The number of directional changes alters the physiological, perceptual and neuromuscular responses of netball players during intermittent shuttle running.

Abstract

This study investigated whether an increased number of changes in direction altered the metabolic, cardiovascular, perceptual and neuromuscular responses to intermittent shuttle running. Using a randomized crossover design, ten female netball players completed 30 min of intermittent shuttle running over a 10 m (ISR_{10}) and 20 m (ISR_{20}) linear course. Measures of expired air, heart rate (HR), RPE, blood lactate concentration ([BLa]) and peak torque of knee extensors and flexors were measured. Differences (% ± 90% CL) in VO_2 (1.5 ± 5.6%) was unclear between conditions, while HR was possibly higher (1.5 ± 2.5%) and [BLa] very likely lower in ISR_{20} compared to ISR_{10} (-32.7 ± 9.9%). RPE was likely lower in the ISR_{20} compared to the ISR_{10} condition at 15 (-5.0 ± 5.0%) and mosly likely lower at 30 min (-9.4 ± 2.0%). Sprint times over 20 m were likely slower during ISR_{20} at mid (3.9 ± 3.2%) but unclear post (2.1 ± 5.4%). Changes in muscle function were not different between ISR_{10} and ISR_{20} conditions for knee extension (-0.2 ± 0.9%) but were likely different for knee flexion (-5.7 ± 4.9%). More directional changes during shuttle running increases the physiological and perceptual load on female athletes that also causes a greater reductions in knee extensor torque. These findings have implications for the effective conditioning and injury prevention of female team sport athletes.

Key words: Female, change of direction, fatigue, effort perception, injury

Introduction

During female team sports athletes perform repeated maximal effort, short duration sprints combined with phases of low intensity activity and rest over extended periods of between 30-90 minutes (10,22). Sports such as netball comprise high intensity, intermittent movements, with distances covered and actions varying depending on the highly specific roles of each player (9,15). Players also perform frequent changes of activity and changes of direction occurring every ~6 m (9,10). Indeed, the ability to execute these movements are fundamental requirements for most players in order to gain a distinct advantage over an opponent (10).

Despite the importance of accelerations and decelerations to team sport activity (4,23), these movements clearly inflict an increased internal and external load on an individual (5,6,8,32). Repeated high intensity sprints involving changes of direction resulted in greater increases heart rate, blood lactate concentration and ratings of perceived exertion when compared to sprints of the same distance over a linear course (5,17). The energy cost of submaximal running (6) and repeated sprints (5) also increased when changes of direction were incorporated as opposed to linear running. Additionally, an increased number of changes in direction and angle of change resulted in larger decreases in straight line speed (5). Such observations are likely to be attributed to the increased time required to produce a greater number of accelerations and decelerations (5,38) and decreased lower limb explosive force production (17). Repeating rapid decelerations between multiple sprint bouts also elicits higher eccentric force production at the hip, knee and ankle joints that increases muscle fatigue (23).

Team sport players experience large variability in high intensity actions during training and matches (16). An increased occurrence of such actions, including changes of direction, might therefore contribute to greater fatigue (1,5) and an increased risk of fatigue-related injury (30). This is particularly important for female team sport athletes where fatigue responses are different to males and might contribute to increased injury incidence in this group (29). Coaches should therefore understand how increasing the number of changes of direction alters a player's internal and external response to game-related activity, so that appropriate training and tactical strategies can be implemented. Accordingly, the purpose of this study was to examine the physiological, perceptual and neuromuscular responses to shuttle running with a high and low number of changes of direction in female team sport players.

Method

Experimental Approach to the Problem

The study took the form of a randomised, counterbalanced cross-over design where participants completed two conditions of an intermittent shuttle running (ISR) protocol over a 10 m (ISR_{10}) and a 20 m (ISR_{20}) linear course. While average running speeds and total distance covered (4,000 m) remained unchanged between conditions, the distance of the shuttle was altered to increase (ISR_{10}) or decrease (ISR_{20}) the number of changes of direction completed during the protocol. Participants completed 2 x 15 min bouts of intermittent shuttle running separated by a short break (~3 min). Measurements of expired air, blood lactate concentration ([BLa]), heart rate and perceived exertion were measured during the protocol. Sprint performance over 20 m was measured before, during and immediately on completion of the intermittent shuttle running protocol. Isokinetic muscle function of the knee extensors and flexors was also measured before and after the protocol. Conditions were separated by seven days and took place in the same indoor location and at the same time of day (± 1 hour) to avoid any time of day effects.

