Carbohydrate mouth rinse improves resistance exercise capacity in the glycogen-lowered state

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Abstract

The effect of carbohydrate mouth rinse (CHO MR) on resistance exercise performance is equivocal, and may be moderated by carbohydrate availability. This study determined the effect of CHO MR on low-load resistance exercise capacity completed in a fed but glycogen-lowered state. Twelve resistance-trained men (age: 22±4 years; height: 1.79±0.05m; weight: 78.7±7.8kg; bench press 1-RM: 87±21kg; squat 1-RM: 123±19kg) completed two fed-state resistance exercise bouts consisting of 6 sets of bench press and 6 sets of squat to failure at 40% 1-RM. Each bout was preceded by glycogen-depleting cycling the evening before, with feeding controlled to create acute energy deficit and maintain low muscle glycogen. During resistance exercise, participants rinsed with either a 6% CHO MR solution or a taste-matched placebo (PLA) between sets. Total volume workload was greater with CHO MR (9354±2051kg vs. 8525±1911kg, p=0.010). Total number of repetitions of squat were greater with CHO MR (107±26 vs. 92±16, p=0.017); the number of repetitions of bench press were not significantly different (CHO MR: 120±24 vs. PLA: 115±22, p=0.146). This was independent of differences in feeling or arousal. CHO MR may be an effective ergogenic aid for athletes completing resistance exercise when in energy deficit and with low carbohydrate availability.

Novelty

- CHO MR can increase low-load resistance exercise capacity undertaken in a glycogen-lowered but fed state.
- This effect was driven by a greater number of repetitions-to-failure in the squat – using muscles lowered in glycogen content with exhaustive cycling on the evening prior to resistance exercise – but not bench press.

Key words:

Ergogenic aid, rinsing, sports performance, muscular endurance, strength training.

Introduction

While debate persists (Brietzke et al., 2019; Li et al., 2019; Borszcz & de Lucsa, 2020), mouth-rinsing with a carbohydrate solution has been proposed as a potential ergogenic practice for improving endurance exercise performance (Carter et al., 2004; Chambers et al., 2009; Lane et al., 2013; Pottier et al., 2010; Rollo et al., 2011). It is proposed that the presence of carbohydrate in the oral cavity stimulates oropharyngeal receptors, eliciting a central neural response and resulting in enhanced central drive for increased or sustained work output (Carter et al., 2004; Jeukendrup & Chambers, 2010), via activation of brain regions associated with reward (Chambers et al., 2009).

There remains contention regarding the effects of carbohydrate mouth rinse on resistance exercise performance. Previous studies have failed to demonstrate improvements in strength and muscular endurance with carbohydrate mouth rinse (Clarke et al., 2015; Dunkin & Phillips, 2017; Krings et al., 2019; Painelli et al., 2011). However, such bouts have typically been of relatively low total workloads (Clarke et al., 2015; Dunkin & Phillips, 2017) and have been conducted with high or adequate carbohydrate availability (Clarke et al., 2015; Dunkin & Phillips, 2017; Krings et al., 2019; Painelli et al., 2011). When performed in the fasted state, increased capacity for resistance exercise has been observed with carbohydrate mouth rinse. Clarke et al. (2017), reported that, when exercise was performed after an 11-hour overnight fast, the repetitions of the bench press and squat, performed to failure at 60% of one-repetition max, were significantly greater with a 10-second rinse of a 6% carbohydrate solution. Similarly, administration of a 6% maltodextrin mouth rinse elicited a 12% increase in total volume workload during whole-body resistance training session performed after an 8-hour overnight fast (Decimoni et al., 2018).

Such findings are perhaps unsurprising, as the effect of carbohydrate mouth rinse on endurance performance are suggested to be moderated by carbohydrate availability. Carbohydrate mouth rinse has been shown to improve endurance cycling performance (Lane et al., 2013) and capacity (Fares & Kayser, 2011) to a greater extent in the fasted state, compared with exercise undertaken after consuming a high-carbohydrate meal, while both Beelen et al. (2009) and Ispoglou and colleagues (2015) failed to observe an improvement in 1-hour cycle time trial performance when conducted in a postprandial state.

However, it is noted that others have failed to observe an ergogenic effect of a sucrose mouth rinse in both the fed and fasted state (Trommelen et al., 2015), while Kulaksiz et al. (2016) did not see any improvement in 4km time trial performance with carbohydrate mouth rinse in the fasted state. Nonetheless, carbohydrate mouth rinse has been shown to attenuate reductions in 20-km cycle time trial performance when in a glycogen depleted state (Ataide-Silva et al., 2016), while Kasper et al. (2016) demonstrated a ~45% increase in the number of 1-minute high-intensity (80% VO_{2max}) running repetitions completed to failure after glycogen-depleting exercise with carbohydrate mouth rinse. As such, carbohydrate availability may have a moderating effect on the ergogenic effect of carbohydrate mouth rinse.

Current nutritional advice recommends periodising nutrition and fuelling adequately for intense training sessions and competition, to avoid low carbohydrate availability (Jeukendrup, 2017; Stellingwerff, 2012). This may not always be preferred by athletes who suffer nerves and gastrointestinal distress during competition, and may not be feasible for athletes seeking an optimal power-to-weight ratio and attempting to make weight. Such athletes will have the aim of maintaining or increasing strength and muscular endurance, and maintaining muscle mass while in a chronic energy deficit. Thus, resistance training, including high-volume, low-resistance resistance exercise for the development of muscular endurance and maintenance of muscle mass (ACSM, 2002), is likely to be undertaken in a postprandial yet energy-restricted and glycogen-lowered state. In such instances, ergogenic aids that could increase training capacity without intake of energy would prove desirable.

Therefore, the aim of this study was to investigate the effect of a carbohydrate mouth rinse on morning low-load resistance exercise capacity in the postprandial state, after a glycogen-depleting bout of cycling completed the night before resistance training.

