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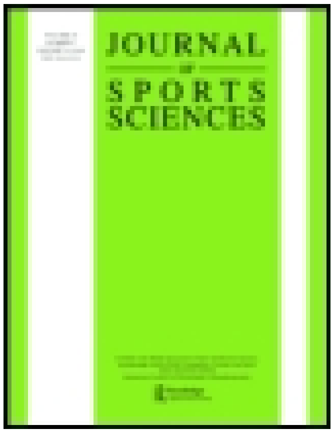

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Physical and psychomotor performance of Australian football and rugby league officials during a match simulation

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Abstract
The onset of exercise facilitates an improvement in psychomotor performance until the second ventilatory threshold, after which performance is reduced. This inverted-U relationship appears valid for incremental and steady-state exercise, however, not for intermittent exercise. This study examined changes in psychomotor performance of team sport officials during a laboratory-based match simulation. Twelve elite Australian football (n = 5) and rugby league (n = 7) officials (32.5 ± 5.5 years; 180.0 ± 6.8 cm; 78.8 ± 7.6 kg) completed the match simulation on a non-motorised treadmill. Physiological measures were routinely taken, while psychomotor performance was assessed using the Eriksen flanker task (multiple-choice response time). Significant reductions ($P < 0.05$) were observed in distance covered and high-speed running during the second half when compared to the first. No significant differences ($P > 0.05$) in psychomotor performance at different time points were observed. Response time was significantly improved when running above 65% of maximal sprinting speed ($P < 0.01$). This data questions the application of the inverted-U hypothesis for intermittent exercise and suggests that the short high-intensity efforts may not result in the same physiological events that limit psychomotor performance during sustained high-intensity exercise. More so, the high-intensity efforts during the match protocol appeared to promote psychomotor performance during the intermittent exercise.

Keywords: *cognition, perceptual skill, intermittent exercise, decision making, team sport officials*

Introduction

Decision-making is the ability to integrate information from the current situation with your knowledge and expertise, to plan, select and execute an action or set of actions (Causer & Ford, 2014). For team sport officials, superior decision-making is a vital aspect of their performance and may be important for the outcome of a match. By extracting information from the match play environment, officials enforce the laws of the game, by penalising players who breach these laws during a match. Match-specific data from soccer (Fuller, Junge, & Dvorak, 2004; Mallo, Frutos, Juárez, & Navarro, 2012; Mascarenhas, Button, O'Hare, & Dicks, 2009) and Australian football (Elsworthy, Burke, Scott, Stevens, & Dascombe, 2014) officials has highlighted considerable variation (~65–85%) in their decision-making accuracy during match play. Currently there is no known data reporting on the decision-making accuracy of officials within other sports such as rugby league. In addition, these decision-making skills are executed whilst undertaking extensive physical demands in order to be positioned well in relation to play (Mascarenhas et al., 2009). The resultant physiological effects of exercise have been shown to negatively impact decision-making performance, most likely due to changes in blood flow distribution and central nervous system arousal at higher exercise intensities (Kashihara, Maruyama, Murota, & Nakahara, 2009; Lambourne & Tomporowski, 2010; Tomporowski, 2003).

Psychomotor performance is a term used to describe the performance of a specific motor task in response to a sensory stimulus (i.e. choice reaction tasks) (Chmura, Krysztofiak, Ziemba, Nazar, & Kaciuba-Uscilko, 1997; McMorris, Sproule, Draper, & Child, 2000; Reilly & Smith, 1986). Psychomotor performance has been shown to improve upon the onset of exercise (Chmura & Nazar, 2010). With increasing exercise intensities

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towards the aerobic–anaerobic transition (i.e. onset of blood lactate accumulation or second ventilatory threshold [VT_2]), psychomotor performance continues to improve, after which psychomotor performance declines towards baseline levels (Chmura & Nazar, 2010). This decline in cognition coincides with variations in cerebral blood flow, which may limit oxygen delivery to the brain and contribute to the development of central fatigue (Nybo & Rasmussen, 2007). As such, an inverted-U curve has commonly been used to describe the relationship between exercise intensity and psychomotor performance (Kashihara et al., 2009; Lambourne & Tomporowski, 2010). However, such a relationship has only been shown in steady-state or incremental exercise protocols and little is known on the changes in psychomotor performance throughout prolonged high-intensity intermittent exercise. Furthermore, a recent study suggested that the inverted-U relationship may only be valid for non-athletes, whilst expert performers exhibit a linear improvement in attentional performance with increases of exercise intensity (Hüttermann & Memmert, 2014).

