Scand J Med Sci Sports 2011
doi: 10.1111/j.1600-0838.2011.01353.x

SCANDINAVIAN JOURNAL OF
MEDICINE & SCIENCE
IN SPORTS

Effects of different half-time strategies on second half soccer-specific speed, power and dynamic strength

R. Lovell[1], A. Midgley[1], S. Barrett[1], D. Carter[1], K. Small[2]

[1]Department of Sport, Health and Exercise Science, University of Hull, Hull, UK, [2]Quality Group of Sport & Physical Activity, University of Cumbria, Lancaster, UK
Corresponding author: Dr Ric Lovell, Department of Sport, Health & Exercise Science, University of Hull, Cottingham Road, Hull HU6 7RX, UK. Tel:+44 1482 463431, Fax:+44 1482 463855, E-mail: R.J.Lovell@hull.ac.uk

Accepted for publication 23 May 2011

This study compared the effects of whole body vibration (WBV) and a field-based re-warm-up during half-time (HT) on subsequent physical performance measures during a simulated soccer game. Ten semi-professional male soccer players performed 90-min fixed-intensity soccer simulations (SAFT^{90}), using a multi-directional course. During the HT period players either remained seated (CON), or performed intermittent agility exercise (IAE), or WBV. At regular intervals during SAFT^{90}, vastus lateralis temperature (T_m) was recorded, and players also performed maximal counter-movement jumps (CMJ), 10-m sprints, and knee flexion and extension contractions. At the start of the second half, sprint and CMJ performance and eccentric hamstring peak torque were significantly reduced compared with the end of the first half in CON ($P \leq 0.05$). There was no significant change in these parameters over the HT period in the WBV and IAE interventions ($P > 0.05$). The decrease in T_m over the HT period was significantly greater for CON and WBV compared with IAE ($P \leq 0.01$). A passive HT interval reduced sprint, jump and dynamic strength performance. Alternatively, IAE and WBV at HT attenuated these performance decrements, with limited performance differences between interventions.

There is a growing body of literature that has reported a decrement in the physical performance of soccer players during the initial phase of the second half of competitive match-play. The total distance covered (Bangsbo et al., 1991; Weston et al., 2011) and the distance covered at high speed (Bradley et al., 2009; Weston et al., 2011) have been shown to be reduced in the first 15 min of the second half in comparison with the corresponding period of the first half. Similarly, Mohr et al. (2003) observed a decline in the distance covered at high speed in the first 5 min of the second half in comparison with the same period of the first half.

The reason for this reduced physical performance after the half-time (HT) interval has been suggested to be a consequence of a lack of preparation for the second half (Mohr et al., 2004; Lovell et al., 2007), as the players routinely perform a pre-match warm-up before the start of the game, but not before the second half. As such, the 2.0 °C reduction in muscle temperature (T_m) observed after the HT interval (Mohr et al., 2004) has been purported as the primary mechanism, since an increased T_m results in increased neural potentiation (Gray et al., 2006) and subsequently improves high-intensity exercise performance (Sargeant 1987; Stewart & Sleivert, 1988; Mohr et al., 2004). Furthermore, this period of play has also been associated with an increased incidence of muscular injuries (Hawkins & Fuller, 1996; Rahnama et al., 2002) that have also been linked to a reduced muscle temperature (Agre, 1985; Safran et al., 1988). In soccer players, hamstring strains are the most common injury reported (Árnason et al., 1996; Woods et al., 2004), with common etiological factors including muscle fatigue (Rahnama et al., 2002, 2003) and inadequate warm-up (Safran et al., 1988). Both of these factors result in muscle strength deficiency, which has been proposed to increase susceptibility to injury (Rahnama et al., 2003). Since 45 min of simulated soccer match-play has induced lower limb muscle fatigue and imbalance (Small et al., 2010), and a passive HT interval reduces T_m (Mohr et al., 2004), it is surprising that to date studies have not assessed the impact of HT re-warm-up strategies on muscular strength.

Regardless of any tactical alterations or pacing strategy that may also affect the tempo of the game, it is clear that players are physically sub-optimally prepared subsequent to a 15-min passive HT interval. Research has shown that sprinting performance (Mohr et al., 2004) and soccer-specific endurance (Lovell et al., 2007) are decreased after a passive HT interval. However, when a moderate-intensity (~ 70% heart rate maximum) active re-warm-up was undertaken by the players for the final 7 min of HT, these performance decrements were abolished (Mohr et al., 2004; Lovell et al., 2007). However, the data from the Mohr et al. (2004) study were recorded during a non-competitive match. While this methodological approach provided a high degree of ecological validity, the internal validity in a field based setting could be questioned given the high degree of match-to-match variability in high-speed activities (~ 16–30%, Gregson et al., 2010). Furthermore, the intermittent nature of soccer match-play causes players to experience "temporary fatigue" after short-term intense periods (Mohr et al., 2003; Krustrup et al., 2006; Bradley et al., 2009), and a degree of inter-player variation in high speed running exists due to positional demands (Bradley et al., 2009; Gregson et al., 2010). Accordingly the physiological status of the players in the Mohr et al. (2004) study is likely to have been variable during sprint performance testing at the end of the first half. Therefore, laboratory-based studies using standardized soccer match-play simulations are warranted to isolate the effects of different HT re-warm-ups on aspects of physical performance.

The application of re-warm-ups at HT is challenging at the professional level due to governing body regulations, for example, the English Premier Leagues Pitch Protection Policy only permits substitutes to use the playing surface during the HT interval. As such, practical dressing-room-based interventions such as acute whole body vibration (WBV) exercise might be more appropriate in these settings. WBV exercises have been shown to increase acute maximal power (Torvinen et al., 2002; Cochrane & Stannard, 2005), with an observed residual effect of up to 5 min (Bosco et al., 1999). This enhanced muscle power is thought to be produced via improved neuromuscular functioning (Cardinale & Bosco, 2003; Rittweger et al., 2003), and an elevated T_m, the latter of which is generated at a greater rate than during steady-state moderate intensity exercise (Cochrane et al., 2008).

