Carbohydrate Mouth Rinse Counters Fatigue Related Strength Reduction

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The purpose was to determine the effect of carbohydrate (CHO) mouth rinse on maximal voluntary contraction (MVC) and neuromuscular output in a fatigued state. It was hypothesized that CHO mouth rinse would potentiate torque output in a fatigued state. In a double-blind, cross-over design, 12 competitive male athletes (9 rowers, 1 cyclist, 1 runner and 1 volleyball player) initially performed 3 × 5 s MVC isometric knee extensions followed by a 50% MVC contraction until volitional exhaustion, with quadriceps muscle activity measured via electromyography (EMG). Immediately after, either an 8% CHO maltodextrin (WASH), or noncaloric artificial sweetener (PLA) was mouth rinsed for 10 sec, before 3 × 5 s final MVCs. Fatigue caused a significant decline in post fatigue MVC trial 1 for 3 s average torque (p = .03) and peak torque (p = .02) for PLA. This fatigue related decline in torque was not noticed for WASH, with a 2.5% and 3.5% less attenuation in peak and average torque, respectively in post fatigue MVC1 compared with PLA. The effect size for MVC trial 1 between WASH/PLA was seen to be small positive (ES = 0.22; 55% likelihood of positive). Overall for EMG RMS, there were no significant differences between PLA and WASH among all muscles. EMG median frequency showed comparable results between conditions with significant reductions due to fatigue. Taken together, this evidence suggests that the attenuation of torque post fatigue was less for CHO mouth rinse than a placebo. Even though the gains were marginal, these discoveries may play an important role in sport performance, as small performance effects can have significant outcomes in real-world competitions.

Keywords: carbohydrate mouth rinse, maximal strength, neuromuscular strategy, fatigue, isometric

Carbohydrate (CHO) consumption can improve performance during long duration endurance exercise (>90 mins), with the primary mechanisms likely related to maintenance of high rates of CHO oxidation and hypoglycemia prevention (Jeukendrup, 2004). While these mechanisms support energy/metabolic benefits of CHO during prolonged exercise, there have also been positive effects of CHO on shorter duration (<1 hr), high-intensity exercise. Interestingly, acute and short-term effects appear unrelated to muscle glycogen concentrations (Jeukendrup, 2004; Romijn et al., 1993) or through increased availability of plasma glucose (Carter et al., 2004b). Therefore, the acute performance enhancement from CHO intake during high-intensity exercise (<1 hr) are probably based on alternate mechanisms.

It is theorized that CHO ingestion may impact short duration high-intensity exercise performance (<1 hr) through central/cognitive effects (Chambers et al., 2009). Recent studies have shown improvement for high-intensity endurance exercise (~1 hr) by rinsing the mouth with a CHO solution, without oral CHO consumption (Carter et al., 2004a; Chong et al., 2011; Gam et al., 2013; Rollo & Williams, 2011). The results support a central mechanism as CHO mouth rinse has been shown to increase activation of pleasure and reward centers of the brain (Chambers et al., 2009) and improve performance related to the duration of oral cavity CHO exposure (Sinclair et al., 2013).

The performance effects of CHO mouth rinse have primarily been studied over short duration cycling (Carter et al., 2004a; Gam et al., 2013; Pottier et al., 2010; Taylor et al., 2013), and running (Rollo et al., 2010, 2011b; Whitham & McKinney, 2007), with only a few studies examining CHO mouth rinse on maximal strength/power type exercise, finding contradictory performance outcomes (Beaven et al., 2013; Chong et al., 2011; Painelli et al., 2011). However, all of these strength/power based studies did not use subjects in a prefatigued state, where a decrease in performance may be due to central and/or peripheral mechanism(s) related to energy availability (Allen et al., 2008). Thus, central mechanisms of performance enhancement may be more readily evident in a fatigued state. This is supported by Gant et al. (2010) who found an instantaneous increase in motor output due to a CHO mouth rinse following a fatiguing contraction, suggesting central modifications in muscular fatigue and power output.