Field-based team sports, such as rugby league and Australian football, typically last between 80 and 120 min, with the activity profile of competitors best described as high-intensity intermittent exercise (Bangsbo, 1994). Specifically, this activity consists of short bouts of high-intensity exercise that are interspersed by extended periods of low-intensity recovery. As such, players and officials are exposed to extensive physical and physiological demands throughout a match. The main officials within these sports have previously been referred to as “interactor referees” as they have an impact on the pace of the game, ensure the safety of competitors and apply the laws of the game (MacMahon & Plessner, 2008). Their role requires them to move throughout the playing arena in response to movement of the ball and players. As a result, they may cover up to 12 km during soccer (Weston, Drust, & Gregson, 2011) and Australian football (Elsworthy et al., 2014) matches, while in rugby league, the match coverage is less (approximately 8 km) (O’Hara et al., 2013). Previous studies have also reported an average maximum heart rate of 80–95% during matches (Elsworthy & Dascombe, 2011; Mallo, Navarro, Aranda, & Helsen, 2009). While these officials heavily rely on aerobic energy metabolism, the frequent high-intensity activities required significant anaerobic contribution, as supported by the observation of blood lactate concentrations of up to 14 $\text{mmol} \cdot \text{L}^{-1}$ being reported at the end of matches in soccer referees (Krustrup & Bangsbo, 2001). This could suggest that psychomotor ability may be inhibited by the competing physiological demands during such intermittent exercise.

However, a recent study examining psychomotor performance during a soccer simulation concluded that multi-choice response time improved throughout an intermittent exercise protocol (Wiśnik, Chmura, Ziemba, Mikulski, & Nazar, 2011). The reported changes were similar to constant, moderate-intensity exercise, where response time progressively decreases throughout the exercise bout. The authors suggested that the improved response times were likely facilitated by increases in central nervous system arousal. Moreover, it is likely that the frequent changes in running speed during intermittent exercise help prevent the adverse effects of high-intensity exercise on psychomotor performance. When compared to incremental exercise protocols that require work rates to be sustained for extended periods (i.e. >1 min), the intermittent protocol employed by Wiśnik et al. (2011) consisted of changes in running speed (increasing or decreasing) every 5–15 s to replicate the time–motion characteristics of soccer match-play. Such methodological differences would likely place varying effects on cerebral blood flow and central nervous system arousal. Therefore, the examination of psychomotor performance during such an intermittent protocol is more applicable to team sport match officials compared to steady-state or incremental exercise.

Whilst team sport officials undertake a critical role during competitive match play, the psychomotor ability of this cohort during intermittent exercise remains relatively unknown. It has only been in recent years that the decision-making accuracy of officials has been assessed during actual match play. Only two existing studies have examined the relationship between the physical and physiological demands of the role on decision-making accuracy (Elsworthy, Burke, & Dascombe, 2014; Mascarenhas et al., 2009). The decisions made during match play are completed while performing high-intensity intermittent exercise that is similar to that reported for players. While there is no significant effect of instantaneous speed or heart rate on decision-making accuracy of soccer referees (Mascarenhas et al., 2009), there was a greater likelihood of a decisional error when a higher running speed was maintained 5 s prior to a decision within Australian football officials (Elsworthy et al., 2014). Given these findings, it is important that the psychomotor performance of team sport officials during intermittent exercise be examined further. As such, the current study aimed to determine changes in the psychomotor performance of elite team sport officials during an intermittent match simulation.

Methods

Twelve highly trained male Australian football (n = 5) and rugby league (n = 7) officials (mean age: 32.5 ± 5.5 years; height: 180.0 ± 6.8 cm; body mass: 78.8 ± 7.6 kg) volunteered to participate in the study. All participants were currently officiating within the highest level of professional competition within their respective sports (i.e. National Rugby League and Australian Football League). Prior to inclusion in the study, all participants gave informed written consent and completed a pre-exercise health screening questionnaire. Participants were instructed to abstain from physical training 24 h prior to the testing sessions. All methods and experimental procedures were approved by the University Human Research Ethics Committee (Approval No: H-2012–0045).