Therefore, the purpose of this study was to investigate the effects of a soccer-specific re-warm-up and acute intermittent WBV exercise during HT on subsequent explosive physical performance and the physiological responses during a simulated game under laboratory controlled conditions.

Materials and methods

Ten male semi-professional outfield soccer players (mean: age 20 ± 1 years; height: 1.83 ± 0.09 m; weight 79.9 ± 7.0 kg; VO_{2max} 60.5 ± 4.2 mL kg^{-1} min^{-1}) consented to participate in the study, which had ethical approval from the institutional board. The study was conducted during the mid-season in which the players typically performed one competitive match and two to three training sessions each week. Participants were included in the study if they had no recent history of musculo-skeletal injury or rehabilitation during the testing schedule.

Players initially reported to the laboratory to perform a graded-exercise test on a motorized treadmill to determine maximal oxygen uptake (VO_{2max}) and maximal heart rate (HR_{max}) for future exercise prescription and classification of sub-maximal intensity. The exercise test consisted of an initial running velocity of 10 km h^{-1} with 1 km h^{-1} increments every minute until exhaustion. The treadmill grade was maintained at 2% throughout the test. Breath-by-breath gas analysis was performed using a portable telemetry system (Cortex Metamax 3B, Leipzig, Germany) that was calibrated in accordance with the manufacturer's instructions before each test. Breath-by-breath data were averaged over 15-s intervals, whereas HR_{max} was taken as the highest recorded value measured at 5-s intervals (Team System, Polar, Kempele, Finland).

Within 4 weeks of the initial visit, the players attended the laboratory on three subsequent occasions for randomized trials, having performed no vigorous exercise or consumed caffeine or alcohol in the previous 24 h. The pre-trial diet and hydration strategy were standardized for each trial, which were separated by 4–8 days and commenced at the same time of day to account for chronobiological rhythms. Participants performed a standardized soccer-specific warm-up for 25 min that consisted of multi-lateral movements, dynamic stretching and high-intensity exercises before resting for 10 min to replicate the common pre-match routines of professional players. Players then performed a 90-min fixed-intensity soccer simulation ($SAFT^{90}$) interceded by a 15-min HT period (see Fig. 1). The $SAFT^{90}$ protocol uses an agility based course, performed in individual lanes of 20 m, and is based on contemporary time-motion analysis data from English Championship level match-play (Prozone®, Leeds, UK). The protocol incorporates acceleration, deceleration, cutting, side-stepping, and backwards and forwards running in a randomized and intermittent fashion prescribed by verbal signals from an audio CD. The players cover 10.8 km in total, 17% of this distance (1.8 km) is performed at high-speed ($\geq$ 15 km h^{-1}) with 1269 changes in speed (every 4.3 s), and 1350 changes in direction over the 90 min. A full description of the protocol has been previously reported (Small et al., 2010) and the physiological responses are indicative of the demands of competitive match-play (Lovell et al., 2008).

During the 15-min HT period players either remained seated (CON), or between 9 and 14 min performed intermittent agility exercise (IAE), or intermittent exposure to WBV. During the first experimental trial, players were invited to drink water *ad libitum* during the first 9 min of the HT interval, this volume was then recorded so that identical volumes could be consumed in subsequent visits. The IAE and WBV re-warm-up strategies were designed to be applicable to the professional team sports environment, allowing time for the players to rehydrate, and for the coaches to deliver any necessary tactical information and motivational encouragement. The IAE incorporated repeated 20-m soccer-specific runs using the $SAFT^{90}$ agility course. The players were asked to negotiate the course at moderate to high speed and then walk back to the start and await the signal for the next bout. The duration of the rest interval was manipulated during the intervention to elicit approximately 70% of the players predetermined HR_{max}, this intensity has been prescribed in previous HT re-warm-up articles and has improved soccer-specific sprinting (Mohr et al., 2004), and endurance (Lovell et al., 2007) performance at the start of the second half. The WBV trial was performed using a compact and portable commercial machine (Power Plate® pro5™ High Performance

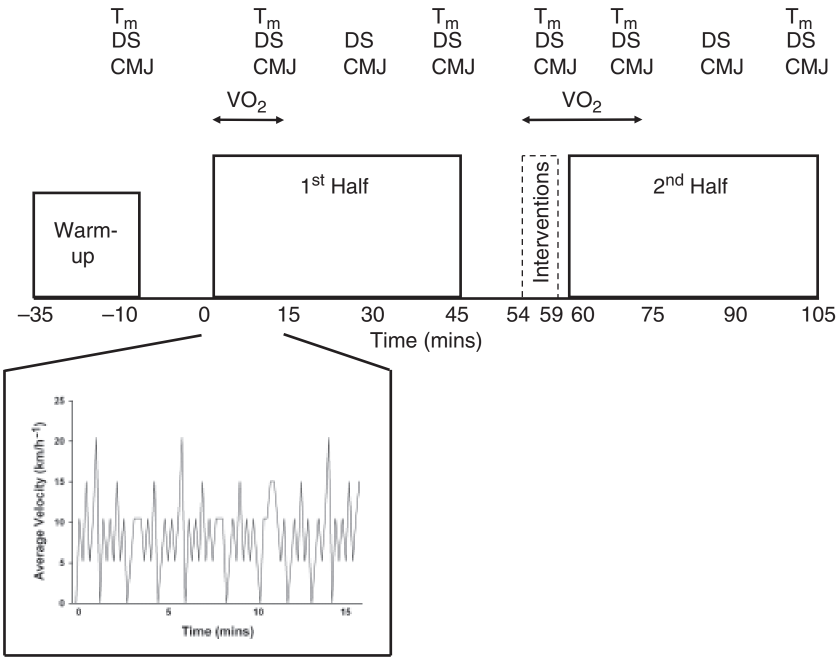

Fig. 1. Schematic representation of the experimental design. Inset figure shows the 15-min velocity profile of the SAFT^{90} protocol that was repeated three times for each 45 min half. The velocities shown here represent the mean velocity required to complete the bout in the required time; during sprints the players were instructed to perform maximum effort. Heart rate was measured continuously during each trial. T_m, *vastus lateralis* muscle temperature; DS, dynamic strength assessment; CMJ, counter-movement jump; VO_2, expired gas analysis.