The fatigue state of an individual can be directly measured through performance modifications as well as

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indirectly by changes in muscle activity through electromyography (De Luca, 1997). Based on the idea that CHO mouth rinse may benefit endurance performance in part through central mechanisms, it can be hypothesized that EMG may be useful to quantify changes in muscle activation associated with a CHO mouth rinse. Therefore, the aim of this study was to investigate the effect of a CHO mouth rinse on 1) muscular force production and 2) neuromuscular output (EMG), during a maximal isometric knee extensor contraction in an acute fatigued state. This is the first study of its kind to combine measures of neuromuscular and force performance to evaluate the effect of CHO rinse on performance. We hypothesized that a single CHO mouth rinse postfatigue would provide enhanced force performance during a maximal isometric knee extension contraction in an acute fatigued state, and that changes would be positively correlated with modification to muscle activation.

Methods

Participants

Twelve competitive male athlete participants (26.7 ± 6.7 years, 78.2 ± 5.5 kg and 184.9 ± 6.1 cm, for age, body mass (BM) and height (mean ± SD), respectively) were recruited and all gave written consent under Human Ethics at the University of Victoria. The study participants were regularly active (training 3–4 times a week at time of the study) and had previous athletic experience from varsity to national level (9 rowers, 1 cyclist, 1 runner and 1 volleyball player).

Participant Setup

Upon laboratory arrival each participant was prepared for EMG electrode placement by shaving hair and cleaning the skin with 70% alcohol. EMG electrodes (Delsys Trigno, USA) were then placed on anatomical landmarked sites over the vastus lateralis (VL), rectus femoris (RF) and vastus medialis (VM) (Merletti et al., 2012). The distance from the anterior superior iliac spine (ASIS) to the lateral and medial border of the patella was used as reference lines for identical placement of the EMG electrodes on the participants’ perceived dominant leg for each trial. The anatomical landmark (AL) for the VL was the distal portion of the muscle belly and oriented 20 degrees (°) with respect to the reference line on the lateral side of the patella. The electrode was placed 165mm from the AL. The AL for the VL was the distal portion of the muscle belly and oriented 50° with respect to the reference line on the medial side of the patella. The electrode was placed 95mm from the AL. The AL for the RF was a line between the ASIS and the superior part of the patella. The electrode was placed at 50% of the distance of the AL, as previously described (Merletti et al., 2012). All measurements were recorded so that on subsequent trials all electrodes could be positioned in the same place. EMG and force were sampled at 2 kHz with a 16-bit A/D converter.

Before experimental trials, all participants completed a standardized submaximal cycling warm-up for 15 min (70–80 rpm) on a cycle ergometer at varying intensities normalized to the participants’ body weight (2, 3 and 4% body weight) (Monark Ergomedic 828E; Sweden). Following warm-up, subjects were seated in a Cybex-6000 with axis of rotation of the leg-extension dynamometer aligned to the knee joint line. The backrest and seat angles were adjusted so that the hip was at 80° of flexion, with a strap placed across the pelvis and upper body to minimize extraneous movements. The dominant leg to be tested was secured and fixed to the dynamometer lever arm by a pad secured 1 cm above the lateral malleolus. Contralateral knee extension was restrained at the distal tibia and all contractions were performed at 60° angle of knee flexion (0°=full extension). During experimental trials, participants folded their arms across their chest and received visual force feedback on a computer monitor. Knee extension force was measured through the use of a tension/compression load cell (Omegadyne, LC101–500; USA) attached between the Cybex-6000 lever arm and base of the Cybex-6000. Torque (Nm) was then calculated as the product of the measured force and the lever arm length for each individual subject.

Experimental Protocol

Each participant completed two experimental trials in double-blind randomized crossover fashion while maintaining regular training for the duration of the study and to abstain from any intense exercise, caffeine, and alcohol in the previous 24 hr before each test. The trials were separated by 4.6 ± 2.2 days and subjects were overnight fasted and conducted each trial at the same time (between 7 and 10 a.m.) to minimize the effects of diurnal variation. Participants recorded their food and liquid consumption for 24 hr before the first trial, which they replicated for the subsequent trial.

