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Abstract

This study investigated the effect of ingesting carbohydrate alone or with caffeine, on performance of a rugby union-specific shuttle running protocol. On three occasions, at least one week apart in a counterbalanced trial order, eight male rugby union forwards ingested either placebo (Plac) or carbohydrate ($1.2 \text{ g}\cdot\text{kg body mass}\cdot\text{hr}^{-1}$, CHO) before and during a rugby union-specific protocol, with pre-exercise caffeine ingestion ($4 \text{ mg}\cdot\text{kg}^{-1}$) before one of the CHO trials (CHO-C). The intermittent exercise protocol included walking, jogging and cruising at pre-determined intensities, simulated contact events, a sustained high-intensity test of speed and agility (Performance Test) and a 15-m sprint. Ratings of perceived exertion (RPE) were recorded every 5 min and a Motor Skills Test (MST) was performed after 21-min blocks. Performance Test times were not significantly different between trials but the likelihood of 2% improvements for CHO-C over Plac and CHO were 98% and 44%, respectively. For CHO-C, 15-m sprints were faster than Plac ($P = 0.05$) and the MST was performed faster in CHO-C than CHO and Plac ($P < 0.05$), while RPE was lower in CHO-C than CHO and Plac ($P < 0.05$). These results indicate a likely benefit to rugby performance following carbohydrate and caffeine co-ingestion.

Introduction

Prior to and during competition, it is common practice for team sport participants to consume both carbohydrate (Williams & Serratos, 2006) and caffeine (Chester & Wojek, 2008). Carbohydrate ingestion improves intermittent, high-intensity exercise performance (Nicholas, Williams, Lakomy, Phillips, & Nowitz, 1995; Welsh, Davis, Burke, & Williams, 2002; Winnick *et al.*, 2005), and caffeine ingestion has been shown to improve performance over a range of different exercise protocols (Doherty & Smith, 2004). Although rugby union and team sports such as soccer (Bradley *et al.*, 2009) and hockey (Spencer *et al.*, 2004) are all characterised by high-intensity intermittent running and the execution of motor skills, rugby players experience match demands with unique exercise patterns including high-intensity bouts which combine running and a large proportion of physical contact (Roberts, Trewartha, Higgitt, El-Abd, & Stokes, 2008). While the isolated effects of carbohydrate and caffeine have been well established, to date no study has investigated the effect of combined carbohydrate and caffeine ingestion on rugby union-specific performance.

There is emerging information regarding the effects of caffeine in team sports lasting at least 80 minutes (e.g. rugby and soccer) involving intermittent, high-intensity exercise bouts. For example, during a sprint-cycling protocol based on work rate of team sports, sprinting work was greater following caffeine ingestion (6 mg.kg^{-1}) in both the first and second 36-min halves of exercise compared with placebo (Schneiker, Bishop, Dawson, & Hackett, 2006). In running-based sport-specific protocols, pre-exercise caffeine ingestion (6 mg.kg^{-1}) improved the performance of rugby union-specific activities from the early stages of exercise (sprinting, drive power and passing accuracy) (Stuart, Hopkins, Cook, & Cairns, 2005) and soccer skill performance throughout exercise (Foskett, Ali, & Gant, 2009) compared with a

placebo. There is also evidence that caffeine may attenuate a decline in some aspects of tennis skill performance during simulated match-play (Hornery, Farrow, Mujika, & Young, 2007).

During prolonged high-intensity, intermittent exercise, carbohydrate ingestion can improve sprint performance (Ali, Williams, Nicholas, & Foskett, 2007), improve motor skill performance (Welsh *et al.*, 2002) and maintain faster sprint times relative to a placebo late in exercise (Welsh *et al.*, 2002; Winnick *et al.*, 2005). In the course of such protocols, carbohydrate ingestion appears to spare endogenous muscle glycogen and possibly enhance glycogen resynthesis during periods of low-intensity exercise, particularly in Type II muscle fibres (Nicholas, Tsintzas, Boobis, & Williams, 1999). To date, no studies have investigated the effect of carbohydrate ingestion on the performance of match-length rugby union-specific exercise including sustained high-intensity exercise bouts and short sprints.

Cureton *et al.* (2007) investigated the combined effects of carbohydrate and caffeine on intermittent exercise performance. Participants cycled for 120 min, alternating between 60 and 75% $\dot{V}O_{2max}$, and then carried out a 15-min performance test during which they completed 23% more work following carbohydrate-caffeine ingestion compared with placebo or carbohydrate alone. Although an interesting finding, this protocol was not designed to represent the intermittent patterns of team sports. In another study, carbohydrate was shown to improve aspects of tennis performance but the addition of caffeine to the carbohydrate did not provide any additional benefits (Vergauwen, Brouns, & Hespel, 1998). When carbohydrate and caffeine are co-ingested, the potential caffeine-induced increase in fat oxidation is suppressed by the increased carbohydrate oxidation (Weir, Noakes, Myburgh, & Adams, 1987). However, a number of studies have shown caffeine-induced performance

improvements in the absence of increased fat oxidation leading to the suggestion that central nervous system (CNS) stimulation is a more likely action by which caffeine acts (Cox *et al.*, 2002; Graham, Battram, Dela, El-Sohemy, & Thong, 2008).

While carbohydrate ingestion may be ergogenic late in exercise, caffeine is most likely to be beneficial via stimulation of the central nervous system from the early stages of exercise (Schneiker *et al.*, 2006; Stuart *et al.*, 2005). However, recommendations regarding co-ingestion of carbohydrate and caffeine require sport-specific evidence. Ecological validity would be maximised in actual match-play, but the lack of experimental control would limit the detection of changes in performance outcomes. Therefore, the purpose of the present study was to examine the effects of ingesting carbohydrate alone, or with a moderate dose of caffeine ingested pre-exercise, on performance tasks completed during a simulated rugby union match-play protocol. It was hypothesised that (1) carbohydrate would attenuate a decline in performance during exercise compared with placebo and (2) ingesting caffeine and carbohydrate prior to exercise would improve performance from the beginning of the exercise protocol.

Methods

Participants

Eight male rugby union forwards (mean \pm s: age = 22.0 \pm 3.5 years, height = 182 \pm 3 cm, body mass = 92.2 \pm 14.0 kg, playing experience = 12 \pm 4 years) volunteered to take part in this study and provided written informed consent. Approval for the study was granted by the institutional ethics committee. All participants played to University standard and were involved in competitive match-play and regular training. A preliminary questionnaire indicated that six participants habitually consumed caffeine in low doses (<100 mg per day), and that two participants were non-consumers.

