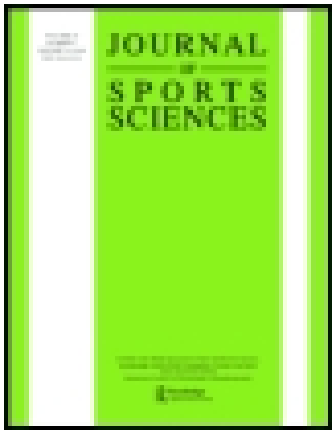

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Effects of caffeine chewing gum on race performance and physiology in male and female cyclists

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Abstract
This investigation reports the effects of chewing caffeinated gum on race performance with trained cyclists. Twenty competitive cyclists completed two 30-km time trials that included a maximal effort 0.2-km sprint each 10-km. Caffeine (~3–4 mg · kg^{-1}) or placebo was administered double-blind via chewing gum at the 10-km point following completion of the first sprint. Measures of power output, oxygen uptake, heart rate, lactate and perceived exertion were taken at set intervals during the time trial. Results indicated no substantial differences in any measured variables between caffeine and placebo conditions during the first 20-km of the time trial. Caffeine gum did however lead to substantial enhancements (mean ± 90% confidence limits (CLs)) in mean power during the final 10-km (3.8% ± 2.3%), and sprint power at 30-km (4.0% ± 3.6%). The increases in performance over the final 10-km were associated with small increases in heart rate and blood lactate (effect size of 0.24 and 0.28, respectively). There were large inter-individual variations in the response to caffeine, and apparent gender related differences in sprint performance. Chewing caffeine gum improves mean and sprint performance power in the final 10-km of a 30-km time trial in male and female cyclists most likely through an increase in nervous system activation.

Keywords: *ergogenic, sprint, time trial, lactate, heart rate*

Introduction

Caffeine is a substance that is frequently used by athletes as an ergogenic aid during training and competition (Graham, 2001). Previously published meta-analytical reviews by Doherty and Smith (2004) and more recently by Astorino and Robertson (2010) and Warren, Park, Maresca, McKibans, and Millard-stafford (2010) have clearly documented the performance enhancing effects of caffeine at various doses for both aerobic- and anaerobic-based sporting activities. There are several potential sites of action and proposed mechanisms underpinning caffeine's ergogenic effects. The proposed mechanisms responsible for caffeine's ergogenic effect include enhancements in free fatty acid oxidation, an increase in catecholamine concentration and glycolytic flux, and increases in central nervous system activation (see Graham, 2001; Davis & Green, 2009; for comprehensive mechanism reviews).

In the majority of studies, the effective dosage and method of caffeine administration is typically in the low-to-moderate 3–10 mg · kg^{-1} range via the oral ingestion of either tablets or capsules (Doherty & Smith, 2004). However, recently an alternative delivery method via caffeine encapsulated chewing gum has become more widely available, and may provide an advantage over traditional delivery methods. Caffeine in tablet form is normally ingested in the hours before exercise in order to allow sufficient absorption time through the hepatic system (Astorino & Roberson, 2010). However chewing caffeinated gum allows absorption directly into the blood stream via the buccal mucosa, thereby bypassing hepatic metabolism, potentially speeding up caffeine delivery and enhancing caffeine's bioavailability. A study by Kamimori et al. (2002) comparing identical doses of caffeine administered in traditional tablet form or via chewing gum reported similar levels of bioavailability for both delivery methods but a significantly faster absorption rate with the caffeinated chewing gum. Therefore, it is possible that caffeinated gum may prove beneficial in sporting events where athletes wish to mitigate the effects of accumulated fatigue and provide a rapid increase in performance such as at half-time during a football match or when preparing for a sprint finish

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in an endurance event. Indeed, a study by Paton, Lowe, and Irvine (2010), has reported that chewing caffeinated gum (~3 mg · kg^{-1}) allowed trained cyclists to rapidly offset fatigue and maintain exercise intensity during multiple repeated efforts of high-intensity sprint activity. Similarly, caffeinated chewing gum has also been shown to enhance longer duration steady state endurance performance with trained cyclists when administered just 5 min immediately prior to exercise (Ryan et al., 2013).

