Caffeinated carbohydrate gel ingestion improves 2000 metre rowing performance

Original Investigation

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Abstract

Purpose The aim of this study was to investigate the effect of ingesting a caffeinated carbohydrate gel (CC) 10 minutes prior on 2000 m rowing performance compared with a carbohydrate-only placebo gel (CP). **Methods** A counterbalanced, single-blind, cross-over study was employed (n=13). All participants completed one familiarisation trial followed by two experimental time trials (TT). The experimental trials were performed 10 minutes after ingesting CP (21.6 g of carbohydrate, 0 mg caffeine) or CC (21.6 g carbohydrate, 100 mg caffeine), and heart rate (HR), oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation ($\dot{V}_E$), respiratory exchange ratio (RER), rating of perceived exertion (RPE), gastrointestinal discomfort (GI) and thirst perception (Thirst) were recorded every 200 m. Blood lactate [La^-] was recorded immediately before and after exercise. **Results** A paired samples t-test identified a significant improvement in 2000 m performance of 5.2 ± 3.9 s (1.1 ± 1.7%; p=0.034). Two-way repeated-measures ANOVA revealed no significant treatment effect for HR (177 ± 8 $b \cdot min^{-1}$ vs 177 ± 9 $b \cdot min^{-1}$; p=0.817), $\dot{V}O_2$ (46.1 ± 6.5 $ml \cdot kg \cdot min^{-1}$ vs 46.6 ± 6.2 $ml \cdot kg \cdot min^{-1}$; p=0.590), $\dot{V}_E$ (121.8 ± 14.7 $L \cdot min^{-1}$ vs 124.8 ± 15.7 $L \cdot min^{-1}$; p=0.490), or for RPE, GI) or Thirst for CP and CC, respectively. Paired samples t-tests revealed no treatment effect for post-exercise [La^-] between CP and CC (11.72 ± 2.69 $mmol \cdot L^{-1}$ vs 12.26 ± 3.13 $mmol \cdot L^{-1}$; p=0.534). **Conclusion** A relatively low dose of caffeine (1.3 ± 0.1 $mg \cdot kg^{-1}$BM) in an isotonic CHO gel ingested only 10 minutes prior to performance, improved 2000 m rowing time by 5.2 ± 7.8 s (1.1 ± 1.7%).

Keywords: *Caffeine, Isotonic gel, High intensity, Time trial*

Introduction

Research has demonstrated that caffeine significantly improves performance during rowing, cycling, running, and weight-lifting, however some studies show no performance change[1]. Contrasting findings may be a result of the lack of testing protocol standardisation such as differing doses, timing of ingestion and exercise mode.

Bruce et al.[2] and Anderson et al.[3] both demonstrated improved 2000 m following the ingestion of either 6 and 9 mg·kg^{-1}BM of caffeine 1 hour prior to rowing in competitive oarsmen and women, respectively. A more recent, but differently designed study, found that 3 mg·kg^{-1}BM of caffeine significantly increased distance completed during 6 minutes of rowing by 1.0 ± 0.8% in light-weight rowers and by 0.3% ± 0.8% in open-weight rowers[4]. Skinner et al's study[5] demonstrated that there was no dose-response relationship between 2, 4 or 6 mg·kg^{-1} BM of caffeine on 2000 m rowing performance and concluded that inter-individual characteristics affect the response to caffeine more than the dose itself, such as diet and nutritional status. The implication here was that the type of pre-exercise meal may impact upon caffeine absorption, therefore exercising following a fast may allow for expedited caffeine absorption. Recent research has provided further evidence that a linear dose-response relationship between caffeine and cycling time trial performance may not exist, where the provision of 6 mg·kg^{-1} BM 90 minutes prior to performing a set amount of work equivalent to 75% of VO_{2peak} for 60 minutes was not more effective than 3 mg·kg^{-1} BM[6]. Compared to the placebo trial the lower dose improved cycling performance by 164 s (4.2%) while the higher dose improved performance by only 2.9%. This research suggests that the presence of caffeine may be enough and that increasing the dose has no additional ergogenic value.