Experimental Trial/Treatments

Participants completed three main trials: Placebo (Plac), Carbohydrate (CHO) and Carbohydrate with Caffeine (CHO-C), between 6-15 days apart in a randomised cross-over design. In the Plac trial, participants consumed a low-calorie (0.3 g carbohydrate per 100 ml) orange-flavoured concentrate (Robinsons, Britvic, Chelmsford, UK) with water and aspartame artificial sweetener (Hermesetas, Zurich, Switzerland). In the CHO and CHO-C trials, participants consumed a carbohydrate-electrolyte solution (GlaxoSmithkline, UK) containing 1.2 g·kg body mass·hr⁻¹ (Jeukendrup & Jentjens, 2000) in a 9% carbohydrate solution (dextrose/maltodextrin). An initial bolus of 500 ml was consumed 1 hour prior to exercise with the remaining solution (mean volume = 1189 \pm 255 ml) divided equally into three separate opaque drinking bottles and consumed during the exercise protocol rest periods between blocks 1 and 2, 2 and 3 (half time) and 3 and 4. In the CHO-C trial, a caffeine dose of 4 mg·kg⁻¹ (caffeine FCC kosher, product code: W222402, Sigma-Aldrich, Gillingham,

UK) in the form of 98% anhydrous powder was dissolved in the initial 500 ml bolus only to allow pre-exercise ingestion of caffeine.

Participants were asked to record their diet for 48 hours prior to their first main trial and then to replicate this before the other trials. Participants were provided with a list of foods and beverages containing a large amount of caffeine and asked to avoid these in the 48 hours prior to each main trial. They were also requested to refrain from strenuous exercise for 24 hours before each main trial while continuing with their normal training and playing schedule for the remaining days between trials.

Preliminary testing

At least 7 days prior to their first main trial, participants attended a habituation session during which the rugby simulation protocol (BURST) was performed for 30 min and the Motor Skills Test (MST) and Performance Test (see below for descriptions) were practiced. Participants also practiced the MST on two further occasions prior to the first main trial (Welsh *et al.*, 2002).

Exercise protocol

Bath University Rugby Shuttle Test (BURST)

The BURST is a rugby union specific match-play protocol (Roberts, Stokes, Weston, & Trewartha, 2010) derived from physical demands data for elite rugby union forwards (Roberts *et al.* 2008). The protocol comprises 16 x 315-s exercise periods grouped into 4 x 21-min blocks (Figure 1). Blocks 1 and 3 were followed by 4-min breaks, with 2 min allocated each to standing and walking. A 10-min 'half time' break followed block 2, comprising 7 and 3 min of sitting and walking, respectively.

The exercise was performed in a 20-m lane on an indoor athletics track. An exercise cycle required the participants to walk 20 m (mean speed: $1.4 \text{ m}\cdot\text{s}^{-1}$), turn 180° and cruise 20 m (mean speed: $4.4 \text{ m}\cdot\text{s}^{-1}$), turn 180° and jog 10 m (mean speed: $3.0 \text{ m}\cdot\text{s}^{-1}$), then perform either a scrum [a 1.5-m drive of a single person scrummaging machine (120 kg Rhino, London, UK) in 7 s], ruck [5-m drive of a 20-kg tackle bag (Gilbert, UK; dimensions: 140 cm height, 40 cm diameter) in 3.5 s, on which shoulder contact was made at a marked point on the bag to standardise body position] or maul [participants competed alternately, always against the same person, for 5 s to either maintain (starting with the ball) or to gain possession (starting without the ball)]. The participants then jogged backwards 10 m and repeated the cycle following a standing rest. A 315-s period included five exercise cycles with scrums in cycles 1 and 3, rucks in cycles 2 and 4 and a maul in cycle 5 followed by a Performance Test and 15-m sprint (Figure 1). Participants were reminded which activity to perform by spoken commands and timing was maintained by audible signals from a specifically pre-recorded compact disc.

Insert Figure 1 here

Performance Test and 15-m sprint

The Performance Test was designed to replicate a sustained high-intensity bout during rugby union match-play, combining elements of resistance work, sprinting and agility. The Test involved the participant passing through an initial infra-red timing gate (starting the timer) and carrying one tackle bag over 9 m, followed by carrying a second over the same distance then picking up a ball and sprinting 14 m before completing an unanticipated rapid change in direction (cutting action) prompted by a flashing beacon (Smartspeed, Fusion Sport,

Australia), then continuing to sprint through a final infra-red timing gate (stopping the timer). Total time taken between the two timing gates was recorded (Performance Test time). Participants had 25 s to return to the start of the test and then perform a single timed 15-m sprint from a standing start between two infra-red timing gates. Apart from the 25 s of recovery, the Performance Test and 15-m sprint were performed with maximum effort. Coefficient of variation over two trials for mean Performance Test times and 15-m sprint times during the BURST were previously determined to be 1.3% and 0.9%, respectively (Roberts *et al.*, 2010).

Motor Skills Test (MST)

The MST is a pseudo hopscotch task made up of twelve, 30-cm squares arranged in a six by two formation (Welsh *et al.* 2002). Participants hopped on one leg, landing on alternate diagonal squares, then on reaching the end, hopped backwards on the opposite leg to the start. This was performed twice and participants were told to perform this test as quickly as possible but were reminded that a time penalty of 0.5 s would be incurred every time approximately half of the shoe did not land in the appropriate square. The accumulated time penalty was added to the time taken to perform the MST. The test was performed twice with a 10-s recovery between tests and a mean of the two tests recorded. The same experimenter timed each test and judged time penalties throughout both the familiarisation process and the main trials.

Experimental trial procedure (Figure 1)

All main trials were performed in the morning after an overnight fast. On waking on the morning of each main trial, participants were asked to ingest 500 ml of water to help ensure euhydration. On arrival in the laboratory, participants were asked to void and were then

weighed in underwear using a beam balance scale (Avery Berkel, UK). They then sat quietly while a resting 300 µl capillary blood sample was obtained via a fingertip (Softclix Pro, Roche, Switzerland), after which they ingested 500 ml of the Plac, CHO or CHO-C. After one hour, a further 300 µl capillary blood sample was obtained. The participants then began a standardised 10-min warm-up consisting of two practices of the MST, stretching, self-paced jogging and sprinting and one 315-s period of the exercise protocol, excluding the Performance Test. The MST was then performed, followed by a Performance Test and a 15-m sprint (Baseline tests). After 5 min of recovery, the participants began the BURST exercise protocol during which heart rate (HR) was recorded every 5 s and averaged for every 315-s period. Ratings of perceived exertion (RPE) were recorded on a scale of 6-20 (Borg, 1973) following the completion of each Performance Test at the end of every 315-s period. A 300 µl capillary blood sample was obtained on completion of every 21-min exercise block and then the MST was performed. Drinks were consumed during the rest period between each 21-min block. Temperature and relative humidity were recorded at the end of every 21-min block. At the end of exercise, participants towel dried themselves to remove sweat and then body mass was recorded in underwear.

