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1 **The effect of caffeine mouth rinse on self paced cycling performance**

2

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24

25 **Abstract**

26 The aim of the study was to determine whether caffeine mouth rinse would improve 30
27 minutes self-paced cycling trial. Twelve healthy active males (age 20.5 ± 0.7 yrs, mass 87.4
28 ± 18.3 kg) volunteered for the study. They attended the laboratory on 3 separate occasions
29 performing a 30 minute self-paced cycling trial. On one occasion water was given as a
30 mouth rinse for 5 s (PLA), on another occasion a 6.4% CHO solution was given for 5 s and
31 finally a caffeine solution (containing 32 mg of caffeine dissolved in 125ml water; CAF) was
32 given for 5s. Distance cycled, heart rate, ratings of perceived exertion, cadence, speed and
33 power output were recorded throughout all trials. Distance cycled during the CAF mouth
34 rinse trial (16.2 ± 2.8 km) was significantly greater compared to PLA trial (14.9 ± 2.6 km).
35 There was no difference between CHO and CAF trials ($P=0.89$). Cadence, power and
36 velocity were significantly greater during the CAF trial compared to both PLA and CHO
37 ($P<0.05$). There were no differences between trials for HR and RPE ($P>0.05$). Caffeine
38 mouth rinse improves 30 minute cycling performance by allowing the participant to increase
39 cadence, power and velocity without a concurrent increase in perceived exertion and heart
40 rate.

41

42 **Key words:** carbohydrate, oral receptors, ergogenic

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44

45

46 Introduction

47 Caffeine has been unequivocally shown to improve cycling endurance performance either by
48 prolonging time to exhaustion (Graham *et al.*, 1998; Van Soeren & Graham, 1998) or by
49 decreasing time to complete set distances (Bridge & Jones, 2006). In fact, very few research
50 studies have found caffeine to have no effect on aerobic performance (Roelands *et al.*, 2011).
51 Although caffeine has been shown to improve endurance performance, the exact mechanism
52 by which this is achieved remains unknown. Caffeine has been found to counter the effects
53 of adenosine, which is a compound similar to caffeine (Davis & Green, 2009). As such,
54 caffeine is believed to enhance motor unit recruitment, bronchodilation, vasodilation, arousal,
55 neuro-excitability, catecholamine secretion, lipolysis, plus reduce sleep and pain perception
56 (Astorino & Roberson, 2010; Beck *et al.*, 2008; Hendrix *et al.*, 2010; Hudson *et al.*, 2008;
57 Sokmen *et al.*, 2008; Warren *et al.*, 2010; Woolf *et al.*, 2008).

58 The dampened pain perception causes an ergogenic effect on performance, via greater
59 exercise duration (Beck *et al.*, 2008; Bruce *et al.*, 2000). Davis & Green (2009) propose that
60 performance decrements correlate with increases in muscle pain and a reduction in motor unit
61 recruitment. However, Sokmen *et al.* (2008), Davis & Green, 2009 and Warren *et al.* (2010)
62 advocate that pain perception does not influence muscular performance; rather,
63 improvements in performance are mediated through maintenance of the Na⁺/K⁺ gradient and
64 increases in calcium ions allowing more forceful contractions to occur and preventing plasma
65 K⁺ to rise. Caffeine also promotes the release of calcium ions from the sarcoplasmic
66 reticulum, which ultimately allows more muscular contractions to take place, increasing
67 strength and muscular endurance (Bellar *et al.*, 2011; Jacobson *et al.*, 1992; Warren *et al.*,
68 2010). Conversely, Davis & Green (2009) state that the concentrations of caffeine required to
69 elicit this effect on the sarcoplasmic reticulum would be toxic to humans. In a recent review
70 by Meeusen *et al.* (2013) they suggest that the main mechanism of action of caffeine is
71 through antagonism of adenosine receptors, influencing the dopaminergic and other
72 neurotransmitter systems. Adenosine and dopamine act on the brain and can influence
73 factors such as motivation (Meeusen *et al.*, 2013) and therefore this may be a large factor in
74 the improvement of endurance performance with caffeine ingestion.

