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Original citation:
Clarke, ND & Richardson, DL 2024, 'Habitual carbohydrate ingestion reduces the efficacy of oral carbohydrate rinsing during repetitions to failure', European Journal of Sport Science, vol. (In-Press), pp. (In-Press). https://doi.org/10.1002/ejsc.12084

DOI 10.1002/ejsc.12084
ISSN 1746-1391
ESSN 1536-7290

Publisher: Wiley Open Access

Received: 29 August 2023 | Revised: 15 December 2023 | Accepted: 24 January 2024
DOI: 10.1002/ejsc.12084

ORIGINAL PAPER

Official ECSS Journal Open Access WILEY

Habitual carbohydrate ingestion reduces the efficacy of oral carbohydrate rinsing during repetitions to failure

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Abstract

Carbohydrate mouth rinsing has been reported to enhance exercise performance although individual variation exists. The present study aimed to investigate the effect of habitual dietary carbohydrate intake on the efficacy of rinsing a 6% carbohydrate solution on the number of bench press repetitions to failure at 60% of 1-RM. Twenty-one recreationally active male participants (Mean ± SD) (age: 24 ± 4 years, height: 177.8 ± 7.8 cm, body mass: 78.6 ± 8.1 kg; bench press 1-RM: 73.3 ± 20.5 kg) performed bench press repetitions to failure at 60% 1-RM following rinsing with 25 mL of a 6% carbohydrate (CHO), an artificially sweetened solution (PLA) and a non-rising control condition (CON) in a randomised cross-over design. A 7-day dietary record was completed prior to the first session and subsequently analysed for daily carbohydrate consumption. The number of repetitions performed during CHO (24 ± 4) was higher than CON [21 ± 4; $p < 0.001$; 95% CI: 1, 4; $d = 0.64$], as was PLA [23 ± 4; $p = 0.002$; 95% CI: 1, 3; $d = 0.48$]. However, there was a large, negative relationship [$r = -0.68$ (95% CI: −0.86, −0.36), $p < 0.001$] between daily relative carbohydrate intake (g kg^{-1}) and the difference in the number of repetitions between CHO and PLA. The present study suggests the existence of an inverse relationship between daily carbohydrate ingestion and the efficacy of carbohydrate mouth rinsing; participants who consumed the most daily carbohydrate were generally less likely to see an increase in performance with carbohydrate rinsing.

KEYWORDS
arousal diet, ergogenic, resistance exercise

Highlights

- The use of either carbohydrate or artificially sweetened mouth-rinses are possible strategies to improve resistance exercise performance without the ingestion of energy, which can be helpful when trying to create a caloric deficit.
- Those who regularly consume larger amounts of carbohydrate in their diet may not report the same positive effects compared with those who generally consume less.

- Rinsing with an artificially sweetened solution reduces the exposure of teeth to sugar and potentially be beneficial for those with a history of dental problems such as sensitive teeth and/or enamel erosion.

1 | INTRODUCTION

Carbohydrate mouth rinsing (CMR) has regularly been reported to enhance short-term endurance and high-intensity performance (Hartley et al., 2022). However, evidence for other modes of exercise such as resistance exercise is equivocal (Clarke et al., 2017; Green et al., 2022; Karayigit, Ali, et al., 2021). Furthermore, Karayigit, Forbes, et al. (2021) reported that mouth rinsing with 6%, 12% or 18% carbohydrate solutions did not affect repetitions to failure at 40% 1-RM in trained females suggesting that carbohydrate concentration may not be a factor. Several additional factors potentially explain these inconsistent findings including; fed-fasted status, training background, timing and nature of the mouth rinsing protocol, and the specific way participants exercised for example, single or multiple sets of repetitions to fatigue at a set percentage (typically 40%–80%) of the participants' 1 repetition maximum (1-RM) (Green et al., 2022). For example, Karayigit et al. (2022) reported that CMR increased the number of bench press repetitions to failure at 80% but not 40% of 1-RM.

The underlying mechanism by which the presence of carbohydrate in the mouth is believed to enhance performance is by inducing increased brain activity within the orbitofrontal cortex (De Pauw et al., 2015). In addition, Gant et al. (2010) demonstrated that carbohydrate ingestion can immediately affect performance by increasing corticomotor excitability through non-sweet receptors in the oral cavity area and counteract decreasing motor activity. Similar findings were reported by Chambers et al. (2009), in that, independent of sweetness, carbohydrates can activate brain regions related to reward and motor control, possibly through non-sweet taste receptors found in the mouth.