Despite the potential advantages of caffeine delivery via chewing gum, there remains little research into its efficacy with trained athletes. Further, to our knowledge there is little research on the effects of caffeinated gum with female athletes. Indeed, there are relatively few studies examining the effects of any type of caffeine administration with female athletes. One of the few studies (Anderson et al., 2000) investigating the effects of caffeine on females, reported small enhancements in 2000-meter rowing performance with competitive oarswomen, but only with higher doses (9 mg · kg^{-1}) of caffeine administered in tablet form. In a more recent study with females, Goldstein, Jacobs, Whitehurst, Penhollow, and Antonio (2010) reported small but significant increases in upper body 1-RM bench press, but not 60% 1-RM maximum repetitions with resistance trained females after supplementation with a moderate (6 mg · kg^{-1}) caffeine dose.

Given the limited published research investigating the effects of caffeinated chewing gum on performance the primary purpose of this study was to investigate the effects of caffeine, delivered via chewing gum, on measures of endurance and sprint performance in trained cyclists. Further supplementary aims of the study were to gain an understanding of any potential gender differences in caffeine's effect and to determine the likely time course of any observed ergogenic effect with caffeine chewing gum.

Methods

Design

The study was a placebo controlled, double-blind and balanced crossover trial. All cyclists gave their written informed consent to participate in the study that was approved by the participating institutes' human research ethic committee in accordance with the Declaration of Helsinki.

Participants

Twenty trained cyclists completed this study (mean ± *s*: weight, 69 ± 10 kg; height; 172 ± 7 cm; age 30 ± 10 years; maximum oxygen consumption, 4.2 ± 0.7 L · min^{-1}). The cohort consisted of 10 males (75 ± 8 kg; 177 ± 5 cm; 36 ± 10 years; 4.7 ± 0.4 L · min^{-1}) and 10 females (63 ± 7 kg; 168 ± 6 cm; 25 ± 7 years; 3.6 ± 0.5 L · min^{-1}) with a minimum of 2 years competitive experience. The male cohort was classified as performance level three (PL3) in accordance with the guidelines of De Pauw et al. (2013). All participants within the current study were familiar with standard laboratory testing procedures, having been previously involved in studies or routine physiological monitoring. The investigation was conducted in the summer months during the cyclists' competitive phase of the season. At the time of the study all cyclists were free from illness, involved in regular training patterns and were completing a minimum of 8 h per week of cycling specific training.

Dietary and menstrual control

A list of dietary caffeine sources including food, beverages and supplements, was given to each cyclist upon entry to the study. Pre-study questioning was used to confirm that all participants were habitually low-to-moderate (<300 mg per day) regular caffeine users. During the 48 h prior to any testing session, cyclists were instructed to prepare as though it were a real competition, and to abstain from caffeine consumption. Cyclists were also requested to keep a record of their dietary intake in the 24 h preceding the first experimental trial and replicate this for subsequent trials. For the female participants the experimental trials were performed during the follicular phase of their menstrual cycle.

Exercise performance tests

Cyclists reported to the laboratory on three separate occasions, over a 10–14-day period and with a minimum of 4 days between tests. All testing was conducted in an environmentally controlled laboratory (temperature 21 ± 1°C: relative humidity 36 ± 4%) on a calibrated Velotron Dynafit Pro cycle ergometer (RacerMate Inc., WA, USA) using the company's associated software package. During the initial visit to the laboratory, cyclists completed an incremental ramp test to exhaustion to determine their maximum oxygen consumption (VO_2 max). Thirty minutes after the incremental test, participants completed a familiarisation of the experimental trial procedure with no supplement regime in order to habituate them to the test protocols and measures. On a further two separate occasions each cyclist completed an experimental time trial with either caffeine or a placebo administered in a randomised balanced crossover design. Experimental sessions were conducted at the same time of day in order to control

for diurnal variation and were separated by 5–7 days. Cyclists were requested to prepare for each trial as if it was a true competition and to complete only light training in the 24 h preceding a session.