Blood sampling and analysis

All capillary blood samples were collected in Ethylenediaminetetraacetic acid (EDTA) prepared collection tubes (Microvette 500, Sarstedt, Numbrecht, Germany) and stored on ice. Within 20 min of collection all samples were analysed for blood lactate and glucose using an automated analyser (YSI 2300 Stat Plus, YSI, Ohio, USA). Samples were then centrifuged at 10,000 rpm for 10 min and the plasma stored at -20°C until further analysis. Plasma free fatty acids (FFA) were measured using the enzymatic colorimetric method (NEFA-C, Wako Chemicals GmbH, Germany) using a Cobas Mira 'N' spectrophotometer (Roche Diagnostics,

Switzerland). The coefficients of variation for 20 replicates for blood lactate, blood glucose and FFA were 2.1, 1.9 and 1.8%, respectively.

Statistical analysis

Data for Performance Tests, 15-m sprints, RPE and HR are presented as the single 'baseline test' and thereafter, the means of 21-min blocks. Results are reported as the mean \pm standard deviation of the mean (*s*). Data were analysed using a two-way (treatment x time) analysis of variance (ANOVA) with repeated measures. When the assumption of sphericity was violated, the Greenhouse-Geisser correction was used. In the event of a significant outcome, a Bonferroni *post hoc* test was applied to reveal where the difference lay. Significance was accepted at $P < 0.05$ for all analyses. When ANOVA was used to test for trial order effects for performance measures, no differences were found.

Practical significance curves (Peyrebrune, Stokes, Hall, & Nevill, 2005) were generated to show the percentage likelihood of a beneficial effect of up to a 10% performance improvement in the Performance Test and 15-m sprint for CHO-C compared to CHO and Plac. The likelihood of a beneficial effect for a given level of improvement in performance is calculated as a function of the *P* value, degrees of freedom and *F* statistic generated by ANOVA (Batterham and Hopkins, 2006).

Results

Performance Test

No main effect for trial was found for time taken to complete the Performance Test (Plac, 17.71 ± 1.31 s; CHO, 17.62 ± 1.09 s; CHO-C, 17.08 ± 1.11 s; $P = 0.150$). There was a main effect of time ($P = 0.01$, Figure 2) with *post-hoc* analysis showing performance times to be significantly longer during block 4 than at baseline ($P = 0.02$) but no interaction effect. With reference to practical significance, the likelihoods that CHO-C will confer a 2% improvement in performance over Plac and CHO were 98% and 44%, respectively (Figure 3).

INSERT FIGURE 2 HERE

INSERT FIGURE 3 HERE

15-m Sprint

There was a main trial effect for sprint times (Plac, 2.81 ± 0.16 s; CHO, 2.81 ± 0.15 s; CHO-C, 2.71 ± 0.17 s; $P = 0.02$) with *post hoc* analysis revealing quicker sprint times for CHO-C relative to Plac only ($P = 0.050$). There was a main effect of time ($P = 0.05$; Figure 4) but no interaction effect. With reference to practical significance, the likelihoods that CHO-C will confer a 2% improvement in sprint performance over Plac and over CHO were 99% and 94%, respectively (Figure 5).

INSERT FIGURE 4 HERE

INSERT FIGURE 5 HERE

Motor Skills Test

For total time taken to perform the MST (Figure 6A) including the addition of error penalties, there was a main effect for trial (Plac, 11.1 ± 0.3 s; CHO, 10.8 ± 0.3 s; CHO-C, 9.8 ± 0.3 s; $P = 0.001$) with *post hoc* analysis showing superior performance in CHO-C than both Plac and CHO ($P < 0.05$). There was a main effect of time ($P = 0.008$) with *post hoc* analysis showing a faster performance at 21 min than at 42 min ($P = 0.04$) but there was no interaction effect. The time taken to perform the MST without the addition of error penalties (Figure 6B) showed a main effect of trial ($P = 0.026$) with *post hoc* analysis revealing faster times for CHO-C than Plac ($P = 0.020$). However, there was no effect of time and no interaction effect. For only time penalties incurred through errors made in the MST (Figure 6C), there were main effects for time ($P = 0.003$) and trial (Plac, 1.6 ± 0.1 s; CHO, 1.5 ± 0.2 s; CHO-C, 1.0 ± 0.1 s; $P = 0.004$). *Post hoc* analysis revealed that less time penalties were incurred in CHO-C than both Plac and CHO ($P < 0.05$). There was no interaction effect for error penalties.

INSERT FIGURE 6 HERE

Heart Rate (HR) and Ratings of Perceived Exertion (RPE)

There was no difference in HR between Plac (160 ± 5 beats·min⁻¹), CHO (162 ± 3 beats·min⁻¹) and CHO-C (163 ± 4 beats·min⁻¹) and no effect over time. There was a main effect for trial for RPE (Plac, 14.8 ± 2.0 ; CHO, 14.4 ± 1.5 ; CHO-C, 13.5 ± 1.3 ; $P = 0.020$), with *post-hoc* analysis revealing a difference between CHO and CHO-C ($P = 0.004$). There was also a main effect of time ($P = 0.003$, Figure 7) but no trial-time interaction effect.

INSERT FIGURE 7 HERE

Blood lactate, blood glucose and free fatty acids

For blood lactate, there was no main trial effect but there was an effect of time ($P < 0.01$, Table 1). There was a main trial effect for blood glucose ($P = 0.011$), with *post-hoc* analysis showing greater values for CHO than Plac ($P = 0.032$). There was also a significant effect of time ($P = 0.024$, Table 1), and a significant trial-time interaction effect ($P = 0.020$) with lower values at 0 min and after block 4 for Plac compared with CHO and CHO-C ($P < 0.05$, Table 1). For FFA, there was a main effect for trial ($P = 0.01$) with *post hoc* analysis revealing higher values in Plac than CHO-C ($P = 0.048$). There was also an effect for FFA over time ($P < 0.001$, Table 1).

