THE INFLUENCE OF DIFFERENT WORK AND REST DISTRIBUTIONS ON PERFORMANCE AND FATIGUE DURING SIMULATED TEAM HANDBALL MATCH PLAY

ABSTRACT

This study investigated the effect of different interchange strategies on performance and pacing strategy during a simulated team-sports protocol. Eight youth male team handball players completed two conditions (LONG; work: 3 x 13:00 min, rest: 8:00 min, SHORT; work: 5 x 7:48 min, rest: 3:45 min). Participants were tested for 20 m sprint, counter-movement jump, throwing performance and heart rate during conditions. Post-condition measures included repeated shuttle-sprint and jump ability, session rating of perceived exertion, blood lactate and glucose. Faster sprint (3.87 ± 0.27 s *cf.* 3.97 ± 0.24 s, ES = 0.39, $P = 0.03$) and throwing performance (70.02 ± 7.40 $\text{km}\cdot\text{h}^{-1}$ *cf.* 69.04 ± 5.57 $\text{km}\cdot\text{h}^{-1}$, $P > 0.05$, ES = -0.15) occurred in SHORT compared to LONG by a 'likely small' difference. Higher summated heart rate (157 ± 21 *cf.* 150 ± 15 AU) occurred in SHORT compared to LONG by a 'likely small' difference (ES = 0.37, $P > 0.05$). SHORT resulted in lower session rating of perceived exertion (224 ± 45 AU *cf.* 282 ± 35 AU, ES = 1.45, $P = 0.001$) and higher blood glucose (6.06 ± 0.69 $\text{mmol}\cdot\text{l}^{-1}$ *cf.* 4.98 ± 1.10 $\text{mmol}\cdot\text{l}^{-1}$, ES = -1.17, $P = 0.03$) by a 'most likely moderate' difference compared to LONG. Repeated shuttle-sprint was better preserved after SHORT, with 'moderately lower' 10 m and 25 m times ($P < 0.05$). Interchange strategies using SHORT rather than LONG work and rest periods result in lower physiological load, leading to improved fatigue resistance and better preservation of high-intensity movements during matches.

Keywords: team handball, simulation, interchange, strategy, recovery

INTRODUCTION

Match-related fatigue in team sports is typically defined as a decrease in high-intensity running from the first to second half of a match (33). For example, in male team handball matches, fatigue has been reported as a 16.2% reduction in second half high-intensity running (32). This is also accompanied by a lower number of high-intensity actions in the second half, such as the frequency of stops, changes of direction, and one-on-one situations (36). Due to the intense nature of team handball competition, i.e. repeated sprints, jumps, throws, side-cutting, changes of direction, accelerations, and body contact (32), strategies that minimise fatigue are therefore essential to ensure that players can perform optimally during a single match or tournament.

Strategies to limit match-related fatigue seldom focus on the distribution of player work and rest periods, despite their potential to have an immediate impact on team performance. Effective management of player rotations could help to reduce physiological loading and subsequent fatigue throughout matches, thus limiting decreases in performance. In a recent study by Nicolo *et al.* (34), intermittent exercise bouts of the same absolute intensity but with work-to-rest ratios of 2:1 and 1:1 were performed to exhaustion. Despite no differences in the neuromuscular responses between conditions, differences in the metabolic demand resulted in a ~4 times greater time to exhaustion when work and rest times were equal.

Anticipatory pacing, where an individual allocates appropriate physiological resources based on the known end point of exercise (3), might explain why individuals adopt a particular intensity during exercise. Using information provided on the proposed duration and end point can influence subjective ratings of fatigue, perceived exertion and muscle activation (3), altering performance in the proposed exercise activity. Recent work has examined the role of pacing strategies during team sports (3,5,38,43). These studies show that repeated sprint ability is altered in relation to the exercise end point, with individuals increasing muscle recruitment and mechanical output when a lower total work-load was anticipated, compared to (i) no knowledge of the end point, and (ii) knowledge that there was a need to complete a greater workload (3,18). It is also proposed that 'interchanged' players set higher pacing strategies, completing greater overall distances and high-intensity effort bouts in comparison to 'whole-match' players (5,9,43). While sport-specific factors relating to the mode of activity, opposition quality and rules could account for differences in pacing strategy (16-17,24) bout duration and knowledge of the exercise end point can influence the exercise intensity during team sport activity.