Materials and Methods

Participants

Twelve healthy, resistance-trained young men (age: 22±4 years; height: 1.79±0.05m; weight: 78.7±7.8kg; bench press 1-RM: 87±21kg; squat 1-RM: 123±19kg) were recruited for the study. Inclusion criteria were: a minimum of two years' experience of resistance training, undertaking of resistance training ≥ once per week, with both squat and bench press typically conducted ≥ once per week; aged 18-30 years. Exclusion criteria were: illness, such as upper respiratory tract infection; smoker; currently taking any ergogenic aid (not including vitamin and mineral supplementation). Ethical approval was obtained from the Research Ethics Committee of the Carnegie School of Sport, Leeds Beckett University.

Study Design

Using a single-blind, within-subject, counterbalanced study design, participants complete two trial condition: carbohydrate mouth rinse (6.4% maltodextrin solution, CHO MR), and placebo (taste-matched sucralose solution, PLA). In each trial, a fed-state morning resistance exercise training session was completed, consisting of bench press and squat lifts (6 sets to failures, at 40% of one-repetition maximum (1-RM)). This was preceded by a glycogen-depleting cycling session the previous evening, with a controlled diet followed until the resistance training sessions. This was done to create an acute energy-restricted and glycogen-lowered state, mimicking that which may be experienced by athletes in energy deficit. The primary outcome measure was total work done in the session. Secondary measures were affective valence and arousal.

Pre-testing

Two pre-testing sessions preceded the exercise trials. Participants reported to the Carnegie Research Institute, at Leeds Beckett University after a minimum 2-hour fast and having refrained from strenuous exercise during the previous 48 hours. Participants were provided with written information about the study, which was also reiterated verbally. After being afforded the opportunity to ask any questions regarding their potential participation, participants provided informed written consent to partake. Health screening (Riebe et al., 2015), screening for food allergies, and measurement of height and weight were conducted. An incremental exhaustive exercise test was then completed on an electromagnetically-braked cycle ergometer (Lode Excalibur Sport, Groningen, Netherlands) to obtain a value for maximal aerobic power ($Watt_{max}$). The test, preceded by a five-minute warm-up at a self-selected power output, consisted of 3 minute stages, starting at a power output of 95W and increasing in increments of 35W (Achten et al., 2002). Participants were adjudged to have reached the end of the test when they voluntarily stopped pedalling, or if their cadence dropped to <60 rpm. $Watt_{max}$ was calculated as:

$$W_{max} = W_{final} + (t/180) \times 35$$ (Achten et al., 2002).

Where "W_{final}" is the power output of the final completed stage and "t" is the time (seconds) completed of the final uncompleted stage.

Two-to-five days after the incremental exhaustive exercise test, participants returned to the Carnegie Research Institute to complete a four-repetition maximum (4-RM) test (Dohoney et al., 2002) for the squat and bench press exercises. A short warm-up period preceded the test, consisting of 5-minutes of cycling on a cycle ergometer at a self-selected intensity followed by 15-20 repetitions of each exercise using a low load of 20kg. The test began at a load identified by the participant as one which they could comfortably complete 5-10 repetitions of the bench press. Once four repetitions were completed, fully and with correct form, the weight was increased in increments of 5-10%. This was continued until the participant was unable to complete four repetitions. At the point of failure, the load was reduced to the midpoint between the failure load and the last completed load. The greatest load for which four repetitions were successfully completed was determined as the participant's 4-RM value. All sets of lifts were separated by a recovery period of 4-5 minutes. After a recovery period of ~10 minutes, the test was repeated for the squat exercise. During all resistance training procedures participants were spotted by a member of the research team with a relevant qualification in gym instruction and personal training, to ensure safety and correct lifting techniques. From the 4-RM value, a one-repetition maximum (1-RM) was calculated as:

$$1\text{-RM (kg)} = -24.62 + (1.12 \times \text{load(kg)}) + 5.09 \times 4)$$ (Dohoney et al., 2002)

Exercise Trials

Day One.

Participants attended the Carnegie Research Institute in the evening, between 17.50 and 19.30 to complete a glycogen-depleting bout of exercise on a cycle ergometer. Participants were instructed to avoid strenuous exercise on the day of and the day prior to this visit, and to consume a normal diet but to avoid eating in the two-hours prior to the exercise bout. An established protocol for depleting muscle glycogen was implemented (Kuipers et al., 1987) The bout consisted of 2-minute intervals at 90% $Watt_{max}$, separated by 2-minute recovery period of cycling at 50% $Watt_{max}$. When the participant could no longer maintain a cadence of >60 RPM during the 90% $Watt_{max}$ interval, the intensity of the interval was lowered to 80% $Watt_{max}$. When this could no longer be maintained, the intensity was lowered to 70% $Watt_{max}$. The bout terminated when a cadence of >60RPM could not be maintained at this intensity. The duration of the interval and recovery period remained 2-minutes, and the recovery intensity remained at 50% $Watt_{max}$ throughout. All tests exceeded 60-minutes in duration. Water was consumed *ad libitum*, but no other feeding was permitted. The test was conducted at an ambient temperature of 20°C.

After completing the exercise session, participants consumed a chocolate milk beverage (268 kcal, 41.6g CHO) before leaving the research institute. They were provided with a standardised evening meal of chicken and vegetable stir fry (408 kcal, 12.3g CHO; see Supplementary Material S1 for ingredients and preparation) with the intention of providing sustenance but only partial repletion of glycogen stores (see Table 1 for full nutritional information).

Day Two

In the morning of Day Two, participants consumed a standardised, energy restricted and low-carbohydrate breakfast consisting of scrambled egg on toast (223 kcal, 14.4g CHO; See Table 1 for full nutritional information of evening and morning food intake). Participants arrived at the Carnegie Research Institute to begin a resistance exercise training session 120 minutes after consuming breakfast. The session, preceded by a short warm up of 15 repetitions of each exercise using a low load of 20kg, consisted of six sets of bench press and six sets of the squat exercise, each to failure, at an intensity of 40% 1-RM. Repetitions were completed at a self-selected speed but participants were instructed not to pause between repetitions. A two-minute recovery period separated sets, with 5-minute recovery between the bench press and the squat exercises. This intensity of exercise (40% 1-RM) has been recommended for muscular endurance by the American College of Sports Medicine (2002).