INSERT TABLE 1 HERE

Changes in body mass

Changes in body mass pre- to post-exercise was 1.27 ± 0.47 kg, 1.13 ± 0.74 kg, 1.44 ± 0.48 kg for Plac, CHO and CHO-C, respectively, corresponding to percentage losses of 1.4, 1.2 and 1.6 %. There were no significant differences between trials.

Environmental conditions

There was no difference between trials for temperature (Plac: $16.8 \pm 2.0^\circ\text{C}$; CHO: $16.8 \pm 1.8^\circ\text{C}$; CHO-C: $16.9 \pm 1.7^\circ\text{C}$, $P = 0.999$) or relative humidity (Plac: $60.9 \pm 5.5\%$; CHO: $62.9 \pm 4.1\%$; CHO-C: $61.4 \pm 4.3\%$, $P = 0.722$).

After each trial, participants were asked to attempt to identify which treatment they had received. Of the 24 trials completed, the correct treatment was only identified for 8 trials.

Two participants successfully identified all three trials correctly while a further two participants only identified the placebo trial. All others guessed incorrectly for all three trials.

Discussion

The purpose of this study was to examine the effect of carbohydrate alone and carbohydrate with pre-exercise ingestion of caffeine on the performance of high-intensity performance tasks and a motor skills test during a rugby union-specific exercise protocol. The first hypothesis that carbohydrate would attenuate a decline in performance was not supported given that there was no evidence of attenuation of fatigue in the Performance Test or sprint performance in either of the carbohydrate conditions. The second hypothesis was that pre-exercise ingested caffeine with the carbohydrate would improve performance from the beginning of exercise. This was partially supported with practical significance curves demonstrating a likely improvement in performance of a rugby-specific maximal-intensity test, a sprint test and a motor skill task when participants ingested a moderate dose of caffeine with the carbohydrate solution one hour prior to exercise. Since these performance benefits were not found for carbohydrate alone compared with the placebo, it is likely that it was either the effect of caffeine alone or an interaction between the ingested carbohydrate and caffeine that improved performance.

Due to the unique exercise patterns of the BURST and the fact that no other studies have investigated the combined effect of caffeine and carbohydrate on team sport activity, direct comparisons with other studies are difficult. However, the current findings are in broad agreement with the work of Stuart *et al.* (2005) who found that caffeine ingestion alone improved the performance of a 'tackle sprint' lasting ~9 s by 2.9% during a prolonged exercise protocol incorporating rugby-specific performance measures. Similarly, caffeine ingestion improved mean peak power in 4-s cycle ergometer sprints by 7.0% and 6.6% in the first and second halves, respectively of a protocol replicating the intermittent exercise

patterns of team sports (Schneiker *et al.*, 2006). These findings are comparable to the current study in which there was a 98% likelihood that Performance Test time was improved by 2% in CHO-C compared with Plac. There was also a 3.6% improvement in 15-m sprint performance in the CHO-C trial compared with Plac, whereas Stuart *et al.* (2005) reported a smaller improvement of 0.5% in 20-m sprint performance following caffeine ingestion. In contrast to the current study, no improvement in 15-m sprint time during a 90 min intermittent shuttle running protocol was found when participants consumed 6 mg·kg⁻¹ of caffeine prior to exercise compared with a placebo (Foskett *et al.*, 2009). While co-ingestion of carbohydrate and caffeine was beneficial for the Performance Test and 15-m sprint during the BURST, the absence of an interaction effect indicates a similar pattern of fatigue across trials.

Any performance improvement in the current study may have been mediated by caffeine passing through the blood brain barrier and binding to adenosine receptors in the brain, thus blocking the inhibitory action of adenosine on the CNS (Davis *et al.*, 2003; Graham, 2001). This is reinforced by the lower RPE in the CHO-C trial compared with CHO. In line with the findings of the present study, it is widely reported that caffeine lowers perception of effort during exercise (Cole *et al.*, 1996; Doherty & Smith, 2005), potentially allowing maintenance of performance when metabolic mechanisms are not limiting. In the current study, exercise commenced 60 min after caffeine ingestion, at which point plasma concentrations of caffeine were likely to be elevated (Magkos & Kavouras, 2005), possibly resulting in a CNS-mediated improvement in performance from the early stages of exercise.

It has been suggested that caffeine increases lipid metabolism early in exercise via elevated plasma adrenaline levels (Spriet *et al.*, 1992). In the current study, FFA was higher in Plac

compared with CHO-C, suggesting that any effect of caffeine on lipolysis in the CHO-C trial may have been negated by the ingestion of carbohydrate (Kovacs, Stegen, & Brouns, 1998; Weir *et al.*, 1987). In addition, there was no difference in FFA concentration between CHO and CHO-C which is in agreement with the findings of Jacobson *et al.* (2001) during 120 min of cycling. Furthermore, an ergogenic effect via altered substrate metabolism is more plausible in prolonged exercise models where muscle glycogen levels are a limiting factor to performance. In the current study, the quantity of carbohydrate ingested during the CHO and CHO-C trials ($1.2 \text{ g}\cdot\text{kg body mass}\cdot\text{hr}^{-1}$) meant that exogenous carbohydrate oxidation was likely to have been maximised (Jeukendrup & Jentjens, 2000), and glycogen availability is unlikely to have been challenged. Some studies have shown improved sprint performance with CHO ingestion during prolonged high-intensity shuttle running (Ali *et al.*, 2007; Welsh *et al.*, 2002; Winnick *et al.*, 2005), while another did not (Foskett, Williams, Boobis, & Tsintzas, 2008). That no differences in performance were found between CHO and Plac in the present study, suggests that muscle glycogen stores were adequate in both conditions and that performance enhancement in the CHO-C condition is likely to be mediated via mechanisms such as CNS stimulation rather than alterations in substrate metabolism. Although the potential for an interaction between carbohydrate and caffeine cannot be ruled out, further research comparing the ingestion of caffeine alone and caffeine with carbohydrate is needed to explore this further.