Many of the investigations regarding resistance exercise have been conducted with sufficient carbohydrate availability (Clarke et al., 2015; Dunkin & Phillips, 2017; Krings et al., 2020). When performed in a fasted state, increased capacity for resistance exercise has been reported following carbohydrate rinsing. Clarke et al. (2017) and Decimoni et al. (2018) observed improvements in resistance exercise performance undertaken after an 8–11 h overnight fast. Similarly, Durkin et al. (2021) observed that rinsing with a carbohydrate solution throughout a low-load resistance exercise bout increased exercise capacity when performed in a postprandial, but glycogen-lowered state. One potential explanation for these differences is the efficacy of the carbohydrate receptors in the mouth. Beelen et al. (2009) speculated that from an evolutionary perspective the receptors may be important under conditions when liver or muscle glycogen stores are reduced, but when glycogen stores are available to sustain intense exercise of short duration the relevance of these receptors is questionable. In addition, there is evidence that consuming sugar-sweetened beverages can impact cortico-striatal responses. Sugar consumption signals the release of dopamine and opioids in the striatum (Lenoir et al., 2007), reinforcing feelings of pleasure and reward (Small et al., 2001). Burger (2017) reported that regular consumption of sugar-sweetened beverages downregulates the striatal response during the intake of those beverages. These data are also consistent with previous reports that showed that habitual eating behaviour was related to decreases in the response to those foods (Green & Murphy, 2012). Therefore, regular high-carbohydrate consumers may not benefit from carbohydrate rinsing to the same extent as those who consume less.

Consequently, the aim of the present study was to investigate the effect of rinsing carbohydrate or artificially sweetened solutions on the number of bench press repetitions to failure at 60% of 1-RM, and in a novel aspect, assess the relationship between habitual carbohydrate intake and performance. The primary outcome measured was the number of bench press repetitions to failure at 60% of 1-RM. Our hypothesis was that rinsing with a carbohydrate solution would be more effective than an artificially sweetened solution. Moreover, we hypothesised that this would be accompanied by an inverse relationship with habitual carbohydrate consumption.

2 | METHODS

In a double-blind (for rinsing) randomised design, 21 recreationally active male participants (Mean ± SD) (age: 24 ± 4 years, height: 177.8 ± 7.8 cm, body mass: 78.6 ± 8.1 kg; bench press 1-RM: 73.3 ± 20.5 kg) were recruited. Participants undertook resistance exercise three to four times a week for at least to 8–12 months, therefore meeting the intermediate resistance training experience classification outlined by the National Strength and Conditioning Association (Sheppard & Triplett, 2015). In addition, the participants had not been taking any supplements, such as beta alanine and creatine, that may influence exercise performance for at least 3 months prior to data collection. Participants reported for testing on four separate occasions. On the first visit bench press 1-RM was determined. On the three subsequent visits participants performed bench press repetitions to failure while rinsing with carbohydrate or placebo, or a control (no rinse) trial. Trials were separated by 4 days. The order of the conditions for each participant was randomised using an online software programme (www.randomizer.org). Participants were instructed to abstain from caffeine ingestion for a minimum of 12 h prior to the trials and to refrain from strenuous exercise for 24 h. In addition, a 7-day dietary record was completed by each participant prior to the first experimental trial. All trials were completed following a 4 hour fast, during which participants were instructed to avoid consumption of food, caffeine, tobacco, or alcohol but were permitted to drink water ad libitum prior to all trials. All trials were conducted at the same time of day and were consistent for each participant in order to minimise circadian variation (Drust et al., 2005). All procedures were undertaken in accordance with the Declaration of Helsinki and approved by the institutional ethics committee with all participants providing written informed consent. The CONSORT guidelines for reporting randomised crossover trials (Dwan et al., 2019) have been followed during the preparation of this manuscript.

