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Research article

Caffeine Ingestion Improves Repeated Freestyle Sprints in Elite Male Swimmers

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Abstract
The purpose of this investigation was to determine the efficacy of a moderate dose of caffeine to improve repeat-sprint performance in elite freestyle sprinters. Nine highly trained male swimmers performed 6 x 75 m freestyle sprints on two occasions 1-h after consuming either 3 mg·kg^{-1} caffeine (CAF), or placebo, in a cross-over manner. Capillary blood samples for the analysis of blood lactate concentration and pH were collected after the 1st, 3rd, and 5th sprint, while heart rate and perceived exertion (RPE) were collected after every sprint. There was a moderate effect for improved mean sprint time in the CAF condition (0.52 s; 1.3%; *d* = 0.50). When assessed individually, there was a large effect for improved performance in sprints 3 (1.00 s; 2.5%; *d* = 1.02) and 4 (0.84 s; 2.1%; *d* = 0.84) in CAF compared to placebo, with worthwhile performance improvement found for each of the first 5 sprints. There was a significant treatment effect for higher blood lactate concentration for CAF (p = 0.029), and a significant treatment*time effect for reduced pH in the CAF condition (p = 0.004). Mean heart rate (167 ± 9 bpm vs 169 ± 7 bpm) and RPE (17 ± 1 vs 17 ± 1) were not different between placebo and CAF trials, respectively. This investigation is the first to demonstrate enhanced repeat-sprint ability in swimmers following acute caffeine ingestion. It appears likely that the combination of a moderate dose of caffeine (3-6 mg·kg^{-1}) with trained athletes is most likely to enhance repeat-sprint ability in various athletic populations; however, the exact mechanism(s) for an improved repeat-sprint ability following acute caffeine ingestion remain unknown.

Key words: Adenosine receptor antagonism, repeat-sprint ability, stimulant, intermittent exercise.

Introduction

Caffeine is a popular ergogenic aid among athletes, with investigations into its effect on swimming performance dating back to the 1970's (Makoc and Vorel, 1974). Research into the human response to moderate doses of caffeine (3-6 mg.kg^{-1}) has demonstrated that plasma caffeine levels rise to between ~15-40 µmol·L^{-1} between 40 – 80 min post-ingestion (Spriet, 2014). Additionally, there is now a large and accepted body of literature which demonstrates that a moderate dose of caffeine is ergogenic for endurance performance in a range of sports, including freestyle swimming (Macintosh and Wright, 1995). The mechanism for endurance performance enhancement was first thought to be an epinephrine-induced increase in free-fatty acid oxidation and glycogen sparing (Davis and Green, 2009). However, it is now thought that a central nervous system (CNS) mechanism, via adenosine receptor antagonism, is more likely, and may also translate into high-intensity performance improvement (Davis et al. 2003).

Sprint swimmers are one group of athletes who could benefit greatly from caffeine's ergogenic potential for high-intensity performance. Events from the 50 m to 400 m freestyle typically last from ~20 - 240 s at the elite level, and strategies to improve one off sprint performance and repeated sprint training sessions are constantly being sought. However, investigations into the effect of caffeine on high-intensity exercise performance are less researched than for endurance exercise, with an early swimming study finding that 250 mg of caffeine enhanced 2 x 100 m freestyle sprint performance only in trained participants (Collomp et al. 1992), and a later trial (6 mg·kg^{-1}) finding no improvement in repeated 30 s cycle sprint performance (Greer et al. 1998). More recently, some evidence supports the use of caffeine to improve repeat-sprint performance in trained males (Pontifex et al. 2010) and team sport athletes (Schneiker et al. 2006), while other investigations have demonstrated no improvement (Astorino et al. 2012; Lee et al. 2012). It should be noted that these investigations differed in calibre of athlete recruited, gender of participants, mode of caffeine ingestion (capsules, vs pills vs caffeine containing energy drink) and duration of repeat-sprint task (from 2 min – 72 min), but very little research exists into the efficacy of caffeine to improve sprint swimming, where efforts are typically longer in duration than for traditional repeat-sprint exercise. Pruscino et al. (2008) reported that 6.2 mg·kg^{-1} caffeine did not improve 2 x 200 m (separated by 20 min) freestyle performance in six elite male swimmers, but recent research involving shorter rest durations and a greater number of repetitions is lacking. Additionally, there is a scarcity of field based investigations utilising elite athletes to determine the efficacy of caffeine to improve high-intensity performance in this highly trained population (Burke, 2008).

