such, future research may want to consider alternative RWU methods or applying similar methods to other participant groups. Alternative RWU methods may want to consider the use of exercises that promote increase muscular simulation and/or additional resistance to try and develop a further increased performance effect. Any future manipulation of the current RWU method should however be completed with the consideration that it needs to be practically relevant and administered in a time frame that has been identified as feasible during a HT period.

Conclusion

The current study identified immediate increases in SJ, CMJ, and 10 and 20m sprint performance following the completion of a 3-minute RWU. Additional performance benefits were also identified for 5, 10, and 20m sprint performance at 10 minutes into the second half, and for 10 and 20m sprint performance 15 minutes into the second half. These data therefore suggest that the current RWU strategy elicit performance benefits during the initial stages of the second half of match-play. The discrepancy in the rate of development and maintenance of these performance responses appears to suggest differences in the mechanisms associated with these observations; however, these mechanisms have not been considered in the current study. Nevertheless, the current study suggests that the current RWU strategy is beneficial for soccer performance, especially when considering the typical reduction in workload following a passive HT period, and the association between successful jumping and sprinting performance for goal scoring opportunities in soccer.

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Figure legends

Figure 1 Schematic representation of the experimental design, durations, and measures. Vertical arrows depict point measurements, and horizontal arrows depict values recorded continuously. The zoomed image depicts a representation of the HT procedures.