During a 4 km cycling time trial the ingestion of 5 mg·kg^{-1} BM of caffeine by recreationally-trained male cyclists significantly improved their time to completion by 10 s (419 ± 13 s vs 409 ± 12 s) compared to the placebo, which is of a similar time and energy requirement of the 2000 m rowing time trial[7]. Interestingly, despite the significant improvement in performance only power output was significantly different between the trials with no differences observed in integrated electromyography, blood lactate concentration, heart rate, and ratings of perceived exertion between the conditions. Furthermore, the ingestion of 3 mg·kg^{-1} BM of caffeine in a commercial energy drink during a simulated female international rugby 7s tournament significantly increased power output during a 15 s maximal jump test compared to the caffeine-free placebo (23.5 ± 10.1 kW vs. 25.6 ± 11.8 kW) performed before the tournament[8]. Running pace during the games (87.5 ± 8.3 m·min^{-1} vs. 95.4 ± 12.7 m·min^{-1}) and pace at sprint velocity (4.6 ± 3.3 m·min^{-1} vs 6.1 ± 3.4 m·min^{-1}) were also significantly increased compared to the placebo drink demonstrating the potential for caffeine to improve high intensity sport performance. Research from the same group found that when elite female volleyball players ingested 3 mg·kg^{-1} BM of caffeine in a commercial energy drink 60 minutes prior to a power-based skills test that ball velocity in the standing spike (19.7 ± 1.9 vs 19.2 ± 2.1 m·s^{-1}), jumping spike (18.8 ± 2.2 vs 17.9 ± 2.2 m·s^{-1}), squat jump height (29.4 ± 3.6 vs 28.1 ± 3.2 cm), countermovement jump height (33.1 ± 4.5 vs 32.0 ± 4.6 cm), spike jump height (44.4 ± 5.0 vs 43.3 ± 4.7 cm), block jump height (36.1 ± 5.1 vs 35.2 ± 5.1 cm) significantly increased and the time to complete the agility T-test (10.9 ± 0.3 s vs 11.1 ± 0.5) decreased significantly compared to placebo[9].

The ingestion of 3 mg·kg^{-1} BM of caffeine in a low glycogen state has been found to improve power output during intermittent high intensity cycling by 3.5% compared to only a 2.8% improvement in the 'normal' muscle glycogen state, suggesting that the effect of caffeine on performance may be augmented in the fasted state[10]. A meta-analysis of caffeine and endurance performance studies concluded that the magnitude of the performance benefit of caffeine is lower when taken with CHO (6.9 ± 9.2%) than when taken on its own (16.1 ± 12.5%), suggesting that the ergogenic effects of these well-known ergogenic aids are not completely additive. The authors suggested that caffeine is a more robust ergogenic aid than CHO and the favourable improvements found with the ingestion of caffeine are largely parallel to performance gains found through CHO ingestion[11].

The caffeine dose administered in the various studies has varied, with caffeine provided in absolute doses, per unit of lean mass, repeated doses and more typically relative to body mass[1]. The ergogenic effect of caffeine has been evident with doses ranging from 1 $mg \cdot kg^{-1}$ BM[12] to 13 $mg \cdot kg^{-1}$ BM[13]. Caffeine has also been shown to increase glucose absorption from the intestine and increasing plasma glucose levels, which is vital to improve high-intensity exercise performance[14]. Despite evidence supporting the metabolic effect of caffeine when co-ingested with carbohydrate, research is still limited on the effect of combining carbohydrate (CHO) and caffeine on exercise performance[15]. The timing of ingestion has also varied with the majority of investigators performing testing 1 h after ingestion[1], however protocols with testing 6 h after ingestion have also been successful with non-habitual caffeine users[16]. However, in the sport situation it is not always possible to optimise the ingestion of nutritional products or to have custom-made products produced that are provided with ideal formulations especially relative to an athlete’s body mass. Therefore, the aim of this study is to investigate the effect of ingesting a commercially-available carbohydrate gel containing only 100 mg of caffeine consumed only 10 minutes prior to performing a 2000 m rowing time trial compared to a carbohydrate gel. It was hypothesised that the caffeine CHO gel would improve 2000 m rowing performance compared to the CHO gel.

Methods

Participant Characteristics

Thirteen males (mean ± SD, age 21 ± 2 years, height 1.78 ± 0.04 m, mass 77.5 ± 9.1 kg, a mean caffeine intake 82 ± 59 $mg \cdot d^{-1}$) who competed in the British Universities and Colleges Sport competition in a variety of sports participated in the study, which was approved by the BioSciences Research Ethics Committee on behalf of the University of Portsmouth, in the spirit of the Helsinki Declaration. Participants provided written informed consent prior to participation.