Team handball and other team sports such as hockey, basketball, American football, and Australian Rules football, allow an unlimited number of interchanges, making it possible for coaches to control durations of work and rest to optimise the performance of a team. Having knowledge of the end point and duration of a particular playing bout and the rest period that follows could influence an individual's pacing strategy, allowing the player to manipulate their exercise intensity to increase the potential of competitive success (5,38). Considering the higher work-rates found in interchanged players during team sport matches (5,9,43), it would be beneficial to establish the impact of different player work and rest distributions on key team-sport movements such as sprinting, jumping, shooting, and repeated sprint performance, alongside physiological and subjective parameters. This has direct practical implications for coaches, as being better informed on the impact of work and rest distributions could contribute to enhanced interchange strategies and the use of different conditioning strategies for interchange compared to whole game players. This would allow more effective distribution of individual workloads to preserve running and technical performance. Accordingly, the aim of this study was to examine two different interchange strategies on performance and fatigue during a simulated team-sports protocol, with the addition of team handball movements to increase suitability for the participant group.

METHODS

Experimental approach to the problem

Using a randomised cross-over design, participants completed two conditions of a team sport simulation (Figure 1) with either long (LONG) or short (SHORT) work-to-rest bouts. LONG comprised 3 x 13:00 min periods of work, separated by 8:00 min rest between activity periods. SHORT comprised 5 x 7:48 min periods of activity, separated by 3:45 min rest between work periods. Absolute work time (39:00 min) and rest (16:00 min) periods were the same for both conditions. During rest periods, participants were asked to remain seated until required to resume the protocol. Total work and rest times were based on those employed by the England Handball Team during training camps and tournaments (Moss, personal observation). Participants were required make three visits, the first of which involved baseline testing of maximal counter-movement jump (CMJ), 20 m sprint time, throwing velocity, the Repeated Shuttle Sprint and Jump Ability test (RSSJA) and the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1). All players were accustomed to the performance tests as part of their regular monitoring procedures. In the same visit participants were familiarised to the simulation, completing the protocol six times with instruction from the researcher. After minimum of two days LONG and SHORT conditions were performed at similar times of the day (± 1 h) with 5 - 10 days between each. Participants were asked to consume and record their habitual diet for 48 h before the first experimental condition, which they were asked to replicate for the second condition. Participants were asked to refrain from heavy exercise 24 h before each trial, and instructed that no caffeine was to be consumed during this period. All participants stated that they had adhered to instructions at the beginning of each condition.

Subjects

After ethical approval in accordance with the Declaration of Helsinki, eight outfield youth male handball players (age: 16.1 ± 1.0 y, range: 15 - 17 y, stature: 1.82 ± 0.11 m, body mass: 69.3 ± 6.6 kg) were invited to participate in the study. Five played for the English national team (U16/ U18), and all players competed in the U18 Men's National English League. Participants provided written informed consent alongside parental consent. Participants also completed a health screening questionnaire before taking part.

****Insert table 1 about here"**

Procedures

Simulated Team-Game Protocol

Match performance was simulated using the protocol described by Bishop *et al.* (4), which comprises movements and actions that replicate those observed in team sports (Figure 1). Participants completed a standardised warm-up, which included six circuits of the protocol (as recommended by Singh *et al.*, 39) beginning at 50% maximum effort on circuit 1, with progressive increases to maximum effort on the final circuit. This was followed by a series of passing and shooting drills for ~5 min. The simulation involves sets of intermittent running around a circuit as previously described (4). Extra team handball movements included jump shots, (9 attempts), and moderate intensity pushes (contact) onto the bump pad (20 attempts), performed at the same time-points for each condition. The circuit was completed in pairs on a staggered start (~30 s apart). Each circuit lasted ~50 s, allowing ~10 s rest before the next circuit (on 1 min).

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

Measurements of heart rate (HR), 20 m sprint time, CMJ and throwing velocity were recorded throughout each protocol (details below). To enable comparison between LONG and SHORT conditions, the mean sprint time and CMJ height were recorded for the first, middle and last six circuits of each condition. Mean throwing velcoity was taken from the first, middle and last three shots for each condition. In addition, blood lactate ([BLa]), blood glucose ([Glu]) and session rating of perceived exertion (sRPE) were recorded on completion, after which participants completed the Repeated Shuttle Sprint and Jump Ability test (RSSJA; 11) within 10 min of completing the trial. A schematic of timings of where each measurement was performed is shown in Figure 2.