by Power Plate International Ltd., London, UK) that has been previously used in elite team sports settings. During the WBV treatment, the players wore their indoor footwear and assumed a static partial squat posture ($\sim 30°$ knee flexion) on the platform, which produces vertical sinusoidal vibration. A similar isometric squat posture with continuous (5 min) exposure to WBV has been shown to increase muscle temperature by ~ 0.9 °C (Cochrane et al., 2010). However, pilot data indicated that prolonged isometric WBV reduced our acute measures of athletic performance, in line with other published data (Stewart et al., 2009). Since the aim of a HT re-warm-up strategy is to improve subsequent performance, an intermittent WBV protocol was administered in an attempt to achieve both an increase in T_m and soccer-specific physical performance. Therefore, in the current study the players maintained the static posture on the plate for three sets of 60 s, interspersed with 60-s recovery periods. Furthermore, we considered that this protocol would be more suitable in team sports settings due to both the financial and logistical factors of inserting multiple WBV platforms in the dressing-room environment. The peak-to-peak z-axis vibration displacement was 0.83 mm (manufacturer range 0.71–0.96 mm), and the vibration frequency set at 40 Hz (manufacturer range: 38.4–41.6 Hz) to generate a maximal acceleration of 52.7 m s^{-2} (5.4 g: manufacturer range: 44.8–60.6 m s^{-2}) as calculated using the following formula:

$$\alpha_{max} = D_{pk}(2\pi f)^2$$

where α_{max} is maximum (peak) acceleration, D_{pk} is peak-to-peak displacement, and f refers to the oscillation frequency. The peak-to-peak displacement administered in this study was low in comparison with other investigations as the portable platform had a more limited amplitude capacity. However, this comparatively low amplitude may also be caused by erroneous reporting the parameter in previous investigations (see Lorenzen et al., 2009).

Performance measures

Sprint performance was recorded (Smartspeed™, Fusion Sport, Queensland, Australia) as the average of three maximal 10-m sprints (using a 3 m rolling start) embedded in the SAFT^{90} protocol within each 15-min interval. After the pre-trial warm-up and at 15-min intervals throughout the SAFT^{90} simulation the players performed a number of performance tests to assess lower-limb strength and power. Firstly, two maximal vertical counter-movement jumps (CMJs) were performed on a force plate (AMTI, Watertown, Massachusetts, USA) with hands placed on the hips throughout. Each jump was separated by a 20-s rest period with the best performance at each time-point used in the analysis. Jump height was calculated using the flight time method equation (Lithorne, 2001). After a 1-min rest period, three maximal dominant limb isokinetic contractions were performed for concentric quadriceps (CQ), concentric hamstring (CH), and then eccentric hamstring (EH) strength, with a minutes rest in between. Isokinetic peak torque (gravity corrected) was measured using a dynamometer (Biodex System 3, Biodex Medical, Shirley, New York, USA) with an angular velocity of 2.09 rad s^{-1} (120° s^{-1}) through a range of 0–90° knee flexion and extension (with 0° being full knee extension). This angular velocity was selected because it is the fastest and safest for reliable assessment of EH muscle contractions (Rahnama et al., 2003).

Physiological measures

During the first 15-min period of each half and during the half time intervention (9–14 min), breath-by-breath gas analysis was performed using a portable device, as described earlier. Oxygen uptake was recorded as the mean value over each measurement period. Throughout the simulation, HR was recorded at 5-s intervals (Team System, Polar, Kempele, Finland) and was reported as both the average elicited by the SAFT[90] simulation (excluding HT), and also during the intervention period of the HT interval (9–14 min). At selected intervals during the experimental procedures (see Fig. 1) T_m was recorded (MKA-08050-A, ELLAB, Rødovre, Denmark) during seated rest just before the dynamometry assessment. A needle probe (13050, ELLAB) was inserted 4 cm perpendicular to the *vastus lateralis*. To ensure consistency between repeated samples, a permanent pen was used to mark the mid-point of the line between the lateral epicondyle and the greater trochanter of the femur. A rubber bung was attached 4 cm down the shaft of the thermocouple to ensure consistency of measurement depth. The temperature was recorded 3 s after insertion and the needle was then immediately removed. Data from three participants were discarded or incomplete due to technical faults, and one player revoked their consent for this technique due to the discomfort experienced in their initial trial.

Statistical analysis

Statistical analyses were completed using SPSS for Windows software (release 17.0; SPSS Inc., Chicago, Illinois, USA). Normality of each dependent variable was checked using Q–Q plots and deemed plausible in each instance. The sample data were described using the mean (s). The effect of condition (CON, WBV, IAE) and time on all physiological variables, within-subjects, were analyzed using repeated measures linear mixed models. Condition and time and their interaction were modeled as fixed effects and subjects as a random effect. The linear mixed model also was used to analyze the effect of condition on the change in physiological responses from the end of the first half to the HT period, using the change scores as the dependent variable. Various covariance structures common to repeated measures data were assumed and the one that minimized the Hurvich and Tsai's criterion (AICC) value was chosen for the final model for each dependent variable. In the event of a significant *F*-ratio, pairwise comparisons were conducted using Fisher's least significance difference test. Paired *t*-tests were used to analyze the change in physiological responses from the end of the first half to the HT period within each condition. Two-tailed statistical significance was accepted as $P<0.05$. Data are presented as mean ± standard deviation (SD).

