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Title: **Glucose ingestion does not improve maximal isokinetic force**

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ABSTRACT

The purpose of this study was to assess maximal isokinetic leg extension force in response to glucose ingestion and to determine whether any performance changes occur in a time-dependent manner. Seventeen young (22.1±3.9 years), lean (%BF: 14.3±8.0; %BF Males: 9.7±4.2; %BF Females: 23.7±4.2) and recreationally active (>150min/week of physical activity) male (n=11) and female participants completed the trials. Using a double-blinded cross-over design, participants performed sets of 3 maximum isokinetic efforts on a dynamometer (HumacNorm) before and after (5-, 15-, 30-, 45-, 60-, 75- and 90-min post) ingesting either a carbohydrate (75 g glucose) or isovolumic placebo (saccharin-flavored) drink. Blood glucose and EMG were recorded concurrent with force output (max peak force; mean peak force). Despite a significant rise in blood glucose (mean glycemic excursion = 4.01±1.18 mmol/L), there were no significant interactions in any (absolute or percentage) force (mean peak force: $p \geq 0.683$; max peak force: $p \geq 0.567$) or EMG (mean peak EMG: $p \geq 0.119$; max peak EMG: $p \geq 0.247$) parameters measured. The ingestion of glucose resulted in a 3.4% reduction in mean force across subsequent time points (highest: +2.1% at 15min; lowest: -8.6% at 90min post ingestion), however this effect was small (d<0.1). The ingestion of glucose does not alter performance of maximal isokinetic efforts in recreationally active young individuals. Additionally, there were no differences in force when assessed as a function of time following glucose ingestion. Consequently, in the absence of fatigue, carbohydrate ingestion is unlikely to present any ergogenic benefits to athletes performing resistance-based exercise.

Keywords: Carbohydrate; MVC; Strength; dynamic; contraction

INTRODUCTION

The ergogenic effects of glucose ingestion either prior to (29) or during (21) sustained (>60 min) bouts of exercise are well documented (26). However, the effect of glucose supplementation on performance of shorter duration (<60 min) is inconsistent, with only a limited number of studies reporting some improvements in performance (1, 13, 15, 27, 28); wherein two of these studies had a duration greater than 50 min (1, 15). Additionally, while the study by Lee et al (13) demonstrated improved performance during multiple short-duration (2 x 30 sec efforts interspersed with 10 x 10 sec efforts) cycling bouts following ingestion of carbohydrate, this benefit was ascribed to improved performance in the first 30 sec effort only.

With respect to the role of carbohydrate supplementation in resistance training and force output, the literature is equally conflicting. Some studies have reported a benefit in time to exhaustion tasks (~16 min vs 29 min, placebo vs. carbohydrate; 50% MVC (27, 28)) and performance over multiple resistance training sessions (8), while others observed no improvements in either performance (12, 14, 25) or perceived exertion (24) with dietary carbohydrate manipulation or acute carbohydrate ingestion. Given the ingestion of carbohydrate has other potential benefits (e.g. promoting an anabolic environment (23)) and has not previously been associated with decrements in performance, the ingestion of carbohydrate is still generally recommended for resistance training (7, 19).

More recently, studies have demonstrated that a carbohydrate mouth rinse at regular intervals can stimulate central motor drive and reduce perceived exertion during exercise (4, 6). Specifically, the presence of carbohydrate in the mouth was shown to facilitate corticomotor

output and increase maximal voluntary force (6). This provides an additional previously unrecognised mechanism by which endogenous glucose may improve exercise performance. Based on the current knowledge, we would anticipate the ergogenic effects of endogenous glucose to occur either: (i) shortly following the ingestion of glucose in response to stimulation of glucose-sensitive receptors in the oral cavity (6, 10); or (ii) when blood glucose concentration peaks, thereby increasing total availability of glycolytic substrate (21) and/or regulating muscle activity, specifically by altering electrical properties of the muscle membrane (5, 11) which is associated with increased maximum dynamic force (11). To our knowledge no previous research has assessed changes in force output following glucose ingestion with respect to time. Since multiple potential mechanisms explaining the ergogenic role of glucose exists and time to peak blood glucose concentration following ingestion of glucose varies between individuals, it seems prudent to establish whether force output may alter as a function of time following glucose intake. Thus, the purpose of this study was to determine whether the ingestion of glucose was associated with greater force output during maximal isokinetic contractions, and whether this is altered with time from ingestion. We hypothesised that there would be a moderate, albeit significant increase in force output in response to glucose ingestion, and this would coincide with peak blood glucose concentration.