Performance tests

20 m sprint time. Sprint performance over 20 m (CV = 1.19%) was measured using electronic photo cell gates (Brower Timing Systems, Colorado, USA) placed at 0 and 20 m in an indoor sports hall. Players were instructed to begin from a stationary standing start, with their foot behind the 0 m line.

Counter-movement jump. For the counter-movement jump (CMJ; CV = 2.4%), participants began in an upright position, and were told to flex at the knee to a self-selected depth and then jump for maximal height, keeping the hands placed on the hips throughout. Jump height was recorded from flight time using the equation of 9.81 x flight time^2 / 8 (7) and measured using an infrared timing system (Optojump, Microgate S.r.l., Bolzano, Italy) interfaced with a laptop.

Throwing performance. Throwing velocity (km·h^{-1}) was assessed using a velocity speed gun (Bushnell CBV00, Surrey, UK) held 1 m to the side of the goal post, and perpendicular to the player (CV = 1.88 - 2.22%). Players completed a maximal jump shot with 3-step run-up from 9 m. Accuracy was measured as success rate, based on the percentage of goals scored.

Yo-Yo Intermittent Recovery Test (Level 1). The Yo-Yo intermittent recovery test (Yo-Yo IR1; 27, CV = 4.6%) requires performance of 2 x 20 m shuttle running bouts, interspersed with 10 s recovery at progressive speeds dictated by a pre-recoded audio signal. The final score was recorded as the total distance covered at exhaustion or after the second failed attempt to complete the shuttle running bout in the required time. Maximal heart rate (HR_{max}) was recorded upon completion (Activio Sport System, Perform Better, BM-CS5EU, China) and used to represent an individualised absolute measure during matches.

Repeated Shuttle Sprint and Jump Ability test. This comprised six maximal 2 × 12.5 m shuttle sprints (~5 s) starting every 25 s. Participants had ~20 s recovery between sprints, where they were required to decelerate, perform a CMJ, and then an active recovery (covering 36 m ≈ running at 2.1 m·s^{-1}). Averages were calculated for CMJ variables, and times for 10 m, agility (the time between 10 m, and the 2 x 2.5 m turn-around), and total 25 m. Average sprinting and jumping performance during RSSJA has previously shown good reliability (8).

Blood lactate, glucose, and sRPE measures

Blood lactate ([Bla]; Lactate Pro, Akray, Kyoto, Japan) and glucose concentrations ([Glu]; ACCU-CHECK Aviva Blood Glucose Meter System, Roche Diagnostics, Mannheim, Germany) were measured after each condition. For each participant, the finger was cleaned with a medi-wipe to remove any contaminants and dried with a gauze swab. A softclix lancet device was used to puncture the site, with the first drop of blood wiped away. Light pressure was applied around the site with blood applied to the lactate (15 μl) and glucose (0.6 μl) strips for automatic analysis. Finally, sRPE using the 0-10 scale as described by Foster *et al.* (15) was recorded immediately post-test and with verbal anchors placed on a numerical ratio scale, at the locations appropriate to their quantitative meaning. The sRPE is a modification of the category ratio (CR) RPE scale (6), and has demonstrated good reliability in a number of exercise modes and across a range of exercise intensities (11,21). In each instance, participants were showed the scale and were verbally prompted with "How physically exerting was that exercise?" sRPE was calculated by multiplying the number selected by the total duration of activity periods. Players were familiar with the measure, having used it regularly to monitor load during training.

Heart rate

Heart rate was recorded continuously (Activio Sport System,Perform Better, BM-CS5EU, China) throughout each condition. Peak and average values were expressed both as absolute ($b \cdot min^{-1}$) and relative to maximal heart rate (%HRmax). In addition, summated HR (AU) was calculated using the following equation (13):

(*Duration in zone* 1 x 1) + (*Duration in zone* 2 x 2) + (*Duration in zone* 3 x 3) + (*Duration in zone* 4 x 4) + (*Duration in zone* 5 x 5).

Hydration testing and diet

Participants were asked to ensure that they were euhydrated prior to visits, and urine osmolality was measured upon arrival (Pocket Osmocheck, Vitech Scientific Ltd., Sussex, UK). Body mass (Tanita, BWB-800, Tanita Corporation, Tokyo, Japan) of all participants was taken immediately prior to each simulation condition in shorts only. Participants were able to drink water *ad libitum* but were asked to refrain from urinating during simulation conditions. On completion of simulation conditions, participants were asked to towel-dry themselves and body mass was recorded.

