European Journal of Applied Physiology (2021) 121:2849–2858
https://doi.org/10.1007/s00421-021-04753-x

ORIGINAL ARTICLE

Carbohydrate mouth rinsing does not affect 6-min walk test performance and blood glucose responses in older adults

Elizabeth S. Evans[1] · Terrence Brophy[1] · Matthew R. Braswell[1] · Joshua Boyle[1] · G. Keith Harris[2] · Ruth H. Watkins[2] · Stephen P. Bailey[1]

Received: 2 October 2020 / Accepted: 15 June 2021 / Published online: 26 June 2021

Abstract

Purpose Carbohydrate (CHO) mouth rinsing (MR) prior to exercise has been shown to elicit enhanced performance and energy availability in some studies. Previous literature has concentrated on examining CHO MR strategies for improving aerobic endurance performance in younger athletic adults. Knowledge of the impact of CHO MR on functional performance in older adults is scarce. The purpose of this investigation was to determine if CHO MR would improve 6-min walk test (6MWT) performance, perceived exertion, and blood glucose responses in older adults.

Method Thirty-three individuals (16 males, 17 females), age ≥ 70 years performed two 6MWT trials, one of which utilized a 6.4% maltodextrin CHO MR and one of which utilized a placebo MR. Participants held the MR in their mouth for 20 s prior to the 6MWT, and trials occurred in a counterbalanced fashion. Total distance walked and rating of perceived exertion (RPE) were recorded upon completion of each 6MWT. Heart rate (HR), peripheral blood oxygen saturation (SpO_2), systolic and diastolic blood pressures (BP), blood glucose, and blood lactate were measured before and after each 6MWT.

Result CHO MR did not alter the response of any study parameter compared to the placebo MR ($p = 0.13$–0.94). HR, systolic BP, and blood lactate increased and SpO_2 decreased across time ($p < 0.01$).

Conclusion A 6.4% maltodextrin CHO MR did not alter total distance walked, perceived exertion, or other physiological responses elicited by the 6MWT in older adults.

Keywords Functional performance · Geriatric population · Carbohydrate mouth rinse · Blood glucose responses

Abbreviations

CHO	Carbohydrate
MR	Mouth rinse or mouth rinsing
6MWT	6-mn walk test
RPE	Rating of perceived exertion
HR	Heart rate
BP	Blood pressure
SpO_2	Peripheral blood oxygen saturation
PARQ	Physical Activity Readiness Questionnaire
SD	Standard deviation

Communicated by Michael Lindinger .

✉ Elizabeth S. Evans
bevans12@elon.edu

1 Department of Physical Therapy Education, Elon University, 2085 Campus Box, Elon, NC 27244, USA

2 Department of Food, Bioprocessing, and Nutrition Sciences, North Carolina State University, Raleigh, NC, USA

Introduction

Carbohydrate (CHO) mouth rinsing (MR) is an approach that involves holding a CHO solution in the mouth for a specific period of time, and then expectorating it into a container. Previous research has demonstrated that the use of a CHO MR before or during exercise may have potential ergogenic effects in a variety of athletic populations. In cyclists, CHO MR has been shown to improve power output and/or performance time during time trials of varying distances (Baltazar-Martins and Del Coso 2019; Bavaresco Gambassi et al. 2019; Carter et al. 2004; Chambers et al. 2009; Jensen et al. 2018; Murray et al. 2018). In distance runners, rinsing or ingestion of a CHO solution has been shown to increase time to exhaustion during treadmill running (Fraga et al. 2017; Kamaruddin et al. 2019). In recreational soccer players, CHO MR has been shown to increase self-selected jogging speed as well as select aspects of a 15-min sprint exercise (Rollo et al. 2015). In resistance-trained individuals, CHO MR has been shown to improve the number of repetitions performed during a bench press exercise at one repetition maximum (Bastos-Silva et al. 2019). In addition to these observed improvements in exercise performance, CHO MR may also yield positive cognitive effects during exercise such as decreased subjective perception of effort, as well as preserved executive function in response to sustained moderately high-intensity exercise (Konishi et al. 2017; Pomportes et al. 2017).