The experimental trial consisted of maximal and submaximal isometric knee extension tasks while knee extensor muscle activity and force were collected (Figure 1). Before each trial, the participants were familiarized to isometric knee extension tasks by performing three slow ramp isometric knee extensions at submaximal level. Participants then performed three isometric maximal voluntary contraction (MVC) knee extensions lasting 5 s separated by 60 s rest to get baseline measurements, with the highest achieved torque used to calculate the target torque for the fatiguing endurance task (Figure 1).

Following 5 min of rest, participants then performed a fatiguing contraction at 50% of MVC (with visual torque feedback) until volitional exhaustion, defined as the point where the torque dropped more than 10% from the target level for more than 5 sec. Immediately postfatigue, participants rinsed their mouth with one of two randomized solutions (WASH vs. PLA) for 10 s and then expelled all of the solution into a beaker, over
a 30-s rest period. The last exercise set consisted of 3 × 5 s MVCs with 10 s rest between each contraction (Figure 1). Participants were given constant and consistent verbal encouragement for all MVCs and during the fatiguing contraction.

The CHO mouthwash consisted of 8% maltodextrin. Both the WASH and PLA solutions were supplemented with 0.2% artificial sweetener, sucralose (MIO, Kraft Food, USA) to make the solutions indistinguishable. The mouthwash solutions were coded by a nonaffiliated researcher to ensure double-blinding. Drinks were taste-matched and comprised the same quantity of energy-free ingredients (artificial-sweetener, colorings, and flavoring).

Data Analysis

Of the first three baseline measurements, the greatest peak torque was used to compare with all three postfatigue trials. Average torque was calculated using the last 3 s of each MVC, whereas peak torque was defined as the maximal torque reached at any point during the 5 s maximal contraction. The total area under the load-time curve was calculated and compared between days to ensure that a common level of cumulative effort was required by each subject to reach volitional exhaustion in the fatiguing contraction on separate days. Raw EMG signal was filtered using a second-order zero-phase Butterworth band pass filter using low and high cut-off frequencies of 10 Hz and 500 Hz respectively. EMG root mean square (RMS) and median frequency (MDF) were calculated using a 300ms interval centered around absolute maximal torque for all MVCs (Farfán et al., 2010). Baseline MDF and RMS was extracted from the baseline MVC that had the greatest peak torque. RMS and MDF maximal values were determined using a 300 ms moving window for the entire raw signal for each baseline trial. The average maximum windowed RMS/MDF from the 3 baseline MVCs was used to normalize all RMS/MDF values. For each window a discrete Fast-Fourier transform (FFT Hanning) was used to calculate MDF (Merletti et al., 1997).

Statistics

Repeated measure ANOVAs were used to determine the effect of mouth rinse (WASH vs. PLA) and TIME (PRE, POST1,2,3), on Peak torque, 3 s Average torque, RMS, and MDF. Whenever a significant F-value was obtained for main effect or interactions, a Tukey post hoc test was performed. A priori planned orthogonal contrasts were made between prefatigue baseline value and first trial postfatigue, as well as comparing postfatigue trials 2 and 3 (Tabachnick & Fidell 2013). This was done to examine the acute effect of WASH on isometric force production postfatigue as well as the effect over repeated bouts. To determine whether the differences between PLA and WASH trials were meaningful, magnitude-based inferences were calculated for torque. Cohen’s effect size (ES) calculations were made between baseline and all 3 post fatigue trials and interpreted in relation to the likelihood of exceeding the smallest worthwhile change (ES <0.2 trivial, >0.2 small, >0.6 moderate, >1.2 large). Magnitudes of the standardized effects were interpreted using the threshold of ±0.20, which was deemed trivial. The effect of the intervention was expressed as 90% confidence intervals and the probabilities of the intervention being effective was expressed as either positive, trivial or negative (Hopkins et al., 2009).

To test for differences in cumulative effort during the fatiguing contraction between days, a paired t test was used. Intraclass correlation coefficient (ICC) was used to express relative reliability of the EMG signal measures. The reliability between trials was calculated using all baseline EMG raw data and was determined as the estimator of test-retest reproducibility. ICC reproducibility was characterized using the following criteria: good (0.8–1.0), fair (0.6–0.79) and poor (<0.6) (Sleivert & Wenger, 1994). All data were analyzed using SPSS.
Data are reported as means±SE, with significance set at $p < .05$.