Due to the lack of information available on caffeine's ability to improve sprint, and repeated sprint performance in highly trained swimmers, the aim of this investigation was to determine the efficacy of a moderate dose of caffeine to improve 6 x 75 m freestyle performance in elite freestyle sprinters. It was hypothesised that 3 mg.kg^{-1} of caffeine would lead to worthwhile improvement in the first sprint, and mean sprint time throughout the 6 x 75 m repeated sprint trial.

Methods

Participants

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Nine highly trained (≥8 sessions per week) national level male swimmers (aged 20.8 ± 2.8 y; stretch stature 1.90 ± 0.07 m; body mass 83.9 ± 6.4 kg), were recruited. Prior to participation in the study, swimmers gave informed consent and completed a pre-participation health history form. Ethical approval was granted by the Human Ethics Committee of the University of Western Australia (RA/4/1/4734).

Research design

To assess whether CAF ingestion enhanced 6 x 75 m freestyle performance, a three week, single-blind, crossover study was designed. Initially, all participants completed a familiarisation session at the same pool to be used during the investigation (25 m indoor pool, 26.5 °C). Both sessions throughout the subsequent two week trial were performed at the same time of day, on the same day of the week (to minimise the effects of any possible confounding variables such as diurnal variations in treatment metabolism). The weekly micro cycle of training volume and intensity for each individual was kept consistent and participants were asked not to train in the morning prior to testing. The two sessions were completed under a CAF condition (using commercially available caffeine tablets: NoDoz), with the other utilising an artificial sweetener placebo (Equal). Participants were asked to refrain from consuming any products containing CAF in the 48 h prior to each session and completed a food diary in the 24 h prior to each session and kept their nutrition consumption consistent prior to each testing session. A sleep diary was kept for the week following each trial to assess the effect of each substrate on sleep.

Treatment group allocation

Participants were allocated into a treatment group prior to their first session via simple randomisation. Each week, substrate tablets were ground up and body weight corrected doses were deposited into white gelatine capsules (Capsuln Co). Participants consumed the same number of capsules in both trials. All capsules were consumed with 600 mL of water over 5 min, commencing 60 min prior to the first sprint.

Warm up: All participants completed a standardised 1500 m warm up commencing 45 min prior to the testing session. The warm up consisted of 500 m of easy freestyle swimming followed by two sets of: 3 x 100 m freestyle on a 1:40 min time cycle, 2 x 50 m freestyle at on a 45 s time cycle and 2 x 50 m freestyle as: 15 m explode and 35 m easy.

Experimental Protocol: The experimental trial comprised of 6 x 75 m maximal freestyle sprints from a dive start. Swimmers were pair matched to ensure a competitive environment and departed every 10 min. Sprints were started by the same researcher for each trial using a battery powered gun (Stanley) that let off a sharp tone and simultaneous flash. Upon completion of each sprint a self-perceived rating of exertion (RPE) was given using Borg's 6-20 scale (Borg, 1982) and a waterproof heart rate bar (Polar T31, Finland) was immediately placed on the participants' chest, with heart rates collected within 10 s of the conclusion of each trial. Following this, capillary blood samples were collected from each participant after the 1st, 3rd and 5th sprint, before they commenced a between-sprint recovery which consisted of 2 x 100 m low intensity freestyle. After finishing the protocol, participants completed 800 m of easy swimming as a standardised recovery. Finally, participants were asked which substrate they thought they had consumed before that session.