Thirty-second before beginning each set of lifting, 25mL of a mouth-rinse solution was “swilled” for a duration of 10-seconds before being expectorated. In CHO MR, this consisted of a 6.4% maltodextrin solution, with the addition of sucralose ($0.1g\bullet L^{-1}$). The taste-matched solution in PLA consisted purely of sucralose. Both solutions were provided at room temperature.

Due to the single-blind study design, no verbal encouragement was given to participants during the session. Blinding was assessed at the end of each participant’s second trial; five of the participants correctly identified the CHO MR solution, representing successful blinding.

Standardised Meals

Feeding was tightly controlled from the glycogen depletion exercise bout until and throughout the resistance exercise session, with the intention of mimicking an energy-restricted, low-glycogen yet fed state for the resistance training session. Food and drink were provided immediately after the glycogen-depletion bout, for the evening of Day One and for the morning of Day Two. For the evening meal of Day One and breakfast of Day 2, the participant was provided with weighed ingredients and cooking instructions (Supplementary Material S1). Nutritional information is provided in Table 1. In summary, carbohydrate intake was restricted to 68.5g, equating to $1.24\text{-}1.71g\bullet kg$ bodyweight^{-1}. (~$0.09g\bullet hr^{-1}$ intake during the ~16-hour period of dietary control). Total energy intake for the ~16-hour period of dietary control ranged from 25 to 33% of total energy requirements (estimated using the Mifflin equation (Mifflin et al., 1990)).

Participants were instructed to refrain from consuming any additional food, while water was permitted *ad libitum*. Adherence to dietary control was checked upon arrival to the laboratory on Day Two.

Measures

The primary outcome measure was total volume workload for the resistance exercise session. This was calculated as the number of completed repetitions, multiplied by the weight lifted. For ease of interpretation, number of repetitions was presented and compared between the two conditions separately for each exercise and across sets. As the glycogen depletion exercise session consisted only of lower-limb exercise, this allowed for a comparison on training capacity in exercise utilising largely glycogen-restricted muscles of the legs (squat) with exercises utilising muscle which are likely to have been in a much less glycogen-restricted state (bench press).

Secondary outcome measures were obtained to assess mood and perception during exercise. Arousal was assessed using the Felt Arousal Scale (Svebak & Murgatroyd, 1985) and mood was assessed using the Feeling Scale (Hardy & Rejeski, 1989). Measures were obtained immediately prior to the session (during a two-minute rest period between the warm-up and commencement of the training session), at the midpoint of the exercise session, and immediately post-session.

Statistical Analysis

Values are presented as means±standard deviation in the text and tables and means±standard error in figures. Total work done in the session was compared between CHO MR and PLA using a paired-samples T-test. A paired samples T-test was also used to compare the total number of repetitions completed during each exercise between CHO MR and PLA. Repetitions completed across each of the six sets in each exercise was compared between CHO MR and PLA using a two-way (condition x set) repeated-measures analysis of variance (ANOVA). Feeling and arousal scores were also compared using a two-way (condition x time) repeated-measures ANOVA. Any significant interaction or main effects were investigated further using Bonferroni pairwise comparisons. Trial order effects were assessed using paired sample T-tests. For T-tests, effect size was calculated as Cohen's d (d), with 95% confidence intervals (CI) expressed. An effect size of 0.2 or greater was considered small, 0.5 or greater considered medium and 0.8 or greater considered large (Cohen, 1988). For ANOVA, effect size was calculated as partial eta squared (η^2_p).

An *a priori* power calculation was conducted using G*power, based on the findings of previous studies investigating the effect of carbohydrate mouth rinse on performance in a low-carbohydrate-availability state (Kizzi et al., 2016; Lane et al., 2013). A sample size of 12 was required to detect a large effect size (d = 0.8, performance improvement of >3%), with statistical power of >0.8 and an alpha value of 0.05.

Results

Resistance Training Capacity

Total volume workload during the training session was significantly greater in CHO MR vs PLA (9354±2051kg vs. 8525±1911kg, $p = 0.010$; $d = 0.418$, 95% CI = 238kg – 1419kg. Figure 1a and Figure 1b (individual responses)). For the bench press, there was no significant difference in the total number of repetitions completed in CHO MR and PLA (120±24 repetition vs. 115±22 repetitions, $p = 0.146$; $d = 0.198$, 95% CI = -1.9 – 11.0 repetitions), nor when comparing changes in the number of repetitions completed across sets ($p = 0.939$ for condition x set interaction) (Figure 2). For the squat, total number of repetitions completed was significant greater in CHO MR vs PLA (107±26 repetitions vs. 92±16 repetitions, $p = 0.017$; $d = 0.685$, 95% CI = 3.1 – 26.2 repetitions), with no significant difference in changes in the number of repetitions completed across sets ($p = 0.366$ for condition x set interaction) (Figure 3).

There were no trial order effects for any outcome measures (all $p \geq 0.688$).

Figure 1a here

Figure 1b here

Figure 2 here

Figure 3 here

Feelings and Arousal

Feeling and arousal did not differ between conditions (time x condition interactions and condition main effects, $p > 0.05$). Data not shown.

Discussion

The novel finding of this study is that carbohydrate mouth rinse can increase resistance exercise capacity in a glycogen-lowered state. Total volume workload during the session was increased by 9.7% with carbohydrate mouth rinse, equating to 19 more repetitions. Previous studies have failed to demonstrate an ergogenic effect of carbohydrate mouth rinse during resistance exercise (Clarke et al., 2015; Dunkin & Phillips, 2017; Krings et al., 2019; Painelli et al., 2011), but none of these studies investigated responses when resistance exercise was conducted with low carbohydrate availability. The findings of the present study are in agreement with studies investigating the ergogenic effects of carbohydrate mouth rinse on resistance exercise when performed in a fasted state (Clarke et al., 2017; Decimoni et al., 2018).