**Results**

**Torque**

Repeated-measures ANOVA demonstrated that there was significant main effect for TIME for peak and average torque with collapsed conditions (WASH/PLA) showing that grouped fatigue trials 1, 2, 3 were significantly lower than prefatigue values. There was no significant difference in measures of peak torque or average torque between prefatigue WASH and PLA conditions (peak torque WASH: 364.0 ± 12.6 vs. PLA: 351.5 ± 10.9Nm, $p = .24$; and average torque WASH: 344.2 ± 11.2 vs. PLA: 334.1 ± 10.2Nm $p = .27$; Figures 2a and 3a). Planned contrasts for WASH showed that postfatigue MVC1 for peak and average torque did not have a significant decrease ($p > .05$) from prefatigue baseline (Figures 2a and 3a). Planned contrasts for PLA showed a significant decrease from baseline in peak torque for postfatigue trial 1 ($p = .02$) and average torque for trial 1 ($p = .03$). The peak torque for all postfatigue MVCs for WASH had a smaller decrease from baseline compared with PLA (MVC1: WASH: -31.7 ± 9.9 vs. PLA: -38.7 ± 9.8Nm; MVC2 WASH: -30.3 ± 9.5 vs. PLA: -32.7 ± 8.3Nm; and MVC3: WASH: -31.6 ± 7.4 vs. PLA: -33.1 ± 7.7Nm). Effect size for peak torque MVC1, MVC2, MVC3 between WASH/PLA was seen to be small positive (ES = 0.22; 55%), trivial (ES = 0.10; 76%), and trivial (ES = 0.05; 71%), respectively. For average torque, WASH had a smaller decrease from baseline compared with PLA for all 3 postfatigue trials (MVC1: WASH: -25.9 ± 10.1 vs. PLA: -36.0 ± 11.5Nm; MVC2: WASH: -27.2 ± 8.8 vs. PLA: -32.5 ± 8.5Nm; and MVC3: WASH: -28.2 ± 7.3 vs. PLA: -30.6 ± 8.2Nm). Effect size for average torque MVC1, MVC2, MVC3 between WASH/PLA was seen to be small positive (ES = 0.32; 64%), trivial (ES = 0.16; 50%), and trivial (ES = 0.07; 55%), respectively. There was no significant difference between PLA and WASH cumulative effort during the fatiguing contraction on separate days ($p > .05$)

**RMS**

Repeated-measures ANOVA showed there was no-significant main effect for TIME for VL, RF and VM, with

![Figure 2](image-url) — The effect of CHO mouth rinse on (A) peak torque of pre- and postfatigue MVCs, (B) peak torque decrease (%) from baseline. † represent significantly decreased torque production in postfatigue MVCs compared with prefatigue for PLA condition, $p < .05$. Data are presented as means ± SE.
collapsed conditions (WASH/PLA) \((p > .05)\). There was no significant difference between trial days on absolute RMS values \((p > .05)\). The reliability for the absolute RMS values showed good reproducibility for the VL \((ICC = 0.98)\), VM \((ICC = 0.92)\) and RF \((ICC = 0.80)\).

MDF

Repeated-measures ANOVA demonstrated that there was a significant main effect for TIME for VL, RF, and VM with collapsed conditions (WASH/PLA) showing that grouped fatigue trials 1, 2, 3 were significantly lower than grouped prefatigue values \((p < .05)\). The absolute prefatigue values for VL, RF, and VM were WASH: 121.5 ± 9.6, 127.1 ± 7, and 127.9 ± 10 Hz; PLA: 124.4 ± 11.4, 120.8 ± 6.8 and 120.3 ± 9.3, respectively. Planned contrasts for RF showed a significant decrease from baseline, for both WASH \((p = .002)\) and PLA \((p = .015)\) for postfatigue trial 1. There was no significant difference between trial days for MDF \((p > .05)\). The reliability for MDF showed good reproducibility for the VL \((ICC = 0.81)\), and VM \((ICC = 0.83)\) and fair reproducibility for RF \((ICC = 0.74)\).