Blood sampling: Five capillary blood samples were collected from the earlobe of each participant during the course of each session. The first drop of blood was discarded before a sample was collected into a 95 µL heparinised glass capillary tube (Radiometer Medical ApS). Samples were stored on ice and later analysed for blood lactate concentration and pH following the session using a blood gas analyser (ABC625, Radiometer Medical A/S, Copenhagen, Denmark).

Sprint times: All sprints were filmed using a 50 Hz mini DV camera recorder (Sony Mini DV Camera – HDR-HC9E) on a tripod. Filming was conducted from a raised platform perpendicular to the finishing end of the pool giving a vertical view of the hand making contact with the wall. Sprints times were analysed using sports video software (Pro Suite Dartfish Software 4.0.0.0). Clips were viewed at 50 frames per second and therefore times were recorded to the nearest 0.02 s. Time was recorded from the first frame that showed light being emitted from the top of the starting gun until the first frame showing the participants' hand making contact with the wall.

Statistical analysis

All data was entered into Statistical Package for Social Sciences (IBM SPSS 19.0) and analysed using a two-way repeated measures ANOVA with significance set at α=0.05. In the event of a significant interaction, paired samples *t*-tests were used to clarify any differences. Trends in performance data were also established using Cohen's effect sizes (*d*) using the methods detailed by Cohen (1988), where the following descriptors were used; 0-0.2 (trivial); 0.2-0.5 (small); 0.5-0.8 (moderate); >0.8 (large), with only moderate to large effect sizes reported. The smallest worthwhile change in performance was deemed to be 0.2*standard deviation (SD) (between-participant SD across all sprints in the placebo trial). All data were expressed as m ± SD.

Results

Performance

There was a significant treatment effect for improved sprint time in CAF ($p = 0.015$), but no time ($p = 0.082$) or treatment*time effect ($p = 0.170$; Table 1). Effect size calculations revealed a large effect for improved sprint performance for CAF in the 3rd (2.5%; *d*=1.02), and 4th (2.1%; *d*=0.84) sprints, and a moderate effect for improved mean sprint times (1.3%; *d*=0.50). The smallest worthwhile change in sprint time was determined to be 0.22 s, with sprints 1-6 improving by 0.36, 0.36, 1.00, 0.84, 0.48, and 0.12 s, respectively. This indicates that worthwhile improvement to sprint time occurred in each of the first 5 sprints in the CAF trial.

Table 1. Mean (±SD) performance times (s) in a 6 x 75 m maximal freestyle sprint protocol after supplementation of placebo or caffeine in national level swimmers (n = 9).

Sprint Number	Placebo	Caffeine *	Effect Size (*d*)
1	40.24 (1.22)	39.88 (.74)	.36
2	40.30 (1.16)	39.94 (1.18)	.31
3	40.70 (1.00)	39.70 (.96)	1.02 §
4	40.98 (1.02)	40.14 (.98)	.84 §
5	40.68 (1.26)	40.20 (1.42)	.36
6	40.60 (1.30)	40.48 (1.70)	.09
Mean	40.58 (1.08)	40.06 (1.02)	050 #

* Denotes significant treatment effect (α=0.05). § Denotes large effect (*d* >0.80). # Denotes moderate effect (*d* >0.50).

Haematology

There were no differences in blood lactate concentration prior to capsule ingestion or after warm-up between placebo and CAF ($p > 0.05$, Figure 1). There was a significant treatment effect for higher blood lactate concentrations in CAF ($p = 0.029$), and time effect ($p < 0.001$), but no treatment*time effect ($p = 0.117$).