METHODS

Experimental Approach to the Problem

Following the initial visit and familiarisation session, the experimental trials were completed using a cross-over, double blind experimental design. Allocation to treatment (CHO or PL) occurred by assigning de-identified participant codes to a computer generated randomized number list (consisting of 1's and 2's; counterbalanced) by an individual not involved in the testing session (TJF). Participants were instructed to consume their regular diet on each day prior to participation and to avoid physical activity. All testing was conducted in the morning (0700-1000 hr) following an overnight fast (>12 hours) and was kept consistent between trials.

Subjects

Participants (11 males, 6 females; Height: 175.2 ± 8.1 cm; Weight: 69.5 ± 9.6kg) were young (22.1 ± 3.9 years), lean (BMI: 22.5 ± 2.0 $kg.m^{-2}$; %BF: 14.3 ± 8.0) and recreationally active (>150min/week of physical activity). All participants had resistance training experience in the prior 6 months and were free from illness at the time of testing. The exclusion criteria for study participation were: Existing diabetes mellitus (Type 1 or 2); Pregnancy; BMI>30; medications known to alter glucose concentration; Previous or current injuries and conditions which may be exacerbated as a result of study participation (assessed via the Exercise and Sports Science Association *Pre-Exercise Screening Tool*). Participants were recruited to this study through local advertisement. All aspects of the study were approved by the University's Human Research Ethics Committee in accordance with National Statement on Ethical Conduct in Human Research, 2007.

Procedures

At least three days prior to the first testing session, participants attended a familiarization session which also included collection of anthropometric data including height, weight and percentage of body fat (%BF; 3-site skinfold method (17)). For the familiarization, participants were then fitted to the isokinetic dynamometer (HUMAC NORM, CSMi) in accordance to manufacturer instructions and provided some practice trials (≥5 sets of 3repetitions, with ≥2 sets at maximum effort) using the participants' perceived dominant leg. The back rest was adjusted to create a hip joint angle of 100 degrees from flexion and all trials were performed at a knee angle speed of $60°•sec^{-1}$. The range of motion was set at 10 degrees from anatomical extension to 100 degrees from anatomical extension while the contralateral limb was secured at 90 degrees. These settings were recorded and kept consistent between trials.

Bipolar adhesive surface electrodes (Ag-AgCl, Duo-Trode, Kent, WA, USA) were placed over the muscle bellies of the Vastus Medialis and Vastus Lateralis for assessment of motor recruitment using surface EMG TelemyoDTS (Noraxon, Scotsdale, AZ, USA). Participants then completed a standardised warm-up (2 sets of 3 repetitions at 50% and 75% maximum effort); all repetitions during the warm-up and subsequent trials were performed at $60°•sec^{-1}$. A finger-stick blood sample was then taken for assessment of blood glucose (Accu-Chek glucometer) concentration. All measures were performed in duplicate; where these values differed by more than 20% a third sample was taken. Participants then performed a 3RM followed by ingestion of either the PL or CHO drink. The CHO drink consisted of 75g glucose (Glucodin powder) dissolved in 280ml of water and 20ml of a green-coloured

artificially sweetened (predominantly sucralose; 4kJ•10ml^{-1} undiluted solution) cordial. The PL drink consisted of 260ml of water and 40ml of the same green-coloured artificially sweetened cordial. The drinks were prepared by an individual not directly involved in the data collection, with those conducting data collection remaining naïve to the condition. The drinks were provided in non-transparent drinking containers and participants asked to ingest the solution in 2min. Blood glucose, EMG and isokinetic force were then recorded at 5-min, 15-min, 30-min, 45-min-60-min, 75-min and 90-min from ingestion of the solution. Blood glucose was consistently recorded 1-min prior to the force and EMG recordings. Participants were then asked to recall their dietary intake the day prior to the first testing session (24 h recall) and asked to replicate this diet on the day preceding the next testing session.

After seven days, participants then returned to the laboratory and performed the identical study protocol with the exception of ingestion the alternative drink (CHO or PL). Compliance to a similar diet and restriction of physical activity for the 24 hour period preceding the testing was determined through verbal report from participants.

Force was calculated in two ways; (i) as the maximum peak-force attained during the 3 repetitions (MaxPeak); and (ii) the average force produced during the single repetition which resulted in the greatest peak-force (MeanRep). The raw EMG signal was processed using a custom MATLAB (The Mathworks, USA). Initially the signal was band pass filtered using a 4th order Butterworth filter at 20 and 500Hz. Subsequently the signal was full wave rectified and a linear envelope created using a 6Hz low pass 4th order Butterworth filter. Finally the data was normalised to the maximum EMG recorded in the baseline trial. The mean normalised EMG was then calculated for each of the concentric phases of the isokinetic

exercise. Finally these values were average to provide as estimate of the muscle activation across the three phases.