Statistical Analyses

Assumptions of sphericity were assessed using Mauchly's test of sphericity ($P < 0.05$), with any violations adjusted by use of the Greenhouse-Geisser correction. Separate 2 (condition) x 3 [(time) beginning, middle, and end of simulation] analyses of variance (ANOVA) with repeated measures were used to examine for any differences in 20 m sprint, CMJ, and throwing velocity. A Friedman test was used to examine for any differences in throwing accuracy over time (beginning, middle, and end of simulation), while a Wilcoxon test was used to analyse throwing accuracy between conditions. Beginning, middle, and end = the mean of the first six scores, middle six scores, and last six scores for each condition (20 m sprint, CMJ), respectively. Analysis for throwing variables comprised the means of three scores at each respective time point. Variables for the RSSJA were analysed using 2 (condition) x 6 (time) repeated measures ANOVA, using paired samples *t*-tests to follow up any significant effects.

Separate paired-samples *t*-tests were used to assess differences in heart rate, [Bla], [Glu], sRPE, time to complete and $m \cdot s^{-1}$ covered between conditions. Analyses were performed using SPSS v.19 (SPSS Inc., Chicago, IL), with the alpha level set at $P < 0.05$. Effect sizes and magnitude-based inferences (2), were also calculated for all variables. Based on the 90% confidence limits, threshold probabilities for a substantial effect were: <0.5% most unlikely, 0.5 – 5% very unlikely, 5 – 25% unlikely, 25 – 75% possibly, 75 – 95% likely, 95 – 99.5% very likely, >99.5% most likely. The threshold for the smallest important change was determined as the within-participant standard deviation x 0.2, with 0.2 - 0.6 being small, 0.6 – 1.2 being moderate, 1.2 being large and >2.0 representing very large effects, respectively. Effects with confidence limits across a likely small positive or negative change were deemed unclear (23). A predesigned spreadsheet (22) was used for all calculations.

RESULTS

Changes in external, internal and performance demands between conditions

Despite no differences between conditions ($F(1,7)= 0.39$, $P > 0.05$), there was a main effect of time on circuit completion time ($F(2,14)= 11.66$, $P = 0.001$), and movement speed ($F(2,14)= 9.53$, $P = 0.002$). *Post-hoc* analyses revealed shortest completion times ($P = 0.001$) and greater movement speeds ($P = 0.002$) at the beginning compared to the end of each condition.

Changes in body mass from pre- to post-condition were similar for LONG (-0.17 ± 0.30 kg) and SHORT (-0.225 ± 0.25 kg; $t(7) = 0.51$, $P > 0.05$). There was a main effect of condition on 20 m sprint ($F(1,7)= 7.420$, $P = 0.03$), with overall sprints during the SHORT being faster than LONG. There was also a main effect of time on 20 m sprint time ($F(2,14)= 7.803$, $P = 0.005$), with *post-hoc* analysis revealing differences between the beginning and middle ($P = 0.01$) only. However, there was no condition x time interaction on 20 m sprint ($P > 0.05$). There were no differences in CMJ ($F(1,7)= 0.38$, $P > 0.05$) or throwing velocity ($F(1,7)= 0.49$, $P > 0.05$) between conditions, although magnitude-based inferences revealed a 'likely small' differences that were indicative of higher throwing velocity in SHORT compared to LONG. There were also no main effect of time ($F(2,14)= 2.35$, $P = 0.13$) or condition x time interaction ($F(2,14) = 0.95$, $P = 0.41$) on CMJ, nor was there a main effect on time ($F(2,14)= 1.31$, $P = 0.13$) or condition x time interaction ($F(2,14)= 0.094$, $P = 0.91$) for throwing velocity ($P > 0.05$).

Throwing accuracy was not different between conditions at the beginning ($z= -1.236$), middle ($z= -0.816$), or end ($z= -1.179$, all $P > 0.05$), and there were no main effects over time for LONG ($x^2= 4.16$, $P > 0.05$) or SHORT ($x^2= 0.33$, $P > 0.05$).