Subjects

After institutional ethical approval, 10 female university netball players (age = 19.3 ± 1.0 years; body mass = 59.6 ± 5.6 kg; stature = 166 ± 9 cm; VO_{2peak} = 39.4 ± 5.6 $ml\cdot kg^{-1}\cdot min^{-1}$; years playing = 10.0 ± 2.9 y) were recruited to take part in the study. All participants played predominantly in the centre court position for their club, attended training at least twice and played one match per week. After receiving verbal and a written explanation of the study, all participants provided written informed consent before taking part.

Baseline measurements

The 20 m multistage shuttle run test (33) was used to establish each individual's VO_{2peak} and peak heart rate (HRpeak) using a pre-calibrated portable gas analyser (Cosmed K4b2, Cosmrd S.r.I, Rome, Italy). The test involved participants running back and forth along an indoor 20 m linear course with the speed consistently increasing until volitional exhaustion. VO_{2peak} and HRpeak were taken as the highest values recorded over a 30 s epoch during the test. Participants were also familiarised to the procedure for the assessment of isokinetic muscle function of the knee flexors and extensors during this visit.

Intermittent shuttle running protocol

To simulate the intermittent shuttle-orientated activities associated with team sports, participants completed 2 x 15 min of the Loughborough Intermittent Shuttle Test (31), which equated to a total distance of 4,000 m. Selection of this protocol was not to replicate match performance *per se*. Instead we hoped to replicate the internal and external loads that would be typical of female games players during training and match related activities (e.g. 9,10), while also enabling the number of directional changes to be easily manipulated. The protocol required participants to move back and forth along a 10 m (ISR_{10}) or 20 m (ISR_{20}) linear course at speeds dictated by an audio signal from a CD player. The audio signal indicated when the participants needed to turn at each end of the 20 m course. During the ISR_{10}, participants completed two shuttles in the duration of one signal. During each protocol walking, jogging, cruising, sprinting and recovery equated to 48, 25, 19, 3 and 5% of the activity, respectively (31). The number of shuttles completed during each locomotive activity along with the respective speeds is presented in Figure 1a and 1b. Participants were fully familiarised to one cycle of each protocol before testing began to ensure they understood the required movement sequence. Prior to starting each condition, participants performed a 5-minute warm up comprising various dynamic stretches and jogging as dictated by the researcher. All tests took place in an indoor sport facility where environmental temperature and humidity were consistent between both trials.

***** Insert Figure 1a and 1b about here *****

During the protocol expired air was collected continuously using a pre-calibrated portable gas analyser (Cosmed K4b2, Cosmed S.r.I, Rome, Italy) to calculate VO_2, which was then averaged over the entire trial. Participants HR was also recorded using a HR monitor (Polar Electro Oy, Kempele, Finland) synchronised with the metabolic analyser and averaged for each condition. A capillary blood sample was taken from a finger before and 3 min after completing the intermittent shuttle running protocol, and immediately analysed for [BLa] using a portable lactate analyser (Lactate Pro, Arkray, Kyoto, Japan). The participant's rating of perceived exertion (RPE; 3) was also recorded at 15 min and on completion of the shuttle running protocol.

Assessment of muscle function

The participants completed a single maximal 20 m sprint before, at 15 min and on completion of the protocol, with times recorded using electronic timing gates (Brower Speed Trap 2, Brower, Utah, USA). Each sprint started from a standing start with the participant positioned 0.5 m behind the initial gate with their preferred foot forward. All participants were familiar with maximal effort sprints as part of their own training and were familiarised to the procedures beforehand and instructed to decelerate once past the final timing gate. Strong verbal encourgament was provided by the researcher for each sprint trial. An isokinetic dynamometer (Biodex 3, Biodex Medical Systems, Shirley, NY, USA) was also used to measure knee extensor and flexor peak torques at 60 $deg \cdot s^{-1}$ in the participant's dominant limb. The participant was fitted to the dynamometer in a standardised position and the mass of the limb was recorded to enable gravitational correction of peak torque values. After familiarisation, participants completed five maximal efforts for extension and flexion, with the highest recorded torque for each taken for analysis. Visual feedback, displaying real-time force, was used to encourage maximal efforts and participants were consistently encouraged to exceed target values, based on those achieved during familiarisation. Measurements were made 15 minutes before and within 15 minutes of finishing the intermittent shuttle running protocol.

