# Effect of Carbohydrate and Caffeine Ingestion on Badminton Performance Following Fatiguing Exercise

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## Introduction

To successfully compete in sports such as badminton players must accelerate, decelerate, change direction, move quickly, maintain balance, and repeatedly generate optimum stroke production (Girard & Millet, 2008). Furthermore, this physiologic strain is influenced by hydration and nutritional status (Hornery et al., 2007; Kovacs, 2006). However, the mechanism by which fatigue influences badminton performance largely relates to a decrease in shot accuracy combined with weak positional play (Lees, 2003). Neuromuscular fatigue during badminton is thought to manifest itself due to the reduced capacity to produce and maintain the required force to generate powerful and accurate shots (Enoka, 2002). Research also suggests associations between fatigue in racket sports and cognitive components (Girard, et al., 2006; Girard et al., 2008). This cognitive approach has been identified through delayed reaction times and decreased mental function in fatigued conditions (Welsh et al., 2002). However, several metabolic factors may also limit performance, including decreased phosphocreatine availability, depleted muscle glycogen stores, and increased muscle acidity have also been suggested (Girard & Millet, 2008). A further potential mechanism underlying the phenomenon of fatigue is hypoglycaemia, due to a reduction in muscle metabolism and function (Girard & Millet, 2008). Supporting this mechanism, Vergauwen et al. (1998) found that after 2 h of simulated tennis match-play, carbohydrate supplementation attenuated the number of errors compared with ingestion of a placebo.

It has been demonstrated that the addition of carbohydrate to the fluid ingested prior to and during exercise can improve exercise performance (Wright et al., 1991), possibly due to the sparing of muscle glycogen (Tsintzas et al. 1995) and maintaining blood glucose and carbohydrate oxidation (Clarke et al., 2005; Clarke et al., 2008). In addition, previous studies suggest that compared with fluid alone, carbohydrate ingestion is able to maintain badminton serve accuracy following fatiguing exercise (Bottoms et al., 2012). Similarly, caffeine supplementation has been reported to increase serve velocity, specifically during the final stages of the simulated tennis match, although no improvements in stroke accuracy were observed (Hornery et al., 2007). The suggested mechanisms underlying these findings are caffeine's central and molecular stimulatory properties (van Duinen et al., 2005).

In addition to the actions of carbohydrate and caffeine individually, the ingestion of a combined caffeine and carbohydrate solution has been shown to improve sprinting and jumping performance and the subjective experiences of players during intermittent exercise (Gant et al., 2010). Furthermore, caffeine appears to offset the fatigue-induced decline in self-selected components of performance (Gant et al., 2010), such as running speed. The results indicate a likely benefit to performance following co-ingestion of carbohydrate and caffeine, possibly due to altered subjective perceptions of exercise intensity and fatigue (Roberts et al., 2010). Supporting this suggestion are findings that show that caffeine, when co-ingested with a sports drink, provides an ergogenic benefit greater than that afforded by the carbohydrate alone (Cureton et al., 2007; Hulston & Jeukendrup, 2008; Kovacs, et al., 1998).

Therefore, the ingestion carbohydrate and caffeine have the potential to improve badminton performance either individually or synergistically. Furthermore, despite the mounting evidence regarding the ergogenic effect of caffeinated carbohydrate solutions, there remains a dearth of knowledge concerning the outcome of caffeine ingestion on motor-skill performance and other more specific measures of athletic ability that are central to success in sports such as badminton. Therefore, the aim of the present study was to investigate the effect of ingesting carbohydrate and caffeine on measures that are central to success in badminton.

## Method

Following institutional ethics committee approval 12 healthy males players (mean±SD age: 28±9 y, height: 178±5 cm, mass: 78±9 kg, $\dot{V}O_{2max}$: 59±5 ml·kg$^{-1}$·min$^{-1}$) who were regularly involved in competitive badminton (mean playing experience: 8±3 y) participated in this study. Following the assessment of maximal oxygen uptake ($\dot{V}O_{2max}$) and maximum heart rate (HRmax) using Yo-Yo intermittent recovery level 1 test, as described by Krustrup et al. (2003), in order to determine relative intensity during the experimental trials, the participants performed four trials. The investigation incorporated a double-blind, randomized crossover design, placebo (PLA), carbohydrate (CHO), caffeine (CAF) and carbohydrate with caffeine (C+C) with each experimental trial separated by one week.