The first session was to establish a 1-RM for the bench press, and to allow familiarisation of the repetitions to failure protocol. Following a standardised warm-up with a light resistance that allowed 10 repetitions and then two heavier warm-up sets of two to five repetitions, bench press 1-RM testing was conducted following the National Strength and Conditioning Association guidelines (McGuigan, 2015) until the 1-RM attempt was unsuccessful, or the participant refused to continue. The highest load successfully lifted with proper technique was recorded as the 1-RM value. Throughout the protocol, a spotter was at the head end of the bench to help in raising the bar on a failed attempt and to help the athlete place the bar back on the rack. In addition, a 7-day dietary record was completed by each participant prior to this first session; it was then analysed (Nutritics Research Edition v5.093, Nutritics; Table 1). The dietary record was photocopied and handed back to the participants so that the same diet could be repeated for subsequent trials, which was confirmed verbally prior to each trial. The subsequent three sessions were to complete bench press repetitions to failure at 60% 1-RM. Participants performed repetitions to failure at that weight, ensuring that every repetition was lowered to the chest to standardise the process. A metronome (2 s for both eccentric and concentric phases) was used to control the speed of each repetition. The felt arousal scale (FAS) (Svebak & Murgatroyd, 1985) and rating of perceived exertion (RPE) (Borg, 1982) were used to assess perceptual variables after rinsing and upon completion of repetitions to failure, respectively.

Thirty seconds prior to the repetitions to failure, either 25 mL of a 6% carbohydrate solution (maltodextrin: My Protein) flavoured with orange (no added sugar orange squash, Sainsbury's) (CHO) or water flavoured with orange (no added sugar orange squash, Sainsbury's) (PLA) prepared in accordance with the manufacturer's guidelines and served at room temperature were rinsed around the buccal cavity for 10 seconds. Participants then expectorated the solution back into the plastic cup before starting the exercise protocol. No solution was rinsed during the CON session.

TABLE 1 Participant's mean (±SD) daily diets (n = 21).

	Mean ± SD	Range
Daily energy intake (kcal)	2367 ± 489	1754–3241
Carbohydrate (g)	257 ± 76	138–430
Carbohydrate (g kg^{-1})	3.3 ± 1.1	1.7–5.6
Protein (g)	111 ± 39	53–221
Protein (g kg^{-1})	1.4 ± 0.5	0.7–2.9
Fat (g)	92 ± 35	29–156
Fat (g kg^{-1})	1.2 ± 0.5	0.4–2.0

A statistical power analysis was performed for sample size estimation based on the repetitions to failure at 80% 1-RM in a previous carbohydrate rinsing study (Karayigit et al., 2022). As this study did not present correlation values between conditions, a conservative effect size value of 0.5 was used for the calculation. Consequently, an a priori power calculation suggested a sample size of 18 participants was deemed necessary to detect a difference between conditions given an estimated effect size of 0.34, a $1-\beta$ error probability of 0.95 and an α value of less than 0.05. Data are reported as the mean ± the standard deviation (SD). A one-way analysis of variance (ANOVA) for repeated measures was applied to all variables, except for FAS where a two-way ANOVA was used. Univariate analyses were conducted to test for differences between CHO and PLA using CON and mean relative daily intake of carbohydrate as covariates. When any differences were identified, post-hoc pairwise comparisons with Bonferroni correction were conducted. All data was analysed using JASP (Version 0.16.3). Lastly, 95% confidence intervals (95% CI) and effect sizes [partial eta squared (η_p^2)], defined as trivial (<0.01), small (0.01–0.05), moderate (0.06–0.13) or large (≥0.14), and Cohen's d defined as trivial (≤0.19), small (0.20–0.49), moderate (0.50–0.79) and large (≥0.80) (Cohen, 1992) were also calculated. A Pearson correlation coefficient was also used to examine the relationship between daily carbohydrate intake and the difference in the number of repetitions between CHO and PLA. The magnitude of the correlation (r, 95% CI) was considered as trivial ($r < 0.1$), small ($0.1 \leq r < 0.3$), moderate ($0.3 \leq r < 0.5$), large ($0.5 \leq r < 0.7$), very large ($0.7 \leq r < 0.9$), nearly perfect ($0.9 \leq r < 1.0$), and perfect ($r = 1.0$) (Cohen, 1992).