Results

Performance Measures

Sprint times increased during SAFT[90] ($P<0.001$), with decrements in performance observed in the last 15 min of both the first (CON: 2.4 ± 2.6; IAE: 1.4 ± 2.6; WBV: 2.2 ± 1.5%) and second halves (CON: 7.2 ± 4.8; IAE: 5.8 ± 4.0; WBV: 4.5 ± 2.6%), in comparison with the first 15 min of the first half. Sprint times increased from the end of the first half to the start of the second in CON ($P = 0.028$), but there were no such changes observed for WBV ($P = 0.32$) and IAE ($P = 0.82$). The change in sprint times over the HT interval was greater for CON than IAE ($P = 0.019$). The difference denoted between CON and WBV was not statistically significant ($P = 0.058$), and there was no difference between IAE and WBV ($P = 0.67$; see Fig. 2).

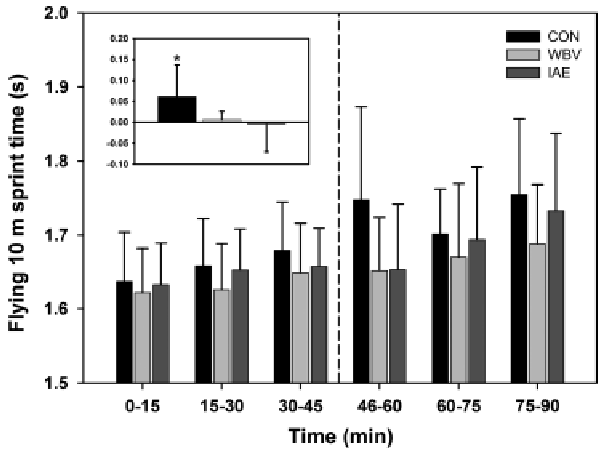

Fig. 2. Mean ± SD 10 m sprint time during the 90-min soccer match-play simulation in each of the three experimental trials. Inset figure shows the change in sprint performance between the start and end of the half-time period. *Significant differences between CON and the intervention trials, IAE and WBV ($P<0.05$). The vertical dashed line represents the half-time period. CON, control; WBV, whole body vibration; IAE, intermittent agility exercise.

CMJ height data is presented in Fig. 3. There was a significant main effect for CMJ over time ($P<0.001$), with decreases from baseline (post warm-up) in the magnitude of 2.1 ± 6.5% and 5.2 ± 5.1% at the end of the first and second halves, respectively. There were no between condition differences in the decrease in CMJ at the end of the first (IAE: 4.4 ± 2.7; WBV: 3.5 ± 2.4%) and second halves (IAE: 4.6 ± 4.0; WBV: 2.7 ± 4.4%). Significant differences between conditions were only observed immediately after the HT period, with CMJ significantly lower in CON than in WBV ($P = 0.031$) and IAE ($P = 0.002$), with no significant difference between WBV and IAE ($P = 0.34$).

Isokinetic dynamometry

The CQ, CH, and EH peak torques and the functional strength ratio (CQ:EH) for all three trials during SAFT[90] are presented in Table 1. Peak torques for CQ, CH, and EH all demonstrated a main effect for time, with strength decreasing over the duration of the 90-min simulation ($P \leq 0.001$). The decrease in CH peak torque from the end of the first half to the start of the second was significantly less for IAE than for CON ($P = 0.008$), whereas the differences between CON and WBV ($P = 0.065$) and between WBV and IAE ($P = 0.094$) were not significant. The decrement in EH peak torque across the HT interval was significant in CON ($P = 0.046$), but not apparent in the intervention trials (IAE: $P = 0.23$; WBV: $P = 0.81$). There was no between-

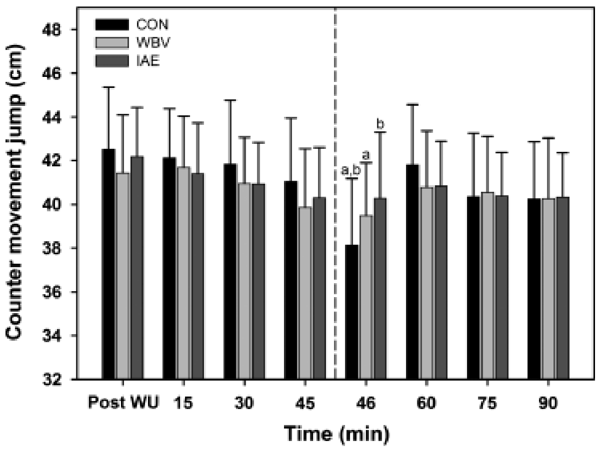

Fig. 3. Mean ± SD Peak counter-movement jump height during the 90-min soccer match-play simulation in each of the three experimental trials. Like letters above error bars represent significant differences between means ($P < 0.05$). The vertical dashed line represents the half-time period. CON, control; WBV, whole body vibration; IAE, intermittent agility exercise.

condition differences observed in CQ, and no effect of either time or condition on the CQ:EH.

Physiological responses

Muscle temperature data is presented in Fig. 4. The T_m increased after the first 15 min, but did not further increase over the subsequent 30 min, in both the first and second halves. *Vastus lateralis* temperature decreased by 1.5 ± 0.4, 1.1 ± 0.4, and 0.5 ± 0.4 °C over the HT periods in CON, WBV, and IAE, respectively. Consequently T_m was significantly higher at the end of HT in IAE, than in CON ($P = 0.002$) and WBV ($P = 0.005$), but no significant difference was observed between CON and WBV ($P = 0.41$). No other differences in *vastus lateralis* T_m were observed between experimental conditions.