Experimental design

Participants visited the laboratory on two occasions separated by 4–7 days. Visit 1 included a basic anthropometrical assessment (height, weight, Σ7 skinfolds), familiarisation with testing procedures, a maximal sprinting speed (MSS) assessment, followed by treadmill test to assess maximal oxygen consumption (VO_2max). Visit 2 consisted of a match simulation that closely replicated the physical aspects of typical team sport match play, such as Australian football, on a non-motorised treadmill (Curve 3.0^{TM}, Woodway, Waukesha, USA). Prior to each testing session, the treadmill was calibrated according to the manufactures procedures. Treadmill data (velocity and distance) were recorded (25 Hz) via transducers built into the treadmill platform attached to a personal computer using the Pacer Performance software package (XPV7, Fitness Technologies, Adelaide, Australia).

Preliminary testing

Following familiarisation to the non-motorised treadmill, individual MSS was determined and used to prescribe the running speeds throughout the simulation. Upon completion of a standardised 5 min warm up, each participant completed three maximal 3-s and 6-s sprints, alternately, interspersed by 2 min of active recovery. The MSS was calculated as the highest speed obtained for a single second during one of the sprints (Sirotic & Coutts, 2008).

Following a 15 min passive recovery, participants then completed a treadmill test for VO_2max using a ramp protocol that commenced at 7 km · h^{-1} and increased by 1 km · h^{-1} per min until volitional exhaustion. Measurements of oxygen consumption (breath by breath; Jaeger Oxycon Pro, CareFusion, Leibnizstrasse, Germany) and heart rate (1 Hz; RS800X, Polar Electro, Kempele, Finland) were collected throughout the maximal exercise test. The first (VT_1) and second (VT_2) ventilatory thresholds were calculated using the V-slope method as previously described by Beaver, Wasserman, and Whipp (1986).

Match simulation protocol

The simulation used in the current study was based upon that from Sirotic and Coutts (2008), which was based on the time–motion data of sports such as soccer, rugby league, rugby union and Australian football. However, to replicate the typical playing duration of Australian football (~120 min), the simulation was lengthened to 132 min inclusive of breaks (quarter time (6 min), half time (20 min) and three-quarter time (6 min) breaks). As such, the simulation was divided into 4 equal quarters (25 min), and each quarter consisted of 2 × 12.5 min blocks, which were performed in succession (Figure 1), with an overall "playing duration" of 100 min.

The simulation consisted of six categories of movement, relative to the individual's MSS: standing (0%); walking (20%); jogging (35%); running (45%); fast running (65%); and sprinting (100%). Throughout the simulation, the relative time spent in each category was standing (28.5%); walking

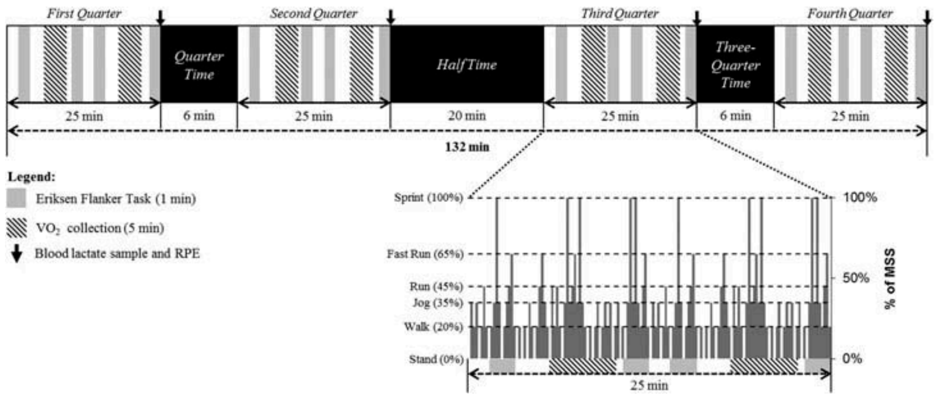

Figure 1. Schematic diagram of the match simulation.