To explain these improvements in performance, current literature has attempted to uncover the mechanisms behind the physiological effects of a CHO MR. Previous studies suggest the existence of a neural network found in cortical and subcortical structures dedicated to the recognition of forthcoming energy (Gant et al. 2010; Turner et al. 2014). Mouth rinsing a CHO may activate this neural network, by stimulating specific oral taste receptors, which then send afferent signals to the brain indicating that energy is coming (Gant et al. 2010; Turner et al. 2014). Descending motor pathway activity becomes enhanced, thus increasing voluntary muscular force production (Gant et al. 2010; Jeukendrup et al. 2013). Turner et al. (2014) demonstrated this by investigating the effect of a CHO MR vs. a taste-matched placebo solution on handgrip exercise performance while undergoing functional magnetic resonance imaging (MRI). The authors reported that there was greater cortical activation of the sensorimotor cortex while performing the handgrip exercise under the influence of a CHO solution, suggesting that this form of sensorimotor integration occurs devoid of post oral mechanisms (Turner et al. 2014). In addition to improved activation of the sensorimotor cortex, CHO MR has been shown to activate brain regions involved in reward and pleasure, which may also facilitate improved muscular performance (Bailey et al. 2019; Chambers et al. 2009; Yates and Stocker 1998).

With aging, individuals tend to experience a decline in the function of their cardiovascular, musculoskeletal and nervous systems, particularly involving decreases in cardiac output, maximal oxygen uptake, skeletal muscle mass, and nerve conduction velocity (Goodman and Fuller 2015). These physiological declines can make completion of activities of daily living or participation in physical activity increasingly difficult. Therefore, exploring the utility of CHO MR as a technique to improve function and decrease fatigue during activity in this population is relevant.

The majority of studies involving the effects of CHO MR utilize athletic and younger adult populations; however, literature examining the effects of CHO MR in older adults is sparse. One study by Chaffin et al. (2018) suggests that CHO MR improves lower extremity muscle power during a sit-to-stand maneuver in adults age ≥ 70 years. However, studies examining the potential effect of CHO MR on aerobic endurance in older adults are yet to exist. Since endurance capacity is a significant determinant of long-term health and the ability to live independently, investigating techniques to improve energy availability during tasks requiring endurance is warranted (Paterson et al. 2004).

The purpose of this study was to assess if CHO MR will improve performance and decrease perceived exertion during the 6-min walk test (6MWT) in adults age ≥ 70 years. The 6MWT is a valid, reliable, and commonly used test to measure functional endurance in a multitude of populations and is a strong indicator of health status in the geriatric population (Arcuri et al. 2016; Bautmans et al. 2004; Mänttäri et al. 2018; Sciurba and Silva 1998). A secondary purpose was to examine if CHO MR increases blood glucose levels during the 6MWT, a finding which has been observed in previous literature, and could suggest increased energy availability for physical exertion (Ataide-Silva et al. 2016). Thus, this study hypothesized that 6MWT distance would be higher, rating of perceived exertion after the 6MWT would be lower, and that post-6MWT blood glucose levels would be increased after mouth rinsing with a CHO solution compared to a placebo solution. If effective, CHO MR could be a potential strategy to reduce fatigue during exertion and facilitate a transient improvement in exercise capacity, which could foster positive physical rehabilitation outcomes and improve overall physical conditioning.

Methods

Participants

This study included a total of 33 participants; 16 males and 17 females. Individuals were eligible to participate in this study if they were adults, age ≥ 70 years, and were able to ambulate unassisted. Individuals were excluded if they had a cardiovascular, pulmonary, renal, metabolic, neurological, or orthopedic condition that would prevent completion of a 6MWT. Approval was obtained from the Elon University Institutional Review Board for Protection of Human Subjects before proceeding with participant recruitment and testing procedures. All participants read and signed the written informed consent document prior to performing any study procedures.

Overview of the study design

All participants reported to the laboratory facilities in the School of Health Sciences at Elon University for three separate study sessions: a familiarization session and two experimental sessions. During the familiarization session, participants performed a practice 6MWT and were oriented to the procedures and processes that would be used to collect data during the two subsequent experimental sessions. During the two experimental sessions, participants performed the 6MWT under two treatment conditions: a carbohydrate mouth rinse (CHO MR) condition and a placebo MR condition. All participants performed both conditions, and conditions were performed in a counterbalanced fashion, where half of the participants performed the CHO MR condition first and the other half performed the placebo MR condition first. Two of the study researchers (GKH and RHW) prepared the vials of MR solutions, using different vial cap colors to indicate each MR condition. The rest of the study researchers (ESE, TB, MRB, JB, and SPB) were completely blinded to which vial cap colors corresponded to each MR condition until the study was complete. Thus, both the study researchers who directly interacted with the study participants, as well as the participants themselves, were blinded to the contents of the MR vials for the duration of the study. Study participants were not asked to identify which MR vial they thought corresponded to each MR condition.