Participants abstained from caffeine, alcohol, and strenuous activity for 12 h, and recorded their dietary intake for 48 h before the initial experimental trial. This diet was then replicated before the subsequent experimental trials. Before performing any exercise body mass was recorded and a capillary blood sample drawn from the index finger for determination of blood glucose and lactate concentrations (*Biosen* HbA1c, EKF-diagnostic GmbH, Germany). The participants then performed a sport-specific warm-up before any fatiguing physical activity. This warm-up consisted of playing and returning badminton shots to an opponent, as usual before a competitive match.

Following the warm-up the coincidence anticipation timing (CAT), defined as the estimation of arrival of a stimulus and the required time for a response to intercept it (Payne, 1986) was assessed. A Bassin anticipation timer (Model 35575, Lafayette Instrument Company, USA) was supported 180 cm from the floor at the far end and 70 cm at the near end, similar to the method of Williams et al. (2002) (Figure 1). A red light stimulus travelled towards the participant at a low (3 mph) and high (5 mph) velocity with the end of the lighted runway representing the target point. A photoelectric beam (Model 63501IR, Lafayette Instrument Company, USA) was aligned vertically below the target point so that the participant's racket could pass through it without hindering the swing in order to stop the light.

**Figure 1:** Bassin anticipation timer set-up.

The following measures were recorded for each attempt: Absolute error: The absolute value of each raw score disregarding whether the response was early or late. Constant error: The temporal interval between the arrival of the visual stimulus and the end of the participant's motor response. It represents the mean response of an individual and the direction of error: early or late (Schmidt, 1982). Variable error: The participant's standard deviation from their mean response; this represents the variability or inconsistency of the responses.

Participants then performed the badminton serve accuracy test (Edwards et al., 2005), consisting of 10 short serves and 10 long serves towards a target (50 x 50 cm), with the number of successful hits recorded. The targets were positioned in the far left corner behind the net, and in the back tramline next to the ''T'' for determining long and short serve accuracy respectively (Edwards et al., 2005). Following the serve accuracy test participants performed a choice reaction time test prompted by a flashing beacon (Smartspeed, Fusion Sport, Australia), before then sprinting 5 m through one of three infrared timing gates (randomly selected by the programme), with the time to reach the timing gates being recorded (Figure 2).

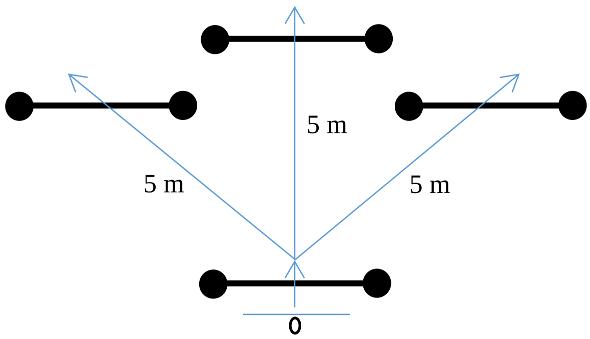


**Figure 2:** Schematic of choice-reaction time course.

One hour before exercise participants consumed 7 ml·kg body mass$^{-1}$ of either water (PLA), 6.4% carbohydrate solution (CHO), a solution containing a caffeine dose of 4 mg·kg$^{-1}$ (CAF) or 6.4% carbohydrate and 4 mg·kg$^{-1}$ caffeine (C+C). All solutions were flavoured with low-calorie (<0.3 g carbohydrate per 100 ml) orange-flavoured concentrate with water and aspartame artificial sweetener. During the 33 min fatigue protocol, participants were provided with a further 3 ml·kg body mass$^{-1}$ of solution, which was ingested before the end of the protocol.

