

Effects of caffeine and carbohydrate mouth rinses on repeated sprint performance

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Abstract: Our purpose was to examine the effectiveness of carbohydrate and caffeine mouth rinses in enhancing repeated sprint ability. Previously, studies have shown that a carbohydrate mouth rinse (without ingestion) has beneficial effects on endurance performance that are related to changes in brain activity. Caffeine ingestion has also demonstrated positive effects on sprint performance. However, the effects of carbohydrate or caffeine mouth rinses on intermittent sprints have not been examined previously. Twelve males performed 5 × 6-s sprints interspersed with 24 s of active recovery on a cycle ergometer. Twenty-five milliliters of either a noncaloric placebo, a 6% glucose, or a 1.2% caffeine solution was rinsed in the mouth for 5 s prior to each sprint in a double-blinded and balanced cross-over design. Postexercise maximal heart rate and perceived exertion were recorded, along with power measures. A second experiment compared a combined caffeine-carbohydrate rinse with carbohydrate only. Compared with the placebo mouth rinse, carbohydrate substantially increased peak power in sprint 1 (22.1 ± 19.5 W; Cohen's effect size (ES), 0.81), and both caffeine (26.9 ± 26.9 W; ES, 0.71) and carbohydrate (39.1 ± 25.8 W; ES, 1.08) improved mean power in sprint 1. Experiment 2 demonstrated that a combination of caffeine and carbohydrate improved sprint 1 power production compared with carbohydrate alone (36.0 ± 37.3 W; ES, 0.81). We conclude that carbohydrate and (or) caffeine mouth rinses may rapidly enhance power production, which could have benefits for specific short sprint exercise performance. The ability of a mouth-rinse intervention to rapidly improve maximal exercise performance in the absence of fatigue suggests a central mechanism.

Key words: mouth wash, fatigue, power, cycle sprints.

Résumé : Cette étude se propose d'analyser l'efficacité de rince-bouche contenant du sucre ou de la caféine dans l'amélioration de la capacité à reprendre des sprints. Antérieurement, on a attribué à des modifications de l'activité cérébrale les effets bénéfiques d'un rince-bouche contenant du sucre (sans ingestion) sur la performance en endurance. On a aussi démontré l'effet positif de la consommation de caféine sur la performance au sprint. Toutefois, il n'y a pas d'études sur les effets de rince-bouche contenant du sucre ou de la caféine sur les sprints intermittents. Douze hommes effectuent 5 sprints de 6 s intercalés chacun par 24 s de récupération active sur un cycloergomètre. Selon un plan croisé contrebalancé à double insu, on demande aux sujets de se rincer la bouche, 5 s avant chaque sprint, avec 25 mL d'une solution contenant soit un placebo sans calories, 6 % de glucose ou 1,2 % de caféine. En plus des mesures de puissance, on évalue après la fin de l'exercice la fréquence cardiaque maximale et la perception de l'intensité de l'effort. Dans une deuxième expérimentation, on compare le rince-bouche contenant le sucre et la caféine au rince-bouche ne contenant que du sucre. Comparativement au rince-bouche placebo, le rince-bouche contenant du sucre augmente substantiellement la puissance de pointe du sprint 1 ($22,1 \pm 19,5$ W; AE, 0,81); le rince-bouche contenant de la caféine ($26,9 \pm 26,9$ W; AE, 0,71) et le rince-bouche contenant du sucre ($39,1 \pm 25,8$ W; AE, 1,08) augmentent la puissance moyenne produite dans le sprint 1. Dans la deuxième expérimentation, la combinaison du sucre et de la caféine dans le rince-bouche améliore la production de puissance dans le sprint 1 comparativement au rince-bouche ne contenant que du sucre ($36,0 \pm 37,3$ W; AE, 0,81). Les rince-bouche contenant du sucre ou de la caféine ont le potentiel d'augmenter rapidement la puissance produite, ce qui peut être utile pour l'amélioration de la performance dans un exercice spécifique de sprint court. Le potentiel ergogène de l'utilisation du rince-bouche sur la performance physique maximale en l'absence de fatigue suggère un mécanisme central. [Traduit par la Rédaction]

Mots-clés : rince-bouche, fatigue, puissance, sprints répétés.