Total distance walked and rating of perceived exertion (RPE) were recorded at the completion of the 6MWT while blood glucose and lactate concentrations were recorded immediately before and after the 6MWT. Prior to the two experimental sessions, participants were instructed to refrain from food and drink for at least 4 h as well as to refrain from exercise, caffeine and alcohol for at least 12 h. However, participants were instructed to drink water as they normally would. Participants were reminded of these instructions prior to each session, and compliance was confirmed by a research team member at the beginning of each session. The two experimental sessions occurred at the same time of day, and all three sessions for each participant occurred within a 2-week time frame. Each session for each participant was separated by at least 48 h in order to minimize effects of fatigue.

Methodology

Familiarization session

Participants received an explanation of the study purpose, procedures, risks and benefits before signing the informed consent document. Participants completed a medical history questionnaire in order to obtain general health history information and medication use, as well as the Physical Activity Readiness Questionnaire (PARQ) to verify eligibility for participation [Physical Activity Readiness Questionnaire-PARQ (revised 2002)]. Height and body mass were measured using a portable stadiometer and balance beam scale (Health O Meter®, McCook, IL), from which body mass index (BMI) was calculated. Participants were then taken through the procedures involved in performing the 6MWT, including instructions on how the MR solutions would be administered during the subsequent experimental sessions, the instructions for how to complete the 6MWT itself, and a demonstration on how RPE, blood glucose and lactate, heart rate, blood pressure, and peripheral blood oxygen saturation would be measured. Regardless of prior familiarity and experience, all participants performed a practice 6MWT.

Mouth rinse

The two MR conditions were a CHO MR (6.4% maltodextrin) condition and a placebo MR condition. Artificial sweeteners and coloring were added to each MR so that they were indistinguishable in color and taste. Each MR solution was given to participants in a semi-opaque plastic tube, and each was 25 mL in volume. Each participant was instructed to quietly hold the entire 25 mL MR fluid in their mouth for 20 s, and then return the MR back into the tube prior to commencing the 6MWT. As mentioned previously, both the study researchers and participants were blinded to the contents of the MR vials for the duration of the study.

Experimental sessions, 6MWT performance, blood glucose and blood lactate responses

All testing procedure occurred in the exact same manner for all participants during each of the two MR condition sessions. At the beginning of each session, resting blood pressure was measured using a stethoscope and sphygmomanometer (Omron Healthcare Inc., Lake Forest, IL). Resting heart rate and peripheral blood oxygen saturation (SpO_2) were measured using a pulse oximeter placed on a finger and secured to the wrist (Nonan Medical 2500 pulse oximeter, Plymouth, MN). Resting blood glucose and lactate concentrations were assessed using a finger-prick blood sample. Blood glucose was measured using a OneTouch UltraMini glucose meter (Lifescan, Inc., Milipitas, CA), and blood lactate was measured using a Lactate Plus lactate meter (Nova Biomedical, Waltham, MA).

All participants were read the same instructional script by a member of the research team prior to commencing the 6MWT, during which they were told that they were to walk back and forth between two cones, placed 30 m apart. Participants were instructed to cover as much distance as possible during the 6 min, without running or jogging. At the conclusion of the research team member's reading of the instructional script, participants were given the 25 mL vial of MR according to the MR condition assigned to them during that particular session. As described previously, participants held the MR solution in their mouth for 20 s before returning it to the vial. At this time, a 5 s countdown was given, after which participants immediately began the 6MWT. Participants were told how much time remained at the end of each minute; otherwise, no other communication occurred during the 6MWT.

At the end of the 6MWT, participants were told to stop where they were, at which time a chair was brought behind the participant so that they could sit down. Blood pressure, heart rate, and SpO_2 were immediately assessed and recorded as previously described. Rating of perceived exertion (RPE) was recorded using the Borg 6–20 point RPE scale (Borg 1982). Blood glucose and lactate were once again assessed via finger prick and were measured and recorded as previously described. Total distance covered during the 6MWT was recorded.