Study design

The study employed a single-blind placebo-controlled, counterbalanced, repeated-measures design involving three 2000 m rowing time-trials (TT) on a rowing ergometer (Concept II, USA). The first trial was a familiarisation trial in order to reduce learning effects, while the second and third trials were performed after ingesting 60 mL of a CHO gel (CP) or a caffeinated CHO gel (CC). The CP contained 21.6 g of carbohydrate (Go Isotonic Energy Gel, Science in Sport, energy 367.2 kJ, carbohydrate 21.6 g). The CC contained 21.6 g of carbohydrate and 100 mg of caffeine (Smart 1 Energizer Gel, Science in Sport, energy 367.2 kJ, carbohydrate 21.6 g, caffeine (100 mg), anthocyanins (12.6 mg) and bioflavonoids (1.8 mg)). Both gels were isotonic (290 $mOsmol \cdot kg^{-1}$).

Pre-trial procedures

All participants were instructed to abstain from all caffeine-containing foodstuffs, and alcohol and strenuous exercise for 24 hours prior to each trial, and to fast for 12 hours before each trial to ensure that intra-participant energy substrate stores were uniform before time trials. Participants were asked to keep a record of their food intake 24 hours prior to the first trial and instructed to replicate the same diet 24 hours prior to the second and third trials. This was in order to reduce the possibility that prior exercise/diet could influence measures of substrate metabolism and exercise performance[17]. Participants were instructed to maintain their usual exercise patterns outside of these limitations. The participants completed a self-report questionnaire to determine their habitual caffeine intakes to aid in comparing the effects of caffeine on performance[1].

Familiarisation and experimental trials

Participants arrived at the physiology laboratory in the morning after a 12 hour overnight fast and their height (Harpenden stadiometer, Holtain, UK) and body mass (770, Seca, Germany) were recorded. Before the second and third trials, each participant consumed either the CP or CC 10 minutes before each exercise trial. The rowing ergometer was adjusted to a comfortable position as specified by the participant and set to a maximum resistance of 10.

Once mounted, participants were requested to remain stationary for 2 minutes to enable resting data to be recorded. Each participant then performed a self-paced warm-up for 2 minutes followed by 1 minute of rest before the trial began, as used previously[3]. Oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation ($\dot{V}_E$) and respiratory exchange ratio (RER) were recorded breath-by-breath using an online gas analyser (Oxcon Delta 4.5, Jaeger, Germany) via a face mask (7400 series, Hans Rudolph, USA). Heart rate (HR) (T31, Polar, UK), RPE using the Borg 6–20 Scale, gastrointestinal discomfort (GI) using a 1–10 visual analogue scale and thirst perception (Thirst) using a 1-9 visual analogue scale were recorded at rest and after every 200 m. Time to complete each 200 m was also recorded. A fingerprick capillary blood sample was taken to determine $[La^-]$ at rest and 30 s post-exercise (EFK-diagnostics GmbH, Biosen C_line sport, UK). Participants were instructed to complete the 2000 m at maximum effort, were only allowed to see distance left to complete and kcal expended, and blinded of the time taken to complete the 2000 m until all trials were completed. This ensured the participants did not have increased motivation to beat previous times[3]. Each test was conducted at the same time of day (9.00 am) in order to reduce the effect of biological variation and circadian variance. Each trial was separated by a minimum of 3 days and a maximum of 14 days.

Data analyses

Data were explored for normality and then paired samples T-tests were applied to performance time and the pre- and post-exercise $[La^-]$ deltas ($\Delta[La^-]$) using PASW statistics v18 (SPSS, Chicago, USA). A Pearson's Correlation Coefficient was used to explore relationships between habitual caffeine intake and performance change. Repeated-measures two-way ANOVAs were applied to all remaining dependent variables. The alpha was accepted at $p<.05$ and all data are presented as mean ± SD.