After 1 h a heart rate monitor (Polar RS400, Polar Electro Oy, Finland) was strapped to the chest of the participant and they commenced the fatigue protocol as detailed by Bottoms et al. (2012). In brief, each circuit consisted of three sections, which were repeated continuously for 33 min, replicating the exercise time of a badminton match. The sections forming each circuit were 1 min of intense ghosting at allocated targets on the badminton court with directions given by the investigator, an adapted agility course, followed by 3 min of active recovery (walking at 5.0 km·h$^{-1}$). Ratings of perceived exertion (RPE) were recorded on a scale of 6–20 (Borg, 1973) following the completion of each circuit. In addition, the Felt Arousal Scale (Svebak & Murgatroyd, 1985), a 6-point single-item scale, was used as a measure of perceived activation and recorded prior to fluid ingestion and before and after the fatiguing protocol. As soon as the 33 min fatigue protocol was completed, lactate and glucose concentrations were measured again. This was followed by the retest of the CAT test, accuracy test of the short and long badminton serves and choice reaction time.

Data are reported as the mean ± the standard deviation (SD). The Shapiro-Wilk test was applied to the data in order to assess for a normal distribution. All variables, with the exception of heart rate and RPE were assessed using a two-way analysis of variance with repeated measures. Heart rate and RPE were assessed using a one-way analysis of variance with repeated measures. All statistical procedures were conducted using IBM SPSS Statistics for Windows, Version 20.0 (Armonk, NY: IBM Corp.). An alpha level of *P*<0.05 was considered statistically significant. Furthermore, effect sizes using partial eta squared ($\eta_p^2$) were calculated, which were defined as trivial, small, moderate and large (Hopkins et al., 2009).

## Results

There were trivial differences in heart rate (PLA: 160±15, CHO: 159±17, CAF: 161±18, C+C: 161±17 beats·min$^{-1}$) ($F_{1,16}$=0.048; *P*=0.906; $\eta_p^2$ =0.01) and percentage of maximum heart rate (PLA: 83±8, CHO: 82±10, CAF: 83±10, C+C: 83±11 %) ($F_{1,16}$=0.060; *P*=0.886; $\eta_p^2$ =0.01) between experimental conditions during the fatiguing exercise protocol. In contrast, RPE was significantly lower during CAF and C+C compared with PLA (PLA: 15±1, CHO: 13±3, CAF: 12±2, C+C: 12±2) ($F_{1,15}$=4.696; *P*=0.036; $\eta_p^2$ =0.30). Arousal increased significantly during the completion of the exercise ($F_{1,11}$=41.424; *P*<0.001; $\eta_p^2$ =0.79; Table 1). However, there were only small differences between conditions ($F_{2,18}$=1.494; *P*=0.249; $\eta_p^2$ =0.12).

**Table 1:** Mean (±SD) arousal pre- and post-fatiguing exercise. A main effect for time for arousal was found (*P*<0.001).

| | **Pre** | | | | **Post** | | | |
|---|---|---|---|---|---|---|---|---|
| | PLA | CHO | CAF | C+C | PLA | CHO | CAF | C+C |
| Arousal (AU) | 2±1 | 2±1 | 2±1 | 2±0 | 3±1 | 3±1 | 3±1 | 3±1 |

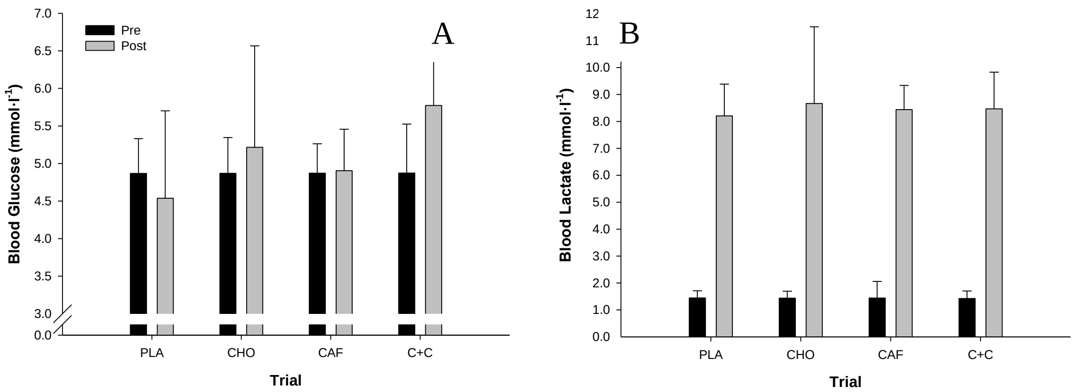


**Figure 3:** Mean (±SD) blood glucose (A) and lactate (B) pre- and post-fatiguing exercise. A significant interaction between condition and time for blood glucose (*P*<0.05) and a main effect for time for blood lactate was found (*P*<0.001).