Introduction

Recent research demonstrated that a carbohydrate mouth rinse enhanced endurance performance, and that this beneficial effect was related to changes in brain activity in the reward centre via a putative mechanism involving oral receptors (Chambers et al. 2009). This phenomenon was first reported in 2004 and has been demonstrated to improve time-trial performance in both running and cycling exercise (Carter et al. 2004; Pottier et al. 2010; Rollo

et al. 2008). The study by Pottier et al. (2010) went on to show that a carbohydrate mouth rinse was superior to carbohydrate ingestion, suggesting that the duration of time the solution spent in the oral cavity is important. Further research showed that a carbohydrate mouth-rinse protocol that effectively increased treadmill running performance was not associated with changes in blood glucose concentration during exercise or at rest (Rollo et al. 2010). It should be noted that beneficial effects of a carbohydrate mouth

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rinse have not been consistently reported (Beleen et al. 2009; Whitham and McKinney 2007).

One proposed mechanism that may explain the effects of carbohydrate mouth rinses is increased activation of the brain regions believed to be responsible for motivation and motor control. Indeed, a carbohydrate mouth rinse has demonstrated increased power in cycling time-trial studies (Carter et al. 2004; Pottier et al. 2010) and can rapidly enhance voluntary motor output in the arm (Gant et al. 2010). However, 1 study that assessed whether a carbohydrate mouth rinse could affect maximal strength showed no effect on either strength or total exercise volume (Painelli et al. 2011). Furthermore, a study that assessed the effect of both maltodextrin and glucose on a 30-s maximal sprint effort reported no difference in either peak or mean power output, although there was an improvement in a calculated fatigue index (Chong et al. 2011). Despite the widespread interest in this topic throughout the scientific community, equivocal results are apparent, and it seems that the effects of a carbohydrate mouth rinse on repeated sprint performance have yet to be established.

Caffeine ingestion can enhance endurance and sprint performance via a mechanism that is believed to involve the central modulation of motor unit activity and adenosine receptor antagonism (Kalmar 2005), and has been reported to enhance repeated sprint performance in running (Carr et al. 2008; Mohr et al. 2011) and cycling exercise (Lee et al. 2011). Paton et al. (2010) have also demonstrated that, in a group of trained cyclists, chewing caffeinated gum can improve repeated sprint performance, although, interestingly, the caffeine was only administered immediately prior to the observed beneficial effects. The method of caffeine delivery here may be of interest because adenosine receptors have been identified in the oral cavity in other mammals (Rubenstein et al. 2001). The effects of a caffeine-containing mouth-rinse solution on exercise performance have not been investigated. One of the benefits of such a treatment would be the low systemic dose required, thus reducing the possible side effects of the caffeine. Although independently caffeine and carbohydrate have demonstrated positive effects on exercise performance, it is currently unknown whether a synergistic positive effect could be attained via a possible interaction with oral receptors. Of particular interest is the observation that both caffeine and carbohydrate have been suggested as activating the reward circuitry of the brain with the potential to modulate behaviour (Hagger and Chatzisarantis 2012) and performance (Chambers et al. 2009).

Research is required to better understand the effects of a carbohydrate mouth rinse and (or) a caffeine mouth rinse on repeated maximal sprint efforts. As a result, this investigation sought to assess the effectiveness of carbohydrate and caffeine mouth rinses in enhancing repeated sprint performance, using a double-blinded, randomized cross-over design. It was hypothesized that rinsing the mouth with carbohydrate and caffeine solutions would improve repeated cycle sprint performance.

Materials and methods

Participants

Twelve recreationally trained males (age, 32 ± 7.5 years; height, 175 ± 7.3 cm; mass, 82.2 ± 7.16 kg) volunteered to participate in the exercise trial. The subjects reported being low caffeine users, consuming ≤ 2 doses of caffeinated beverages daily. All participants were fully informed of the nature and possible risks of the study before giving written consent. The Waikato Institute of Technology Ethics Committee approved the experimental protocol.

Experimental protocol

Experiment 1

The participants attended 4 sessions within a 10-day period at a testing laboratory. The first session acted as a familiarization ses-

sion so the participants could become accustomed to the repeated sprint effort protocol, and written informed consent forms were obtained. Water was used as a mouth rinse in this initial session. Anthropometric data were collected and a health questionnaire (Physical Activity Readiness Questionnaire) was administered. The remaining sessions acted as test trial sessions, with the participants performing the repeated sprint effort protocol between 0900 h and 1200 h under 1 of the following 3 conditions: carbohydrate mouth rinse (6% w/v glucose solution), caffeine mouth rinse (1.2% w/v caffeine solution), or placebo mouth rinse (noncaloric saccharin solution). The caffeine and carbohydrate solutions were made up in an equivalent saccharin solution to make them indistinguishable. The participants were instructed to not participate in any intense activity for 24 h prior to the testing session. Furthermore, 2 h of fasting were enforced prior to the testing session, and caffeinated products were forbidden on testing days. All testing sessions for a given participant were performed at the same time of day in a double-blinded, randomized, cross-over design, and each session was separated by at least 48 h.