Results

The caffeine dose administered (100 mg) resulted in a mean relative dose of 1.3 ± 0.1 $mg{\cdot}kg^{-1}$BM (range 0.98-1.47 $mg{\cdot}kg^{-1}$BM). Mean performance time was 471.4 ± 28.5 s and 466.2 ± 26.6 s for CP and CC, respectively, a mean improvement of 5.2 ± 7.8 s (1.1 ± 1.7%) (range -28 to 2 s) (t_{12}=2.390; p=0.034). There was a non-significant trend for the time difference between conditions to reach 6.3 ± 11.9 s by 1200 m. Of the 13 participants 10 were faster with the gel and one participant achieved the same time in both experimental trials. The improvement in performance time between conditions was not significant until the 2000 m was completed, highlighting the variety of pacing strategies between the participants (Figure 1). The participants' mean habitual caffeine intake was 507 ± 418 $mg{\cdot}wk^{-1}$ (range: 0-1110 mg·wk^{-1}) and there was a non-significant negative correlation between self-reported habitual caffeine intake and time difference between trials (r=-0.510; p=0.075).

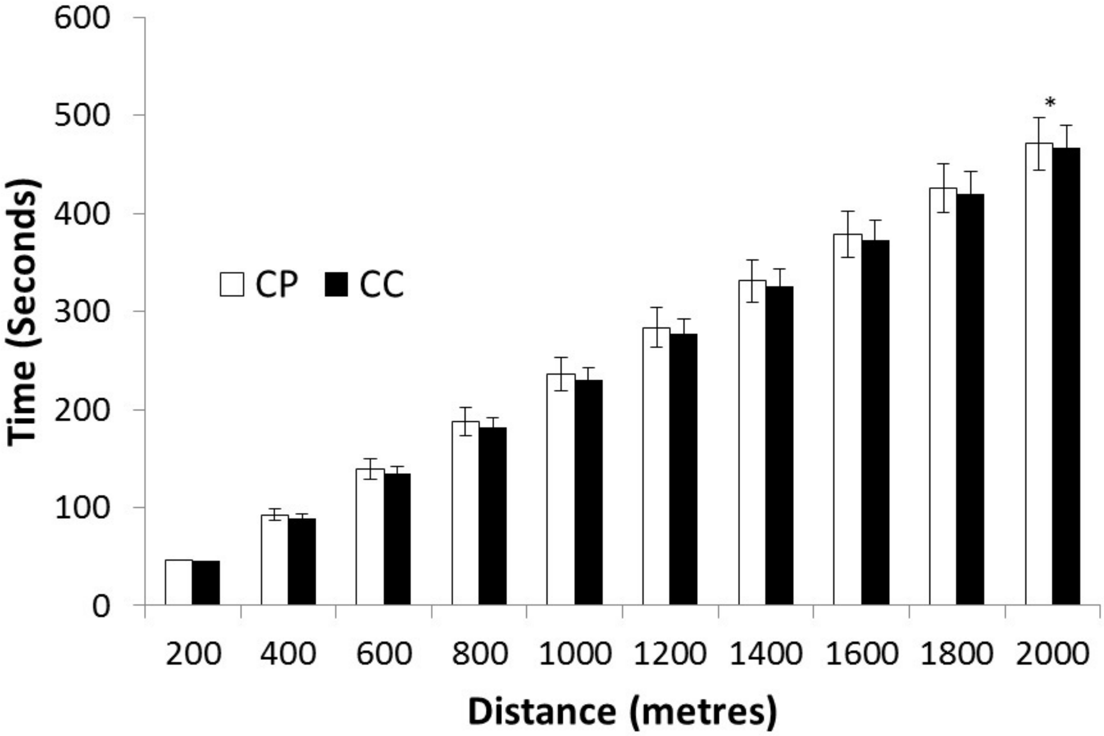

Figure 1 Mean 2000 m performance times *p=0.034

There was no significant treatment effect on HR ($F=0.056_{12,1}$ P=0.817; Figure 2), where mean pre-exercise HR was 77 ± 9 b·min^{-1} in CP and 77 ± 14 b·min^{-1} in CC and mean HR throughout the 2000 m rowing TT was 177 ± 8 b·min^{-1} and 177 ± 9 b·min^{-1} for CP and CC, respectively. There were no significant differences between treatments for Δ[La$^-$] (9.99 ± 2.67 mmol·L^{-1} for CP and 10.89± 3.26 mmol·L^{-1} for CC; p=0.275) and similar mean post-exercise [La$^-$] (11.72 ± 2.69 mmol·L^{-1} for CP and 12.26 ± 3.13 mmol·L^{-1} for CC).