Maximal incremental exercise test

Initially the cycle ergometer was adjusted to a position that resembled the set-up of the participants own racing bicycle. The selected dimensions were recorded, and replicated for subsequent tests. Cyclists performed a 10-min warm-up at a self-selected intensity followed by 5 min at a fixed power of 75 W before commencing the incremental phase of the test. Thereafter, power output was increased continuously at a rate of 25 $W \cdot min^{-1}$ until the cyclist reached volitional exhaustion. All participants achieved minimum test duration of 8 min. During the incremental test, respiratory gases and heart rate were measured continuously with a calibrated metabolic system (Metamax, Cortex, Leipzig, Germany) using breath-by-breath recording mode; VO_2 max was subsequently defined as the highest VO_2 measured over any 30-s period during the test.

Performance sessions

Experimental sessions were performed on the same ergometer previously described using the manufacturers supplied 3-D software. Prior to each experimental trial, cyclists completed a 20 min prescribed warm-up. The warm-up consisted of two 5-min periods at a fixed workload of ~100 W separated by two repeated sets (5 min each) of varying intensity efforts (2-min at 2.5 $W \cdot kg^{-1}$, 2-min at 3.5 $W \cdot kg^{-1}$, and 1-min at 4.5 $W \cdot kg^{-1}$). All experimental trials commenced immediately at the end of the warm-up period with a 3-s countdown. The experimental trials required cyclists to complete three laps of a computer simulated 10-km course for a total of 30-km; during the last 0.2 km of each lap cyclists were required to perform a maximal effort sprint (~15 s duration). Each 10-km lap consisted of flat and undulating sections in order to better replicate a real race situation. Studies from our laboratory (unpublished observations) indicate a high reliability for this test with a coefficient of variation of ~1% for time and ~2% for power output. The three laps were performed consecutively with no rest periods between. Participants were able to view their progress over the course on a computer monitor and were provided with information on distance completed and gear selected; all other information was blinded to remove any potential pacing effect. Participants were requested to complete each time trial as quickly as possible with no restriction on gear selection, cadence or cycling posture (seated or standing). Participants were not restricted to a set pacing strategy and were not coached on how to best ride the course. During each trial, individual measures of perceived exertion (RPE 6–20 scale) and blood lactate [La] were obtained at each 5 km. Oxygen consumption and heart rate were measured from the 5.5–9-km distance on each lap. Whole blood samples were taken from the participant's earlobe and immediately assayed for lactate concentration using a calibrated automated system (YSI 1500, Yellow Springs, OH, USA). Throughout the experimental sessions, cyclists were cooled with standing floor fans and permitted to drink plain water only *ad libitum*. A diagram depicting the 10-km lap along with indicative physiological sampling periods is shown in Figure 1.

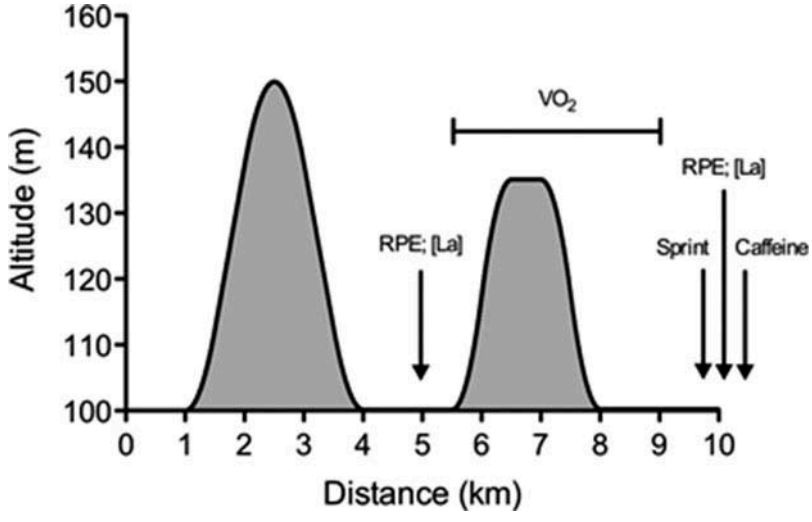

Figure 1. One lap course profile (10 km) for the simulated race performance, showing the sample points. Caffeine was administered via chewing gum at the end of the first lap.