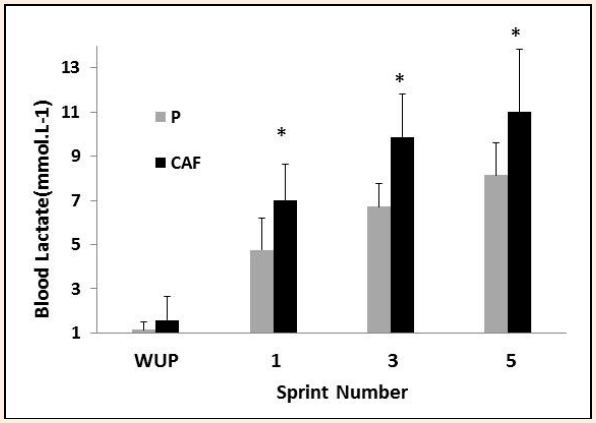

Figure 1. Blood lactate concentration (mmol.L^{-1}) after warm-up (WUP), sprint 1, 3 and 5 of a 6 x 75 m freestyle protocol following ingestion of either placebo (P) or caffeine (CAF) in national level swimmers (n = 9). * Denotes significant treatment effect (α=0.05).

There were no differences in blood pH prior to the capsule ingestion or after warm-up between placebo and CAF ($p > 0.05$, Figure 2). There was a significant treatment ($p = 0.024$), time ($p < 0.001$) and treatment*time effect ($p = 0.004$) demonstrating lower pH in CAF. Follow-up *t*-tests revealed that blood pH was significantly lower in CAF than placebo after the 1st and 5th sprint during the repeat-sprint trial ($p = 0.000$ and $p = 0.001$ respectively), but not following the 3rd set ($p = 0.058$).

Heart rate and perceptual responses

Mean heart rate during the repeat-sprint protocol was 167 ± 9 and 169 ± 7 for placebo and CAF, respectively. There was no treatment ($p = 0.132$) or treatment*time ($p = 0.755$) effect for heart rate, but a significant time effect ($p < 0.001$) indicated heart rate increased throughout the trial.

Mean RPE during the repeat-sprint protocol was 17 ± 1 and 17 ± 1 for placebo and CAF, respectively. There was no treatment ($p = 0.312$) or treatment*time ($p = 0.335$) effect for RPE, but a significant time effect ($p < 0.001$) indicated RPE increased throughout the trial.

Five participants correctly guessed the order in which they ingested each substrate, resulting in a 56% success rate. Three participants reported that CAF may have affected their sleep that night, with one missing the next morning's training session.

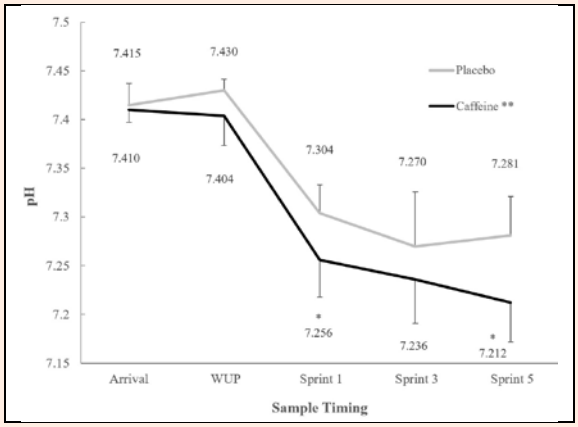

Figure 2. Blood pH at arrival, after warm up (WUP), sprint 1, 3 and 5 of a 6 x 75m freestyle protocol following ingestion of either placebo (P) or caffeine (CAF) in national level swimmers (n = 9). ** Denotes significant treatment*time effect (α=0.05). * Denotes significant difference from placebo (α=0.05).