Statistical Analysis

Data are presented as means ± SD unless otherwise noted. Treatment effects were estimated using separate, random-intercept linear mixed models for each outcome variable (glucose concentration; force output; EMG data). Condition (CHO, PLA) and time (pre, 0, 5, 15, 30, 45, 60, 75, 90 min) were modelled as fixed effects. The hypothesis of interest was the condition by time interaction which we examined with pairwise comparisons of the estimated marginal means. To explore whether MaxPeak or MeanRep force output was different at either the 5-min or at the time-point corresponding to peak glucose concentration, separate repeated measures (Time: pre, 5min; Time: pre, force at peak glucose concentration) ANOVA's were conducted. The glycaemic excursion was calculated as the absolute difference between peak glucose concentration and the blood glucose concentration measured at baseline. Effect size (Cohen's *d*) calculations were performed to assess the magnitude of difference within experimental trials ($d \leq 0.2$, small; 0.5 - 0.79, moderate; ≥ 0.8, strong). All data analysis was performed using IBM SPSS package (ver 21). Significance was set at $\alpha \leq 0.05$.

RESULTS

Ingestion of glucose resulted in a rapid and significant increase in blood glucose concentration, which remained significant until the completion of the 90 min testing period (Figure 1). The mean glycaemic excursion in response to glucose ingestion was 4.01 ± 1.18 mmol/L (95% CI pre-glucose [4.83 – 5.25]; 95% CI peak-glucose [8.51 – 9.59]) indicating a very strong effect (*d*: 5.03) of ingestion on blood glucose. The time to peak glucose concentration varied between participants, ranging from 30 to 60 min (30 min: n=11; 45 min: n=5; 60 min: n=1) following the ingestion of glucose.

There were no significant differences in force when compared as either MaxPeak (p=0.567) or MeanRep (p=0.843). When force output was adjusted for respective baseline values there was no significant interaction, but a significant main effect of condition (Figure 2). The force data corresponding to the glucose condition was extracted and explored further using univariate analysis (Figure 3). There was no difference in either the MaxPeak (p=0.252; *d*=0.076) or the MeanRep (p=0.217; *d* =0.095) 5-min following ingestion of glucose. Likewise, there were no differences in MaxPeak (p=0.337; *d* =0.084) or MeanRep (p=0.703; *d*=0.037) when the time-point corresponding to the maximum glucose concentration was compared to baseline force data.

In agreement with the force data, there were no significant differences in the EMG data corresponding to either the MaxPeak or MeanRep (both p>0.955), although there was a significant main effect of condition (Figure 2). No significant differences were observed when the EMG was expressed relative to the force output during MeanRep (p=0.948).

DISCUSSION

The purpose of this study was to determine whether the ingestion of glucose would enhance force output during maximal isokinetic contractions, and whether this would occur in a time-dependent manner. The main finding of this study was that ingestion of carbohydrate provided no clear benefits to force output during an isokinetic 3RM performance, despite a significant increase in blood glucose concentration. Indeed, when assessing the effect of condition on force output (Figure 2), participants performed better during placebo than glucose ingestion; which may be explained by a slight increase in force output over time during the placebo condition, while force output slightly declined over time during the glucose condition. Similar changes were observed in the EMG (Figure 2) and as a consequence, there was no difference in the Force:EMG ratio response to glucose ingestion.

While the findings of the current study are contrary to the stated hypothesis, closer inspection of the available literature casts some light on these findings. The studies by Wax et al. (27, 28) which demonstrated significant improvements in performance with carbohydrate consumption during a time to exhaustion task used a very different protocol to the one adopted in the current study. Their protocol consisted of repeated 20 sec isometric contractions at 50% MVC followed by 40 sec of rest until exhaustion. As a consequence, the average exercise duration was 16.0 ± 8.1 min and 29.0 ± 13.1 min during the placebo and carbohydrate trials respectively (27); demonstrating a very large effect of the carbohydrate ingestion (d=1.2). Another study investigating the role of carbohydrate ingestion during a time to fatigue task found no significant difference (carbohydrate vs. placebo) in either the number of successful sets (3.5 ± 3.2 vs. 3.5 ± 2.7), repetitions (20.4 ± 14.9 vs. 19.7 ± 13.1), or

total work (29.9 ± 22.3 kJ vs. 28.6 ± 19.5 kJ) performed in the squat exercise (5 repetitions per set) at an intensity of 85% 1RM (12). Possible explanations for the differences observed between the studies of Wax et al. (27, 28) and Kulik et al. (12) may stem from the type of muscular contractions adopted. In particular, isometric contractions at 50% of MVC are expected to partially occlude blood supply (2) and therefore increase the reliance on anaerobic metabolism, specifically via glycolysis. As such, glucose availability may have become a limiting factor to performance in the study of Wax et al. Additionally, participants in the study of Kulik et al ingested the carbohydrate supplement immediately preceding the exercise and then every other successful set of squats; while in the study of Wax et al. participants ingested the carbohydrate every 6 min during exercise. Whether the timing of carbohydrate ingestion may have contributed to the differences observed between studies, or whether altering the timing or pattern of ingestion (i.e. minimum of 15 min pre-exercise to ensure endogenous glucose appearance in blood) influenced results within studies, has not previously been investigated and is therefore unknown.