75 Previous research has shown that the optimum time for complete caffeine absorption is
76 between 15 and 120 minutes post ingestion (Blanchard & Sawers, 1983; Bonati *et al.*, 1982;
77 Kamimori *et al.*, 1995; Kamimori *et al.*, 2000) therefore researchers have often tested
78 performance 1 hour post ingestion (Ryan *et al.*, 2013). However, research has shown that
79 absorption at the mouth is much more rapid and can produce quicker response to caffeine
80 ingestion than capsule ingestion (Kamimori *et al.*, 2002). This observation led researchers to
81 use caffeine chewing gum to improve cycling performance with positive effects (Ryan *et al.*,
82 2013; Paton *et al.*, 2010). Caffeine can be absorbed through the buccal mucoa and therefore
83 does not appear to require ingestion in order to produce ergogenic benefits (Nicolazzo *et al.*,
84 2003; Thakur *et al.*, 2007). Caffeine could then potentially increase performance by
85 decreasing perceived exertion and reducing pain perception as mentioned previously as
86 potential mechanisms for the ergogenic effect. Other mechanisms require a longer period of
87 time for absorption therefore performance improvements are most likely pain perception and
88 perceived exertion.

89 Carbohydrate mouth rinsing has been shown to improve high intensity cycling performance
90 (Sinclair *et al.*, 2014; Chambers *et al.*, 2009; Pottier *et al.*, 2010; Rollo *et al.*, 2008) and is
91 thought to improve performance through carbohydrate mouth receptors which control central

92 mechanisms associated with motivation (Chambers *et al.*, 2009). As the presence of caffeine
93 receptors in the oral cavity is now established it could be hypothesised that a caffeine mouth
94 rinse will also improve self paced cycling performance. Recent work by Beaven *et al.* (2013)
95 has shown that a 1.2% caffeine mouth rinse solution improved repeated sprint performance
96 which further supports the notion that caffeine mouth rinsing could improve high intensity
97 cycling performance. However, more recent work of Doering *et al.* (2014) observed no
98 improvements in time trial cycling performance when mouth rinsing 35mg of caffeine for
99 10s, nor was there an increase in plasma caffeine concentrations. These conflicting results
100 show that further research is needed. Therefore the aim of the current investigation was to
101 determine whether caffeine mouth rinse improves 30 minute cycling time trial performance
102 and whether there is a difference compared to a carbohydrate mouth rinse.

103

104 **Materials and Methods**

105 *Participants*

106 Twelve male participants (age 20.5 ±0.7 yrs, height 170.5 ±18.8 cm, mass 87.4 ±18.3 kg)
107 were recruited for this investigation. Participants were recreationally trained cyclists and free
108 from musculoskeletal pathology at the time of data collection. All participants also provided
109 written informed consent. The procedure utilised for this investigation was approved by the
110 University of Central Lancashire, School of Sport Tourism and Outdoors, ethical committee.

111

112 *Procedure*

113 Data collection involved four laboratory sessions. Participants were familiarized with the
114 experimental procedure in session 1, whereas sessions 2-4 were utilized for data collection.
115 Participants completed 30 minute simulated time trials for maximum distance using a cycle
116 ergometer (Monark Ergomedic 874E, Monark Exercise, AB, Varberg, Sweden). For sessions
117 2-4 in which experimental data was collected participants were administered either 25ml of a
118 tasteless 6.4 % maltodextrin (Maltodextrin, My Protein) solution (CHO), 0.032 % caffeine
119 (My Protein; this was selected as being the concentration of caffeine found typically in
120 commercially available caffeinated drinks) solution (CAF) or a water bolus (PLA) which
121 were rinsed for 5s at each 6 minute interval of the cycling time trial in accordance with the
122 overall time intervals utilised by Sinclair *et al.* (2014). This study utilized a blinded
123 counterbalanced design, and each session was separated by 7 days.