Statistical analysis

Effect sizes (ES) ± 90% confidence limits, relative change (%) expressed as the transformed (natural logarithm) %change ± 90% confidence limits and magnitude-based inferences were calculated for all variables between ISR_{10} and ISR_{20} conditions (2). Where appropriate, data were log transformed for analysis to reduce bias arising from non-uniformity error. Threshold probabilities for a substantial effect based on the 90% confidence limits 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. Thresholds for the magnitude of the observed change for each variable was determined as the between-participant standard deviation (SD) x 0.2, 0.6 and 1.2 for a small, moderate and large effect, respectively. Effects with confidence limits across a likely small positive or negative change were classified as unclear (19). All calculations were completed using a predesigned spreadsheet (18).

Results

Physiological and perceptual responses to ISR_{10} and ISR_{20}

While the mean VO_2 response (ES = 0.04 ± 0.32; 1.5 ± 5.6%, *Unclear*) was similar between conditions, HR was higher in ISR_{20} (0.22 ± 0.36; 1.5 ± 2.5%, *Possibly higher*). Blood lactate concentrations were lower immediately after ISR_{20} compared to ISR_{10} (-0.97 ± 0.44; -32.7 ± 9.9%, *Very likely lower*). RPE was lower in the ISR_{20} compared to the ISR_{10} condition at both 15 and 30 min (Figure 2).

*****Insert Figure 2 here*****

Sprint times over 20 m during ISR_{20} were slower than ISR_{10} at mid but similar between conditions immediately after intermittent shuttle running (Figure 3). Changes in muscle function were similar between ISR_{10} and ISR_{20} conditions for knee extension (0.05 ± 0.22; -0.2 ± 0.9%, *Unlikely lower*) but knee flexion was lower after ISR_{10} compared to ISR_{20} (-0.94 ± 0.77; -5.7 ± 4.9%, *Likely lower*).

*****Insert Figure 3 here*****

Discussion

The primary aim of this study was to investigate whether an increase in the number of turns affected metabolic, cardiovascular, perceptual and neuromuscular responses during intermittent shuttle running in female team sport players. We observed that mean oxygen uptake was not different during 30 minutes of intermittent shuttle running regardless of the number of turns required. However, an increase in the number of turns during prolonged intermittent shuttle running did result in lower average heart rate, higher ratings of perceived exertion and a higher blood lactate concentration. A higher number of turns during intermittent shuttle running also caused greater reductions in peak knee flexion torque compared to the same duration and distance of running with less turns.

The mean VO_2 (~32 $ml \cdot kg^{-1} \cdot min^{-1}$ [~81% VO_{2peak}]) during both conditions was similar to the demands reported from matchplay in other female court-based team sports (35,39), and re-affirms the significant contribution from aerobic metabolism to intermittent team sport activity. That VO_2 was similar during ISR_{10} and ISR_{20}, regardless of the number of turns performed, is expected given the average running speed and distance covered were the same for both conditions. Such findings are also consistent with those of Hader et al. (17), who reported no difference in VO_2 for repeated sprints performed with or without a change of direction. Interestingly the average heart rate for ISR_{20} was *possibly* higher than ISR_{10} (176 $b \cdot min^{-1}$ [90%HRmax] cf. 173 $b \cdot min^{-1}$ [88% HRmax], respectively). This is in contrast to studies comparing linear versus shuttle running (e.g. 11), where heart rate is typically lower when no changes of direction are included. While both conditions employed here included changes of direction, a lower heart rate probably reflects the more intermittent nature of the ISR_{10} caused by the greater number of directional changes during this condition.