3 | RESULTS

There was a large increase in the number of bench press repetitions performed at 60% 1-RM following carbohydrate and placebo rinsing compared with the control condition ($F_{2,40-} = 13.782$; $p < 0.001$; $\eta_p^2 = 0.41$; Figure 1). The number of repetitions performed in the carbohydrate trial (24 ± 4) was higher than the control [21 ± 4; $p < 0.001$; 95% CI: 1, 4; $d = 0.64$ (95% CI: 0.23, 1.06)], as was placebo [23 ± 4; $p = 0.002$; 95% CI: 1, 3; $d = 0.48$ (95% CI: 0.10, 0.86)]. However, only a trivial difference was observed between the carbohydrate and placebo trials [($p = 0.592$; 95% CI: −1, 2, $d = 0.17$ (95% CI: −0.17, 0.50)]. In addition, only a trivial order effect was observed [$F_{2,40} = 0.066$; $p = 0.936$; $\eta_p^2 = 0.003$. In univariate analysis, the CON trial was not associated with the difference in performance between CHO and PLA ($F_{1,18} = 2.886$; $p = 0.107$; $\eta_p^2 = 0.14$), whereas mean relative daily intake of carbohydrate was ($F_{1,18} = 16.420$; $p < 0.001$; $\eta_p^2 = 0.47$). Furthermore, when daily carbohydrate intake was considered, there was a large, negative relationship [r = −0.68

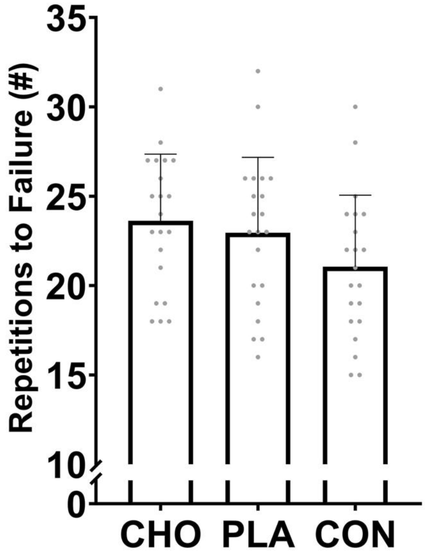

FIGURE 1 The number of bench press repetitions to failure at 60% 1-RM following CHO and PLA rinsing, and a non-rinsing control condition. * The number of repetitions performed during CHO ($p < 0.001$; $d = 0.64$) and PLA ($p = 0.002$; $d = 0.48$) were higher than CON. A trivial difference was observed between CHO and PLA ($p = 0.592$; $d = 0.17$). CHO, carbohydrate; CON, condition; PLA, placebo.

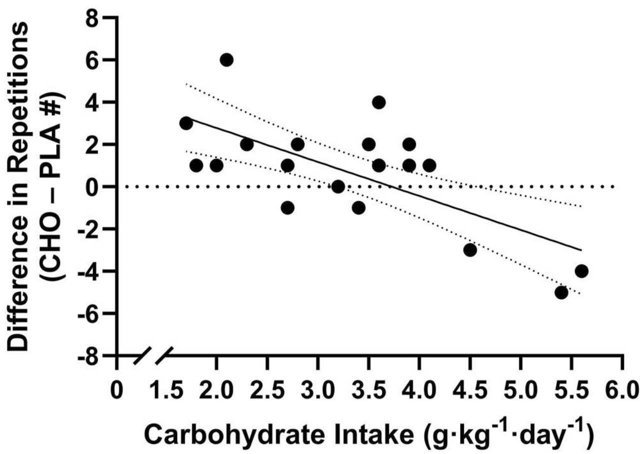

FIGURE 2 The relationship between daily carbohydrate intake and difference in the number of repetitions performed during the carbohydrate and placebo trials ($r = -0.64$ (−0.84, −0.28), $p = 0.002$).

(95% CI: −0.86, −0.36), $p < 0.001$] between daily carbohydrate intake and the difference in the number of repetitions between CHO and PLA (Figure 2).