Average HR corresponded to 85% HR_{max} in LONG and 83% HR_{max} in SHORT, while maximum values reached 92% HR_{max} for both conditions. Despite no main effect of condition on HR_{max} ($F(1,7)= 0.04$) average HR ($F(1,7)= 2.05$) or summated HR ($F(1,7)= 0.07$, all $P > 0.05$), there were 'likely small' lower average heart rate and summated heart rate in SHORT compared to LONG. A main effect over time occurred for average HR ($F(2,14)= 30.53$, $P < 0.01$), with *post-hoc* analyses revealing lower heart rates at the beginning compared to the middle ($P < 0.001$), but no further changes were apparent after Bonferroni adjustment (see Table 2). There was also a significant condition x time interaction ($F(2,14)= 13.72$, $P = 0.001$), with *post-hoc* analyses revealing lower heart rates for SHORT only at the beginning compared to the middle ($t(7)= -3.72$, $P = 0.007$), and end ($t(7)= -6.15$, $P < 0.001$), whereas no changes were found for LONG ($P > 0.05$, see Table 2). Post-condition measures showed that SHORT resulted in 'most likely moderate' lower sRPE (*t*(7) = 5.61, *P* = 0.001), in addition to 'most likely moderate' higher [Glu] (*t*(7) = -2.64, *P* = 0.03) compared to LONG. However, there were no differences in [Bla] (*t*(7) = 1.11, *P* > 0.05) between conditions. All data are shown in Table 3.

****Insert table 2 about here****

****Insert table 3 about here****

The post-trial RSSJA test indicated differences in 10 m sprint time between conditions (*F*(1,7)= 6.862, *P* = 0.03), and a condition x time interaction (*F*(5,35)= 2.485, *P* = 0.05). *Post-hoc* tests revealed faster times for SHORT at sprint 4 (*t*(7)= 2.325, *P* = 0.05; 2.31 ± 0.15 *cf*. 2.21 ± 0.11 s for LONG and SHORT, respectively), and sprint 5 (*t*(7)= 4.051, *P* = 0.005; 2.31 ± 0.14 *cf*. 2.19 ± 0.08 s for LONG and SHORT, respectively; see Figure 3). Furthermore, SHORT resulted in 'likely moderate' faster times for sprints 2, 3 and 4, and 'very likely moderate' faster times for sprint 5 (CI: -0.1 ± 0.1 s for all) when compared to LONG. Total time for each 25 m sprint during the RSSJA also showed a condition x time interaction (*F*(2.74,19.20)= 3.133, *P* = 0.05). *Post-hoc* tests revealed faster times for SHORT at sprint 5 (*t*(7)= 2.708, *P* = 0.03; 5.98 ± 0.35 *cf*. 5.75 ± 0.26 s for LONG and SHORT, respectively; see Figure 4). This was supported by 'very likely moderate' faster times for sprint 4 and 5 CI: (-0.2 ± 0.2 s for both). There were no differences in agility time or CMJ performance between conditions (all *P* > 0.05).

DISCUSSION

This is the first study to investigate the influence of different work and rest distributions on performance and pacing strategy during a simulated team-sports protocol. Despite sprint time deteriorating progressively over the course of the simulation, a key finding was that faster sprint performances were maintained at the middle and end time-points when SHORT rather than LONG work and rest periods were adopted. Furthermore, reduced internal and external loading was apparent in SHORT, determined by lower average and summated heart rate, sRPE, and higher blood glucose concentrations. Repeated shuttle sprint running performance was also better preserved after SHORT work and rest periods, with moderate decreases in 10 m and 25 m sprint times. Collectively, interchange strategies using SHORT (~8 min and ~4 min) compared to LONG work and rest periods (~13 min and ~8 min) result in lower internal load. This leads to improved fatigue resistance and a better preservation of high-intensity movements during a match. This information can be used to maximise player performance both during a match and a tournament where multiple matches are played consecutively.

Although 20 m sprint time did not differ between conditions at the beginning of the simulation, faster sprint performance was practically meaningful in the SHORT compared to LONG conditions at the middle (4.01 ± 0.25 s *cf.* 3.93 ± 0.29 s) and end (4.06 ± 0.39 s *cf.* 3.97 ± 0.38 s) time points. The faster sprinting performance in SHORT at the middle and end time points mean that fatigue induced decrements in sprinting were more pronounced when work was distributed into three long periods, in comparison to five short periods. Indeed, the relative length of work time and knowledge of its end point is integral to how players distribute intensity and inform pacing strategy (5). In both rugby league (5,38,43) and soccer (9) interchanged players adopted faster pacing strategies than whole-match players, evidenced by a greater amount of high-intensity activity during their involvement on the field. While these studies did not provide information relating to the average duration of work time in interchanged players, the positive impact of shorter work-bouts on high-intensity activity is clear. Therefore, awareness of the shorter work periods and knowledge that a rest period was in close proximity might have contributed to players setting higher pacing strategies that enabled faster sprints.