Blood lactate concentration was similar to those reported previously from female team sports during matches (26), but were *very likely* lower in the ISR_{20} compared to the ISR_{10} (3.5 ± 1.1 cf. 5.3 ± 1.8 $mmol \cdot l^{-1}$, respectively). While the mean movement speeds and distance covered were identical in both conditions, more directional changes in ISR_{10} resulted in a greater reliance on anaerobic metabolism. Our findings thus reaffirm studies reporting a greater blood lactate production in shuttle compared to linear running over the same distance and at the same mean speed (11,17). A greater blood lactate concentration is potentially caused by the increased number of eccentric contractions during decelerations (23) coupled with sporadic increases in running speed to offset the slowing caused by multiple changes of direction in the ISP_{10} condition (11,12). Eccentric muscle actions would increase the recruitmemt of type II muscle fibres (14), which possess a greater glycolytic capacity and affinity for blood lactate production. Incorporating a greater number of turns during shuttle running over a given distance and speed therefore increases the blood lactate response to exercise.

RPE was *likely* to be higher at 15 min and *most likely* to be higher on completion of the ISR_{10} when compared to the ISR_{20}. This means, irrespective of the distance and running speed, participants perceived intermittent exercise to be harder when the number of changes of direction were increased. These findings are similar to those reported previously using repeated high intensity efforts or sprints (11,17), suggesting for a given speed and distance RPE is higher when performed with changes of direction compared to those without. Greater increases in muscle temperature, metabolic and mechanical stress during the ISR_{10}, as a consequence of more changes of direction, are likely to have influenced the higher RPE in this condition. Afferent feedback from Group III and IV fibres within the skeletal muscle respond to these increased stimuli, causing the individual to increase their perceived rating of exertion (20). Additionally, increases in the task complexity of shuttle running created by a greater number of directional changes could also have contributed to a higher RPE during the ISR_{10} condition. Based on the work of de Morree and colleagues (12), increases in central command would be expected to accompany this more complex exercise task, leading to a concomitant increase in perceived exertion. A higher RPE during intermittent exercise with more changes of direction would have implications for exercise tolerance (25) and skilled actions (21).

An interesting observation of this study was the impairment of 20 m sprint performance during the intermittent shuttle running protcols. Reductions in 20 m sprint performance from baseline were greater during the ISR_{20} compared to the ISR_{10} after 15 min (~6.0% cf. 1.6%, respectively) but less so after 30 min (7.7% cf. ~4.9%, respectively). The likely greater changes in 20 m sprint performance at 15 min during the ISR_{20} are somewhat surprising given the greater blood lactate concentrations and RPE responses observed during the ISR_{10}. Such findings are consistent with those of Buchheit et al. (5), who reported greater decrements in peak speed during repeated sprints without shuttles compared to those with. As an inverse relationship exists between the initial sprint speed attained and fatigue during repeated efforts (28), it is likely that the longer distances aforded during the ISR_{20} condition resulted in higher peak speeds and thus greater depletion of intramuscular substrates. These higher peak speeds in the ISR_{20} therefore manifested as a greater reduction in 20 m sprint performance.

While studies examining peak knee extensor torque after prolonged intermittent running in female soccer players report post exercise decreases of ~8% (1), there were unlikely differences between the conditions with minimal changes after the ISR_{10} (+0.8%) and ISR_{20} (+2.0%). That our participants only ran for 30 minutes is likely to explain the apparent difference to previous findings. No change in knee extensor peak torque after 30 minutes of shuttle running is, however, consistent with findings that showed female soccer players jump performance was unaffected after a match (22). Given the different responses of 20 m sprint performance and peak knee extensor torque observed here reaffirms that mechanisms of fatigue are different depending on the type of exercise performed (22). Practitioners might therefore carefuly consider the measures used to detect fatigue during and after high intensity, intermittent exercise.

Much larger reductions in peak knee flexor torque were observed after the ISR_{10} (~17.9%) and ISR_{20} (~5.9%), with likely differences between the conditions. Losses in peak knee flexor strength (~10-20%) are typical in females after prolonged intermittent running (1,13,29), indicating the load imposed on this muscle group during this type of exercise. What our study reports for the first time is that the magnitude of force loss in the knee flexors during intermittent exercise is dependent upon the number of changes of direction performed. Therefore, a greater number of changes of direction during intermittent exercise resulted in a much greater reduction in knee flexor peak torque when compared to the same exercise performed with fewer directional changes.