Caffeine administration

Immediately following the first maximal sprint at 10 km, cyclists received either the placebo or caffeine treatment. Caffeine was administered as an absolute dose of either two pieces (200 mg), or three pieces (300 mg) of a commercially available chewing gum (Stay Alert, Ford Gum & Machine Co, New York, USA) for females and males respectively; this absolute doses provided an equivalent dose for each participant of ~3–4 mg · kg^{-1}. The placebo was a similar tasting commercially available non-caffeinated chewing gum (PK gum, Wrigley's, Chicago, USA). Both chewing gums were dissected into small pieces and placed in an opaque container in order to aid blind delivery from the cyclist and the supervising experimenter. Cyclists chewed the gum for 5 min and were then required to expectorate the chewed gum into a tissue. Verbal questioning post testing sessions indicated that athletes were unable to distinguish between the caffeine and non-caffeine-containing chewing gums (odds no greater than chance or 50:50).

Statistical analysis

Simple descriptive statistics are shown as means ± between-participant standard deviation (*s*). The means of the two perceived exertion and blood lactate measure for each 10-km lap were used for subsequent analysis. Mean effects of caffeine on performance and physiological measures, and their 90% CL were estimated with a made-for-purpose spreadsheet (Hopkins, 2006) via the unequal-variances *t*-statistic computed for change scores between the caffeine and placebo conditions. Power measures were log transformed to reduce bias arising from non-uniformity of error and back transformed to obtain changes in means as percents. The spreadsheet also computes chances that the true effects are substantial, when a value for the smallest worthwhile change is entered. We used a value of 1% for the performance power measures, as previous research has shown that this value represents the smallest worthwhile enhancement in power for cyclists competing in time-trial events Paton and Hopkins (2006). To date, no research has established how percentage changes in physiological measures would translate directly to percentage changes in cycling performance, so therefore we interpreted changes in our physiological measures using standardised effects (ES) (the change in mean divided by the between participant *s*). Effects of caffeine on physiological measures were analysed in raw units and magnitudes of the ES are reported and interpreted using the effect thresholds of 0.2, 0.5 and 0.8 for small, moderate and large effects, respectively, in accordance with the recommendations of Cohen (1986). Effect size values <0.2 were considered trivial differences. Analysis of all performance and physiological measures was performed primarily for the entire group. We also completed a secondary analysis for males and female cohorts separately using gender as a covariate.

Results

The mean (± *s*) performance and physiological measures of all participants, recorded for each 10-km lap of the simulated race are shown in Table I. There were no substantial differences in either performance or physiological measures between placebo or caffeine treatments over the first 20 km (2 laps). There were small (~4%) but practically worthwhile increases in mean and sprint power output over the final 10 km (lap 3). The increases in performance power during the final lap were accompanied by small increases in heart rate (ES = 0.24) and blood lactate concentration

Table I. Performance and physiological measures (Mean ± *s*) during each 10-km lap of the 30-km cycling time trial for all participants (n = 20).

Treatment	Placebo			Caffeine		
Lap	1	2	3	1	2	3
Mean power (W)	258 ± 58	240 ± 54	239 ± 55	259 ± 60	241 ± 54	247 ± 52
Sprint power (W)	419 ± 84	415 ± 100	402 ± 91	425 ± 100	411 ± 87	419 ± 98
Time (s)	1056 ± 126	1119 ± 123	1126 ± 131	1049 ± 129	1120 ± 128	1105 ± 115
VO_2 (L · min^{-1})	3.55 ± 0.74	3.44 ± 0.72	3.38 ± 0.70	3.56 ± 0.75	3.44 ± 0.70	3.44 ± 0.65
RER	0.93 ± 0.04	0.92 ± 0.03	0.92 ± 0.03	0.94 ± 0.03	0.92 ± 0.03	0.93 ± 0.04
HR (bpm)	159 ± 10	163 ± 9	164 ± 10	158 ± 9	163 ± 9	166 ± 9*
[La] (mmol · l^{-1})	4.7 ± 2.2	4.4 ± 2.0	4.7 ± 2.2	4.8 ± 2.4	4.5 ± 2.4	5.2 ± 2.3*
RPE (6–20)	15 ± 1	16 ± 1	17 ± 1	15 ± 1	16 ± 1	17 ± 1