The cycle sprint exercise was based on a previously reported reliable protocol for peak power (McGawley and Bishop 2006). Briefly, after a 5-min warm-up on a calibrated Monark cycle ergometer, the participant swirled the prescribed mouth-rinse solution in his mouth for 5 s before expectorating into a waste container. He was then required to pedal at $50 \text{ r} \cdot \text{min}^{-1}$ before being given a verbal countdown to commence a 6-s maximal sprint effort with a resistance of $\sim 10\%$ of body mass applied to the front wheel. Five 6-s sprints were completed, with 24 s of unloaded pedalling between each effort. During each 24-s period of active recovery, additional 5-s mouth rinses were performed. Peak and mean power output data were calculated from the motion of the flywheel, and a rating of perceived exertion (RPE) (Borg et al. 1987) and maximal heart rate (HR) (S810i, Polar, New Zealand) were collected at the completion of exercise.

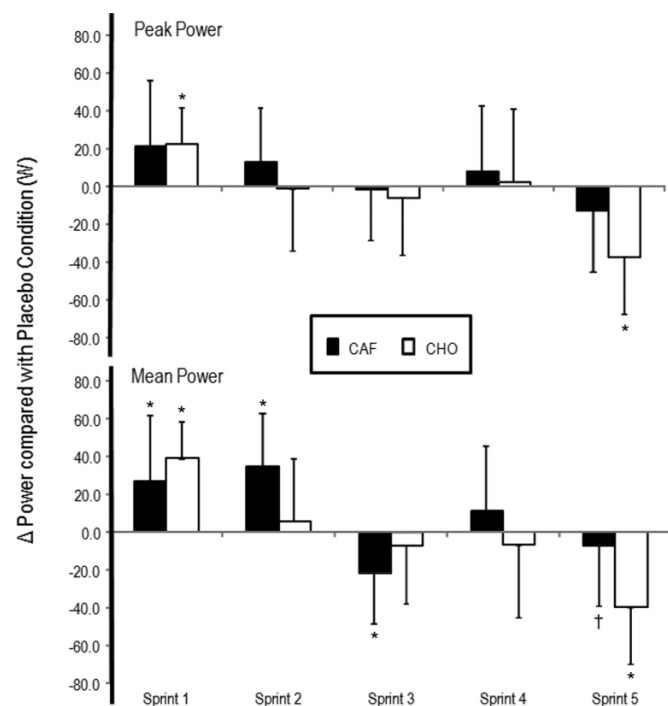
Experiment 2

Eight participants from experiment 1 (4 of whom were identified as caffeine responders) returned to compare a mouth rinse containing both carbohydrate and caffeine with a carbohydrate-only solution in a balanced, double-blinded, cross-over fashion. The participants attended 2 sessions within a 5-day period at the testing laboratory, and each session was separated by at least 48 h. The experimental testing protocol and instructions were identical to those in experiment 1, and all testing sessions for a given participant were performed at the same time of day. The 2 mouth rinses were composed of saccharin solutions identical to those used in experiment 1, with the addition of either 6% w/v glucose solution (carbohydrate mouth-rinse condition) or 6% w/v glucose solution with 1.2% w/v caffeine (caffeine-plus-carbohydrate mouth-rinse condition).