124

125 *Visit 1*

126 This session represented a familiarization visit during which participants completed a 30 min
127 time-trial in the same manner as the experimental conditions. From this session ergonomic
128 aspects such as seat height and ergometer resistance could be obtained and maintained during
129 data collection. In accordance with Sinclair *et al.* (2014) a resistance of 2.0 kg was selected
130 which was deemed to be adequate and achievable for all participants at a cadence of 60
131 revs.min⁻¹.

132 *Visits 2-4*

133 Participants were examined 4 hours post prandial and had not consumed any alcohol/ caffeine
134 or conducted any vigorous exercise in previous 24 hours prior to the commencement of data

135 collection. Immediately preceding data collection all participants were fitted with a heart rate
136 monitor (Polar RS100, Polar Electro), and then asked to position themselves in a comfortable
137 position on the cycle ergometer. Prior to the data collection procedure a standardized warm-
138 up was conducted which consisted of 5 min of cycling using a resistance of 50 W in
139 agreement with the warm up protocol utilized by Sinclair *et al.* (2014) for the same protocol.
140 Data collection was conducted at the same time of day to avoid natural fluctuations in
141 physiological parameters due to variations in circadian rhythmicity.

142

143 The cycling ergometer was connected to a computer using Monark software (Varberg,
144 Sweden) in which the outcome measures of heart rate (HR), cadence ($\text{rev}\cdot\text{min}^{-1}$), power
145 output (W) and distance covered (km) were obtained at 6 min intervals throughout the trials.
146 In addition, participants were also required to state their perceived exertion (RPE) using the 6
147 to 20 point Borg scale (Borg, 1982) also at 6 min intervals. No interaction beyond requests
148 for RPE and administration of the appropriate mouth rinse occurred between researchers and
149 participants.

150

151 *Mouth rinse administration*

152 Each participant was given a 25 ml bolus of a tasteless CHO, CAF or PLA for every 6 min of
153 the total protocol. Participants rinsed the fluid around their mouths for 5s, and then spat the
154 fluid back into a bowl.

155 *Statistical analyses*

156 Descriptive statistics of means \pm standard deviation were obtained for each condition. To
157 compare total distance covered using the three solutions during the 30 min protocol a one-
158 way repeated measures ANOVA was conducted. To examine any effects of mouth rinse on
159 pacing, HR and RPE 5 x 3 (time x trial) repeated measures ANOVA's were also conducted
160 Statistical significance was accepted at the $p \leq 0.05$ level. If the sphericity assumption was
161 violated then the degrees of freedom were adjusted using the Greenhouse–Geisser correction.
162 Effect sizes were calculated using and η^2 (η^2). All statistical procedures were conducted
163 using SPSS v20.0 (SPSS Inc., Chicago, IL, USA).

164

165 **Results**

166 *Distance cycled:*

167 @@@ **FIGURE I NEAR HERE** @@@ Figure I: Mean (\pm SD) distance completed in 30
168 minutes during each condition (n=12). * denotes significant difference from PLA.

169

170 There was a main effect for distance ($P < .01$, $\eta^2 = .51$). Distance cycled during the CAF
171 mouth rinse trial (16.2 ± 2.8 km) was significantly greater compared to the PLA trial (14.9
172 ± 2.6 km; $P < .01$) (Figure I). Distance cycled during the CHO trial (15.9 ± 2.9 km) was also
173 significantly greater than the PLA trial ($P = .03$). There was no significant difference between
174 CAF and CHO ($P = .90$). However, 10 out of 12 participants cycled further during the CAF
175 trial compared to CHO, and 11 cycled further during the CAF trial compared to the PLA.

176

177 *Pacing:*

178 Table I: Mean (\pm SD) overall values for HR, RPE, cadence, power and speed for each
179 condition (n=12).

Mean (\pm SD)	Placebo	CHO	CAF
Cadence (RPM)	72.3 \pm 12.5	77.0 \pm 13.7*	77.6 \pm 13.6*
Speed (km.h⁻¹)	30.0 \pm 5.4	32.3 \pm 5.6*	32.3 \pm 5.9*
Power Output (W)	145.3 \pm 23.5	153.3 \pm 29.0	155.2 \pm 27.5*
Heart Rate (beats.min⁻¹)	160 \pm 26	162 \pm 24	156 \pm 24
RPE (Borg Scale)	13 \pm 1	13 \pm 2	13 \pm 2

180 *denotes significant difference from placebo.