The total time taken for the MST was faster in the CHO-C trial compared with both Plac and CHO. Similarly, rugby passing skill during 80 min of simulated match-play was more accurate following caffeine ingestion compared with a placebo (Stuart *et al.* 2005), as was soccer passing skill during simulated soccer exercise (Foskett *et al.*, 2009). Despite obvious differences between the MST in the current study and the skills tests employed by Foskett *et*

al., (2009) and Stuart *et al.* (2005), the tasks are similar in that they require co-ordinated movements to be performed accurately at speed. Although detailed mechanisms remain to be elucidated for an association between caffeine and improved skill performance, increased arousal and attention derived from the CNS is perhaps the most plausible explanation (Stuart *et al.*, 2005). While there was no difference between Plac and CHO for the MST, CHO-induced performance improvements were found by Welsh *et al.* (2002) using the same MST and by Ali *et al.* (2007) using a soccer shooting test. Both of these studies used very similar intermittent shuttle running protocols, the exercise patterns of which differed from the BURST which possibly explains the difference in findings.

If study outcomes are to be applied to sports performance, it is important to consider whether a specific effect is large enough to have a meaningful impact on the performance outcome, regardless of whether a significant finding is reported (Atkinson, 2003). To this end, the practical significance curves presented allow straightforward assessment of the efficacy of the CHO-caffeine intervention (Peyrebrune *et al.*, 2005; Shakespeare, Gebiski, Veness, & Simes, 2001). It is difficult to assign a criterion level of improvement to the Performance Test as it is difficult to directly transfer performance of this test to a successful outcome during rugby match-play, but it has been suggested that a worthwhile improvement for sprint time in team sport is 0.8% (Paton, Hopkins, & Vollebregt, 2001). Practical significance calculations in the current study indicate that there is greater than 95% likelihood that ingestion of caffeine with carbohydrate improves performance of a 15-m sprint by 0.8%, compared with ingestion of carbohydrate or placebo.

When assessing the efficacy of carbohydrate-caffeine ingestion in the current context, it should be considered that caffeine is socially acceptable, economical, simple to administer

and safe to consume in moderate doses. Indeed, the results from the current study suggest that a single dose of only 4 mg.kg⁻¹, ingested one hour before exercise result in small but worthwhile improvements in rugby performance when co-ingested with carbohydrate. These findings suggest that the co-ingestion of caffeine and carbohydrate one hour prior to exercise, with ingestion of carbohydrate during exercise, provides an attractive ergogenic effect due to low risks compared with potential benefits.

Conclusion

In conclusion, this study demonstrates that a moderate dose of caffeine co-ingested with carbohydrate is likely to improve high-intensity and sprint performance compared to placebo and carbohydrate alone in exercise which simulates the demands of rugby union forward match-play. Although, there are a number of mechanisms by which caffeine might influence performance, the most plausible explanation at the present time is via heightened CNS mediated mechanisms.

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Table 1. Mean values for blood lactate (mmol·L⁻¹), glucose (mmol·L⁻¹) and free fatty acids (mmol·L⁻¹) (n = 8).

Time (min)	-60	0	21	42	63	84	Trial Mean
Blood Lactate (mmol·L⁻¹)							
Plac	0.8 ± 0.4	1.4 ± 0.7	4.7 ± 1.8	4.4 ± 1.3	4.0 ± 1.6	4.2 ± 1.4	3.3 ± 0.2
CHO	0.7 ± 0.2	1.4 ± 0.6	5.1 ± 2.1	4.6 ± 1.7	4.3 ± 2.1	3.9 ± 1.8	3.3 ± 2.3
CHO-C	0.8 ± 0.2	1.4 ± 0.4	5.1 ± 1.7	4.6 ± 1.8	4.6 ± 1.8	4.2 ± 1.6	3.5 ± 2.2
All Trials	0.7 ± 0.3	1.4 ± 0.5 ^a	5.0 ± 1.8 ^{ab}	4.5 ± 1.6 ^{ab}	4.3 ± 1.8 ^{ab}	4.1 ± 1.6 ^{ab}	
Blood Glucose (mmol·L⁻¹)							
Plac	4.7 ± 0.4	4.0 ± 0.4 ^g	5.4 ± 1.4	5.4 ± 1.5	4.2 ± 0.9	4.5 ± 0.3 ^g	4.7 ± 1.0 ^e
CHO	4.6 ± 0.3	6.1 ± 0.8	4.7 ± 0.7	5.9 ± 0.9	5.2 ± 0.8	5.6 ± 0.5	5.3 ± 0.9
CHO-C	4.5 ± 0.5	5.7 ± 0.6	5.1 ± 0.8	5.9 ± 0.8	5.4 ± 0.9	5.3 ± 0.6	5.3 ± 0.8
All Trials	4.6 ± 0.5	5.2 ± 1.1	5.0 ± 1.0	5.7 ± 1.1 ^c	4.9 ± 1.0	5.1 ± 0.7	
Free Fatty Acids (mmol·L⁻¹)							
Plac	0.5 ± 0.3	0.4 ± 0.2	0.3 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	1.0 ± 0.4	0.5 ± 0.3 ^f
CHO	0.4 ± 0.2	0.2 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.6 ± 0.1	0.3 ± 0.2
CHO-C	0.3 ± 0.1	0.3 ± 0.2	0.2 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.6 ± 0.2	0.3 ± 0.2
All Trials	0.4 ± 0.2 ^d	0.3 ± 0.2 ^d	0.3 ± 0.1 ^d	0.3 ± 0.1 ^d	0.3 ± 0.1 ^d	0.7 ± 0.3	

Main effect for time: Blood lactate: (^a*P* < 0.05 vs -60 min), (^b*P* < 0.05 vs 0 min); Blood glucose: (^c*P* < 0.05 vs 0-21 min); FFA: (^d*P* < 0.05 vs 63-84 min). Main effect for trial: Blood glucose (^e*P* < 0.05 vs CHO); FFA: (^f*P* < 0.05 vs CHO-C). Interaction effect: Blood glucose: (^g*P* < 0.05 vs CHO and CHO-C).