Given that the glycogen depletion exercise, completed the evening prior to morning resistance exercise, consisted of cycling, it may be assumed that leg muscles but not arm muscles will have been in a low-glycogen state. This model allowed for the comparison of the effects of CHO mouth rinse on resistance exercise capacity in an exercise utilising largely muscles in an adequate glycogen state (bench press) with an exercise utilising largely muscles in a low-glycogen state (squat). The number of repetitions was greater with CHO mouth rinse in squat exercises, but not in the bench press exercise. This is likely due to the enhanced efficacy of CHO mouth rinse to alleviate fatigue and improve performance when in a state of low-carbohydrate availability, as has been observed in previous studies (Ataide-Silva et al., 2016; Fares & Kayser, 2011; Kasper et al., 2016; Kizzi et al., 2016; Lane et al., 2013). Of interest, Bastos-Silva, Prestes & Geraldes (2019) observed enhanced fed-state performance with carbohydrate mouth rinse in upper-body, but not lower-body resistance exercise, contrasting the findings of the present study. This further suggests that our observations can be explained by the likely glycogen availability of the primary muscles used, and that the ergogenic effect of carbohydrate mouth rinse during resistance exercise is moderated by carbohydrate availability.

An alternative explanation for the differing response to bench press and squat exercise is that all participants completed the bench press exercise first, followed by the squat exercise. It is possible that the ergogenic effect of the CHO mouth rinse simply occurred later in the session, as the participant became more fatigued. However, this notion is challenged by the data of Beaven et al. (2013) who demonstrated an ergogenic effect of CHO mouth rinse on mean and peak power output in only the first of five repeated 6-second sprints on a cycle ergometer. This suggests that the ergogenic effect was attenuated later in the exercise bout, rather than becoming more potent. Nonetheless, it would be interesting to investigate the response to both exercises when completed in a counterbalance order (half of the participants complete the bench press exercise first, half complete the squat exercise first), as this will elucidate whether the different response is due to the likely glycogen state of the primary muscles used, or the duration of the exercise bout.

An increased capacity to perform resistance exercise to failure with a CHO mouth rinse was observed in the absence of any improved perception of feeling or felt arousal. This is perhaps surprising, as improvements in resistance exercise performance with carbohydrate mouth rinse in the study of Clarke et al. (2017) were accompanied by greater felt arousal, and carbohydrate mouth rinse has been shown to increase felt arousal without improving maximal strength or muscular endurance (Clarke et al., 2015). Yet, other studies have failed to observe enhanced feelings of arousal with carbohydrate mouth rinse during resistance exercise when no performance improvements have been achieved (Dunkin & Phillips, 2017; Krings et al., 2019). Lower rating of perceived exertion during resistance exercise have been demonstrated with carbohydrate mouth rinse (Decimoni et al., 2018), but as the current study involved exercise to failure, it was felt that this was not a relevant measure.

It was decided to use a low-load protocol for the current study to target muscular endurance exercise (ACSM, 2002). It was considered that this is a key focus for athletes of weight-category sports, seeking to maintain strength and muscle endurance during periods of weight-loss and hence energy and carbohydrate restriction. It is acknowledged that some athletes may wish to gain strength and optimise the maintenance of muscle mass while losing fat and total body mass. However, each set was completed to failure; it has previously been demonstrated that resistance exercise to failure with low-weight (30%

1-RM) can stimulate myofibrillar protein synthesis to a greater extent as resistance exercise to failure with high-weight (90% 1-RM) (Burd et al., 2010). The meta-analysis of Schoenfeld et al. (2017) evidenced that low-load resistance training can elicit hypertrophy to a similar extent as high-load resistance training, but that maximal gains in strength are achieved with high-load training. Nonetheless, future research should investigate the ergogenic effects of carbohydrate mouth rinse in the glycogen-lowered state during acute bouts of resistance exercise of a greater load.

A strength of the current study is that dietary intake was manipulated to create an acute state of energy restriction and low-glycogen availability but yet avoid conducting a resistance exercise training session in the fasted state. This was deemed important to acutely replicate the training and dietary habits of athletes seeking to maintain strength and muscular endurance while losing body mass. This was achieved through standardised dietary controls which were not individualised for each participant. This was deemed appropriate given the homogeneity of the participants with regard to body mass and activity level. A total carbohydrate intake during the period of dietary control of 68g equated to a range of 1.25-1.71 $g \cdot kg$ $bodyweight^{-1}$ for participants. This resulted in an approximate rate of carbohydrate intake of $0.09g \cdot hour^{-1}$ for the ~16 hours between the glycogen depletion bout and the resistance exercise training session, and a rate of approximately $0.36g \cdot hour^{-1}$ during the ~4 hours post-glycogen-depleting exercise. This ensured that all participants ingested carbohydrate at an amount and rate well below that required to adequately restore muscle glycogen after glycogen-depletion (Jentjens & Jeukendrup, 2003). Similarly, relative energy intake, represented as a percentage of estimated total energy requirements, did not differ considerably across participants.

The findings of this study could relay some important practical implications for athletes and those supporting athletes. Periods of energy restriction can increase fatigue and reduce exercise performance of athletes seeking to control bodyweight (Drew et al., 2018; Franchini et al., 2012; Fogelholm, 1994; Koral & Dosseville, 2009; Rossow et al., 2013). During such periods, increases in or maintenance of lean mass, and improvements in strength and power are difficult to achieve (Garthe et al., 2011; Koral & Dosseville, 2009), but can be observed with increased strength training (Donnelly et al., 1993; Sundgot-Borgen & Garthe, 2011) or the combination of resistance exercise and a high protein intake

(Arteta et al., 2014, Churchward-Venne et al., 2013; Thomas et al., 2016). Our data suggest that rinsing the mouth with a carbohydrate solution during resistance exercise may increase training capacity when exercising with low energy and carbohydrate availability, which could lead to preferred changes in body composition and enhanced performance. As such, the use of a carbohydrate mouth rinse could be considered for athletes undertaking resistance exercise in a state of energy restriction or low carbohydrate availability, such as when attempting to make weight, obtain an optimal body composition, or when observing a period of fasting for religious or cultural reasons.