(36.3%); jogging (21.3%); running (7.7%); fast running (2.1%); and sprinting (4.0%). Further, high-speed running (HSR) distance was calculated as the distance covered above 65% of MSS (Sirotic & Coutts, 2008). A total of 72 activity changes were included within each block with a change of activity on average once every 10 s. Audio cues were provided to indicate a change in activity, along with continuous visual feedback of the current and target speed. Participants were also provided with verbal encouragement to the target speed displayed.

Heart rate was recorded for the entire duration of the simulation. Oxygen uptake was measured using a Jaeger Oxycon Pro (CareFusion, Leibnizstrasse, Germany), which was calibrated prior to each test for volume using a 3 L syringe (Hans Rudolph, Inc., Kansas City, USA) and gas using known concentrations of calibration gases, according to product specifications. These measures were collected in 5 min periods during the simulation, at the same time in each quarter (6.5–11.5 min, 18–23 min). Blood lactate concentration ($[BLa^-]$, 5 µl) was sampled from a hyperaemic earlobe and analysed using a Lactate Scout Analyser (EKF Diagnostics, Magdeburg, Germany), and rating of perceived exertion (RPE) (Borg, 1982) were recorded immediately following the conclusion of each quarter. Participants were permitted to consume water *ad libitum* during the quarter, half and three-quarter time breaks.

Psychomotor performance assessment

A modified Eriksen flanker task was used to examine the psychomotor performance of participants during the match simulation (Davranche, Hall, & McMorris, 2009). The task was created using the SuperLab® stimulus presentation software (v4.5, Cedrus Corporation, San Pedro, USA) on a personal computer and displayed on a wall-mounted monitor (58 cm, T231 H, 60 Hz, Acer Inc., New Taipei City, Taiwan) positioned at eye level, 1.5 m from the participant. Responses were recorded using wireless handheld controllers (Sony Computer Entertainment, Tokyo, Japan) to allow for fast and accurate responses whilst running the simulation. Each Eriksen flanker trial consisted of three coloured circles, horizontally arranged, which were presented at the centre of the screen for 1.5 s, following a 1 s fixation point. The interval between the disappearance of the display and the onset of the next trial was 1.5 s. As such, 15 trials were presented within a 1 min test period. Participants were instructed to respond as quickly and accurately as possible to the colour of the middle circle, while ignoring the "flanker" (distractor) circles. The target colours blue (B) or green (G) required a left-hand response, while red (R) or yellow (Y) required a right-hand response. There were three types of trials: congruent (50%), stimulus-incongruent (25%) and response-incongruent (25%). For congruent trials, the flanker circles were of the same colour as the target circle (i.e. BBB or RRR). For stimulus-incongruent trials, the flanker circles were of a different colour from the target circle; however, they corresponded to the same response (i.e. BGB or RYR). For response-incongruent trials, the target circle was flanked by circles corresponding to the alternate response (i.e. BRB or GYG).

During the familiarisation session, participants completed a training session consisting of 10 blocks of 15 trials each to minimise any potential learning effects of the Eriksen flanker task. This was completed while standing stationary, prior to any physical exertion. Prior to the start of the match simulation, participants completed one block of 15 trials while standing stationary as a pre-simulation measure. During the match simulation, four blocks of 15 trials were performed at various stages throughout each quarter (at 2, 11.5, 14.5 and 24 min) as shown in Figure 1. In order to replicate the combined decision-making and physical aspects of team sport officiating, the psychomotor tasks were performed while concurrently performing the intermittent match simulation protocol. Overall, there were 60 stimuli presented within each quarter, with 10 presented when running >65% MSS (i.e. fast run and sprint), with 50 presented during lower speed running modalities (<65% MSS). Following the simulation (10 min), one block of 15 Eriksen flanker trials was performed while standing stationary to provide a post-simulation measure.