Discussion

The key finding of this investigation was that moderate caffeine ingestion (3 mg·kg^{-1}) improved mean sprint time (1.3%; *d*=0.50) during a 6 x 75 m freestyle repeat-sprint protocol performed by elite swimmers. While there was only a large effect for improvement recorded for the 3rd (2.5%; *d*=1.02) and 4th (2.1%; *d*=0.84) sprint, worthwhile improvement occurred in all of the first 5 sprints. This finding is in agreement with one investigation that found swimming time trial performance improved by 1.3% following caffeine ingestion (Vandenbogaerde and Hopkins, 2010), and other research that has found improved repeat-sprint performance following acute caffeine ingestion (Collomp et al., 1992; Lee et al., 2012; Mohr et al., 2011; Paton et al., 2010; Pontifex et al., 2010; Schneiker et al., 2006). However, it should be noted that repeated sprints are typically longer for competitive freestyle sprinters than traditional repeat-sprint exercise, and there also remain several investigations that have found no improvement to repeat-sprint performance following caffeine ingestion (Astorino et al., 2012; Crowe et al., 2006; Forbes et al., 2007; Glaister et al., 2012; Greer et al., 1998; Lee et al., 2012; Pruscino et al., 2008). Further research into the effects of caffeine on repeated swimming sprints is required; however, with such equivocal results it is essential to examine the protocol differences between investigations that have found caffeine to be

ergogenic in other repeat-sprint protocols compared to those that have found no improvement.

Dose

An insufficient caffeine dose is a likely cause of non-positive findings in caffeine research, as Astorino et al. (2010a) have previously demonstrated 5 mg.kg^{-1} of caffeine to be ergogenic for repeated bouts of a knee flexion/extension task performed on an isokinetic dynamometer, whereas 2 mg·kg^{-1} had no effect. This finding is supported by another recent investigation which reported that 3 mg·kg^{-1} of caffeine significantly improved half-squat and bench press maximal muscle power, while 1 mg·kg^{-1} had no effect on performance (Del Coso et al., 2012). These findings suggest that a moderate dose of caffeine (3-6 mg·kg^{-1}) is required to elicit high-intensity performance changes, while low doses (1-3 mg·kg^{-1}) may not be ergogenic for anaerobic exercise. Unfortunately, neither of these investigations utilised an exercise task with high metabolic demands, as is required for repeated sprints, and therefore further research comparing low to moderate doses of caffeine for repeat-sprint exercise is required to confirm this relationship.

However, it is also noteworthy that all six repeat-sprint investigations which found caffeine to be ergogenic administered a moderate dose of caffeine (Collomp et al., 1992; Lee et al., 2012; Mohr et al., 2011; Paton et al., 2010; Pontifex et al., 2010; Schneiker et al., 2006). However, of the seven trials which found caffeine to be ergolytic, or have no impact on performance, two of these utilised a low dose of caffeine (Astorino et al., 2012; Forbes et al., 2007), whereas five utilised moderate or high (>6 mg·kg^{-1}) doses (Crowe et al., 2006; Glaister et al., 2012; Greer et al., 1998; Lee et al., 2012; Pruscino et al., 2008). Therefore, there appears to be more factors involved than just the dosage of caffeine administered in determining whether caffeine is ergogenic for repeat-sprint exercise.

Athletes vs non-athletes

Collomp et al. (1992) reported that caffeine ingestion improved 2 x 100 m freestyle performance in trained swimmers, while no ergogenic benefit was found in untrained participants performing the same trial. This indicates that caffeine's ergogenic potential may be greater for athletes than it is for non-athletes. In a review of caffeine's effect on anaerobic exercise performance, Astorino et al. (2010b) reported that the majority of studies to report enhanced performance were investigating trained athletes (including competitive cyclists, football players, elite athletes, and competitive swimmers). It is thought that trained athletes are more motivated to perform fatiguing exercise, may have more consistent inter-day exercise performance (reducing variability and improving statistical power), and may be lower habitual consumers of caffeine (Astorino et al., 2010b).

Of the five studies investigating the effect of moderate-high doses of caffeine on repeat-sprint performance which reported to ergogenic benefit, three utilised only recreationally active participants (Crowe et al., 2006; Greer et al., 1998; Lee et al., 2012), while only two investigations reported no improvement in exercise performance following moderate-high doses of caffeine in well-trained participants (Glaister et al., 2012; Pruscino et al., 2008). Interestingly, while all investigations to find caffeine to be ergogenic for repeat-sprint exercise utilised a moderate dose of caffeine, five out of six also investigated trained participants (Collomp et al., 1992; Mohr et al., 2011; Paton et al., 2010; Pontifex et al., 2010; Schneiker et al., 2006). These findings indicate that a combination of a moderate dose of caffeine and trained athletes is most likely to result in performance enhancement during repeat-sprint exercise.