Statistical analyses

The dependent variables were log-transformed before analysis to reduce nonuniformity of errors, with effects derived by back transformation as percentage changes (Hopkins et al. 2009), and a repeated-measures analysis of variance (ANOVA) was used to compare dependent variables among the conditions. Pairwise comparisons across time points were made among the conditions, and differences were interpreted in relation to the likelihood of exceeding the smallest worthwhile change (Cohen's effect size (ES)), with individual change thresholds for each variable. Differences in the means of each measure were assessed by dividing the changes by the appropriate between-athlete SD. Magnitudes of the standardized effects were interpreted using thresholds of 0.2, 0.6, and 1.2 for small, moderate, and large, respectively (Hopkins et al. 2009). Standardized effects of between -0.19 and 0.19 were termed trivial. To make inferences about the large-sample value of an effect, the uncertainty in the effect was expressed as 90%

Fig. 1. Power data for the carbohydrate and caffeine mouth-rinse conditions. Data for the carbohydrate and caffeine mouth-rinse conditions are presented as change scores from the corresponding power data in the placebo mouth-rinse condition. *, Substantially different from the placebo mouth-rinse condition; †, substantially different from the carbohydrate mouth-rinse condition. CAF, caffeine; CHO, carbohydrate.



confidence limits. An effect was deemed unclear if the confidence interval overlapped the thresholds for both small positive and small negative effects. The significance level was set at $p \leq 0.05$.

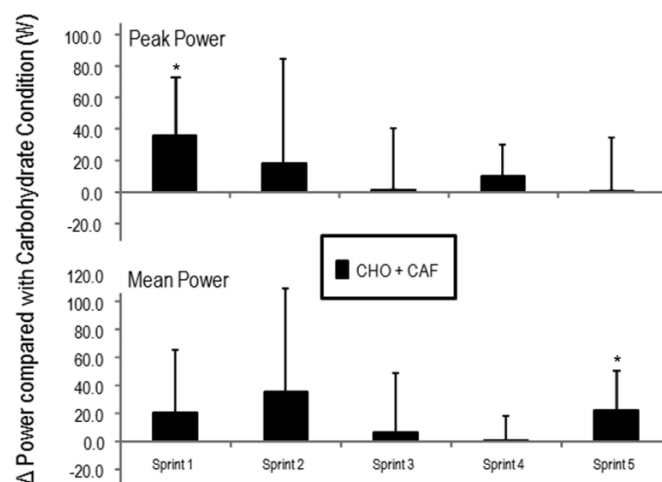
Results

Experiment 1

The participants were unable to correctly identify the 3 solutions more than expected by chance, based on the percentage of successful guesses (25%) when questioned following each exercise bout, which indicates successful blinding. The order of testing was randomized, and all the subjects were familiarized with the test before the trial began, so the changes in performance could not be attributed to the effect of day-to-day variation or learning. Within-subject performance variation was calculated as a coefficient of variation of 3.7% for peak power and 4.8% for mean power. No order effect was detected. No differences in maximal HR (placebo, 158 ± 10 beats·min⁻¹; carbohydrate, 162 ± 15 beats·min⁻¹; caffeine, 157 ± 8 beats·min⁻¹) or RPE (placebo, 16.8 ± 1.3 ; carbohydrate, 16.9 ± 1.3 ; caffeine, 16.8 ± 1.1) were observed among the 3 trials (p all > 0.05).

When the caffeine and carbohydrate mouth-rinse data were presented as change scores from the placebo data, it was apparent that peak power in sprint 1 was enhanced in the carbohydrate condition (22.1 ± 19.5 W; ES, 0.81; $p = 0.0667$), and that the mean power in sprint 1 was substantially improved in both the carbohydrate (39.1 ± 26.9 W; ES, 1.08; $p = 0.0205$) and caffeine conditions (26.9 ± 26.9 W; ES, 0.71; $p = 0.0995$) (Fig. 1). However, sprint 5 was negatively influenced for both peak power (-37.3 ± 30.2 W; ES, -0.84 ; $p = 0.0480$) and mean power (-39.6 ± 27.4 W; ES, -0.76 ; $p = 0.0693$) in the carbohydrate condition when compared with the placebo condition. This decrement was not as apparent in the caffeine condition, with no substantial differences observed be-

Fig. 2. Power data for the combined carbohydrate and caffeine mouth-rinse condition. Data for the combined carbohydrate and caffeine mouth-rinse condition are presented as change scores from the corresponding power data in the carbohydrate-only mouth-rinse condition. *, Substantially different from the carbohydrate mouth-rinse condition. CHO, carbohydrate; CAF, caffeine.



tween the caffeine and placebo conditions in sprint 5 and a substantial difference in mean power of 32.7 ± 43 W (ES, 0.52) between the caffeine and carbohydrate conditions. There was, however, a small decrease (ES, -0.56) in mean power production in the caffeine condition compared with the placebo in sprint 3. Six individuals produced their greatest maximal power during both of their first 2 sprints when they used the caffeine mouth rinse. In these “caffeine responders”, the peak power generated was substantially greater than that observed in the placebo condition for sprint 1 (103.8 ± 116.5 W; ES, 0.87; $p = 0.1361$), whereas in “nonresponders”, no clear difference was seen between the caffeine and placebo condition at any time point.