A principal concern of fatigue to the knee flexors during team sport activity, particularly in females (29), is the increased potential for injury. Non-contact events in team sports involving a deceleration or change of direction are associated with knee injuries, especially in the later stages of match play (34). During high mechanical loading (i.e. landing, turning), knee flexors and extensors work synergistically to maintain knee joint integrity. However, when disproportionate reductions in knee flexor strength occur, this can lead to losses in knee joint stability that reduces the protection of the anterior cruciate ligament (ACL) (27,38). Our data support the notion that prolonged intermittent exercise evokes a greater reduction in knee flexor compared extensor strength. More importantly, a higher number of directional changes during prolonged intermittent exercise are likely to exacerbate this disproportionate force loss in muscles around the knee joint. These reductions in knee flexor strength have implications for knee joint stability during high mechanical loading that might contribute to the high incidence of ACL injury reported in female team sport athletes (24,36).

Practical applications

Recretaional female team sport players involved in more changes of direction during training and matches are likely to have an increased physiological and perceptual load compared to players moving in a more linear manner at the same average speed and covering the same distance. Increasing the number of directional changes performed by an individual can therefore be used as an effective method to increase the internal load during team sport training practices. Coaches must also identify the specific movement requirements of players and prepare them to meet these demands appropriately. This notwithstanding, practitioners must be cognisant of the greater decreases in knee flexor torque caused by increasing the number of directional changes during intermittent exercise. Reductions in force generating capacity of the knee flexors might compromise knee joint integrity that increases the female recreational athlete’s risk of injury to this site, particularly in prolonged intermittent activity that involves multiple changes of direction. Coaches working with players to a similar standard to those in this study should be mindful of this risk when using team sport practices with an increased number of directional changes, particularly in players returning from injury.

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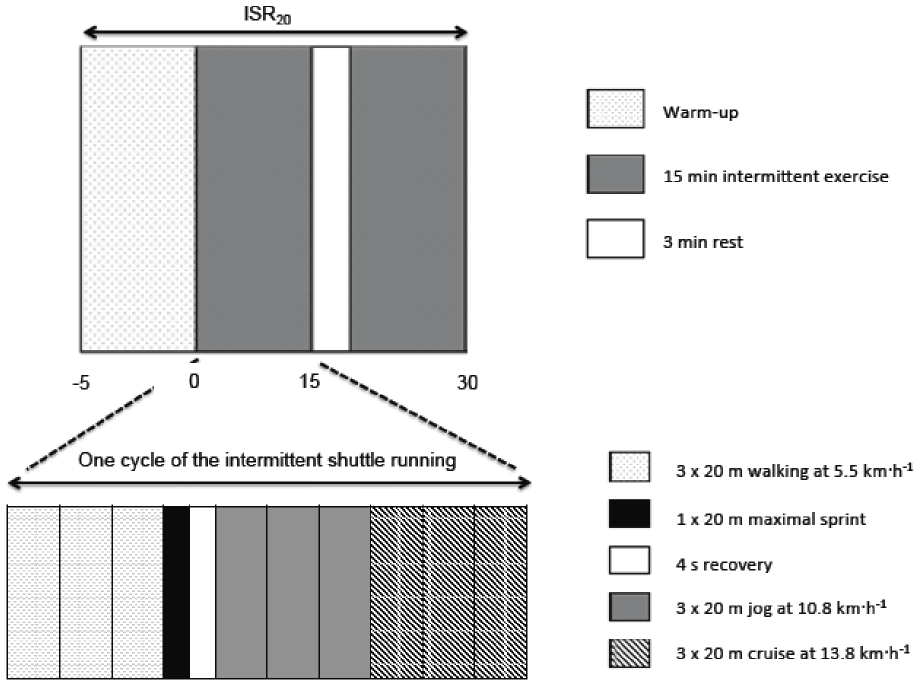
Figure legends

Figure 1a and 1 b. Schematic to show ISR_{10} and ISR_{20} protocols

Figure 2. RPE at 15 and 30 min during ISR_{10} (☐) and ISR_{20} (■) conditions. Values are mean ± SD with ES ±90 CI; relative change (%) expressed as the transformed (natural logarithm) %change ± 90% confidence limits and qualitative descriptor between trials included.