Small differences in blood glucose concentration was observed between conditions ($F_{3,33}$=2.544; *P*=0.073; $\eta_p^2$ =0.19; Figure 3A). However, during CHO and C+C blood glucose increased moderately during the exercise compared with remaining stable during CAF and decreasing during PLA ($F_{3,33}$=3.754; *P*=0.020; $\eta_p^2$ =0.25). Blood lactate (Figure 3B) concentration increased by a very large extent as a consequence of the exercise protocol ($F_{1,11}$=591.098; *P*<0.001; $\eta_p^2$ =0.98).

However, there were only trivial differences in blood lactate concentrations between the conditions ($F_{3,33}$=0.131; *P*=0.941; $\eta_p^2$ =0.01).

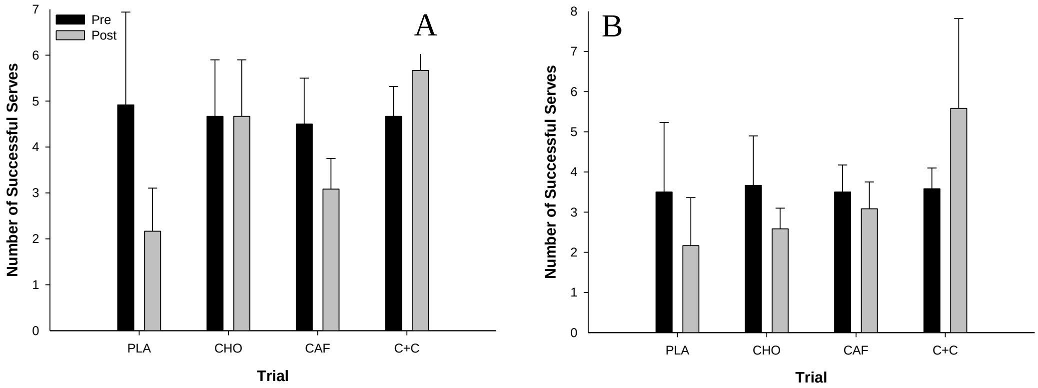


**Figure 4:** Mean (±SD) number of successful short (A) and long (B) serves pre- and post-fatiguing exercise. A main effect was found for condition and time, along with a significant interaction between condition and time for short serves (*P*<0.001) and a main effect was found for condition and a significant interaction between condition and time for long serves (*P*<0.005).

Regarding the number of successful short serves (Figure 4A), a large and significant interaction was identified ($F_{2,18}$=11.173; *P*=0.001; $\eta_p^2$ =0.50). During PLA and CAF accuracy decreased following the exercise protocol. In contrast short-serve accuracy was relatively stable during CHO and improved during C+C. A similarly large effect was observed for long serves (Figure 4B) with all trials demonstrating a reduction in accuracy after the exercise protocol with the exception of C+C, which improved ($F_{3,33}$=12.221; *P*<0.001; $\eta_p^2$ =0.53).

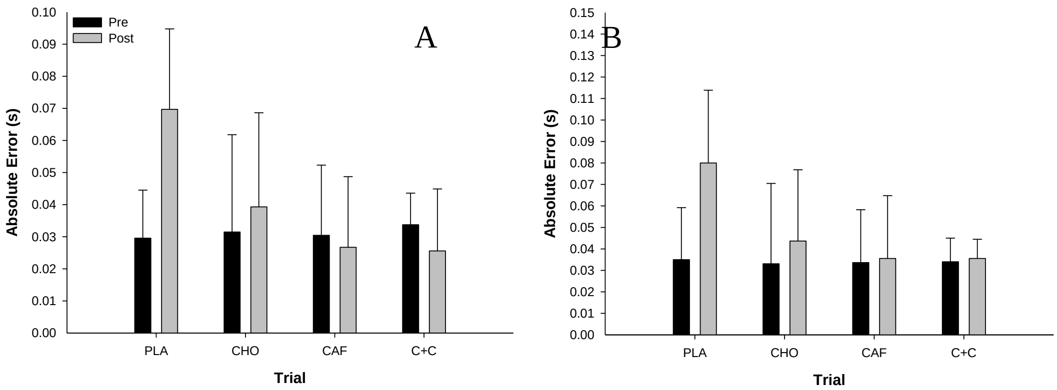


**Figure 5:** Mean (±SD) absolute error during the slow (A) and fast (B) coincidence anticipation test pre- and post-fatiguing exercise. A main effect was found for condition and a significant interaction between condition and time for slow (*P*<0.001) and a main effect was found for condition and time, along with a significant interaction between condition and time for fast (*P*<0.001)