The effect of carbohydrate and caffeine ingestion on performance during a rugby union simulation protocol

Figures

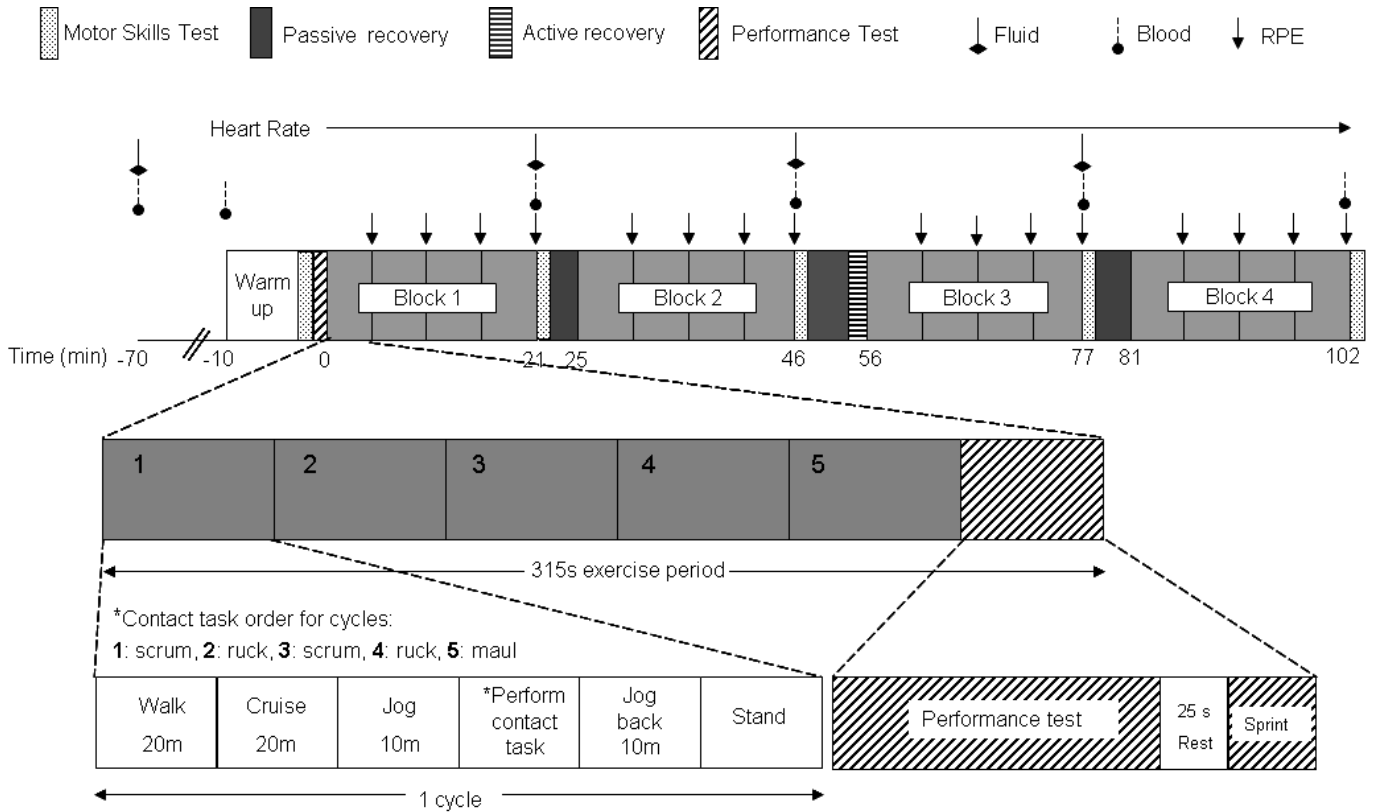


Figure 1. A schematic representation of the study protocol

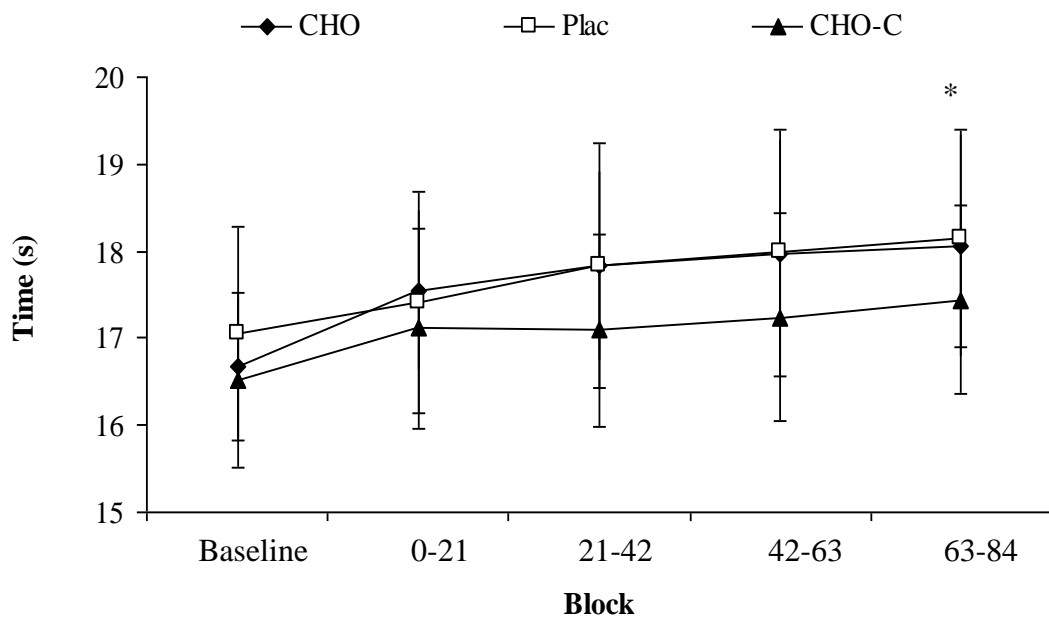


Figure 2. Time taken to complete the Performance Test before the BURST (Baseline) and over consecutive 21-min periods during the exercise (mean \pm s). Main effect for time ($P = 0.01$), **post hoc* $P = 0.02$ vs. Baseline.