The current investigation is not without limitations. It is acknowledged that a double-blind design would have been preferred. However, the absence of any verbal encouragement helped to negate any effect of a single-blind design, and blinding was shown to be successful when assessed. It is also acknowledged that the exercise bout itself, consisting of 6 sets of just two exercises, may lack ecological validity. However, as explained earlier in this section, this model allowed for the comparison of resistance exercises completed primarily using muscles of likely adequate- and low-glycogen availability, within the same exercise bout. Further, the study population was a convenience sample of resistance trained males, and not weight-category sport athletes or athletes currently seeking to optimise body composition. Such athletes would have made for a more relevant study population and for enhanced ecological validity of the findings.

Measuring muscle glycogen was not possible. As such, assumptions were made regarding the glycogen availability of the exercising muscles after the glycogen depleting exercise and at the time of conducting the resistance exercise. However, the depletion protocol followed has been shown to result in very low muscle glycogen concentrations of the vastus lateralis (Jentjens et al., 2001; Kuiper et al., 1987; van Loon et al., 2000) and such low CHO intake in the post-exercise period ensured minimal glycogen resynthesis. Lastly, it is acknowledged that measures of blood glucose concentration prior to and during the resistance exercise bout would have been an interesting addition; this would have confirmed a state of adequate CHO availability in blood at the onset of exercise, as would be representative of fed-state exercise, and would have confirmed that no CHO was ingested form the mouth rinse.

In conclusion, rinsing with a carbohydrate mouth rinse throughout a low-load resistance exercise bout can increase exercise capacity when performed in the fed but glycogen-lowered state. This was specifically driven by an increase in the workload achieved in exercise primarily using muscle of low-glycogen availability. As such, carbohydrate mouth rinse could constitute an effective ergogenic aid for athletes seeking to maintain muscular endurance and muscle mass through resistance exercise during periods of energy deficit and low carbohydrate availability.

Conflict of Interest

There are no conflicts of interests to declare.

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This study received no external finding.

Author Contributions

MD and AH devised the research question and designed the study protocol. All authors contributed to data collection, data analysis and interpretation and the writing of the manuscript.

References

Achten, J., Gleeson, M., & Jeukendrup, A.E. 2002. Determination of the exercise intensity that elicit maximal fat oxidation. Med Sci Sports Exerc, **34**(1); 92-97. doi:10.1097/00005768-200201000-00015

American College of Sports Medicine. 2002. Position Stand: progression models in resistance training for healthy adults. Med Sci Sports Exerc, **34**; 364-380. doi:10.1097/00005768-200202000-00027

Arteta, J.L., Burke, L.M., Camera, D.M., West, D.W.D., Crawshay, S., Moore, D.R. et al.2014. Reduced resting skeletal muscle protein synthesis is recued be resistacne exercise and protein ingestion following short-term energy deficit. Am J Phyiol Endorinol Metab, **306**(8), E989-997. doi:10.1152/ajpendo.00590.2013

Ataide-Silva, T., Ghiarone, T., Bertuzzi, R., Stathis, C.G., Leandro, C.G., & Lima-Silva, A.E. 2016. CHO Mouth Rinse Ameliorates Neuromuscular Response with Lower Endogenous CHO Stores. Med Sci Sports Exerc, **48**(9); 1810-1820. doi:10.1249/MSS.0000000000000973

Bastos-Silva, V., Prestes, J., & Geraldes, A.A.R. 2019. Effects of carbohydrate mouth rinse on training load volume in resistance exercise. J Strength Cond Res, **33**(6); 1653-1657. doi:10.1519/JSC.0000000000002092

Beaven, C.M., Maulder, P., Pooley, A., Kildruff, L., & Cook, C. 2013. Effets of caffeine and carbohydrate mouth rinse on repeated sprint performance. Appl Physiol Nutr Metab, **38**(6); 633-637. doi:10.1139/apnm-2012-0333

Beelen, M., Berghuis, J., Bonaparte, B., Ballak, S.B., Jeukendrup, A.E., & van Loon, L.J.C. 2009. Carbohydrate Mouth Rinsing in the Fed State: Lack of Enhancement of Time-Trial Performance. Int J Sport Nutr Exe, **19**(4); 400-409. doi:10.1123/ijsnem.19.4.400

Brietzke, C., Franco-Alvarenga, P.E., Coelho-Junior, H.J., Silveira, R., Asano, R.Y., & Pires, F.O. 2019. Effect of carbohydrate mouth rinse on cycling time trial performance: A systematic review and meta-analysis. Sport Med, **49**, 57-66. doi:10.1007/s40279-018-1029-7

Borszcz, F.K., & de Lucas, R.D. 2020. Comment on: "Effect of carbohydrate mouth rinse on cycling time trial performance: A systematic review and meta-analysis" and subsequent comment/Author reply from Li et al. Sport Med, **50**, 629-632. doi:10.1007/s40279-019-01216-4

Burd, N.A., West, D.W., Staples, A.W., Atherton, P.J., Baker, J.M., Moore, D.R. et al. 2010. Low-load high volume resistance exercise stimulates muscle protein synthesis more than high-load low volume resistance exercise in young men. PLoS One, 5(8); e12033. doi:10.1371/journal.pone.0012033

Carter, J.M., Jeukendrup, A.E., & Jones, D.A. 2004. The effect of carbohydrate mouth rinse on 1-h cycle time trial performance. Med Sci Sports Exerc, **36**(12); 2107-2111. doi: 10.1249/01.mss.0000147585.65709.6f.

Chambers, E.S., Bridge, M.W., & Jones, D.A. 2009. Carbohydrate sensing in the human mouth: effects on exercise performance and brain activity. J Physiol, **587**(8); 1779-1794. doi:10.1113/jphysiol.2008.164285

Churchward-Venne, T.A., Murphy, C.H., Longland, T.M., Phillips, S.M. 2013. Role of protein and amino acids in promoting lean mass accretion with resistance exercise and attenuating lean mass loss during energy deficit in humans. Amino Acids, **45**; 231-240. doi: 10.1007/s00726-013-1506-0

Clarke, N.D., Hammond, S., Kornilios, E., & Mundy, P.D. 2017. Carbohydrate mouth rinse improves morning high-intensity exercise performance. Eur J Sport Sci, **17**(8); 955-963. doi:10.1080/17461391.2017.1333159

Clarke, N.D., Kornilios, E., & Richardson, D.L. 2015. Carbohydrate and Caffeine Mouth Rinses Do Not Affect Maximum Strength and Muscular Endurance Performance. J Strength Cond Res, **29**(10); 2926-2931. doi:10.1519/JSC.0000000000000945

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*. New York, NY: Routledge Academic.