Notes: VO_2: oxygen uptake; RER: respiratory exchange ratio; HR: heart rate; [La]: blood lactate; RPE: rating of perceived exertion.

*Small effect (ES ~0.2) relative to placebo condition.

(ES = 0.28). Blood lactate concentrations during the final lap were also marginally greater for the males (ES = 0.34) than the females (ES = 0.21). Changes in all other physiological measures for the whole group, and male and female cohorts separately, over the final lap were all trivial (ES < 0.2).

The percentage change (mean ± 90% CL) in mean and sprint power for each 10-km lap for the caffeine trial (relative to placebo) is shown in Figure 2. The main finding for power output was that following caffeine treatment, cyclists showed increases in both mean (3.8 ± 2.3%) and sprint power (4.0 ± 3.6%) during the final 10-km lap. Separate analysis based on gender as a covariate (not shown in figure) revealed similar increases in mean power of 3.2 ± 3.0% and 4.3 ± 3.4% for males and females, respectively, during the final 10-km lap. For sprint power, separate gender analysis showed larger increases for males (6.2 ± 5.2%) compared to females (1.9 ± 5.0%).

Discussion

The main aim of this study was to determine the effects of caffeinated chewing gum on characteristics of performance and physiology during a simulated race with trained cyclists. To our knowledge, this study is the first to assess caffeinated chewing gum effects on both aerobic endurance and anaerobic sprint based performance measures within a single test. The key study finding was that a moderate caffeine dose of ~3–4 mg · kg^{-1} enhanced both endurance (>5 min) and sprint power output (<30 s) by similar amounts (~4%) during the final 10 km of a 30-km race in our mixed gender group.

The magnitude of performance enhancement in endurance power we report over the last 10 km is consistent with the findings of a study by Jenkins, Trilk, Singhal, O'Connor, and Cureton (2008) who reported a 3–4% performance enhancement during a fixed 15 min time trial following a similar (2–3 mg · kg^{-1}) orally ingested caffeine supplementation