To examine whether a time-dependent change in force output in response to glucose ingestion occurs, we assessed force output at 5-min post-glucose ingestion and at the time-point corresponding with peak glucose concentration. The 5-min post glucose ingestion time-point was based on a study demonstrating increased corticomotor excitability and maximal voluntary force with the presence of carbohydrate in the mouth (6). This research builds on previous work demonstrating reduced perceived exertion and improved exercise performance (3, 10, 18, 20) in endurance events when carbohydrate (typically in the form of glucose or maltodextrin) was rinsed in the mouth. In contrast to our hypothesis, we observed no difference in maximal voluntary force at 5-min post glucose ingestion, despite the liberal statistical approach (within-condition univariate analysis). Indeed, the calculated effects

(d<0.1 for all) were interpreted as small within the context of the current study design. This finding being similar to what was observed by Painelli et al. (16), where no differences in 1-RM was observed after a carbohydrate mouth rinse. Likewise, in contrast to our a priori hypothesis, there were no differences in any force parameters measured at the time-point corresponding to the maximum glucose concentration (Figure 3).

The rationale for inclusion of EMG in the current study relates to the potential mechanisms for the expected increase in performance with glucose ingestion. Research on the ergogenic effects of glucose during a range of exercise tasks have now extended beyond simply acting as an energy substrate. Indeed, a number of studies now suggest that glucose may alter the electrical properties of the muscle fibre membrane (5, 11, 22) and that this is independent of entry into the glycolytic pathway. Based on these previous findings, the authors of the current study speculated that the Force:EMG ratio would be altered at the time-point corresponding with peak-glucose concentration. However, there were no changes in the EMG either when assessed in isolation (Figure 2) or as a ratio (Force:EMG ratio).

Previous research identified improved performance during isometric time to exhaustion tasks with glucose supplementation (27, 28), although this benefit of glucose did not translate to improved performance during dynamic contractions (12). Moreover, exercise-induced glycogen depletion of muscle fibres has been associated with a decrement in maximal muscular strength during a single dynamic contraction (9). Here, we sought to determine whether previous inconsistencies in findings are a result of a time-dependent effect of glucose supplementation; with a potential benefit of glucose only occurring at the corresponding peak in blood glucose concentration. Results in the current study however, have demonstrated no

benefit for carbohydrate ingestion during performance of maximal force efforts. This is likely due to an adequate supply of additional energetic substrates (e.g. muscle glycogen, ATP/PC) to meet the energetic demands of a maximal effort, and the other proposed ergogenic mechanisms of glucose supplementation not playing a significant role during this type of task. This is the first study, to the authors' knowledge, to examine maximal force output in response to glucose ingestion over time. While the current study adopted an isokinetic testing protocol to appropriately address the study's aims, the findings from this study are expected to be transferable to other modes of strength training and testing; although this may be the focus of future studies.

PRACTICAL APPLICATIONS

There is limited research assessing the role of glucose supplementation on maximal force output. Although some research supports the ingestion of glucose prior to resistance-based exercise, these studies have typically focussed on delaying the onset of fatigue during sustained submaximal efforts, as opposed to enhancing maximal voluntary force capacity. The results of this current study clearly demonstrate that ingestion of glucose does not improve performance of maximal voluntary force during isokinetic leg extensions. In addition, the results of the current study demonstrate that force output did not change at any time-point after glucose ingestion, despite a significant increase in blood glucose concentration. The ingestion of glucose is therefore not expected to provide any immediate performance benefits to resistance-based exercise training.

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Figures

Figure 1 Mean blood glucose response to ingestion of glucose (open circles) or placebo (closed circles) over time. Error bars represent 95% CI. [a]represents significant difference from 0 min; [b]represents significant difference from 5 min; [c]represents significant difference from 15 min; *represents significant difference between conditions.

Figure 2 Percent of initial MeanRep Force (top left panel) and MaxPeak Force (bottom left panel); where initial represents the pre-drink ingestion (0 min). Percent of initial MeanRep EMG (top right panel) and MaxPeak EMG (bottom right panel). Error bars represent 95% CI.

Figure 3 Individual (thin lines) and mean (bold line) force output recorded prior to ingestion of the drink (pre) and 5-min post-ingestion (top panels), and the corresponding force output when peak blood glucose concentration occurred (lower panels; time from ingestion varied)). MaxPeak force is presented in the two left panels, while MeanRep force is presented in the two right panels.