Decimoni, L.S., Curty, V.M., Almeida, L., Koch, A.J., Willardson, J.M., & Machado, M. 2018. Carbohydrate mouth rinse improves resistance training session performance. Int J Sports Sci Coach, **13**(5); 804-809. doi:10.1177/1747954118755640

Dohoney, P., Chromiak, J.A., Lemire, D., Abadie, B,R., & Kovacs, C. 2002. Prediction of one repetition maximum (1-RM) strength from a 4-6 RM and a 7-10 RM submaximal strength test in healthy young adult males. J Exerc Physiol, **5**(3); 54-59. doi:10.1519/R-15304.1

Donnelly, J.E., Sharp, T., Houmard, J., Carlson, M.G. Hill, J.O., Whatley J.E., & Israel, R.G. 1993. Muscle hypertrophy with large-scale weight loss and resistance training. Am J Clin Nutr, **58**(4); 561-565. doi:10.1093/ajcn/58.4.561

Drew, M., Vlahovic, N., Hughes, D., Appaneal, R., Peterson, K., Burke, L. et al. 2017. A multifactorial evaluation of illness risk factors in athletes preparing for the Summer Olympic Games. J Sci Med Sport, 20(8); 745-750. doi: 10.1016/j.jsams.2017.02.010

Dunkin, J.E., & Phillips, S.M. 2017. The Effect of a Carbohydrate Mouth Rinse on Upper-Body Muscular Strength and Endurance. J Strength Cond Res, **31**(7); 1948-1953. doi:10.1519/JSC.0000000000001668

Fares, E.J., & Kayser, B. 2011. Carbohydrate mouth rinse effects on exercise capacity in pre- and postprandial States. J Nutr Metab, **2011**; 1-6. doi:10.1155/2011/385962.

Fogelholm,M. 1994. Effects of bodyweight reduction on sports performance. Sports Med, **18**; 249-267.

Franchini, E., Brito, C.J., & Artioli, G.G. 2012. Weight loss in combat sports: physiological, psychological and performance effects. J Int Soc Sports Nutr, **9**(52). doi:10.1186/1550-2783-9-52

Garthe, I., Raastad, T., Refsnes, P.E., Koivisto, A., & Sundgot-Borgen, J. 2011. Effect of two different weight-loss rates on body composition and strength and power-related performance in elite athletes. Int J Sport Nutr Exe, **21**(2); 97-104. doi:10.1123/ijsnem.21.2.97.

Hardy, C.J. & Rejeski, W.J. 1989. Not what, but how one feels: The measurement of affect during exercise. J Sport Exercise Psy, **11**(3); 304-317. doi:10.1123/jsep.11.3.304

Ispoglou, T., O'Kelly, D., Angelopoulou, A., Bargh, M., O'Hara, J. P., & Duckworth, L. C. 2015. Mouth Rinsing With Carbohydrate Solutions at the Postprandial State Fail to Improve

Performance During Simulated Cycling Time Trials. J Strength Cond Res, **29**(8), 2316-2325. doi:10.1519/JSC.0000000000000882

Jentjens, R., & Jeukendrup, A.E. 2003. Determinants of post-exercise gylcogen synthesis during short-term recovery. Sports Med, **33**; 117-144. doi:10.2165/00007256-200333020-00004.

Jentjens, R., van Loon, L.J.C., Mann, C.H., Wagenmakers, A.J.M., & Jeukendrup, A.E. 2001. Addition of protein and amino acids to carbohydrate does not enhance postexercise muscle glycogen synthesis. J Appl Physiol, **91**(2); 839-846. doi:10.1152/jappl.2001.91.2.839

Jeukendrup, A.E. 2017. Periodized Nutrition for Athletes. Sports Med, **47**(Suppl 1); 51-63. doi:10.1007/s40279-017-0694-2

Jeukendrup, A.E., & Chambers, E.S. 2010. Oral carbohydrate sensing and exercise performance. Curr Opin Clin Nutr Metab Care, **13**(4); 447-451. doi:10.1097/MCO.0b013e328339de83

Kasper, A.M., Cocking, S., Cockayne, M., Barnard, M., Tench, J., Parker, L. et al. 2016. Carbohydrate mouth rinse and caffeine improves high-intensity interval running capacity when carbohydrate restricted. Eur J Sport Sci, **16**(5); 560-568. doi:10.1080/17461391.2015.1041063

Koral, J., & Dosseville, F. 2009. Combination of gradual and rapid weight loss:Effects on physiological performacne and psychological state of elite judo athletes. J Sport Sci, **27**(2); 115-120. doi:10.1080/02640410802413214

Krings, B.M., Shepherd, B.D., Waldman, H.S., McAllister, M.J., & Smith, J.W. 2019. Effects of carbohydrate mouth rinse on upper body resistance exercise performance. Int J Sport Nutr Exe, **30**(1); 42-47. doi:10.1123/ijsnem.2019-0073

Kuipers, H., Keizer, H.A., Brouns, F., & Saris, W.H.M. 1987. Carbohydrate feeding and glycogen synthesis during exercise in man. Pflugers Arch, **410**; 652-656. doi:10.1007/BF00581327

Kulaksiz, T.N., Kosar, S.N., Bulut, S., Guzel, Y., Willems, M.E.T., Hazir, T., & Turnagol, H.H. 2016. Mouth rinsing with maltodextrin solutions fails to improve time trial endurance cycling performance in receational athletes. Nutrients, **8**(5), 269. doi:10.3390/nu8050269