None of the 12 participants were able to clearly distinguish a taste differences between WASH and PLA solutions.

**Discussion**

This is the first study to demonstrate that a CHO mouth rinse resulted in decreased torque attenuation as compared with a noncaloric control mouth rinse, in a fatigued state. This finding has the potential for real-world application in short duration activities at high exercise intensities, such as sprinting/jumping, cycling, and/or weight lifting where the ability to acutely increase maximal force/strength in a fatigued state could result in an increase in performance. However, while we demonstrated a decreased torque attenuation during the WASH trial it is unclear if this effect persists over repeated trials and the effect is small. Therefore, care must be taken when considering the use of this nutritional intervention over repeated high intensity exercise bouts. In addition we found that there were no differences noticed between PLA and WASH for fatigue related measures of surface EMG. This fails to provide evidence for an acute centrally mediated modification.
CHO mouth rinse has been shown to improve short duration, high intensity cycling, and running protocols lasting approximately 1h, where muscle glycogen is not limiting (for review see Jeukendrup, 2013). However, prior research in the field of CHO mouth rinse and its effect on maximal strength/power has shown contradictory findings, with either no performance increase (Chong et al., 2011; Painelli et al., 2011) or only a slight performance increase (Beaven et al., 2013). However, there are major differences between these strength/power protocols and none have examined the effect of CHO mouth rinse following an acute prefatiguing protocol.

In the present experiment we observed that there was a significant attenuation in peak and average torque for PLA, while there was no significant attenuation during WASH for the first trial post fatigue. Thus, during the CHO mouth rinse trials, peak torque production and torque maintenance did not change, supporting a potential acute influence of CHO mouth rinse on performance. This finding is in contrast to Painelli et al. (2011) who did not observe an effect of carbohydrate mouth rinse on maximal strength or strength endurance during a 1-RM and 6-RM bench press task. However, the author's point out that their results are limited due the lack of accurate force measurement and the poor day-day reliability of their task. In this experiment accurate torque measurement during a simple constrained knee extension task enabled a sensitive and controlled evaluation of the effect of CHO mouth rinse on torque following a fatiguing contraction. In a similar controlled experiment evaluating the effect of CHO mouth rinse on upper limb force production, Gant et al. (2010) found an immediate increase in maximum voluntary force following CHO ingestion and a larger change in motor evoked potentials (MEPs) in fatigued vs nonfatigued conditions. This indicates that CHO can immediately improve human performance by increasing corticomotor excitability. The present finding of ~3% less attenuation of peak torque postfatigue in WASH vs. PLA (Figure 2b) is supported by a qualitative inference of the outcome being 55% likely to be positive, while marginal, could be relevant to the elite athlete/coach. For example, the normal variation (CV) in elite high-jump has been found to be 1.7%, and 0.3 of this is the smallest worthwhile effect (Hopkins, 1999).

An interesting observation from the peak and average torque results is that through effect size calculations (Cohen’s d) it appears that the effect of WASH has a diminishing influence over repeated bouts, as only the first trial post fatigue showed a possible positive benefit while trials 2 and 3 only had a trivial effect. This would suggest that the effect of WASH on torque reduction has a short lasting influence compared with PLA conditions and may be ineffectual for repeated bouts. Further, other studies have shown that, with sprint performances and CHO mouth rinse, there is a greater increase in initial power output with a greater decrement in performance over time versus a non-CHO mouth rinse (Beaven et al., 2013; Dorling & Earnest, 2013). Therefore, in consideration of the present results, and the findings of Beaven et al. (2013), it appears that only the initial maximal efforts following a CHO mouth rinse may demonstrate a performance gain by reducing the attenuation in strength in a fatigued state. As stated previously, one possible mechanism for this short lasting improvement is through enhanced neural drive to motor units from a supraspinal source (Gandevia, 2001). Following a volitional contraction the level of intensity for a subsequent maximal effort may be centrally inhibited based on afferent input to limit damage to muscle tissue and ward off energy depletion. This could result in the down-regulation of motor efferent commands resulting in decreased motor output (St. Clair Gibson et al., 2001). Thus the CHO mouth rinse may act to attenuate centrally mediated inhibition of motor output possibly through afferent signals associated with CHO availability in the mouth (Gant et al., 2010). This is consistent with studies evaluating direct cortical measures during CHO use, demonstrating activation of anterior cingulate cortex and striatum immediately following CHO mouth rinse (Chambers et al., 2009). The authors attributed this activation to reward recognition and Gant et al. (2010) support an enhancement in corticospinal activation. This could suggest that while there are short term benefits to a CHO mouth rinse combating centrally mediated fatigue, there may be a detriment to repeated maximal bouts. However, while this may be true of short duration high intensity events it is important to note that long duration events do not observably suffer from this same issue (for review see Jeukendrup, 2013).