Mechanism

Caffeine is suggested to reduce the deleterious impacts of exercise-induced adenosine (known to include reduced arousal, enhanced pain perception, induce sleep, depress locomotor activity, and act as a neuromodulator), via adenosine receptor antagonism (Davis and Green, 2009). One of the possible effects of adenosine receptor antagonism is to negate decreased motor unit firing rates associated with prolonged high-intensity exercise, resulting in more sustained and forceful muscle contractions (Davis and Green, 2009). It would therefore be expected that caffeine would allow exercise intensity to increase, and blood lactate concentrations to be higher (via greater glycolytic work being performed) due to a reduced perception of pain and effort during the exercise task. In this investigation, mean performance time during the 6 x 75 m freestyle task was improved and blood lactate concentrations were higher with caffeine consumption, while RPE was unchanged. This may indicate that caffeine had no effect on perception of effort, but it could also reasonably be expected that perception of effort should have increased in the caffeine trial, where sprint times were faster, and significantly more acidosis (as indicated by a significantly greater blood lactate concentration, and significantly reduced blood pH) was realised during the protocol. It is therefore plausible that caffeine's role as an adenosine receptor antagonist played some part in the enhanced performance found here. It has also been suggested that an improved reaction time and alterations in cognition or mood might also play a role in caffeine's ergogenic effect during anaerobic exercise (Astorino et al. 2010b); however, these mechanisms were not explored in this investigation. Regardless, Astorino et al. (2010b) concluded that adenosine receptor antagonism likely plays a large role in a multifactorial response of caffeine on anaerobic exercise performance, but the exact mechanism(s) responsible remain unknown.

Conclusion

While two previous caffeine investigations in swimmers have demonstrated improved performance in 2 x 100 m freestyle time trial performance (Collomp et al., 1992), and no improvement in 2 x 200 m freestyle time trial performance (Pruscino et al., 2008), this investigation is the first to demonstrate enhanced repeat-sprint ability in swimmers following caffeine ingestion. Of note, there was no large effect for individual sprint performance here

until the third and fourth sprint of a 6 x 75 m freestyle protocol, resulting in a 1.3% improvement in mean sprint time; however, worthwhile improvement was found for each of the first 5 sprints. It appears likely that the combination of a moderate dose of caffeine (3-6 mg·kg^{-1}) with trained athletes is most likely to enhance repeat-sprint ability in various athletic populations. The exact mechanism(s) for an improved repeat-sprint ability following acute caffeine ingestion remain unknown, but it appears likely that caffeine may act as an adenosine receptor antagonist, which may play a role in a reduced perception of effort during high intensity exercise and result in enhanced performance (Davis et al., 2003). Perceived exertion remained unchanged in the caffeine trial in this investigation despite the caffeine trial resulting in faster sprint times, and more severe acidosis, indicating that this may have played some role in the results found here. Further investigations should attempt to clarify the exact mechanism behind caffeine's ergogenic potential for repeat-sprint exercise, and determine whether sustained acute caffeine intake prior to repeat-sprint training may have any long-term effects on exercise performance.

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Key points

- A moderate dose of caffeine (3 mg·kg^{-1}) ingested 1 h before a repeat-sprint freestyle set significantly improves mean sprint time in elite swimmers.
- The combination of at least a moderate dose of caffeine (>3 mg·kg^{-1}) with trained athletes appears the most likely to result in ergogenic benefit to anaerobic exercise performance.
- Further research is required to determine the precise mechanism(s) responsible for caffeine's ergogenic potential for anaerobic exercise performance.

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