There was no significant difference between treatments for $\dot{V}O_2$ (46.1 ± 6.5 ml·kg·min^{-1} for CP and 46.6 ± 6.2 ml·kg·min^{-1} for CC; $F_{12,1}$=0.308, p=0.590), where mean resting $\dot{V}O_2$ was 8.4 ± 4.3 ml·kg^{-1}·min^{-1} for CP and 7.5 ± 1.3 ml·kg^{-1}·min^{-1} for CC. There was no significant difference between treatments for mean $\dot{V}_E$ (121.8 ± 14.7 L·min^{-1} for CP and 124.8 ± 15.7 L·min^{-1} for CC; $F_{12,1}$=0.508, p=0.490). There was no significant difference between treatments for mean RER (1.15 ± 0.09 for CP and 1.16 ± 0.09 for CC; $F_{12,1}$=0.000, p=0.984).

There was no significant difference between treatments for mean RPE (13.0 ± 2.2 for CP and 13.0 ± 2.1 for CC; $F=0.23_{12,1,}$ p=0.881) with an end RPE of 17.3 ± 3.0 and 17.2 ± 3.1 for CP and CC, respectively. There was no significant difference between treatments for mean GI (1.3 ± 0.4 for CP and 1.3 ± 0.5 for CC; $F=0.316_{12,1}$, p=0.584), where mean GI remained fairly constant with an end GI of 1.5 ± 0.5 for CP and 1.5 ± 0.7 for CC. There was no significant difference between treatments for mean Thirst (3.6 ± 1.1 for the CP and 3.6 ± 1.6 for CC; $F_{12,1}$=0.001; p=0.981).

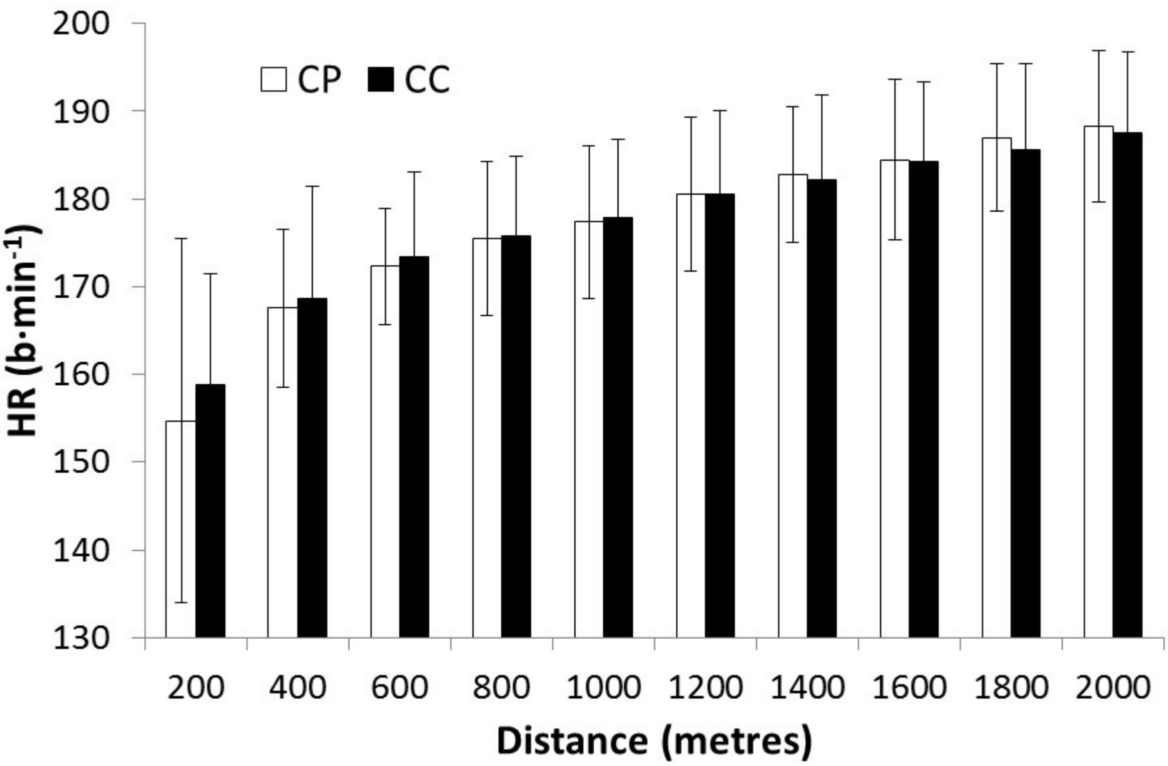

Figure 2 Mean heart rate (HR) during the 2000 m rowing time trials

Discussion

The aim of the present study was to investigate the influence of a caffeinated isotonic CHO gel on 2000 m rowing performance. The primary finding was that CC improved performance by 5.2 ± 7.8 s (1.1 ± 1.7%) compared to CP, therefore our hypothesis can be accepted. This is nearly as large as the difference between first and third place (5.5 s) in the Men's Single Sculls at the London 2012 Olympics.