Average VO_2 during the SAFT[90] was not different between the three experimental trials (CON: 65.5 ± 6.3; IAE: 64.9 ± 5.1; WBV: $65.7 \pm 8.7\%$ VO_{2max}). However during the intervention stage of the HT period (9–14 min), VO_2 was significantly different between all three conditions (CON: 6.3 ± 1.9; IAE: 31.8 ± 4.8 mL kg^{-1} min^{-1} [$55 \pm 9\%$ VO_{2max}]; WBV 10.8 ± 2.8 mL kg^{-1} min^{-1}, $P \leq 0.001$).

The HR during the SAFT[90] protocol was not significantly different between conditions (CON: 161 ± 8; IAE: 157 ± 10; WBV: 157 ± 10 bpm; $P = 0.29$). The IAE trial elicited an average HR of 140 ± 6 bpm ($73 \pm 2\%$ HR_{max}) during the HT intervention period, which was greater than both CON (92 ± 13 bpm, $P < 0.001$) and WBV (104 ± 11 bpm, $P < 0.001$).

Table 1. Isokinetic dynamometer data during the 90 min soccer match-play simulation in each of the three experimental trials [mean (SD)]

	Condition	PWU	15 min	30 min	45 min	HT	60 min	75 min	90 min
Concentric quadriceps PT (Nm)	CON	244.3 (30.0)	243.2 (28.6)	233.3 (35.7)	225.6 (36.1)	212.9 (32.9)	235.4 (34.8)	212.4 (23.7)	206.31 (30.7)
	WBV	243.9 (31.6)	244.5 (21.3)	242.1 (19.8)	238.3 (26.3)	229.5 (24.3)	223.1 (30.0)	227.1 (30.0)	228.5 (31.7)
	IAE	243.4 (24.4)	242.0 (23.5)	237.0 (20.3)	234.6 (25.1)	232.8 (33.0)	235.5 (25.5)	223.6 (23.3)	230.4 (31.5)
Concentric hamstrings PT (Nm)	CON	153.1 (29.6)	154.1 (24.3)	148.3 (19.9)	145.6 (21.9)	132.8 (18.7)	149.8 (19.2)	142.5 (16.6)	132.6 (15.7)
	WBV	162.4 (19.8)	160.5 (18.0)	160.4 (22.1)	154.6 (21.4)	149.2 (20.0)	152.7 (24.6)	143.8 (21.2)	154.6 (29.8)
	IAE	160.3 (21.4)	158.3 (20.8)	153.6 (21.7)	150.3 (17.7)	152.1 (19.7)	146.9 (23.2)	143.9 (22.5)	143.5 (22.0)
Eccentric hamstrings PT (Nm)	CON	253.7 (44.8)	246.0 (27.4)	239.4 (32.9)	226.1 (31.2)	212.9 (36.7)	228.1 (33.8)	217.9 (27.5)	201.3 (35.3)
	WBV	242.8 (46.7)	234.9 (39.2)	236.9 (31.2)	224.2 (45.2)	221.9 (37.4)	225.7 (34.8)	214.7 (42.6)	214.4 (47.1)
	IAE	245.9 (35.5)	240.5 (34.9)	227.2 (29.0)	221.1 (41.6)	229.2 (31.8)	224.2 (41.2)	214.3 (29.5)	209.5 (29.0)
Strength ratio (%)	CON	103.6 (13.5)	101.7 (11.6)	103.4 (11.3)	100.9 (8.9)	100.6 (14.8)	97.4 (11.8)	103.0 (11.9)	98.9 (20.0)
	WBV	99.7 (15.5)	96.4 (15.2)	98.3 (13.8)	94.2 (16.8)	97.2 (16.4)	102.7 (21.4)	94.6 (14.6)	94.1 (17.3)
	IAE	101.4 (14.0)	100.0 (15.7)	96.0 (10.7)	94.7(16.8)	98.9 (9.1)	95.1 (12.7)	96.3 (13.3)	91.4 (9.7)

CON, control; HT, immediately post half time; IAE, intermittent agility exercise; PT, peak torque; WBV, whole body vibration.

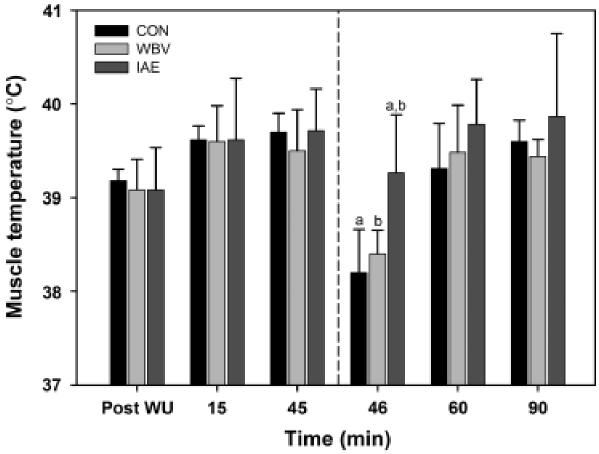

Fig. 4. Mean ± SD *Vastus lateralis* muscle temperature ($n = 6$) during the 90-min soccer match-play simulation in each of the three experimental trials. Like letters above error bars represent significant differences between means ($P < 0.05$). The vertical dashed line represents the half-time period. CON, control; WBV, whole body vibration; IAE, intermittent agility exercise.

Discussion

The main findings of the current study were that IAE attenuated the decreases in T_m and soccer-specific sprint, power and dynamic strength performance typically observed after a passive HT interval. In contrast to our hypotheses, WBV did not prevent the HT associated decrease in T_m, however sprint and CMJ performance did not deteriorate. A novel observation of this investigation was a maintained eccentric hamstring dynamic strength at the start of the second half of soccer match-play when IAE or WBV was used as a HT intervention strategy. Since strength deficiency is considered to increase the players susceptibility to muscular strain, the intervention strategies used in this study may also have the potential to reduce hamstring injury risk.