181 Table I illustrates the mean overall values for each rinse condition. As can be seen in Figure
182 IIa, there was a main effect for time for cadence ($P<.01$, $\eta^2= .49$) with post hoc analysis
183 showing cadence being significantly greater during the last 6 minutes of the trial ($P=.04$).
184 There was a main effect for trial, therefore mouth rinse had an effect on cadence ($P=.01$, $\eta^2=$
185 $.34$), with CAF (80 ± 17 rev.min⁻¹) producing a significantly greater cadence than PLA (74
186 ± 17 rev.min⁻¹; $P=.03$) with no difference to CHO (77 ± 17 rev.min⁻¹; $P=.65$). Speed also
187 increased during the last 6 minutes of the trial (main effect for time; $P<.01$, $\eta^2= .40$). There
188 was a main effect for trial ($P=.02$, $\eta^2= .29$) with CAF mouth rinse producing a significantly
189 greater speed (35.1 ± 8.3 km.hr⁻¹) than PLA (31.1 ± 7.6 km.hr⁻¹; $P<.01$; Figure IIb). There was
190 no difference between CAF and CHO ($P=.57$) and between CHO and PLA ($P=.10$). There
191 was a main effect for time ($P<.01$, $\eta^2= .49$) with power being greater during the last 6
192 minutes of the trial ($P=.03$). There was also an effect of trial ($P=0.01$, $\eta^2= .34$) with CAF
193 producing the greatest power output (161 ± 34 W) compared to PLA (148 ± 33 W; $P<.01$).

194

195 @@@ **FIGURE II NEAR HERE**@@@ Figure II: Mean (\pm SD) cadence (a) and speed (b)
196 during the 30 minute exercise for each condition (n=12).

197

198 *Heart rate and RPE*

199 HR increased throughout all trials with a main effect for time ($P=.00$, $\eta^2= .79$; Figure III)
200 averaging at 160 ± 26 , 162 ± 24 and 156 ± 24 beats.min⁻¹ for PLA, CHO and CAF respectively
201 (Table I). There were no differences between trials ($P=0.15$, $\eta^2= .16$). RPE increased with
202 exercise duration with a main effect for time ($P<0.01$, $\eta^2= .93$). There was also no difference
203 between trials ($P=0.65$, $\eta^2= .04$; Table I).

204

205 @@@ **FIGURE III NEAR HERE**@@@ Figure III: Mean (\pm SD) heart rate (a) and RPE (b)
206 during 30 minute exercise in each condition (n=12).

207

208 *Blinding efficacy*

209 For the CAF rinse trial 5 out of 12 participants correctly identified that they were on a
210 performance enhancing solution, for the CHO rinse trial 5 out of 12 identified the
211 performance enhancing solution. Finally 7 out of 12 guessed the placebo solution correctly.
212

213 **Discussion**

214 The aim of the current study was to determine whether caffeine mouth rinse improved 30
215 minute cycling time trial performance and whether there was a difference compared to a
216 CHO mouth rinse. This study **represents only the second study** to examine the ergogenic
217 effect of caffeine mouth rinsing on cycling time trial performance.

218

219 The results demonstrated both caffeine and CHO mouth rinse increased distance cycled
220 during 30 minutes of self-selected paced cycling. This supports previous observations in that
221 carbohydrate mouth rinse improved high intensity performance (Sinclair *et al.*, 2014;
222 Chambers *et al.*, 2009; Pottier *et al.*, 2010; Rollo *et al.*, 2008). The results also support those
223 of Beaven *et al.* (2013) who found 1.2% caffeine mouth rinse improved repeated sprint
224 performance. **However, the results conflicted with Doering et al. (2014) who found no**
225 **improvement in cycling time trial performance with caffeine mouth rinse. These are the only**
226 **previous research to have investigated caffeine mouth rinse on exercise performance.**