Compared with the control condition, a large increase in FAS following carbohydrate and placebo rinsing was observed ($F_{2,40} = 6.379$; $p = 0.004$; $\eta_p^2 = 0.24$; Figure 3). Post-rinsing, FAS during the carbohydrate [4.3 ± 0.9; $p < 0.001$; 95% CI: 0.4, 1.6; $d = 1.10$ (95% CI: 0.23, 1.97)] and placebo [4.0 ± 1.1; $p = 0.019$; 95% CI: 0.1, 1.3; $d = 0.77$ (95% CI: −0.02, 1.55)] trials were higher than the

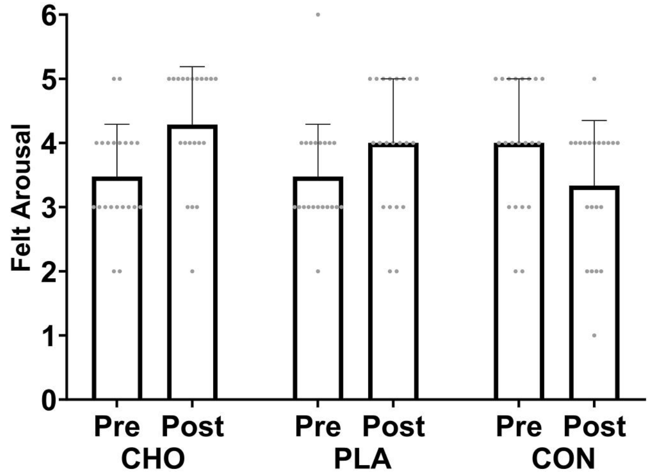

FIGURE 3 Felt arousal following CHO and placebo rinsing, and a non-rinsing control CON. Post-rinsing, FAS during CHO ($p < 0.001$; $d = 1.10$) and PLA ($p = 0.019$; $d = 0.77$) were higher than CON. A small difference between CHO and PLA was observed ($p = 1.00$; $d = 0.33$). CHO, carbohydrate; CON, condition; PLA, placebo.

control condition (3.3 ± 1.0). However, only a small difference between the carbohydrate and placebo trials was observed [($p = 1.00$; 95% CI: −0.3, 0.9, $d = 0.33$ (95% CI: −0.38, 1.04)]. In addition, only a moderate difference in RPE were observed between the CHO (17 ± 2), PLA (17 ± 2) and CON (17 ± 2) trials ($F_{2,40} = 1.340$; $p = 0.273$; $\eta_p^2 = 0.06$).

4 | DISCUSSION

The key finding of the present study was that when compared with a no rinse control condition, oral rinsing with carbohydrate or artificially sweetened solutions significantly improved the performance of bench press repetitions at 60% 1-RM to failure and FAS, without changes in RPE. Furthermore, no significant differences were observed between the carbohydrate and artificially sweetened solution rinsing trials for all variables. However, the novel aspect of the present study highlighted that there was an inverse relationship between habitual daily carbohydrate ingestion and the difference in the number of repetitions between CHO and PLA; those participants who ingested the most carbohydrate tended to exhibit less benefit of carbohydrate rinsing.

Despite the increased number of bench press repetitions performed following CMR compared with the control condition, there was no difference between CMR and PLA. This observation is similar to previous studies (Green et al., 2022) although these findings are not conclusive (Clarke et al., 2017; Karayigit, Ali, et al., 2021). Furthermore, when compared with the control condition, the number of bench press repetitions to failure after orally rinsing a non-carbohydrate solution increased by a similar magnitude as the carbohydrate condition. This observation is similar to that of Green et al. (2022) in that a one repetition increase was observed following rinsing with a taste-matched placebo, although this was compared to a water rinsing trial and not a control condition. In the present study, both rinsing protocols elevated levels of FAS by a similar magnitude which may have contributed to the increased number of repetitions of the bench press exercises observed. Perkins et al. (2001) reported that when athletic performance mainly involves short duration maximal motor activity, like bench press repetitions to failure, increased FAS may be beneficial. In support of this suggestion, the present study observed that when compared with the control condition, mouth rinsing with a placebo solution also caused a large increase in FAS. This occurrence may at least partially explain the improved performance observed in the placebo trial. Perkins et al. (2001) report that relatively high levels of felt arousal are a feature of successful performance where short duration maximal motor activity is required, such as resistance exercise. However, it is possible that the placebo effect is a confounding factor of studies pertaining to the CMR ergogenic effects (Painelli et al., 2022). The placebo effect is a complex phenomenon, but it has been suggested that it involves endogenous opioids and the reward-related dopaminergic system that results in decreased pain and augmented corticospinal facilitation (Pollo et al., 2008), similar to CMR-induced cerebral changes (Chambers et al., 2009). One suggestion for this occurrence is that the presence of water may activate the brain in a similar manner to CMR. De Araujo et al. (2003) reported that the stimulus of water in the mouth activated the medial orbitofrontal cortex region in the brain, which is the same region activated by the prototypical tastants glucose and salt. Consequently, the effect of mouth rinsing itself, may provide ergogenic benefits.