CMJ was not different between conditions or over time, suggesting that these movements were not limited by any fatigue induced by the simulation and not influenced by the differing duration of work and rest distributions. Jump performance during and after team-sport matches and simulations is either unchanged (25,40) or decreased (39-40,41). That this study did not observe changes in CMJ performance, but did report deterioration in sprinting times might be explained by the nature of the protocol involving mainly running related movements with just one jump per circuit. Poor relationships between vertical jump performance and sprinting (12) are likely to contribute to the decreased sensitivity of the CMJ to detect running induced fatigue. The lower training status of players from this study (CMJ = ~34 cm), compared to another team handball study (CMJ = ~38 cm, 39) could also have influenced the magnitude of change. As such, having a lower jumping ability to begin with reduced the extent to which performance deteriorated, in comparison to players with a better jumping ability.

Average throwing velocity was better by a *likely small* magnitude in the SHORT condition, indicating that a player’s throwing performance is compromised during more prolonged work bouts. In contrast, players were able to maintain throwing accuracy regardless of condition or time. Our results conflict with other team handball studies showing decreases in throwing accuracy but not velocity under conditions of simulated fatigue (45-46). One explanation for these discrepancies is likely due to the measure of accuracy used in our study, which was simply a measure of ‘successful’ (the ball entering the goal) or ‘unsuccessful’ (the ball being off-target). Zapartidis and colleagues (45-46) used the deviation of the centre of the ball from a pre-determined target, thus establishing a measure that was more sensitive to changes in performance. Considering that players are required to execute precise shot placement during matches, implementation of more sensitive measures are of greater practical significance when monitoring the impact of work and rest periods over time. Although it was not the aim of the study to identify mechanistic explanations, the greater maintenance of throwing velocity in SHORT could be explained by fatigue-induced changes in muscular coordination patterns (45), causing more pronounced interference in the production of velocity over longer periods of work. Indeed, effective throwing performance requires execution of correct technique while appropriately timing the movement of body segments, in addition to possession and correct execution of strength and power (19).

Only small differences in heart rate were observed between the LONG (~85% HRmax) compared to SHORT (~83% HRmax) conditions. This is likely explained by participants completing each work bout for ~5 minutes longer during the ‘LONG’ exercise condition. The moderately higher perceived exertion further indicates a greater internal load during the LONG compared to SHORT condition. Perception of effort is a major determinant of fatigue (14), whereby a higher perception of effort lowers exercise tolerance independently of afferent feedback from the cardiovascular, respiratory, metabolic and neuromuscular systems (for a review see Marcora *et al.*, 30). In accordance with the psychobiological model of exercise tolerance (30-31), individuals are said to withdraw effort when the task demands exceed the greatest effort they are willing to exert in order to succeed (potential motivation), or when the required effort is greater than their perceived ability (44). As such, it is likely that the greater perception of effort observed in the LONG condition contributed to the more pronounced decrement observed in sprinting performance. Participants’ knowledge that they would have to maintain performance for a longer period of time might have been interpreted as more challenging, leading to a subsequent down-regulation of effort during sprinting activity. This has particularly important implications during matches, or periods of repeated play during tournaments, whereby the relationship between sRPE and percentage decrement in sprinting performance got stronger over the course of an international tournament (*r*= 0.64 – 0.80, Moss, unpublished observations). These findings indicate that longer work bouts, with less frequent recovery periods during multiple interchange efforts, increase internal player load when compared to work periods of the same duration comprising shorter periods. Using shorter work periods during sports permitting multiple interchanges would be useful for reducing a player's internal load and enabling the maintenance of sprint performance during matches.

Interestingly, higher blood glucose concentrations were observed at the end of SHORT compared to LONG condition. This greater availability of glucose might help to partly explain the greater maintenance of sprinting performance throughout the SHORT condition, as high-intensity work relies on plasma glucose tissue uptake for muscle glycogen oxidation (37,42). However, whether a relationship exists between blood glucose and net muscle glycogen utilisation during intermittent exercise is unknown (20). Reasons for higher post-exercise blood glucose concentrations in the SHORT condition are unclear. During exercise, secretion of glucagon promotes the release of glucose into the blood from the liver via glucogenisis and glucogenolysis (28). Although speculative, it might be possible that the different work and rest periods between conditions led to an altered response in these processes, and subsequent hepatic glucose production. However, the exact mechanism and relevance to muscle glycogen utilisation warrants further investigation.