Lane, S.C., Bird, S.R., Burke, L.M., & Hawley, J.A. 2013. Effect of a carbohydrate mouth rinse on simulated cycling time-trial performance commenced in a fed or fasted state. Appl Physiol Nutr Metab, **38**(2); 134-139. doi:10.1139/apnm-2012-0300

Li, S., Wu, Y, & Cao, Y. 2019. Comment on: "Effect of carbohydrate mouth rinse on cycling time trial performance: A systematic review and meta-analysis". Sports Med, **49**; 819-821. doi:10.1007/s40279-019-01076-y

Mifflin, M.D., St Joer, S.T., Hill, L.A., Scott, B.J., Daugherty, S.A., & Koh, Y.O. 1990. A new predictive equation for resting energy expenditure in healthy individuals. Am J Clin Nutr, **51**(2); 241-247. doi:10.1093/ajcn/51.2.241

Painelli, V.S., Roschel, H., Gualano, B., Del-Favero, S., Benatti, F.B., Ugrinowitsch, C., et al. 2011. The effect of carbohydrate mouth rinse on maximal strength and strength endurance. Eur J Appl Physiol, **111**(9); 2381-2386. doi:10.1007/s00421-011-1865-8

Pottier, A., Bouckaert, J., Gilis, W., Roels, T., & Derave, W. 2010. Mouth rinse but not ingestion of a carbohydrate solution improves 1-h cycle time trial performance. Scand J Med Sci Sports, **20**(1); 105-111. doi:10.1111/j.1600-0838.2008.00868.x

Riebe, D., Franklin, B.A., Thompson, P.D., Garber, C.E., Whitfield, G.P., Magal, M., & Pescatello, L.S. 2015. Updating ACSM's Recommendations for Exercise Preparticipation Health Screening. Med Sci Sports Exerc, **47**(11); 2473-2479. doi:10.1249/MSS.0000000000000664

Rollo, I., Williams, C., & Nevill, M. 2011. Influence of ingesting versus mouth rinsing a carbohydrate solution during a 1-h run. Med Sci Sports Exerc, **43**(3); 468-475. doi:10.1249/MSS.0b013e3181f1cda3.

Rossow, L.M., Fakuda, D.H, Fahs, C.A., Loenneke, J.P., & Stout, J.R. 2013. Natural bodybuilding competition preparation and recovery: A 12-month case study. Int J Sport Physiol, **8**(5); 582-592. doi:10.1123/ijspp.8.5.582

Shoenfield, B.J., Grgic, J., Ogborn, D., & Krieger, J.W. 2017. Strength and hypertrophy adaptatins between low- vs. high-load resistance training. A systematic review and meta-analysis. J Strength Cond Res, **31**(12); 3508-3523. doi:10.1519/JSC.0000000000002200

Stellingwerff, T. 2012. Case Study: Nutrition and Training Periodization in Three Elite Marathon Runners. Int J Sport Nutr Exe, **22**(5); 392-400. doi:10.1123/ijsnem.22.5.392.

Sundgot-Borgen, J., & Garthe, I. 2011. Elite athletes in aesthetic and Olympic weight-class sports and the challenge of body weight and body compositions. J Sport Sci, **29**(S1); S101-S114. doi:10.1080/02640414.2011.565783

Svebak, E. and Murgatroyd, S. 1985. Metamotivational dominance: A multimethod validation of reversal theory constructs. J Pers Soc Psychol, **48**; 107-116. doi:10.1037/0022-3514.48.1.107

Thomas, D.T., Erdman, K.A., & Burke, L.M. 2016. Position of the Academy of Nutrition and Dietetics, Dieticians of Canada, and the American College of Sports Medicine: Nutrition and Athletic Performance. J Acad Nutr Diet, **116**(3); 501-528. doi:10.1249/MSS.0000000000000852

Trommelen, J., Beelen, M., Mullers, M., Gibala, M.J., van Loon, L.J.C., Cermak, N.M. 2015. A sucrose mouth rinse does not improve 1-hr cycle time trial performance when performed in the fasted or fed state. Int J Sport Nutr Exerc Metab, **25**(6); 576-83. doi:10.1123/ijsnem.2015-0094

van Loon, L.J.C., Saris, W.H.M., Kruijshoop, M., & Wagonmakers, A.J.M. 2000. Maximizing postexercise glycogen synthesis: carbohydrate supplementation and the application of amino acid or protein hydrolysate mixtures. Am J Clin Nutr, **72**; 106-111. doi:10.1093/ajcn/72.1.106

Tables and Figures

Table 1. Nutritional information of the standardised meals.

Meal	Nutritional Information					
	Energy (kcal)	**Carbohydrate (g)**	**Fat (g)**	**Protein (g)**	**Mean±SD %TER**	**Mean±SD g•kg^{-1} Carbohydrate**
Post-exercise beverage: Chocolate milk	268	41.6	5.2	16.4	8.6±0.7%	0.53 ± 0.06
Evening meal: Chicken and vegetable stir fry	408	12.3	18.0	50.0	12.7±1.0%	0.16 ± 0.02
Total evening intake	**676**	**53.9**	**12.6**	**66.4**	**21.1**±1.8**%**	**0.69 ± 0.07**
Breakfast: Scramble egg on toast	267	14.6	13.9	21.7	8.3±0.7%	0.19 ± 0.02
Total evening and morning intake	**943**	**68.5**	**37.1**	**88.1**	**29.4±2.4%**	**1.41 ± 0.15**

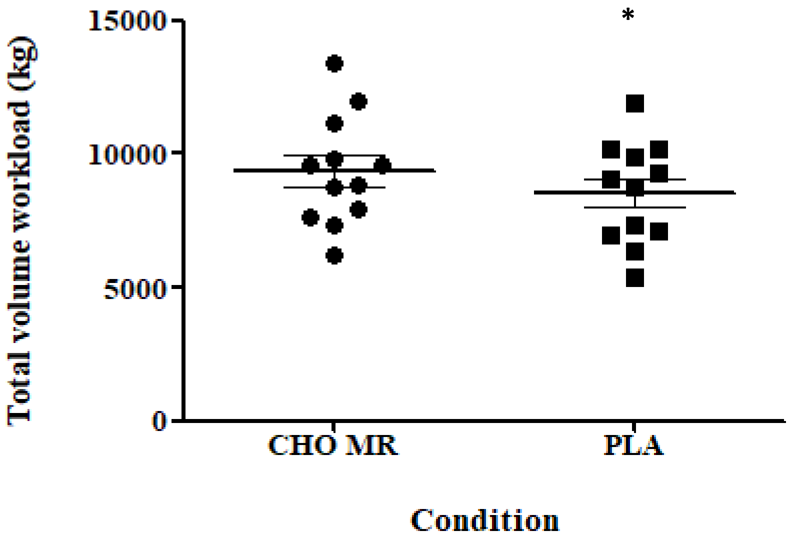

Figure 1a.