Mohr et al. (2004) also reported a higher T_m and sprint performance after a moderate-intensity re-warm-up during the soccer HT interval. The magnitude of the HT decrease in T_m during the CON trial was equivalent (~ 1.5 °C) to that reported by Mohr et al. (2004). In comparison with Mohr et al. (2004), we observed a greater decrement in sprint performance (6.2 vs 2.4%) with a passive HT. It could be argued that the decrement observed in the present investigation could have more practical significance, given that the sprint distance is more indicative of that undertaken during match-play (Stølen et al., 2005; Carling et al., 2008), and sprint performance was measured within standardized bouts of intermittent exercise. Nonetheless our study's results are in support of Mohr et al. (2004), in that moderate-intensity exercise during HT limited the decrease in sprint performance and T_m denoted with a passive interval.

In the current study, WBV attenuated the HT decrement in sprint, and power performance. Soccer-specific lower-limb power was measured with CMJ, which was performed within 60–90 s after WBV exposure, and was increased in relation to CON (~ 4%). This magnitude of temporary CMJ enhancement was within the range reported previously (8%, Cochrane & Stannard, 2005; 2.5%, Torvinen et al., 2002). Few studies have investigated the acute effects of WBV on sprint performance, and the results have not been positive (Bullock et al., 2008; Guggenheimer et al., 2009), this is not surprising given the complexity of the task and the myriad of causative factors on performance. However, in the current study sprint performance was maintained across the HT interval when WBV was applied, whereas sprint times increased in CON. While differences in the measurement of sprint performance and WBV dose may explain these discrepancies, comparisons should be made with caution as our aim was to examine the potential of WBV as a re-warm-up tool, which has additional confounding factors such as fatigue, heat dissipation, and the concurrent down-regulation of cardiovascular and metabolic systems. Furthermore, the different oscillatory nature of vibrating platforms (synchronous and asynchronous vibration), coupled with the wide variety of vibration frequency and peak-to-peak displacement administered by researchers makes between-study contrasts difficult, especially given the lack of clarity and uniform nomenclature for WBV parameters reported in the literature (Lorenzen et al., 2009).

There are a variety of physiological mechanisms for the acute, transient improvements in muscular power output with WBV exposure. The general consensus has been neuromuscular facilitation, through a depressed threshold for myotatic reflex leading to an up-regulated α motorneuron response (Bosco et al., 1999; Cardinale & Bosco, 2003; Cochrane & Stannard, 2005). However, recent evidence has challenged this assertion, as reflex potentiation has not been observed in the quadriceps (Hopkins et al., 2009; Cochrane et al., 2010). Cochrane et al. (2008) reported compelling evidence for the role of intra-muscular temperature in WBV-evoked power improvements. In that study, augmented muscular power output was comparable between a variety of warm-up modalities (including WBV) when increases in T_m (1.5 °C) were matched. Our data does not support this hypothesis, since T_m did not change with the WBV treatment in comparison with CON, despite comparative gains in both CMJ and sprint performance. The disparate T_m findings are probably due to the higher intensity ($160.1\,m\,s^{-2}$, $5.4\,g$) and consequently the elevated metabolic cost

($19\,mL\,kg\,min^{-1}$) of the WBV protocol used by Cochrane et al. (2008), in comparison with this study ($10\,mL\,kg\,min^{-1}$). Furthermore, the applied nature of the current study meant the players undertook WBV trials in footwear, which likely dampened the mechanical vibrations of the platform, thus reducing the generation of intra-muscular heat.

Dynamic strength was taken as the peak torque generated in concentric knee flexors (CH) and extensors (CQ). We observed no performance benefits of WBV on these isokinetic dynamometry measures, which were recorded approximately 3–4 min after the treatment. This supports previous work, which has failed to show acute improvement in peak torque (Pellegrini et al., 2010) and the rate of force development (de Ruiter & de Haan, 2003; Rittweger et al., 2000; Erskine et al., 2007) with WBV. Taken together these findings are indicative of neuromuscular inhibition (de Ruiter & de Haan, 2003; Rittweger, 2010), rather than facilitation and directly contrast to the power-related gains reported both in the current study and in previous studies (Bosco et al., 1999; Torvinen et al., 2002; Cochrane & Stannard, 2005). Rittweger (2010) suggests that this further supports the role of T_m with acute WBV, given its robust effect on muscle power but minimal effect on force generation (de Ruiter & de Haan, 2000). However, since WBV did not elicit T_m elevations at HT in this study, our data is not indicative of this phenomenon. Further work is warranted to establish the neurogenic responses to acute WBV exercise, especially given the wide variety of WBV protocols adopted by researchers.

A unique observation in the current study was the reduced eccentric hamstring dynamic strength after a passive HT interval, yet this was maintained when IAE or WBV was used as an intervention strategy. Decreased eccentric strength of the knee extensors is acknowledged as a fundamental etiological factor associated with hamstring strain injury (Stanton & Purdam 1989; Garrett, 1990), which is the most common injury experienced by soccer players (Árnason et al., 1996; Woods et al., 2004), and its predisposing etiological factors include muscle fatigue (Rahnama et al., 2002, 2003) and inadequate warm-up (Safran et al., 1988). The peak torque decrements observed in EH strength (7.7–10.9%) during the first half of $SAFT^{90}$ were not different between experimental trials, and were comparable to those recently observed in our laboratory (Small et al., 2010). However, the passive HT interval in CON further reduced EH strength, which potentially poses a greater risk to injury since fatigued muscles are more susceptible to stretch injury during eccentric contractions (Mair et al., 1996). In contrast, both WBV and IAE interventions attenuated any HT decline in EH peak torque, lowering the potential risk of hamstring strain. Given that acute WBV bouts have also been shown to increase hamstring flexibility (Cochrane & Stannard, 2005; Gerodimos et al., 2009), and that insufficient flexibility is another pre-disposing etiological factor for hamstring strain injury, WBV may be a useful tool to prevent injuries of this nature in the early stages of the second half. As Rahnama et al. (2003) have shown a relatively high proportion of injuries are sustained during the initial stages of the second half, the potential for injury prevention with HT re-warm-ups warrants further research.