Statistical analysis

All data are presented as mean ± standard deviation from the mean. The primary outcome of the analysis was to determine if there were any variations in psychomotor performance during an intermittent match simulation. The normality of data distribution was checked by Shapiro–Wilk *W*-test. A one-way repeated measures analysis of variance (ANOVA) was performed on the physical, physiological, perceptual and psychomotor performance measures across the simulation. These data were grouped by quarters across the simulation. Effect sizes for the ANOVA were presented as the partial eta squared (η^2) statistic. To examine changes in psychomotor performance in relation to physical and physiological intensities, data were first divided into groups, according to running speed (<65%, ≥65% MSS), as well as heart rate relative to ventilatory thresholds ($<VT_1$, VT_1–VT_2 and $>VT_2$) and percentage of maximum heart rate (<70%, 71–80%, 81–90%, ≥91% HR_{max}). Paired sample *t*-tests identified differences between each group for these measures. To reduce the likelihood of a Type-I error, a Bonferroni correction was applied for significant differences. The corrected P-value was calculated as $P < 0.05$ divided by the number of variables. Cohen's effect sizes (ES) were applied with small, moderate and large ES representing 0.2, 0.5 and 0.8, respectively (Cohen, 1988). Statistical significance was set at $P < 0.05$. All statistics procedures were performed using SPSS (version 19, IBM Corporation, Somers, New York, USA).

Results

From the preliminary testing, the MSS of the participants was $26.6 \pm 1.7\ \text{km} \cdot \text{h}^{-1}$, thus the HSR threshold (65% of MSS) was $17.3 \pm 1.1\ \text{km} \cdot \text{h}^{-1}$. The cardiopulmonary characteristics of the team sport officials are shown in Table I.

Table II shows the main physical and physiological performance measures during the intermittent match simulation. The total distance covered during the simulation was 11,134 ± 665 m, with significantly less distance ($F_{3,33} = 6.900$; $P = 0.001$; $\eta^2 = 0.385$) covered during the third ($P = 0.006$; ES = 0.39; 95% CI: 25.0–115.2 m) and fourth ($P = 0.010$; ES = 0.49; 95% CI: 25.5–151.8 m) quarters compared to the first. There was also a significant reduction in distance covered between the second and fourth quarters ($P = 0.027$, ES = 0.20; 95% CI: 4.2–59.0 m). The HSR distance covered was 1772 ± 190 m (16% of total distance), with a significant main effect observed ($F_{3,33} = 3.112$; $P = 0.039$; $\eta^2 = 0.221$), whereby the fourth quarter was significantly less than the second ($P = 0.029$; ES = 0.45; 95% CI: 1.95–43.7 m).

The average heart rate across the entire simulation (excluding breaks) was $152 \pm 8\ \text{b} \cdot \text{min}^{-1}$ (82 ± 4% HR_{max}) with a main effect of time observed ($F_{3,33} = 4.338$; $P = 0.013$; $\eta^2 = 0.352$). A moderate ES was identified in average heart rate between the first and second ($P = 0.030$, ES = 0.54) as well as the third and fourth ($P = 0.010$, ES = 0.62) quarters. Further, a small ES was identified between the second and third quarter ($P = 0.012$, ES = 0.40). Perceptual scores (RPE) increased throughout the simulation ($F_{3,33} = 38.894$; $P < 0.001$; $\eta^2 = 0.770$), with significant differences identified between each two quarters (Table II). There were no significant differences in other physiological measures (i.e. $[\text{BLa}^-]$ or VO_2) throughout the match simulation ($P > 0.05$).

The average response times for the Eriksen flanker task for the simulation are shown in Figure 2. There were no significant differences in response time ($P > 0.05$) or accuracy ($P > 0.05$) at each time period across the simulation. There were no more than 10 errors committed by any participant, providing an overall accuracy of 98 ± 1%.

When examining psychomotor performance in relation to running speed, significant differences were identified. Specifically, when comparing response time to running speed (i.e. above or

Table I. Cardiorespiratory characteristics of team sport officials during test of maximal aerobic capacity.

Measure	VT_1	VT_2	VO_2max
Oxygen uptake ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	35.0 ± 4.1	49.2 ± 5.0	55.9 ± 6.0
Oxygen uptake (% max)	63 ± 6	88 ± 5	–
Pulmonary ventilation ($\text{L} \cdot \text{min}^{-1}$)	78.9 ± 15.7	126.9 ± 20.0	161.8 ± 28.4
Running speed ($\text{km} \cdot \text{h}^{-1}$)	8.3 ± 1.1	11.5 ± 1.2	15.3 ± 1.4
Heart rate ($\text{b} \cdot \text{min}^{-1}$)	147 ± 13	169 ± 11	186 ± 5
Heart rate (% max)	79 ± 7	91 ± 5	–

Note: VT_1: first ventilatory threshold; VT_2: second ventilatory threshold; VO_2max: maximal oxygen consumption.