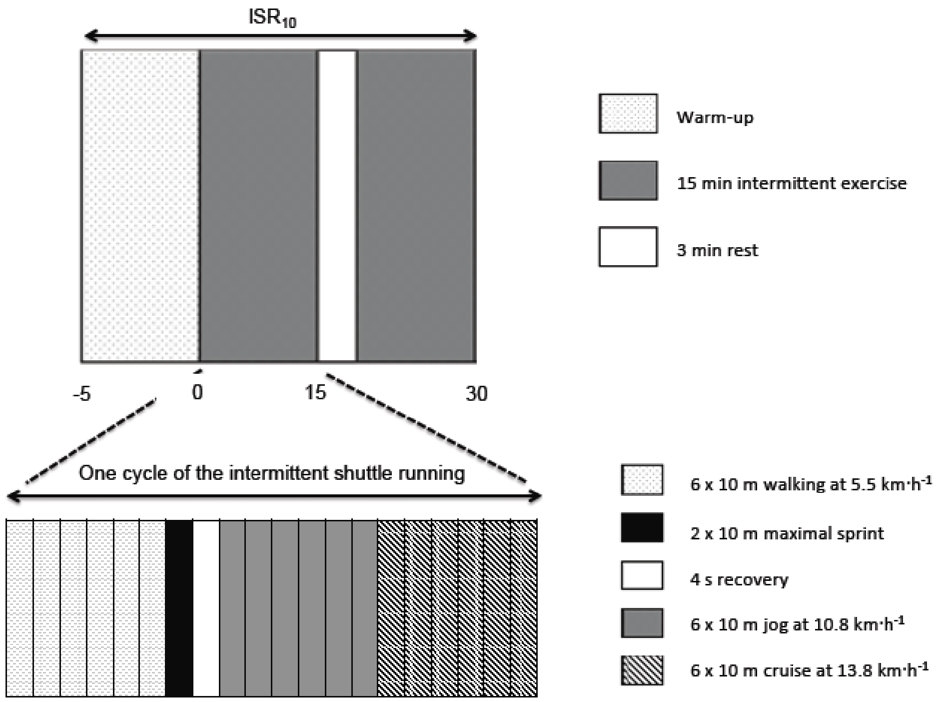
Figure 3. Pre, mid and post 20 m sprint times during ISR_{10} (◆) and ISR_{20} (■). Values are mean ± SD with ES ±90 CI; relative change (%) expressed as the transformed (natural logarithm) %change ± 90% confidence limits and qualitative descriptor between trials included.

1b



ISR20
Warm-up
15 min intermittent exercise
3 min rest
-5
0
15
30
One cycle of the intermittent shuttle running
3 x 20 m walking at 5.5 km·h-1
1 x 20 m maximal sprint
4 s recovery
3 x 20 m jog at 10.8 km·h-1
3 x 20 m cruise at 13.8 km·h-1

1a



ISR10
Warm-up
15 min intermittent exercise
3 min rest
-5
0
15
30
One cycle of the intermittent shuttle running
6 x 10 m walking at 5.5 km·h-1
2 x 10 m maximal sprint
4 s recovery
6 x 10 m jog at 10.8 km·h-1
6 x 10 m cruise at 13.8 km·h-1