Other studies have also reported improvements in short-term, high-intensity exercise performance following caffeine ingestion[2,3]. Bruce et al.[2] reported that ingestion of 6 or 9 mg·kg^{-1}·BM^{-1} caffeine 1 hour before exercise resulted in a 1.2% improvement in 2000 m rowing time, a similar finding to the present study but with significantly higher caffeine doses consumed a greater duration prior- to the time trials, and also reported no effect of caffeine on HR, $\dot{V}O_2$, $\dot{V}_E$, RER and RPE. Anderson et al.[3] reported that the ingestion of 6 or 9 mg·kg^{-1}·BM^{-1} caffeine 1 hour before exercise resulted in a 0.7% and 1.3% improvement in 2000 m rowing time, respectively, a finding similar to the present study and also with significantly higher doses consumed a greater duration before the rowing time trials. The competitive oarswomen (n=8) completed the first 500-m ~3 s and ~1 s significantly faster for the 9 and 6 mg·kg·BM^{-1} doses, respectively. The present study found that the majority of the gains in performance were found by 1200 m, but the difference was not significant until 2000 m due to a variety of pacing strategies in the participants. Conversely, another study reported no effect of caffeine on short-term high-intensity exercise performance. Skinner et al.[18] reported that the ingestion of 2, 4 and 6 mg·kg·BM^{-1} caffeine 1 hour before exercise had no effect on 2000 m rowing time. Furthermore, Crowe et al.[19] reported that the ingestion of 6 mg·kg·BM^{-1} caffeine 90 minutes before 2 x 60 s maximal cycling bouts increased time to obtain peak power, possibly explained by increased [La$^-$] following caffeine ingestion.

There were no significant treatment effects on HR, $[La^-]$, $\dot{V}O_2$, $\dot{V}_E$, RER, RPE, GI and Thirst between the treatments, therefore failing to provide significant evidence of the underlying ergogenic mechanisms. In other studies caffeine ingestion has been shown to increase HR, $\dot{V}O_2$ and $\dot{V}_E$[19], fat oxidation and spare muscle glycogen during moderate to high-intensity endurance exercise[20]. The "metabolic" theory had previously gained widespread acceptance as the mechanism by which caffeine improves endurance, however the view that caffeine enhances fat oxidation is equivocal and is an incomplete explanation of the ergogenic effect of caffeine on short-term exercise performance (<30 minutes)[1]. In the present study, RER and $[La^-]$ values were not significantly different between treatments, whereas caffeine has been shown to increase $[La^-]$[21]. The enhanced 2000 m rowing performance was therefore likely to be independent of any effect of caffeine on substrate metabolism. The mechanism responsible for performance enhancement was more likely through a direct effect on the central nervous system (CNS) or skeletal muscle[22]. It is well known that caffeine affects the CNS by eliciting greater motor unit recruitment causing alterations in neurotransmitter function and enhanced neuromuscular function increasing muscular force[23]. Caffeine could also affect the CNS to override fatigue signals, since performance significantly improved without increasing RPE, and there is support for decreases in RPE in other studies[23]. It has also been previously reported that there are no clear mechanisms for caffeine's ergogenic effect to emerge despite significant rowing performance enhancements[3].

To the authors' knowledge this is the first study to demonstrate an ergogenic effect on rowing with such a low caffeine dose (~1.3 $mg \cdot kg^{-1}BM$). Caffeine dose-response studies suggest the absence of a dose-response relationship, where caffeine has been shown to increase endurance similarly for all doses (58 ± 11 minutes, 59 ± 12 minutes and 58 ± 12 minutes for 5, 9 and 13 $mg \cdot kg^{-1}BM$, respectively) compared to placebo (47 ± 13 minutes)[23]. Smaller doses of 1, 2 and 3 $mg \cdot kg^{-1} \cdot BM^{-1}$ have been investigated and while no ergogenic effect was found with 1 $mg \cdot kg^{-1} \cdot BM^{-1}$, doses of 2 and 3 $mg \cdot kg^{-1} \cdot BM^{-1}$ increased performance by 4% and 3%, respectively[12].