Table II. Physical and physiological measures taken during each quarter across the team sport simulation.

Variable	First quarter	Second quarter	Third quarter	Fourth quarter
Total distance (m)	2833 ± 186	2794 ± 156	2763 ± 172[a]	2744 ± 173[ab]
HSR distance (m)	456 ± 56	455 ± 45	432 ± 52[b]	431 ± 58
Heart rate ($\text{b} \cdot \text{min}^{-1}$)	149 ± 12	154 ± 9[a]	151 ± 7[b]	155 ± 6[c]
Heart rate (% max)	80 ± 5	83 ± 4[a]	81 ± 3[b]	84 ± 4[c]
Oxygen uptake ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	38.3 ± 3.3	38.4 ± 3.7	37.7 ± 3.3	38.8 ± 4.1
$[\text{BLa}^-]$ ($\text{mmol} \cdot \text{L}^{-1}$)	7.7 ± 3.2	7.4 ± 2.6	7.1 ± 2.4	6.5 ± 1.7
RPE (AU)	13.9 ± 1.7	15.0 ± 1.7[a]	15.7 ± 1.4[ab]	17.1 ± 1.2[abc]

Notes: HSR, high-speed running; $[\text{BLa}^-]$, blood lactate concentration; RPE, rating of perceived exertion.
[a]Significantly different from first quarter; [b]significantly different from second quarter; [c]significantly different from third quarter ($P < 0.05$).

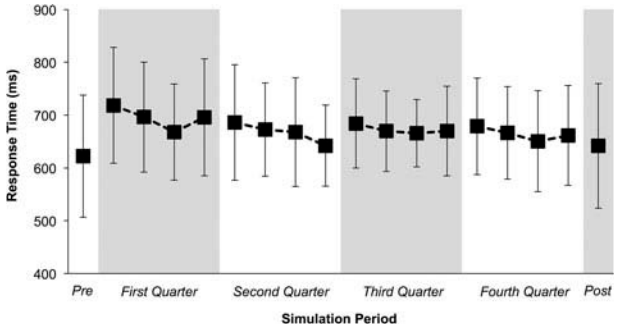

Figure 2. Multiple-choice response time (mean ± SD) across the team sport simulation.

below HSR threshold), responses were significantly faster when running above 65% MSS ($P = 0.002$; ES = 0.55; 95% CI: 21.4–62.9) (Figure 3a). Interestingly, significant differences were present in the response time of congruent ($P = 0.004$; ES = 0.46; 95% CI: 16.3–65.0) and stimulus-incongruent ($P = 0.020$; ES = 0.47; 95% CI: 7.7–74.2) trials when compared to response-incongruent stimuli during low-speed running (Figure 3a). However, these differences were not significant ($P > 0.025$) when running at >65% MSS, although significant improvements were present in