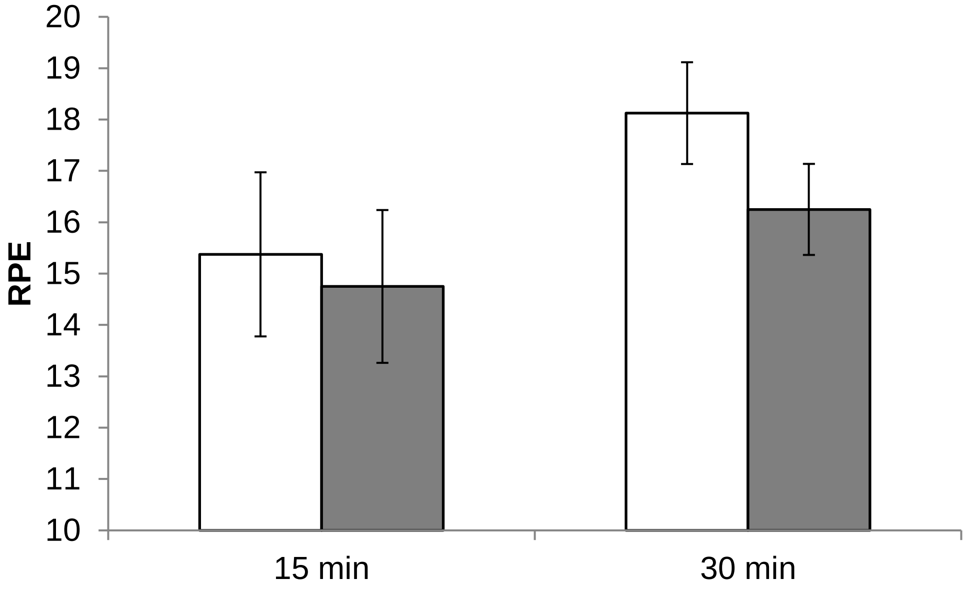


Figure 2. RPE at 15 and 30 min during ISR_{10} (☐) and ISR_{20} (■) conditions. Values are mean ± SD with ES ±90 CI; relative change (%) expressed as the transformed (natural logarithm) %change ± 90% confidence limits and qualitative descriptor between trials included.

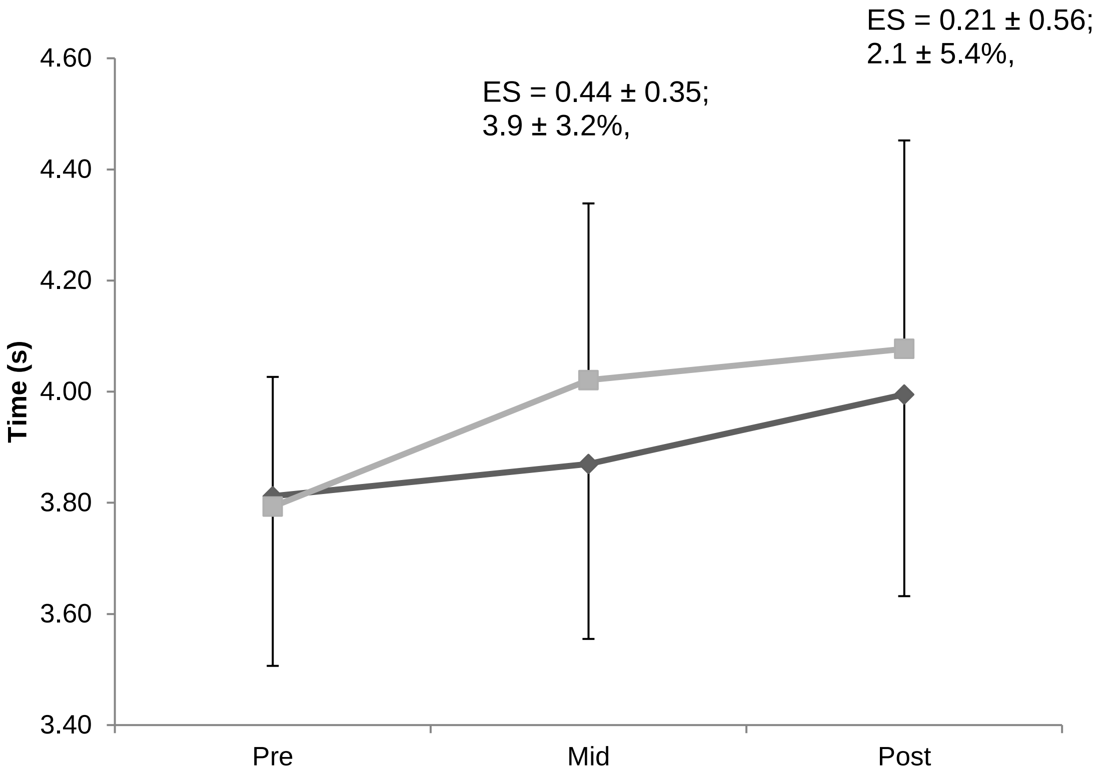


Figure 3. Pre, mid and post 20 m sprint times during ISR_{10} (◆) and ISR_{20} (■). Values are mean ± SD with ES ±90 CI; relative change (%) expressed as the transformed (natural logarithm) %change ± 90% confidence limits and qualitative descriptor between trials included.