Fatigue has been shown to alter NM strategies during maximal performance. This includes, the differential activation of muscles to limit force production to maintain fuel resources and limit tissue damage (St. Clair Gibson et al., 2001). For example, maximal voluntary knee extensions and leg cycling sprints result in a considerable amount of NM fatigue related to alterations in quadriceps activation, limiting performance (Billaut, 2011). When evaluating EMG, a decrease in MDF suggests a decrease in motor unit (MU) firing rate, muscle fiber recruitment and/or a decrease in conduction velocity (Billaut, 2011) and can be used as an index of fatigue (De Luca, 1997; Nagata et al., 1990). In addition, EMG RMS amplitude has been positively correlated with muscle force as greater MU recruitment and higher firing rate contributes to an increase in the cumulative EMG. It is important to note that following fatigue, EMG RMS may increase, while MDF may decrease in conjunction with lower force production (Gandevia et al., 1996). Therefore considering RMS alongside EMG frequency content is necessary to fully account for the factors that alter these variables including MU firing rate, MU action potential amplitude/duration/shape and conduction velocity (De Luca, 1997). In the current study we found that there were no differences in RMS for all quadriceps muscles across all trials compared with baseline (Figure 4). In addition, there was a greater decrease in MDF in RF for WASH and PLA during MVC1 following the fatiguing...
contraction (Figure 5). Taken together these results suggest that there was significant fatigue evident in both conditions. However, the current findings do not support a modification in neuromuscular strategy in either PLA and WASH conditions. A possible explanation for this finding, in light of the torque results, is that WASH may subtly alter overall motor output to enable an increase in immediate torque production. This is in agreement with Gant et al. (2010) who demonstrated that CHO in the mouth immediately increases the excitability of the

Figure 4 — Normalized group EMG RMS amplitude for pre- and postfatigue MVCs. Data are presented as means ± SE.
corticomotor pathway. However, given that this result is only evident in RF MDF, a more detailed EMG analysis and neurophysiological methodology such as interpolated twitch or reflex techniques are required to fully support or refute this interpretation (Gant et al., 2010; Zehr, 2002).

The reproducibility of surface EMG measurements across trials was quite similar and showed good/fair reproducibility, but potential methodological problems associated with surface EMG should not be ignored (e.g., distance to motor points, distance to lateral edge of

**Figure 5** — Normalized group EMG Median Frequency for pre- and postfatigue MVCs. Data are presented as means ± SE † (PLA) ‡ (WASH) represent significantly decreased Median Frequency in postfatigue MVCs compared with prefatigue, p < .05.
muscle, and/or orientation of muscle fibers with respect to electrode (De Luca, 1997)). Further, use of surface EMG in the current study only enabled an indirect analysis of the underlying physiological changes associated with the CHO mouth rinse on performance. However, MVC and EMG during isometric knee extensions has been shown to have a high repeatability, even without familiarization sessions (Rainoldi et al., 2001).

The most important, novel finding of this study was that the attenuation of torque postfatigue was less for CHO mouth rinse than a placebo. Further, this performance effect of CHO mouth rinse in a fatigued state may diminish for subsequent bouts suggesting a time limited contribution of a centrally mediated effect. In addition, CHO mouth rinse does not result in an altered NM strategy in a fatigued state as measured through EMG activity (RMS and MDF). This suggests that there may be no difference in central motor commands measured peripherally through EMG and more detailed techniques are required to evaluate these results. Overall, these discoveries may play an important role in sport performance, as small performance effects can have significant outcomes in real-world competitions.

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