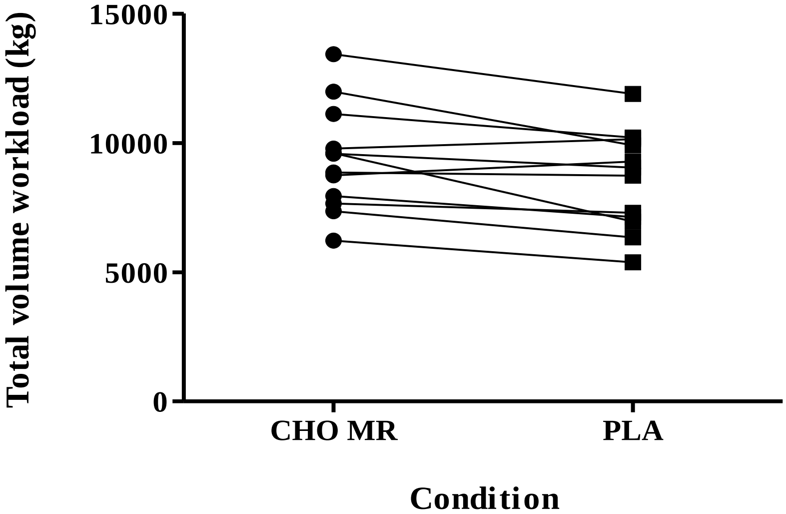

Figure 1b.

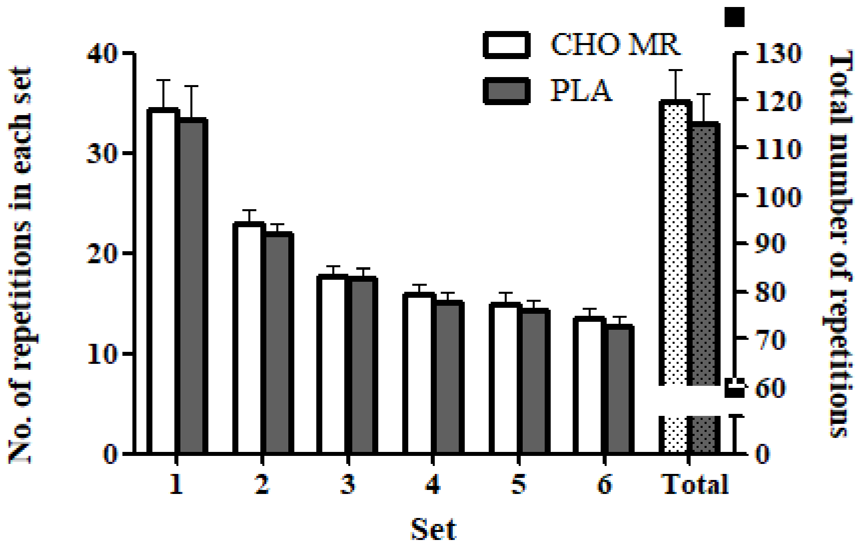

Figure 2.

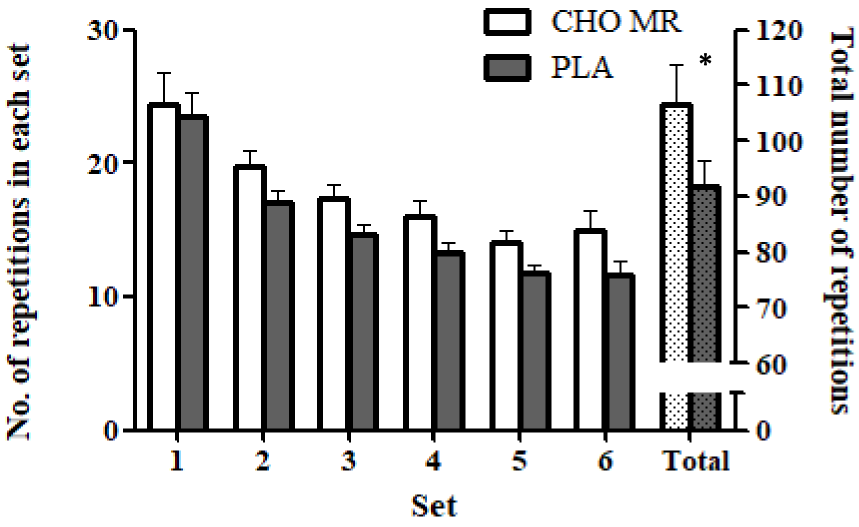

Figure 3.

Figure Captions

Figure 1a. Total volume workload (kg) in CHO MR and PLA. The large horizontal bar represents the mean. The vertical lines represent SEM. The symbols represent individual responses (● = CHO MR, ■ = PLA). * = significant difference between conditions, $p < 0.05$.

Figure 1b. Individual differences in total volume workload (kg) in CHO MR (●) and PLA (■).

Figure 2. Mean±SEM values for total number of repetitions (dotted bars) and repetitions per set (plan bars) for the bench press exercise in CHO MR (white bars) and PLA (grey bars).

Figure 3. Mean±SEM values for total number of repetitions (dotted bars) and repetitions per set (plan bars) for the squat exercise in CHO MR (white bars) and PLA (grey bars). * = significant difference between conditions, $p < 0.05$.