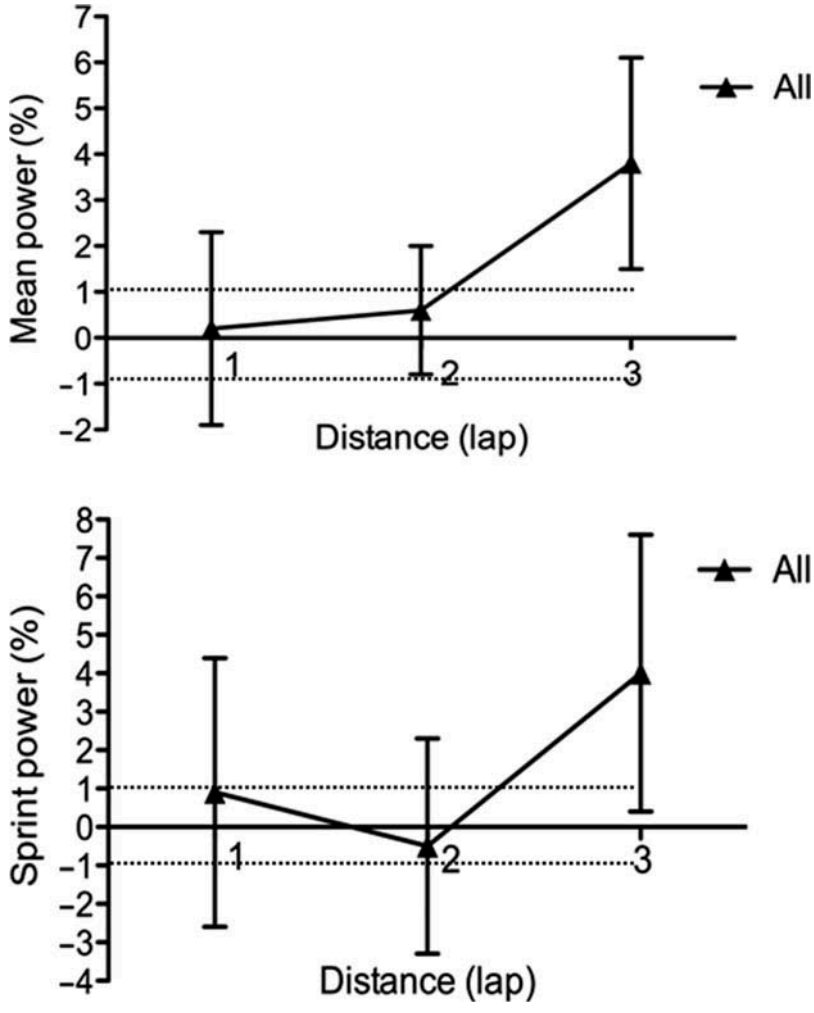

Figure 2. Mean (± 90% confidence limits) percentage change in performance for mean and sprint power over the three laps of the simulated race performance (change is caffeine relative to placebo condition). Dashed line indicates the smallest practical worthwhile effect of 1%.

regime. However, unlike their study that was performed with only male cyclists, we have the uniqueness of the inclusion of separate analyses for both males and females; with respect to gender we found no substantial difference in caffeine gums effect on mean power between males (~3%) and females (~4%).

Like the enhancements in endurance power, we also found substantial increases in the final sprint performance following caffeine supplementation. Original investigations into the effects of caffeine during short-term anaerobic activities are scarce; however, in a similar study also using caffeinated chewing gum, Paton et al. (2010) reported enhancements in repeated 30-s sprint performance of ~6% with male competitive cyclists of similar ability to the males in the current study. The magnitude of enhancements in sprint performance in the current study is also consistent with that reported in a recent systematic review of previous high-intensity studies by Astorino and Roberson (2010). Astorino and Roberson (2010) reported a mean increase in performance of ~6% over a range of short-term anaerobic activities following caffeine ingestion. The ~6% enhancements reported in previous studies is somewhat larger than the 4% we report in our study; however, it is possible that this difference may have been caused by the inclusion of the aerobic phase prior to the sprint and also the mixed gender of our sample. A separate analysis of males and females revealed that there was a substantially larger enhancement in sprint power for the male cyclists (~6%) compared to the female cyclists (~2%). The larger enhancement for the males was clear (in respect to CLs) and is similar in magnitude to that reported in previous studies, which were coincidently almost exclusively performed with male participants. Further evidential support for the possibility of a smaller response to caffeine in high-intensity activities with females comes from the studies of Anderson et al. (2000) and more recently Goldstein et al. (2010), who reported only small improvements in rowing (~1%) and weightlifting (~1.5%) activities, respectively, for females despite using much higher doses (6–9 mg · kg^{-1}) of caffeine compared to the current study. Therefore, there appears to be the possibility of a gender-based difference in the response to caffeine at least with respect to high-intensity anaerobic measures. Unfortunately, it was not possible to categorically ascertain a clear gender difference in our study due to the large inter-individual responses and small sample size; to clarify such gender difference a study with a much larger sample would be required. We know of no studies that have actually compared the performance responses to caffeine between genders, so the reasons for any differences in sprint performance remains unexplained and warrants further investigative studies.

Consistent with the findings of Jenkins et al. (2008), we also found large inter-individual responses to the effects of caffeine in both male and female cyclists. In our current study, 13 (65%) of the cyclists were considered to be positive responders while 5 (20%) of the cyclists experienced negative responses, the remaining 2 (15%) cyclists experienced no observable effect on cycling performance. The reason for such large individual responsible is yet to be established but may be related to differences in the rate of caffeine metabolism or absorption between individuals. Another possible reason for the individual responses in the current study could be the fact that participants did not receive identical caffeine doses. Unfortunately, due to the nature of the caffeine delivery used in the study, it would be difficult to provide exact doses as the caffeine in chewing gum is unlikely to be distributed evenly throughout the product. However, we believe that as the differences in caffeine dose within a gender group were small (<1 mg · kg^{-1}) this is unlikely to have had a substantial effect on the results.