Experiment 2

Successful blinding was again evidenced by the percentage of successful guesses following each exercise bout (37.5%). When the carbohydrate-caffeine mouth-rinse data were presented as change scores from the carbohydrate-only condition, it was clear that peak power in sprint 1 (36.0 ± 37.3 W; ES, 0.81; $p = 0.1102$) and mean power in sprint 5 (22.1 ± 28.3 W; ES, 0.66; $p = 0.1832$) were moderately enhanced (Fig. 2). Interestingly, 7 out of 8 participants produced their best overall peak power on their first sprint in the combined carbohydrate and caffeine condition. Furthermore, all data points for the mean change score were positive in favour of the combined carbohydrate and caffeine condition.

Discussion

Our data demonstrate that a carbohydrate and caffeine mouth rinse can rapidly enhance initial cycle sprint power production when compared with an indistinguishable sweet but noncaloric placebo. Numerous studies have reported power production and endurance benefits of a carbohydrate mouth rinse compared with a blinded placebo (Carter et al. 2004; Chambers et al. 2009; Fares and Kayser 2011; Jeukendrup and Chambers 2010; Pottier et al. 2010; Rollo et al. 2010) or a nonrinse control (Chong et al. 2011; Gam et al. 2012). A brief mouth rinse has been proposed as an alternative to carbohydrate ingestion and has even been proposed to be superior in terms of endurance performance measures (Pottier et al. 2010) and gastric distress (Place 2009). It has been demonstrated that a carbohydrate mouth-rinse protocol, admittedly at approximately 3 times the concentration of the current trial, has a marked effect on the anterior cingulate cortex and

right caudate, which are believed to mediate the physiological response to reward (Chambers et al. 2009). It has been suggested that alterations in power are mediated by a “central governor” and that a carbohydrate stimulus may elicit positive afferent signals capable of enhancing motor output (Jeukendrup and Chambers 2010).

Research employing transcranial stimulation has shown that the presence of carbohydrate in the oral cavity increases the excitability of the corticomotor pathway and can immediately increase maximal force production (Gant et al. 2010). Our data may provide some indirect evidence of improved motor output, because the enhanced maximal exercise performance in the mouth-rinse conditions occurred in the absence of fatigue. This observation suggests a central or supraspinal mechanism that is capable of enhancing the neural drive to the motor units and accessing the muscle recruitment reserve proposed by other researchers (Gandevia 2001; St Clair Gibson and Noakes 2004).

However, in experiment 1, the degree of performance decrement, as evidenced by the inability to maintain power across the 5 sprint efforts, was also greater in the carbohydrate intervention group. Although not measured in this study, this observation could possibly be due to the rapid depletion of ATP, which is the predominant fuel source during high-intensity repeated-sprint protocols. It could reasonably be argued that the increased power outputs in the early sprints came at a cost to the subsequent ones and, indeed, the greater degree of performance decrement observed in the nonplacebo mouth rinses appears to be a result of the relatively greater power produced during the initial sprint efforts.

The ingestion of caffeine as an ergogenic aid has been reported widely, with the antagonism of adenosine receptors being 1 of the mechanisms behind the beneficial effects on exercise performance (Carr et al. 2008; Davis and Green 2009; Kalmar 2005). The obvious difference between the current study and previous research into the effects of caffeine on exercise performance is the method, concentration, and timing of the delivery. The novel evidence presented here is that a 1.2% w/v caffeine solution rinsed in the mouth immediately prior to exercise, without ingestion, elicited a rapid performance-enhancing effect on maximal voluntary power production. These data suggest that a mechanism does exist by which caffeine can rapidly modulate physical capacity via the oral cavity.