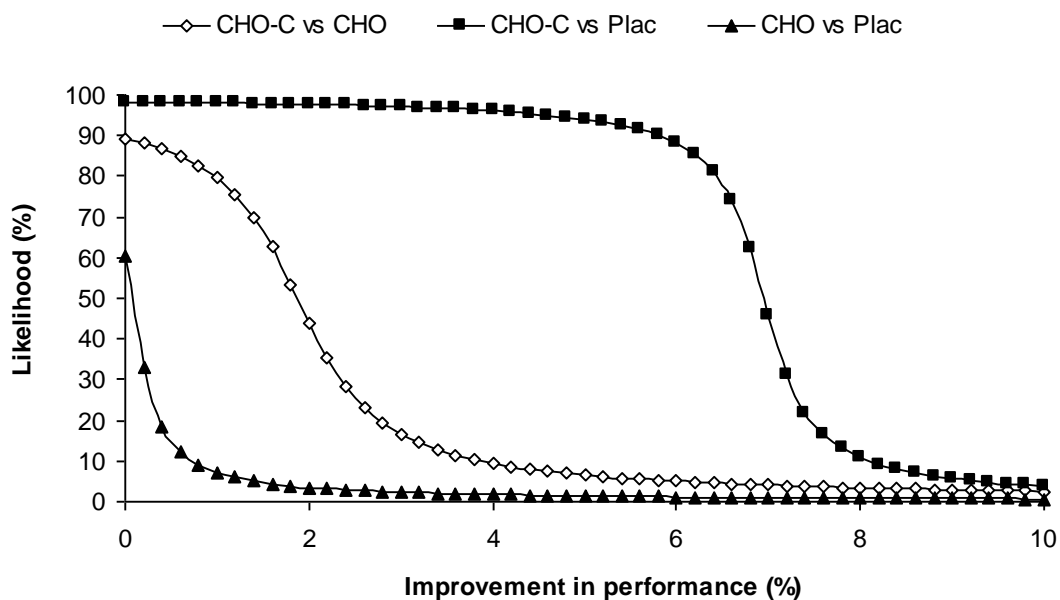


Figure 3. Practical significance curves to show the likelihood of an improved performance of up to 10% for the Performance Test following ingestion of CHO-C vs CHO, CHO-C vs Plac and CHO vs Plac.

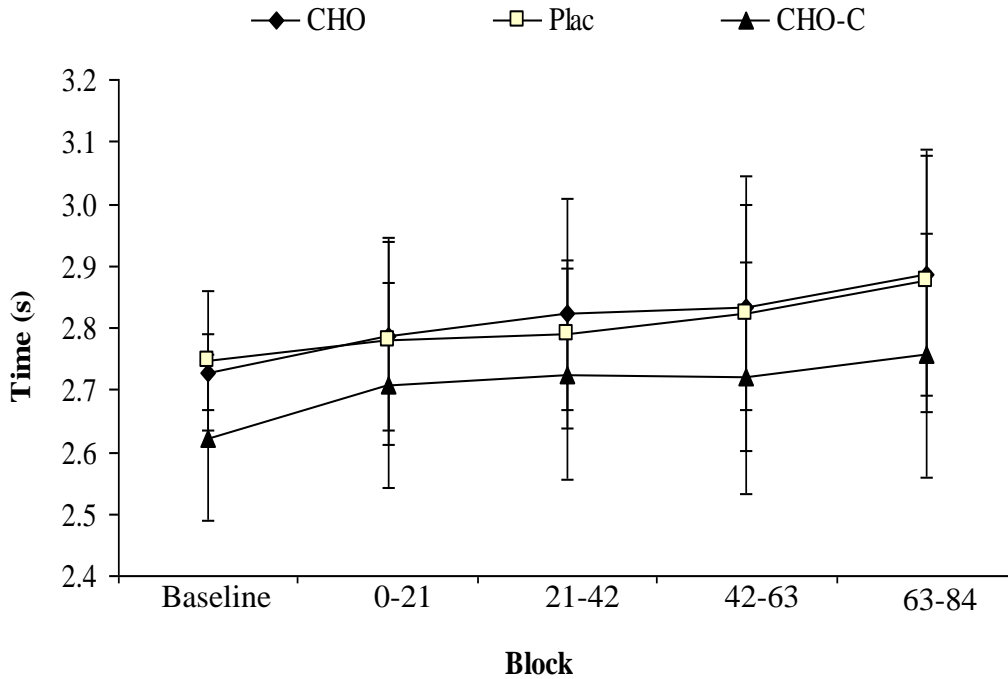


Figure 4. Time taken to complete the 15-m sprint before the BURST (Baseline) and over consecutive 21-min periods during the exercise (mean ± s). Main effect for trial ($P = 0.030$), *post hoc* $P = 0.05$ for CHO-C vs. Plac. Main effect for time ($P = 0.046$).

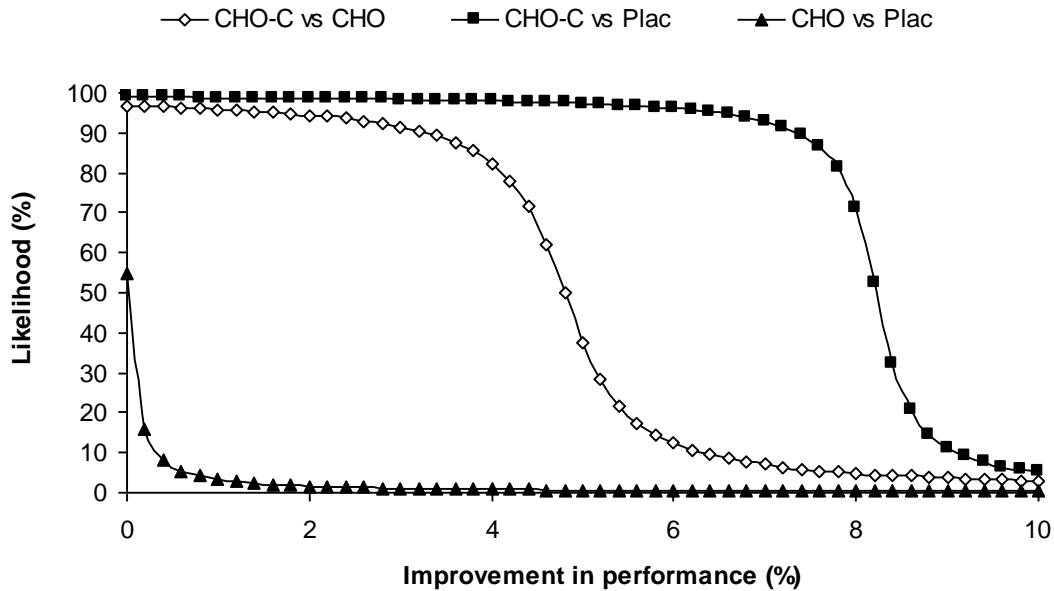


Figure 5. Practical significance curve to show the likelihood of an improved performance of up to 10% for the 15-m sprint following ingestion of CHO-C vs CHO, CHO-C vs Plac and CHO vs Plac.