The timing of caffeine ingestion was also substantially reduced in the present study at 10 minutes prior to commencing exercise. Many studies utilise a 1 hour period between caffeine ingestion and commencing performance since this is when plasma caffeine levels were assumed to peak[20]. However, Skinner et al.[24] demonstrated that commencing a 40 km cycling time trial to coincide with peak serum caffeine concentrations, 120-150 minutes post-ingestion of 6 $mg \cdot kg^{-1}BM$ caffeine, did not significantly improve performance. However, consuming the same dose of caffeine 60 minutes prior to the onset of exercise was significantly effective. Therefore, it is plausible, as indicated by the findings of the present study, that it is not necessary to leave 60 minutes between the ingestion of caffeine and the onset of exercise. The same research team have also demonstrated that the ingestion of a standard high CHO meal (2 $g \cdot kg^{-1}BM$) 20 minutes prior to the ingestion of 6 or 9 $mg \cdot kg^{-1}BM$ of caffeine increased the duration to achieve peak serum caffeine concentrations from 60 minutes to 120 and 180 minutes, respectively. However, the co-ingestion of caffeine with an isotonic CHO source may enhance the intestinal absorption and physiological availability of both[25]. Caffeine (2.1 $mg \cdot kg^{-1} \cdot BM^{-1}$) co-ingested with a 7% CHO-electrolyte solution (CES) improved 1 h TT cycling compared to either caffeine or the CES alone[19]. Yeo et al.[14] investigated the effect of caffeine on exogenous carbohydrate oxidation in eight males cycling at 55% peak power output (~64% $\dot{V}O_{2max}$) for 120 minutes. Participants ingested a 5.8% glucose solution (0.8 $g \cdot min^{-1}$), glucose/caffeine (5 $mg \cdot kg^{-1} \cdot BM^{-1} \cdot h^{-1}$) or water. Exogenous carbohydrate oxidation from 90-120 minutes was 26% higher with glucose/caffeine (0.72 ± 0.04 $g \cdot min^{-1}$) compared with glucose (0.57 ± 0.04 $g \cdot min^{-1}$). Total oxidation rates were highest with glucose/caffeine (2.47 ± 0.23 g·min^{-1}) compared with glucose (1.84 ± 0.14 g·min^{-1}) and water (1.21 ± 0.37 g·min^{-1}). There was a trend towards increased endogenous carbohydrate oxidation with glucose/caffeine (1.81 ± 0.22 g·min^{-1}) compared with glucose (1.27 ± 0.13 g·min^{-1}) and water (1.12 ± 0.37 g·min^{-1}). However, such trends in elevated overall CHO oxidation with the addition of caffeine were not demonstrated by changes in RER in the present study.

The administration of an absolute caffeine dose (100 mg) rather than relative to body mass may have contributed to the variability in responses[20], however caffeine doses in foodstuffs and carbohydrate gels are not prescribed to performers according to body mass so this could be perceived as an ecological strength. The caffeinated gel also contained blackcurrant anthocyanins (0.16 mg·kg^{-1}BM) that were not included in the CHO only gel. Such a low dose may have been unlikely to have affected the outcomes of the study, however future studies may wish to investigate the effect of removing this component from the caffeine-anthocyanin CHO gel. This study also used males who participate in University sport rather than high level competition and may perform less reliably compared to their highly-trained counterparts[26]. Future research should repeat the study with highly-trained rowers to limit inter-individual fitness/ability levels and to be more ecologically valid for elite sport performance. Research should also determine whether the significant effect remains if a standard pre-competition meal was provided 3 h before CHO gel ingestion.

In conclusion, a relatively low dose of caffeine (1.3 ± 0.1 mg·kg^{-1}BM) in an isotonic CHO gel ingested only 10 minutes prior to performance, improved 2000 m rowing performance by 5.2 ± 3.9 s (1.1 ± 1.7%) in University sports performers.

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The study was designed by TO, SW, RO and AS; data were collected and analyzed by TO, SW and RO; data interpretation and manuscript preparation were undertaken by AS and TO. All authors approved the final version of the paper. The authors would like to thank all the participants that took part in the study, technical support received and the gels were provided by Science in Sport, Blackburn, UK. The results of the current study do not constitute endorsement of the product by the authors or the journal.

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