Previous research using caffeine has often identified specific individuals who are apparently more susceptible to the performance-enhancing effects of caffeine (Astorino et al. 2011; Bruce et al. 2000; Cook et al. 2012; Jenkins et al. 2008). In the current study, individuals who were identified as a subgroup of caffeine responders generated significantly greater peak power during their initial sprints. This increase in peak power was approximately double the 5.5% CV reported for a similar cycle sprint protocol (McGawley and Bishop 2006). Notwithstanding the debate between statistical and practical significance, the findings of the current study demonstrate performance improvements in response to mouth-rinse protocols that are of a magnitude similar to those reported previously (Rollo and Williams 2011). It should be noted that few studies have reported performance enhancement greater than the day-to-day variation in testing method (Pottier et al. 2010; Rollo et al. 2010), whereas the results of other studies, although significant, did not meet this criterion (Carter et al. 2004; Chambers et al. 2009).

It is possible that some of the previous observations made with ingested caffeine may be related to localized central rather than systemic effects, depending on the method of delivery. A caffeinated chewing gum has been reported to rapidly improve time-trial performance (Ryan et al. 2011) and increase power output in cycle sprints in a manner that was associated with modified salivary hormone responses compared with a placebo condition (Paton et al. 2010). Interestingly, the pattern of the salivary hormone stress response reported by Paton and colleagues (2010) was dif-

ferent from that reported by others who used caffeine ingestion as the method of delivery (Beaven et al. 2008).

The data from experiment 2 showing a substantial increase in sprint 1 peak power and an enhancement of mean power in sprint 5 resulting from the combined carbohydrate and caffeine mouth rinse when compared with the carbohydrate-only mouth rinse again demonstrate a rapid effect. Further, the additive positive effects of both caffeine and carbohydrate on power production suggest that distinct mechanisms are involved in the performance enhancement. Specifically, the data suggest a rapid contribution of central mechanisms to aspects of muscular function and sprint performance that can be directly manipulated using a mouth-rinse intervention.

A lack of difference in RPE is commonly reported in mouth rinse (Carter et al. 2004; Chambers et al. 2009; Gam et al. 2012; Lee et al. 2012; Pottier et al. 2010) and caffeine trials (Doherty et al. 2004). It has been suggested that lowering the perception of effort during exercise at a given intensity may be a viable mechanism for improved performance, because exercise intensity would increase to compensate for this decrease in perceived effort (Rollo and Williams 2011). Similar to the data presented here, previous research has reported no effect of a carbohydrate mouth rinse (Carter et al. 2004) or caffeinated gum (Ryan et al. 2012) on exercise-induced elevations in HR. An alternative explanation for the lack of difference in HR and RPE between the conditions is that the maximal sprint efforts elicited near-maximal RPE and HR values and, as a result, no appreciable differences in these data were observed (a ceiling effect).

It is worth considering a number of limitations to the current study. First, the participants were recreationally trained only, and thus, the ability to generalize the current results to highly trained individuals is limited. Second, caffeine habituation was not assessed and, although all subjects reported being low caffeine consumers, this may have affected the acute responses to the caffeine dose. Similarly, the effect of hunger and the length of the postprandial period may have influenced the results. There is some evidence to suggest that a carbohydrate mouth rinse is equally efficacious in both the fed and unfed state (Fares and Kayser 2011), although conflicting results have been reported (Beleen et al. 2009). We did, however, enforce a 2-h fasting duration prior to the exercise performance, which is of similar duration to that of previous work that has demonstrated a beneficial effect of a carbohydrate mouth rinse on cycling performance (Pottier et al. 2010). The current study did not utilize a nonrinse control, nor did it address the possibility of a dose-response, and neither blood levels of caffeine nor glucose were assessed. It remains to be established whether higher dosages administered solely within the oral cavity would result in a divergent physiological or functional response.

Overall, the current study adds to the series of mouth-rinse literature and suggests that a mouth rinse with carbohydrate can induce potentially worthwhile physiological outcomes, with increases in power output in a nonfatigued state. The rapidity of these responses suggests a supraspinal mechanism involving the CNS, possibly via oral receptors. These increases were tempered, however, by the observation of a decreased ability to maintain power over a series of repeated sprints when compared with a noncaloric placebo (experiment 1). Thus, in repeated intermittent sprints, there may be a metabolic cost associated with this initial improvement. Therefore, we contend that a carbohydrate mouth-rinse intervention is more likely to have a beneficial effect when longer recovery periods are available between the sprints or when only single efforts are required. A novel finding was that the addition of caffeine attenuated the performance decrement seen in the carbohydrate-only condition, both independently and in conjunction with carbohydrate, improving power output again via a putatively central mechanism. Further research into these effects would help elucidate where and how competitive advantage may

be obtained through the use of both caffeine and carbohydrate using an oral, noningestion approach.

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