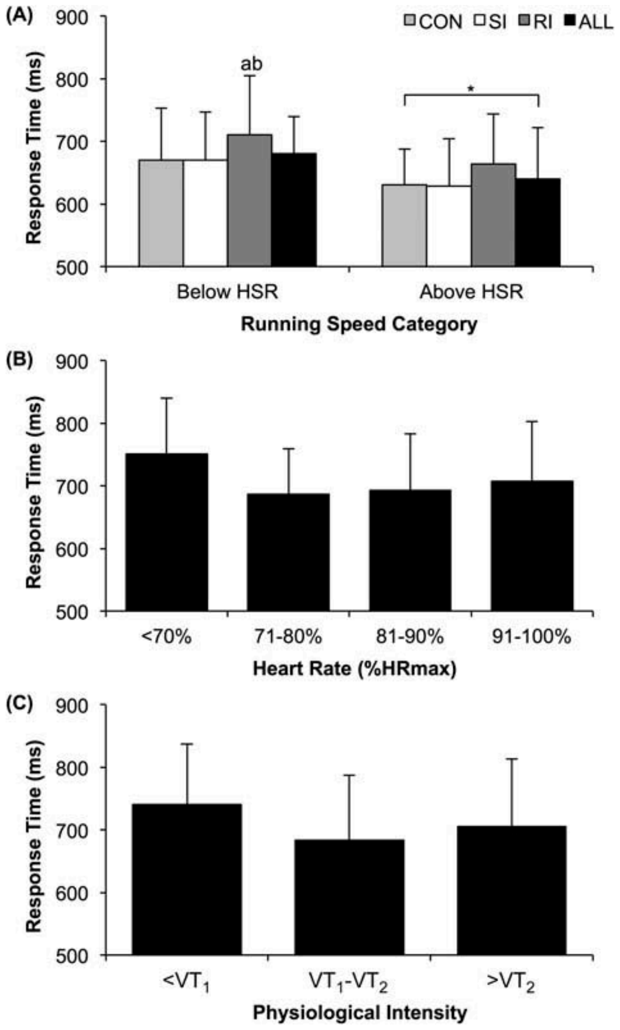

Figure 3. Relationship between response time and (a) running speed, (b) heart rate and (c) ventilatory thresholds.

[a]Significantly different from CON; [b]significantly different from SI; *significantly different from below HSR ($P < 0.025$). CON, congruent; SI, stimulus-incongruent; RI, response-incongruent; HSR, high-speed running; VT_1, ventilatory threshold 1; VT_2, ventilatory threshold 2.

psychomotor performance of all congruencies compared to below HSR ($P < 0.025$, ES = 0.50). There were no significant differences in response time when compared to time spent at different heart rates ($P > 0.013$) (Figure 3b) or above or below the ventilatory thresholds ($P > 0.017$) (Figure 3c).

Discussion

The purpose of the current study was to examine the psychomotor performance of elite team sport officials during a laboratory-based intermittent match simulation. The study demonstrated no differences in psychomotor performance across the simulation, despite significant declines in the total distance covered and HSR distance. These reductions in physical performance are in agreement with various time–motion literature on similar team sport officials during actual match play (Elsworthy et al., 2014) and laboratory-based simulations (Aldous et al., 2014). While the target speed was consistent throughout the simulation, the reduction in the physical capacity to reach the targeted speeds is typical of accumulative fatigue that may limit HSR. Factors such as glycogen depletion, dehydration and potassium accumulation may manifest as fatigue during prolonged bouts of intermittent exercise (Bangsbo, Iaia, & Krustrup, 2007). These mechanisms may explain the reduction in physical performance measures throughout the simulation in the current study.

Examination of the psychomotor performance revealed that there were no significant changes in response time throughout the simulation, or when compared to pre- and post-exercise measures. This agrees with data from within a similar officiating cohort, where there was no change in decision-making accuracy at different stages of a match (Elsworthy et al., 2014). However, recent laboratory data from Wiśnik et al. (2011) reported that intermittent exercise actually promotes psychomotor performance similar to constant work rate moderate-intensity exercise, where significant improvements in choice response time were reported as the exercise bout progressed. These data from Wiśnik et al. (2011) support the findings of Mascarenhas et al. (2009) who examined similar responses in soccer referees. Wiśnik et al. (2011) suggested that periods of low- and moderate-speed running that induce central nervous system arousal are able to prevent the adverse effects of the short periods of HSR.

However, methodological differences may explain the differences in the findings of the current study and data from Wiśnik et al. (2011). The choice reaction test used by Wiśnik et al. (2011) was only performed when exercising at speeds greater than $14.4\ \mathrm{km \cdot h^{-1}}$ on a motorised treadmill. Therefore, the study did not assess overall psychomotor performance of the intermittent exercise, rather it was limited to analysing psychomotor performance at higher intensities. This is relatively important given that during match play, team sport officials may be required to make a decision, while moving at various speeds as the game requires. This could include any speed between standing stationary and a maximal sprinting effort, which has been shown to impact on decision-making accuracy within Australian football officials (Elsworthy et al., 2014). While the authors acknowledge that decisions are made at a range of movement speeds, it remains unknown as to the proportion of decisions made within specific speed categories. This information would allow for more match-specific protocols to be developed; however, this is perhaps a topic of investigation for future studies on this cohort.