The post-simulation repeated shuttle sprint and jump ability test revealed faster sprint times for the SHORT compared to LONG condition. These results highlight that players were able to limit fatigue-induced decrements in repeated sprint performance when performing SHORT work bouts. These results are relevant considering the well documented decreases in sprinting activities during the later stages of matches (32,36). Therefore, effective use of interchange strategies throughout matches might contribute to greater maintenance of repeated high-intensity activity and subsequent performance in the final stages.

Reasons for the poorer repeated sprint performance after the LONG condition are likely to be multifaceted. Although the link between blood glucose and muscle glycogen concentrations during intermittent exercise is currently unknown (20), the finding that blood glucose concentration was higher after the SHORT condition needs to be addressed in relation to repeated sprint performance. Inadequate concentrations of glycogen have previously been associated with poorer sprint performance in soccer (26), and a close relationship between muscle glycogen content and fatigue resistance in intermittent exercise is well established (1). Research suggests that the impact of limited glycogen availability on performance is manifested through inhibited rates of ATP regeneration, causing inadequate production of muscle force (35). Thus, it is possible that lower availability of blood glucose after the LONG condition had a negative impact on participants' ability to complete repeated sprint activity.

An interesting observation revealed that the pacing strategies employed to complete the repeated sprint test were different between conditions. While 25 m sprint times progressively deteriorated with an 'end spurt' in the final sprint after the LONG condition, participants were able to maintain performance in the SHORT condition. That participants were able to produce a similar 25 m time in the final sprint of the test suggests that effort and motivation plays an important role after fatiguing exercise. These findings agree with previous research, which reported that the ability to produce force using a maximal voluntary muscle contraction was not inhibited after exhaustive exercise (30). Moreover, these authors proposed that tolerance to complete an exercise task is negatively influenced by perceived effort (30). It is therefore possible that the much higher perceived effort reported after the LONG condition had a subsequent impact on their perceived ability and/ or motivation to complete the repeated sprint protocol to the best of their ability (30-31).

PRACTICAL APPLICATIONS

This study has been the first to investigate the impact of different work and rest distributions on a variety of performance characteristics during an intermittent team game simulation. Shorter work and rest distributions (SHORT) appeared to provide a practically meaningful preservation of sprinting performance, both during and immediately after exercise when compared to longer work and rest distributions (LONG). These findings can be used to better inform coaches, enabling them to maximise the effective distribution of interchange strategies and aid overall team performance during matches. Specifically, monitoring player performance using different interchange strategies can help to identify those players who might benefit the most from completing shorter periods of work and rest, while also highlighting individual player weaknesses to inform conditioning practices. Furthermore, these findings would become more applicable to tournament scenarios whereby there is a need to maintain team performance for a prolonged period of time. By effectively distributing work-loads, through short but frequent bouts of work and rest, players might be better able to maintain sprinting and throwing activity, and experience lower perceived exertion. However, it is also appreciated that such an interchange process requires skilful management by coaches, who need to ensure that continuous interchanging of players does not affect the ‘flow’ or quality of match play.

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Figure legend

Figure 1: Simulated Team-Game Protocol modified from Bishop *et al.* (2001) (not to scale)

Figure 2: Work (shaded bars) and rest (clear bars) periods for LONG and SHORT conditions. Sprint performance and CMJ were taken during the first, middle and last six circuits of each condition. Throwing performance was taken from the first, middle and last three shots for each condition

Figure 3: Mean ± SD 10 m sprint performance for LONG (black) and SHORT (grey) over 6 repeated efforts during the RSSJA test. * significantly different to SHORT ($P < 0.05$)

Figure 4: Mean ± SD 25 m sprint performance for LONG (black) and SHORT (grey) over 6 repeated efforts during the RSSJA test. * significantly different to SHORT ($P < 0.05$)

Table legend

Table 1: Baseline performance measures. Values are mean ± standard deviation

Table 2: A comparison of performance variables at the beginning, middle, and end of LONG and SHORT conditions

Table 3: Mean values for LONG and SHORT conditions