A moderate and significant interaction ($F_{3,33}$=7.741; *P*<0.001; $\eta_p^2$ =0.41) was identified for absolute error during the slow anticipation test (Figure 5A). During PLA and CHO absolute error increased (i.e. performance became poorer) following the exercise protocol. In contrast, absolute error decreased (i.e. performance was improved) during CAF and C+C. A similarly small effect was observed for absolute error during the fast anticipation test (Figure 5B) with all trials demonstrating an increased anticipation time following the exercise protocol, although by a significantly smaller magnitude during CAF and C+C ($F_{3,33}$=4.901; *P*=0.006; $\eta_p^2$ =0.31).

**Table 2:** Mean (±SD) descriptive data (s) for constant and variable errors slow and fast coincidence anticipation test pre- and post-fatiguing exercise. A main effect was found for condition and time as well as a significant interaction between condition and time for constant error in the slow test ($P<0.05$) and a main effect was found for time in the fast test ($P<0.05$). A main effect was found for condition and time along with a significant interaction between condition and time for variable error in the slow test ($P<0.05$) and a main effect was found for condition for variable error in the fast test ($P<0.05$).

| **Error** | **Pre** | | | | **Post** | | | |
|---|---|---|---|---|---|---|---|---|
| | PLA | CHO | CAF | C+C | PLA | CHO | CAF | C+C |
| *Slow* | | | | | | | | |
| Constant error | 0.014 ±0.097 | 0.014 ±0.089 | 0.014 ±0.055 | 0.014 ±0.021 | -0.162 ±0.151 | -0.004 ±0.081 | -0.004 ±0.091 | 0.005 ±0.034 |
| Variable error | 0.226 ±0.111 | 0.144 ±0.135 | 0.160 ±0.115 | 0.037 ±0.013 | 0.477 ±0.210 | 0.176 ±0.136 | 0.106 ±0.074 | 0.054 ±0.063 |
| *Fast* | | | | | | | | |
| Constant error | -0.067 ±0.066 | -0.067 ±0.153 | -0.067 ±0.088 | 0.012 ±0.013 | 0.036 ±0.129 | 0.039 ±0.096 | 0.008 ±0.074 | 0.021 ±0.014 |
| Variable error | 0.181 ±0.133 | 0.154 ±0.154 | 0.169 ±0.120 | 0.029 ±0.017 | 0.210 ±0.082 | 0.170 ±0.132 | 0.166 ±0.145 | 0.034 ±0.015 |

A moderate time and trial interaction was observed for constant error during the slow anticipation test ($F_{3,33}$=5.792; $P$=0.003; $\eta_p^2$=0.35; Table 2) with performance reducing by a greater margin during PLA compared with the other trails. In contrast, a moderate reduction in constant error performance was observed during the fast anticipation test following the exercise protocol ($F_{1,11}$=10.587; $P$=0.008; $\eta_p^2$=0.49; Table 2), although only trivial differences between the trials ($F_{3,33}$=1.101; $P$=0.363; $\eta_p^2$=0.09). A moderate time and trial interaction was observed for variable error during the slow anticipation test ($F_{3,33}$=5.792; $P$=0.003; $\eta_p^2$=0.35; Table 2) with performance reducing by a greater margin during PLA compared with the other trails. Variable error during the fast anticipation test was significantly smaller during C+C compared with the other trials ($F_{3,33}$=20.742; $P$<0.001; $\eta_p^2$=0.65; Table 2), although performance was relatively unaffected by the exercise protocol with only trivial changes observed ($F_{1,11}$=0.164; $P$=0.694; $\eta_p^2$=0.02).