The increase in endurance performance over the final 10-km lap was accompanied by small (ES ~0.2) increases in mean heart rate and blood lactate concentration, and trivial (ES <0.2) increases in oxygen consumption and respiratory exchange ratio. Interestingly, separate gender analysis revealed that the male participants experienced a larger (ES 0.31) increase in blood lactate concentration than females (0.21); this finding is likely related to the greater enhancement in sprint performance seen in the male cyclists. A small increase in these physiological variables is perhaps unsurprising and most likely simply a consequence of the increase in mean power of the participants over the final lap. However, despite the increases in power and physiological variable there was no increase (ES = 0.04) in the participants rating of perceived exertion. The lack of an increase in perceived exertion coupled with only trivial changes in respiratory exchange ratio leads us to speculate that neural rather than metabolic factors are the most likely mechanism responsible for the performance enhancements in our study. A likely explanation for the enhanced performance is an increase in central nervous system activation caused by the inhibition of adenosine receptors in the brain. An increase in adenosine caused by intense exercise has been shown to increase pain perception, reduce arousal and depress motor activity (Davis & Green, 2009). However, caffeine is similar in structure to

adenosine and as it is lipophilic, it easily crosses the blood–brain barrier and binds with adenosine receptors. A reduction in adenosine receptor activity due to caffeine could therefore result in greater motor unit recruitment, thereby enhancing power output whilst reducing the perception of effort (Doherty, Smith, Hughes, & Davison, 2004).

A further aim of our study design was to assess the potential time course of caffeinated chewing gums effects. In this study, caffeine or placebo was administered following the completion of the first 10-km lap; this design has two benefits. First, it allows a relative control between placebo and control conditions ensuring that no extraneous variable other than the treatment can account for performance changes. Second, the administration of caffeine during a trial allows an analysis of the likely time course of caffeine's action that is not possible in studies where caffeine is administered before the commencement of the trial. Our results indicate that performance power during the first 10-km lap was not substantially different between the control and placebo conditions, providing confidence that any subsequent effects are due to the caffeine treatment only. Caffeine (or placebo) was then administered at the end of the first lap for approximately 5 min. Whilst we would expect caffeine delivered via chewing gum to have a more rapid effect than tablets, our results show no meaningful effect of caffeine on endurance or sprint power during the second lap. Clear effects on performance were only observed during the final lap. As the average time per lap was ~18 min we can tentatively suggest that this is therefore the approximate time required for caffeinated gum to show its potential ergogenic effects; however, to substantiate this a more elaborate timing study would be required. Interestingly, the results from a recent study (Ryan et al., 2013) showed positive ergogenic effects on time-trial performance with caffeine chewing gum but only when it was administered immediately prior to exercise and not in the 1–2 h periods pre-exercise as is normal with caffeine administered in tablet form.

Conclusions

In conclusion, the results of this study show that a moderate dose (~3–4 mg · kg^{-1}) of caffeine administered via chewing gum can improve both endurance and sprint performance by a similar magnitude (~4%) during the latter stages of a simulated cycling race. The improvements in aerobic endurance power appear to be similar in both males and females though males appear to experience a much larger increase in anaerobic sprint power. Caffeine chewing gum appears to quickly exert its ergogenic properties and certainly within 20 min of initial ingestion. The mechanism for the actions of caffeinated gum appears to be by direct effect on the central nervous system, possibly via increasing central nervous system activity. Future studies are advised to further examine the potential differences in the responses to caffeine between genders and elucidate the time course of the ergogenic effects of caffeine chewing gum.

Conflict of interest statement

The authors have no known conflict of interest with this study or its results and do not endorse any commercially available product used in this investigation.

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