It should be recognized that the reduction in distances covered at high speed soon after the HT interval may also be a consequence of a reduced match tempo, due either to a tactical alteration or a sub-conscious pacing strategy adopted by the players. Indeed, we have recently found evidence for this as players decrement in total distance covered, high-speed running distance, and sprinting distance after HT (46–60 min) was not different to that performed by the referees, yet the referees ability to keep up with play was improved immediately after HT (Weston et al., 2011). Nonetheless, the data reported both here and in previous studies (Mohr et al., 2004; Lovell et al., 2007) have shown that the players physical capacity for high-intensity exercise is compromised when a passive HT is administered. Furthermore, there were no differences apparent in either the performance or physiological measures after the initial stages of the second half. As such it may be reasonable to assume that the HT interventions adopted in this study had no additional fatiguing effects on sprint, power, and dynamic strength performance in the latter stages of match-play. However, further work is required to determine whether this phenomenon exists in other physical performance indicators.

Perspectives

This study supports previous work (Mohr et al., 2004; Lovell et al., 2007) demonstrating a negative effect of the sedentary HT interval in elite soccer match-play. While an altered tactical approach or a sub-conscious pacing strategy adopted by the players could reduce the tempo of the game after HT, there is clear evidence that players are sub-optimally prepared for explosive activities, which are regarded as the most decisive actions within a soccer game (Stølen et al., 2005). In addition, this study has observed that a sedentary rest interval reduces eccentric hamstring strength, which may leave players more susceptible to non-contact hamstring strain injury. However, performing an intermittent, moderate intensity re-warm-up during the last few minutes of the HT period attenuated this decrement in sprint, power and dynamic strength performance. While beneficial, HT re-warm-ups are commonly not administered because of coaches' unwillingness to sacrifice tactical/motivational discussions and governing body regulations. Performing WBV exercises in the dressing room may be more acceptable to coaches and does not contravene policy. In this study a short-duration, low-intensity and practical dose of WBV was also ergogenic for sprint and power performance and maintained eccentric hamstring peak torque, potentially reducing the risk of injury. As such WBV might be an appropriate intervention for practitioners where regulations and/or facilities inhibit typical warm-up regimens.

Key words: soccer, half-time, muscle temperature, re-warm-up, whole body vibration.

Acknowledgements

The authors would like to thank Jason Siegler, Matthew Weston, and Christian Lorenzen for their valuable contributions and to Power Plate International Ltd. for providing the WBV platform.

Conflicts of interest: The authors have no potential conflicts.

References

Agre JC. Hamstring injuries: proposed aetiological factors, prevention, and treatment. J Sports Med 1985: 2: 21–33.

Árnason A, Gudmumdsson A, Dahl HA, Johannsson E. Soccer injuries in Iceland. Scand J Med Sci Sports 1996: 6(1): 40–45.

Bangsbo J, Norregaard L, Thorsoe F. Activity profile of competition soccer. Can J Sports Sci 1991: 16: 110–116.

Bosco C, Colli R, Introine E, Cardinale M, Tsarpela O, Madella A. Adaptive responses of human skeletal muscle to vibration exposure. Clin Phys 1999: 19: 183–187.

Bradley PS, Sheldon W, Wooster B, Olsen P, Boanas P, Krustrup P. High-intensity running in English FA Premier League soccer matches. J Sports Sci 2009: 27(2): 159–168.

Bullock N, Martin DT, Ross A, Rosemond CD, Jordan MJ, Marino FE. Acute effect of whole-body vibration on sprint and jumping performance in elite skeleton athletes. J Strength Cond Res 2008: 22(4): 1371–1374.

Cardinale M, Bosco C. The effects of vibration as an exercise intervention. Exerc Sport Sci Rev 2003: 31: 3–7.

Carling C, Bloomfield J, Nelsen L, Reilly T. The role of motion analysis in elite soccer: contemporary performance measurement techniques and work rate data. Sports Med 2008: 38(10): 839–862.

Cochrane DJ, Stannard SR. Acute vertical jump and flexibility performance in elite female hockey players. Br J Sports Med 2005: 39: 860–865.

Cochrane DJ, Stannard SR, Firth EC, Rittweger J. Acute whole-body vibration elicits post-activation potentiation. Eur J Appl Physiol 2010: 108(2): 311–319.

Cochrane DJ, Stannard SR, Sargeant AJ, Rittweger J. The rate of muscle temperature increase during acute whole-body vibration exercise. Eur J Appl Physiol 2008: 103: 441–448.

de Ruiter CJ, de Haan A. Short-term effects of whole-body vibration on maximal voluntary isometric knee extensor force and rate of force rise. Eur J Appl Physiol 2003: 88(4–5): 472–475.

de Ruiter CJ, de Haan A. Temperature effect on the force/velocity relationship of the fresh and fatigued human adductor pollicis muscle. Pflugers Arch 2000: 440(1): 163–170.

Erskine J, Smillie I, Leiper J, Ball D, Cardinale M. Neuromuscular and hormonal responses to a single session of whole body vibration exercise in healthy young men. Clin Physiol Funct Imag 2007: 27(4): 242–248.

Garrett WE Jr. Muscle strain injuries: Clinical and basic aspects. Med Sci Sports Exer 1990: 22(4): 436–443.