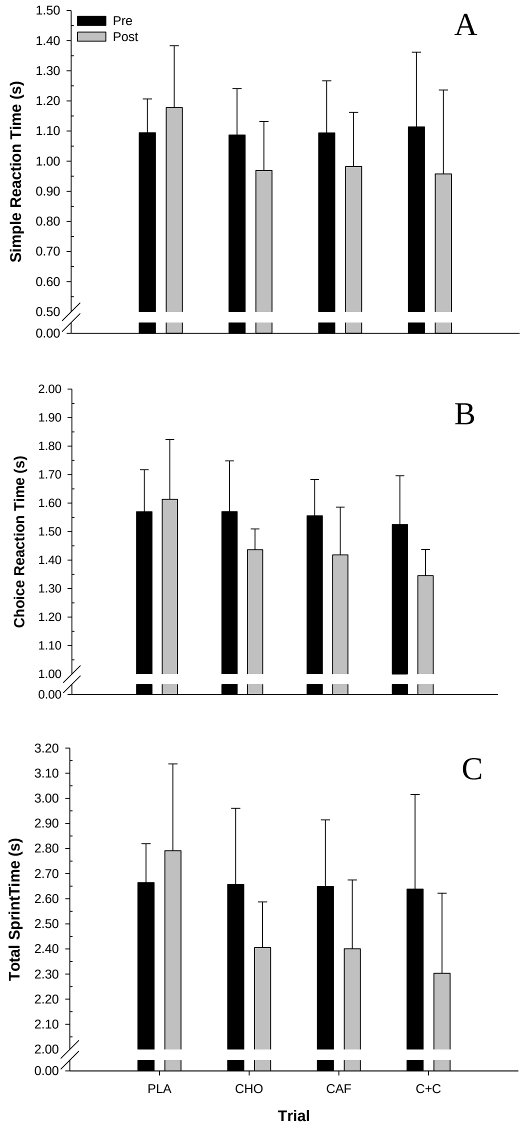


**Figure 6:** Mean (±SD) simple reaction time (A), choice reaction time (B) and total sprint time (C) pre- and post-fatiguing exercise. A significant interaction between condition and time was found for simple reaction time ($P$<0.05). A main effect was found for condition and time for choice-reaction time ($P$<0.05). A main effect was found for time and condition along with a significant interaction between condition and time for total sprint time ($P$<0.001).

A small time and trial interaction was observed for reaction time (Figure 6A) with performance improving in all trials following the exercise protocol with the exception of PLA, which demonstrated a slower reaction time ($F_{3,33}$=3.883; $P$=0.018; $\eta_p^2$ =0.26). Similarly, a small, but not significant time and trial interaction was observed for choice-reaction time (Figure 6B) ($F_{2,20}$=2.473; $P$=0.114; $\eta_p^2$ =0.18). However, a moderate improvement in choice-reaction time was observed between C+C and PLA ($F_{2,23}$=7.097; $P$=0.003; $\eta_p^2$ =0.39). When combined as total sprint time, a large time and trial interaction was observed (Figure 6C) with performance improving in all trials following the exercise protocol with the exception of PLA, which demonstrated a reduction ($F_{3,33}$=60.296; $P$<0.001; $\eta_p^2$ =0.85). Furthermore, total sprint time was significantly faster during C+C compared with the other trials ($F_{2,19}$=35.165; $P$<0.001; $\eta_p^2$ =0.76).

## Discussion

The key findings of the present study demonstrate that the ingestion of a caffeinated carbohydrate solution improves short and long serve accuracy, as well as CAT compared with placebo, suggesting improved shot performance. Furthermore, ingesting a caffeinated carbohydrate solution can preserve reaction time and 5 m sprinting speed.

The findings of the present study suggest that caffeine or carbohydrate ingestion alone do not preserve serving accuracy following fatiguing exercise. However, the co-ingestion of carbohydrate and caffeine successfully maintained serving accuracy post-exercise. Conversely, Hornery et al. (2007) demonstrated that prolonged simulated tennis induced significant decrements in tennis skills and that caffeine supplementation partly attenuated the effects of fatigue and increased serve velocity. Furthermore, carbohydrate ingestion alone had little ergogenic effect on tennis performance (Hornery et al., 2007). In contrast, Bottoms et al. (2012) reported that only the long serve was influenced by fatigue and carbohydrate had a tendency to prevent the deterioration in performance.