227

228 Beaven *et al.* (2013) **demonstrated that 1.2%** caffeine mouth rinse improved repeated sprint
229 performance. The present study examined a 0.032% caffeine solution as this is the quantity
230 commonly found in commercially available caffeinated drinks. Studies investigating the
231 effect of caffeine chewing gum on exercise performance (Ryan *et al.*, 2013; Paton *et al.*,
232 2010) used similar quantities (300mg and 240mg respectively) to that of the present study
233 (128mg). Unfortunately, the different mode of exercise and the concentrations of caffeine
234 make cross comparisons between these studies difficult. However, it is recommended that
235 future research could be performed to determine whether there is a dose response to
236 performance. Since caffeine is absorbed through the buccal mucosa (Nicolazzo *et al.*, 2003;
237 Thakur *et al.*, 2007) it could be hypothesized that absorption is positively correlated with the
238 concentration of caffeine that is present in the rinse solution which would produce and
239 enhanced ergogenic effect. **However, as previously mentioned Doering et al. (2014)**
240 **observed no increases in plasma caffeine concentrations, so may be mouth rinsing will not**
241 **produce a dose response due to absorption. The ergogenic effect could be due to receptors**
242 **detecting caffeine in the mouth, rather than absorption similar to CHO rinsing. Recent**
243 **research by Sinclair et al. (2014) demonstrated that 10 second CHO mouth rinse produced a**
244 **greater performance enhancement than 5 seconds. This could be similar for caffeine mouth**
245 **rinse suggesting that more caffeine activates more receptors in the mouth the longer the**
246 **mouth rinse.**

247

248 The mechanism of action of caffeine is most likely to be adenosine antagonism (Meeusen *et al.*, 2013). This then influences the dopaminergic and other neurotransmitter systems. In the
249 *al.*, 2013). This then influences the dopaminergic and other neurotransmitter systems. In the
250 present study there was no differences observed in RPE between trials, even though distance
251 covered was greater during the caffeine trial as was power, speed and cadence. This
252 suggests that the participants were able to perform at a greater intensity at a similar RPE,
253 indicating that there was an increase in motivation with caffeine ingestion. The increase in
254 motivation is thought to be a result of adenosine and dopamine acting on the brain following
255 antagonism of the adenosine receptors (Meeusen *et al.*, 2013). Improvement in performance
256 may also be a result of a reduction in pain perception which is also thought to be one of
257 caffeine's' ergogenic benefits (Davis & Green, 2009). Chambers *et al.* (2009) investigated
258 functional magnetic resonance imaging (fMRI) during carbohydrate mouth rinsing and
259 determined that a CHO mouth rinse enhanced motivation and activity of motor control
260 centres of the brain. It would of interests to both physiological and neurological populations
261 to repeat this study using a caffeine mouth rinse to determine whether similar areas of the
262 brain were stimulated.

263

264 The key practical implication of this research is that athletes/active individuals involved in
265 moderate to high intensity exercise can use CHO and CAF mouths rinses instead of ingesting
266 these solutions and still achieve meaningful physiological benefits. It appears based on the
267 current findings that a CAF mouth rinse will mediate greater ergogenic improvements in
268 comparison to CHO; combining the two may improve performance to a greater extent as
269 suggested by Beaven *et al.* (2013). Furthermore, the ingestion of both CAF and CHO has
270 been associated with gastrointestinal distress during high intensity exercise as such the
271 observations from the current investigation may have implications for the reduction of
272 discomfort during exercise as rinsing the solution around the mouth does not require
273 ingestion but still appears to provide ergogenic benefits.

274

275 In conclusion, the current investigation provides an addition to the current knowledge
276 regarding the influence of both CHO and CAF mouth rinse on exercise performance and
277 provides evidence to suggest that both CHO and CAF rinse can improve moderate to high
278 intensity cycling performance. The underlying mechanisms behind these improvements in
279 performance with the absence of solution ingestion remain undetermined currently and future
280 work is required to determine the physiological processes that produce these performance
281 enhancements. Nonetheless, this study shows that athletes performing in short duration
282 cycling events could improve their overall performance by a CHO of CAF mouth rinse.

283

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