Gerodimos V, Zafeiridis A, Karatrantou K, Vasilopoulou T, Chanou K, Pispirikou E. The acute effects of different whole-body vibration amplitudes and frequencies on flexibility and vertical jumping performance. J Sci Med Sport 2010: 13(4): 438–443.

Gray SR, De Vito G, Nimmo MA, Farina D, Ferguson RA. Skeletal muscle ATP turnover and muscle fiber conduction velocity are elevated at higher muscle temperatures during maximal power output development in humans. Am J Physiol 2006: 290: R376–R382.

Gregson W, Drust B, Atkinson G, Salvo VD. Match-to-match variability of high-speed activities in premier league soccer. Int J Sports Med 2010: 31(4): 237–242.

Guggenheimer JD, Dickin DC, Reyes GF, Dolny DG. The effects of specific preconditioning activities on acute sprint performance. J Strength Cond Res 2009: 23(4): 1135–1139.

Hawkins RD, Fuller CW. Risk assessment in professional football: an examination of accidents and incidents in the 1994 World Cup finals. Br J Sports Med 1996: 30: 165–170.

Hopkins JT, Fredericks D, Guyon PW, Parker S, Gage M, Feland JB, Hunter I. Whole body vibration does not potentiate the stretch reflex. Int J Sports Med 2009: 30(2): 124–129.

Krustrup P, Mohr M, Steensberg A, Benke J, KjÆr M, Bangsbo J. Muscle and blood metabolites during a Soccer Game. Med Sci Sports Exer 2006: 38(6): 1165–1174.

Lithorne NP. Analysis of standing vertical jumps using a force platform. Am J Phys 2001: 69(11): 1198–1204.

Lorenzen C, Maschette W, Koh M, Wilson C. Inconsistent use of terminology in whole body vibration exercise research. J Sci Med Sport 2009: 12(6): 676–678.

Lovell R., Knapper B., Small K. Physiological responses to SAFT90: a new soccer-specific match simulation. Coach Sports Sci 2008: 3(2): 46.

Lovell RJ, Siegler JC, Kirke I, McNaughton LM, Greig MP. Soccer half-time strategy influences thermoregulation and endurance performance. J Sports Med Phys Fitness 2007: 47: 263–269.

Mair SD, Seaber AV, Glisson RR, Garrett WE Jr. The role of fatigue in susceptibility to acute muscle strain injury. Am J Sports Med 1996: 24(2): 137–143.

Mohr M, Krustrup P, Bangsbo J. Match performance of high-standard soccer players with special reference to development of fatigue. J Sports Sci 2003: 21: 439–449.

Mohr M, Krustrup P, Nybo L, Nielsen JJ, Bangsbo J. Muscle temperature and sprint performance during soccer matches – beneficial effect of

re-warm-up at half-time. Scand J Med Sci Sports 2004: 14: 156–162.
Pellegrini MJ, Lythgo ND, Morgan DL, Galea MP. Voluntary activation of the ankle plantar flexors following whole-body vibration. Eur J Appl Physiol 2010: 108(5): 927–934.
Rahnama N, Reilly T, Lees A. Injury risk associated with playing actions during competitive soccer. Br J Sports Med 2002: 36: 354–359.
Rahnama N, Reilly T, Lees A, Graham-Smith P. Muscle fatigue induced by exercise simulating the work rate of competitive soccer. J Sports Sci 2003: 21: 933–942.
Rittweger J. Vibration as an exercise modality: how it may work, and what its potential might be. Eur J Appl Physiol 2010: 108(5): 877–904.
Rittweger J, Beller G, Felsenberg D. Acute physiological effects of exhaustive whole-body vibration exercise in man. Clin Physiol 2000: 20: 134–142.
Rittweger J, Mutschelknauss M, Felsenberg D. Acute changes in neuromuscular excitability after exhaustive whole body vibration exercise as compared to exhaustion by squatting exercise. Clin Physiol Funct Imag 2003: 23: 81–86.
Safran MR, Garrett WE Jr., Seaber AV, Glisson RR, Ribbeck BM. The role of warm-up in muscular injury prevention. Am J Sports Med 1988: 16(2): 123–129.
Sargeant AJ. Effect of muscle temperature on leg extension force and short-term power output in humans. Eur J Appl Physiol 1987: 56: 693–698.
Small K, McNaughton L, Greig M, Lovell R. The effects of multidirectional soccer-specific fatigue on markers of hamstring injury risk. J Sci Med Sport 2010: 13(1): 120–125.
Stanton P, Purdam C. Hamstring injuries in sprinting: the role of eccentric exercise. J Orthop Sports Phys Ther 1989: 10: 343–349.
Stewart IB, Sleivert GG. The effect of warm-up intensity on range of motion and anaerobic performance. J Orthop Sports Phys Ther 1988: 27: 154–161.
Stewart JA, Cochrane DA, Morton RH. Differential effects of whole body vibration durations on knee extensor strength. J Sci Med Sport 2009: 12(1): 50–53.
Stølen T, Chamari K, Castagna C, Wisløff U. Physiology of soccer: an update. Sports Med 2005: 35: 501–536.
Torvinen S, Kannus P, Sievänen H, Järvinen TAH, Pasanen M, Kontulainen S, Järvinen TLN, Järvinen M, Oja P, Vuori I. Effect of a vibration exposure on muscular performance and body balance. Randomized cross-over study. Clin Physiol Funct Imag 2002: 22(2): 145–152.
Weston M, Batterham A, Castagna C, Portas M, Harley J, Barnes C, Lovell R. Reduction in physical match performance at the start of the second half in elite soccer referees and players. Int J Sports Phys Perf 2011, in press.
Woods C, Hawkins RD, Maltby S, Hulse M, Thomas A, Hodson A. The Football Association Medical Research Programme: an audit of injuries in professional football – analysis of hamstring injuries. Br J Sports Med 2004: 38: 36–41.