Following the ingestion of a placebo or carbohydrate alone CAT absolute error increased following the exercise protocol. In contrast, absolute error decreased following caffeine and carbohydrate and caffeine co-ingestion during the slow test and only small differences in the faster trial. Similarly, Duncan et al. (2013) reported that caffeine ingestion offsets declines in anticipation performance during moderate-intensity exercise. Coincidence anticipation timing is fundamental to a multitude of actions within sports performance includes striking a moving such as a shuttlecock (Singer et al., 1996). Inaccurate CAT has been posited as the major reason why mistakes of a technical or tactical nature occur during competition (Thompson, 2000). The observed improvements in absolute error in the present study, whilst small, would be akin to successfully hitting or not hitting a moving object such as a shuttlecock (Savelsbergh and van der Kamp, 2000).

The ingestion of carbohydrate and caffeine individually improved simple reaction time, choice reaction time and total sprint time. The performance of these tasks were further improved following the ingestion of carbohydrate and caffeine combined. These findings support the studies which have reported the benefits of carbohydrate or caffeine ingestion during high-intensity exercise. Bottoms et al. (2012) found that choice reaction time performance deteriorated after fatiguing exercise in the placebo trial, whereas it was maintained in the carbohydrate trial. Similarly, caffeine ingestion has been reported to improve mean peak power in 4-s cycle ergometer sprints during an intermittent exercise pattern protocol (Schneiker et al., 2006). Similar to the present study Roberts et al. (2010) reported an improvement in 15-m sprint performance in the carbohydrate and caffeine trial compared with placebo. Furthermore, Pérez-López et al. (2014) reported that the time needed to complete a volleyball-specific test was shorter when women volleyball players ingested a caffeinated energy drink, and the total time taken to complete a rugby motor skills test was faster in the carbohydrate and caffeine trial than the carbohydrate and placebo trials (Roberts et al., 2010). Despite the different nature of these tests, all of the tasks are similar in that they require coordinated movements to be performed accurately at speed, suggesting the addition of caffeine to a carbohydrate solution can improve performance.

Whilst the study design does not allow the mechanisms underlying the performance enhancements to be confirmed, the observed improvement are likely to be related to the caffeine-induced changes to the central nervous system (CNS). The performance improvements observed in the present study may have been facilitated by caffeine passing across the blood–brain barrier and binding to adenosine receptors in the brain and thus blocking the inhibitory action of adenosine (Davis et al., 2003). This suggestion is reinforced by the lower RPE associated with carbohydrate and caffeine ingestion than with carbohydrate alone in the present study, and the reported lowering perception of effort during exercise following caffeine ingestion in previous studies (Cole et al., 1996; Doherty & Smith, 2005). Supporting the results of the present study, Gant et al. (2010) reported that no differences in felt arousal between placebo and caffeine conditions leading to speculation that it is an altered perception of fatigue and effort enables players to overcome the reduced central neural drive, which would otherwise negatively influence the excitement and recruitment of skeletal muscle tissue (Meeusen et al., 2006). Finally, the co-ingestion of caffeine with carbohydrates has been shown to increase glucose absorption (van Nieuwenhoven et al., 2000) and exogenous carbohydrate utilization (Yeo et al., 2005). However, metabolic factors are unlikely to be the cause of the performance improvements due the maintenance of euglycemia in all trials and only trivial differences in blood lactate concentration and heart rate measures.

On a practical level these findings suggest that the ingestion of 7 ml·kg body mass$^{-1}$ of a 6.4% carbohydrate solution containing a caffeine dose of 4 mg·kg$^{-1}$ one hour before a match and then supplemented with an additional 3 ml·kg body mass$^{-1}$ during performance can improve badminton match performance. In addition, whilst it should be noted that none of the participants experienced any adverse effects in the present study, as with any new nutritional strategy, this should be implemented in a training session before attempting it in a match.

## Conclusion

These findings suggest that the ingestion of a caffeinated carbohydrate solution before and during a badminton match has the potential to maintain serve accuracy and sprinting actions around the court. Therefore, coaches and players may wish to consider using this as an effective nutritional strategy to enhance overall competitive badminton performance.

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