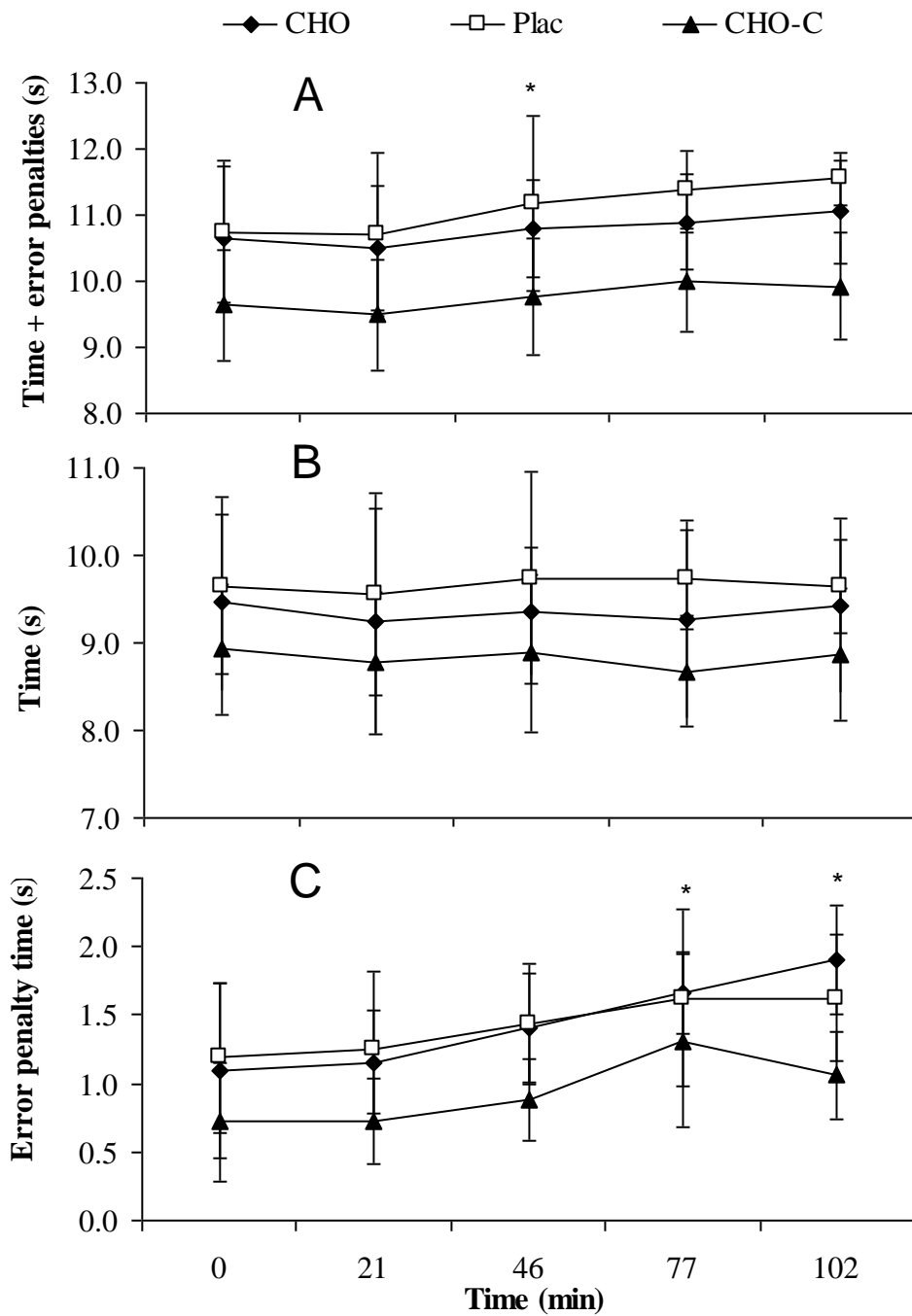


Figure 6. Total time taken to complete the MST including corrections for error penalties (A), total time without error penalties (B) and error penalties (C) at 0 min and for consecutive 21-min periods (mean \pm s). Main trial effect for A, B and C ($P < 0.05$), *post-hoc* $P < 0.05$ for CHO-C vs Plac and CHO in A and C, and CHO-C vs Plac in B. Main time effect for A and C ($P < 0.05$), **post-hoc* $P < 0.05$ vs. 21 min .

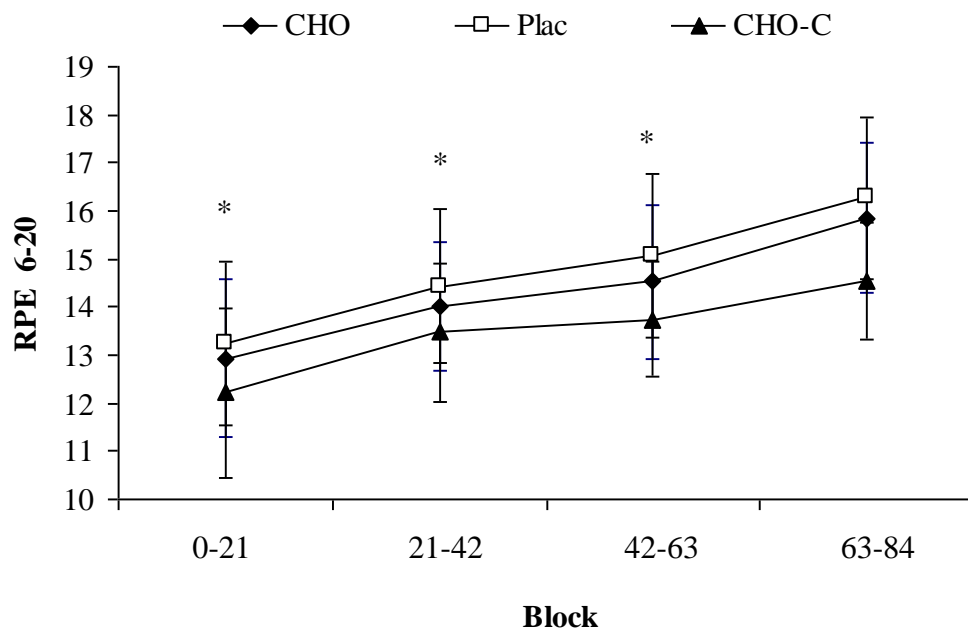


Figure 7. Average Rating of Perceived Exertion (RPE) during consecutive 21-min periods during the exercise (mean \pm s). Main effect for trial ($P = 0.020$), *post-hoc* $P = 0.004$ CHO-C vs. CHO. Main effect for time ($P = 0.003$), **post-hoc* $P < 0.05$ vs. 63-84 min.