A novel aspect of the present study was assessing the influence of typical carbohydrate intake on the efficacy of CMR. This is the first study to suggest the existence of an inverse relationship between habitual carbohydrate ingestion and the difference in performance between the CHO and PLA trials; the participants who consumed the most daily carbohydrate generally found CMR less beneficial. It has been suggested that CMR activates regions in the brain related to motor output and pleasure/reward (Chambers et al., 2009). Similarly, De Pauw et al. (2015) reported that the presence of carbohydrate within the mouth sends signals that activate the reward centres of the brain, due to a direct link between the buccal mucosa and the brain (Nicolazzo et al., 2003). However, there is evidence that regular consumption of carbohydrates can impact cortico-striatal responses. Holsen et al. (2021) suggested that a long-term high-carbohydrate diet may affect brain reward and homoeostatic activity. Regional cerebral blood flow in the nucleus accumbens, part of the mesoaccumbal reward circuitry implicated in craving and addiction, was 43% higher in adults assigned to a high-compared with low-carbohydrate diet (Holsen et al., 2021). In addition, Burger (2017) reported that regular consumption of sugar-sweetened beverages downregulates the striatal response during the intake of that beverage. These observations, taken with previous reports that habitual eating behaviour is related to decreases in the response to those foods (Green & Murphy, 2012), suggest that regular high-carbohydrate consumers may not benefit as much from carbohydrate rinsing compared with those who consume less as a consequence of reduced neural activity within the striatum following rinsing. However, imaging studies will be required to confirm this. Furthermore, Beelen et al. (2009) speculated that carbohydrate receptors in the mouth may be important under conditions when liver or muscle glycogen stores are largely reduced. In support of this theory, Durkin et al. (2021) observed that rinsing with a carbohydrate solution throughout a low-load resistance exercise bout increased exercise capacity when in a glycogen-lowered state. Therefore, participants with a lower carbohydrate intake may have had less muscle glycogen compared to those participants ingesting more carbohydrate and thus are more likely to experience benefits of CMR.

This study was not without limitations. The use of a dietary record was used to assess habitual carbohydrate intake and whilst being an acceptable method and a good reflection of standard nutritional practice, there may be some concern about the accuracy. Poslusna et al. (2009) found that approximately 30% of respondents in dietary surveys significantly under-reported their true intake, and that energy intake was under-reported by around 15%. Going forward, future studies may employ diets controlled for carbohydrate intake, this would also allow for the investigation into the effect of low (<50 g day^{-1}) and high (10 g kg^{-1} day^{-1}) carbohydrate consumption. Furthermore, blinding effectiveness was not measured, and the 'expectancy' phenomenon may affect the outcomes of the current study. Additionally, this study only included a measurement of performance with no indication of neurological activity. Future studies should explore these potential mechanisms to better understand the combination of energy content, sweet taste, and the presence of fluid in the mouth, as well as habitual carbohydrate intake. In addition, a water-only trial would be interesting due to its potential to activate the same regions of the brain activated by the glucose (De Araujo et al., 2003). Furthermore, only upper body performance was assessed, so whether similar results would be found for lower body exercises or other types of exercise such as back squats remain to be seen. Similarly, the participants were recreational lifters with relatively low 1-RMs with potentially more day-to-day variation in performance, so it would be worthwhile investigating the effects in elite populations. Finally, it would be interesting to investigate whether this effect is present for multiple bouts and if the increased training stimulus translates to sport performance to expand these results to real-world settings.

In conclusion, when compared with a no rinse control condition, oral rinsing with carbohydrate or artificially sweetened solutions improved the performance of bench press repetitions at 60% 1-RM to failure and increased FAS by a similar magnitude, without changes in RPE. Therefore, on a practical level, rinsing with any flavoured solution may be beneficial when performing extended bouts of resistance exercise. However, there was an inverse relationship between daily carbohydrate ingestion and the difference in the number of repetitions between CHO and PLA, suggesting that carbohydrate may be of most benefit to those who habitually consume less carbohydrate.

ACKNOWLEDGEMENTS

We would like to thank all the participants who took part in this study. The authors received no funding from an external source for this work.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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