Wiśnik et al. (2011) may have overestimated psychomotor performance, given that there were improvements during HSR compared with lower intensity (<65% MSS) exercise within the current study. The current data demonstrated that short bouts of HSR may promote further improvements in psychomotor performance during intermittent exercise. Within the current study, HSR bouts were a maximum 6 s in length, thus the immediate central nervous system impairment may not reach a magnitude that result in a decrement to performance. Specifically, Chmura and Nazar (2010) suggested that best psychomotor performance occurred at an intensity greater than VT_2 during incremental exercise. These extended periods at a constant work rate appeared to provide sufficient time for changes in central nervous system arousal and cerebral blood flow to occur, resulting in changes in psychomotor performance at specific intensities such as when above VT_2. However, the rate of change within central nervous system arousal following an abrupt increase in running speed remains unknown, and as such, it may not occur within the short-duration HSR bouts throughout the intermittent match simulation.

Interestingly, Edwards, Martin, and Hughson (2002) suggested that cerebral blood flow significantly decreased below baseline throughout the first 5 s following cessation of resistance exercise. Indeed these trends may be different depending on exercise modality; it does, however, suggest these physiological changes could take effect following an HSR bout, and may influence psychomotor performance in a similar manner. Therefore, during intermittent exercise, psychomotor performance may be reduced following an HSR bout (rather than during) as a result of these delays. However, further research is required to support this statement.

Although there were significant changes in response to movement speed, no such relationships were observed with respect to physiological intensities and psychomotor performance. Physiological intensities of ~70–80% HR_{max} were aligned with the fastest response times during the simulation; however, these were not significant. When corresponding to the ventilatory thresholds (VT_1 and VT_2), response time was fastest between these thresholds. While there was a trend for psychomotor performance to be reduced at higher work intensities (i.e. $>VT_2$) during the intermittent protocol, the inverted-U hypothesis was not considered valid given the small magnitude of differences observed across the increasing intensities. The frequent changes of movement speed did not appear to significantly impact upon the relationship between physiological intensity and psychomotor performance.

Typically, steady-state or incremental exercise protocols have been used to examine changes in psychomotor performance, which led to the proposal of the inverted-U relationship with exercise intensity. It is suggested that cerebral blood flow increases in response to the increased cerebral metabolism associated with exercise (Ogoh & Ainslie, 2009). At higher exercise intensities (i.e. above VT_2), it has been reported that cerebral blood flow returns towards baseline levels due to hyperventilation-induced hypocapnia (Ogoh & Ainslie, 2009). However, this phenomenon has only been reported for steady-state and incremental exercise, whereby extended periods are spent at steady-state work rates, which is in contrast to intermittent exercise typical of team sport match play. Short-duration HSR may not elicit the same responses around central nervous system arousal and cerebral blood flow as shown for longer HSR bouts. Thus, it could be suggested that the inverted-U relationship would not demonstrate validity throughout prolonged high-intensity intermittent exercise, given the limited information assessing psychomotor performance during intermittent exercise.

It must be stated that the participant group in the current study were elite performers, as they were officiating at the professional level in their chosen sport. From their match and training experience, it is possible that they may be able to sustain a higher level of psychomotor performance throughout a match, regardless of the timing of the decisions (i.e. early or late in simulation). This may explain the differences in findings between the current study and Wiśnik et al. (2011) in terms of the reported changes in psychomotor performance during intermittent exercise. Previous studies have demonstrated that expert performers possess superior decision-making when compared to less experienced counterparts using actual match footage (Larkin, Berry, Dawson, & Lay, 2011; Roca, Ford, McRobert, & Williams, 2013). Indeed, these studies provide a greater ecological validity by using match-specific decision-making; however, similar differences between athletes and non-athletes were reported for a non-sport-specific (attentional breadth measuring task) psychomotor task (Hüttermann & Memmert, 2014). Therefore, this is a possible area for future research in determining the match-specific decision-making skills of expert decision-makers during intermittent exercise.

Conclusion

The present study is the first to examine the psychomotor performance of elite team sport officials through a simulated intermittent match protocol. In particular, this is vital for such a cohort given their combined physical and psychomotor requirements during match play. The current data demonstrates that psychomotor performance is not affected throughout an intermittent match simulation, despite reductions in measures of physical performance. In fact, psychomotor performance appeared to have been improved during the frequent HSR bouts. This may suggest that there are transient physiological responses during HSR bouts that may influence psychomotor performance during intermittent exercise, such as cerebral blood flow and nervous system arousal. However, these same changes may have negative effects on psychomotor performance during sustained high-intensity efforts, such as the changes observed during incremental exercise.

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No potential conflict of interest was reported by the authors.

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