Statistical analysis

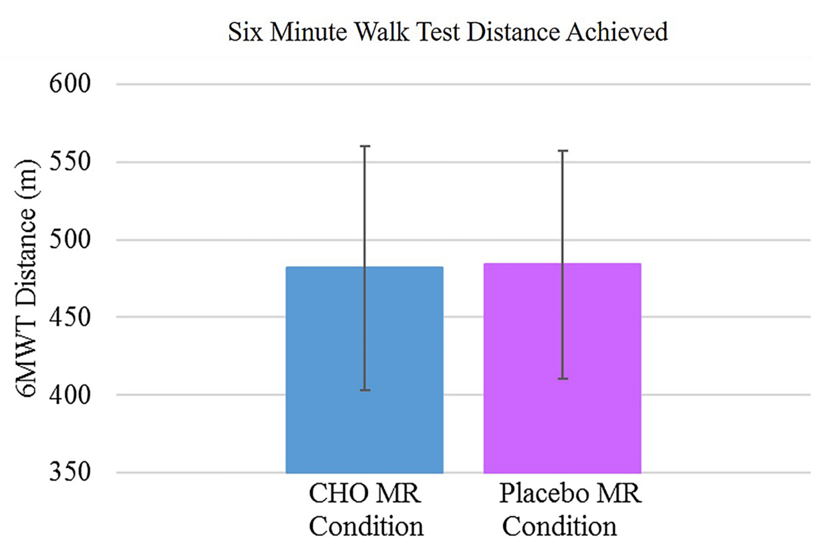
Statistical analyses were performed using IBM SPSS Statistics, version 24.0. Normality of distribution was examined for all variables using the Shapiro–Wilk Test. Since the number of study variables that did and did not meet the assumptions for normality were similar, parametric statistical analyses were used to compare performance between the two MR conditions. More specifically, paired-sample *t* tests were used to compare total distance walked during the 6MWT between the CHO and placebo MR conditions as well as to compare post-6MWT RPE scores between the CHO and placebo MR conditions. 2×2 repeated-measures ANOVAs were used to examine the interactions between condition (CHO MR vs. placebo MR) and time (pre-6MWT vs. post-6MWT) for blood glucose, blood lactate, heart rate, systolic and diastolic blood pressures, and SpO_2. Repeated-measures ANOVAs were also used to examine the interactions between participant-reported sex (male vs. female) and MR condition for total distance walked during the 6MWT and post-6MWT RPE, as well as the interactions between participant-reported sex, MR condition, and time for blood glucose, blood lactate, heart rate, systolic and diastolic blood pressures, and SpO_2. Significance was set a priori at $p < 0.05$, and all data are displayed as mean ± standard deviation (SD).

Results

6MWT performance

Thirty-three adults (16 males, 17 females) participated in the study. Participant physical characteristics were as follows: age = 78 ± 5 years; height = 166 ± 10 cm; body mass = 79 ± 14 kg; and BMI = 29 ± 4 kg/m^2. Total distance walked during the 6MWT for the two MR conditions is shown in Fig. 1. Participants covered similar distances during the 6MWT for the two MR conditions ($p = 0.50$). Participant post-6MWT RPE scores for the two MR conditions are shown in Fig. 2. Participants also reported similar RPE scores after completing the 6MWT for the two MR conditions ($p = 0.26$). Pre- and post-6MWT heart rate, systolic and diastolic blood pressures, and SpO_2 responses for the two MR conditions are shown in Table 1. Heart rate increased significantly from pre-to post 6MWT ($p < 0.01$), an effect that occurred similarly for the two MR conditions ($p = 0.73$). Systolic blood pressure also increased significantly from pre- to post-6MWT ($p < 0.01$), an effect that also occurred similarly for the two MR conditions ($p = 0.25$). Diastolic blood pressure was similar from pre- to post-6MWT ($p = 0.84$), and this effect also occurred similarly for the two

Fig. 1 6-min walk test distance achieved



Abbreviations: CHO = carbohydrate; MR = mouth rinse; 6MWT = six minute walk test.
Values are reported as mean ± SD.

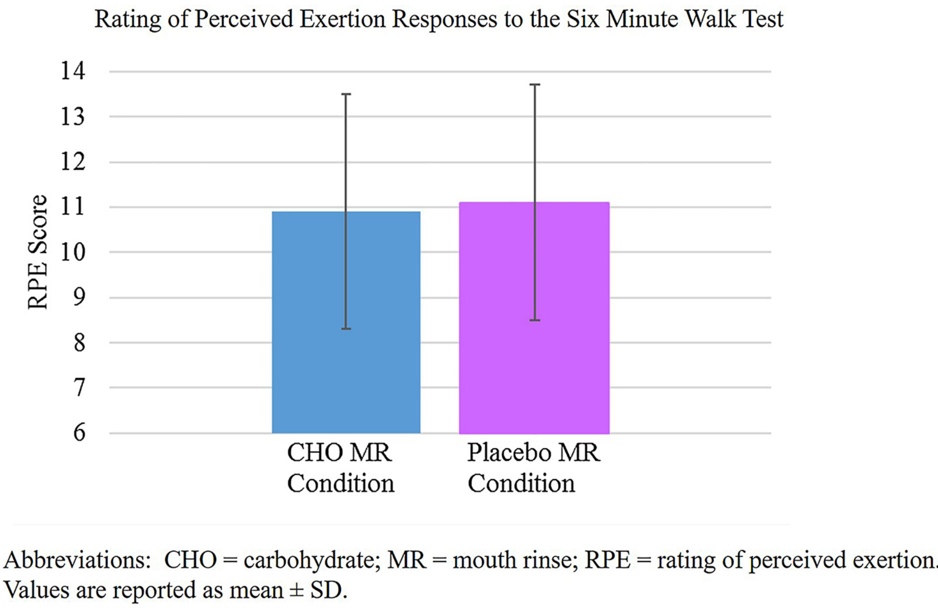


Fig. 2 Rating of perceived exertion responses to the 6-min walk test

Table 1 Heart rate, peripheral blood oxygen saturation, blood pressure, blood glucose and blood lactate responses to the 6-min walk test

Parameter	Time	CHO MR condition	Placebo MR condition
Heart rate (bpm) *	Pre-6MWT	66 ± 11	66 ± 11
	Post-6MWT	98 ± 20	99 ± 18
SpO_2 (%)*	Pre-6MWT	97 ± 1	97 ± 1
	Post-6MWT	95 ± 3	95 ± 3
Systolic blood pressure (mmHg)*	Pre-6MWT	141 ± 13	141 ± 13
	Post-6MWT	162 ± 20	157 ± 17
Diastolic blood pressure (mmHg)	Pre-6MWT	80 ± 6	79 ± 7
	Post-6MWT	80 ± 10	79 ± 9
Blood glucose (mg/dL)	Pre-6MWT	100 ± 15	103 ± 23
	Post-6MWT	100 ± 15	103 ± 24
Blood lactate (mmol/L)*	Pre-6MWT	1.4 ± 0.5	1.3 ± 0.4
	Post-6MWT	2.7 ± 1.0	2.7 ± 1.2

Values are reported as mean ± SD

CHO carbohydrate, *MR* mouth rinse, *6MWT* 6-min walk test, *SpO_2* peripheral blood oxygen saturation

*$p < 0.01$ when comparing pre-6MWT to post-6MWT heart rate, systolic blood pressure, SpO_2, and blood lactate responses for each MR condition

MR conditions ($p = 0.22$). Peripheral blood oxygen saturation (SpO_2) decreased significantly from pre-to post-6MWT ($p < 0.01$), an effect that also occurred similarly for the two MR conditions ($p = 0.54$).

When examining the interaction effects between sex, condition, and time, there was a significant sex × condition interaction effect for diastolic blood pressure. Males exhibited higher diastolic blood pressure responses during the CHO MR condition compared to the placebo MR condition, and females displayed lower diastolic blood pressures during the CHO MR condition compared to the placebo MR condition (82 ± 2 mmHg vs. 78 ± 2 mmHg and 79 ± 2 mmHg vs. 80 ± 2 mmHg, respectively; $p = 0.008$). No other significant interaction effects between sex × time, condition × time, or sex × condition × time were observed for diastolic blood pressure ($p = 0.73$, 0.87, and 0.20, respectively). No significant interaction effects between sex × condition were observed for 6MWT distance ($p = 0.69$) or post-6MWT RPE ($p = 0.57$). No significant interaction effects between sex × condition, sex × time, condition × time, or sex × condition × time were observed for heart rate ($p = 0.93$, 0.37, 0.94, and 0.13, respectively), systolic blood pressure ($p = 0.88$, 0.57, 0.096, and 0.70, respectively), or SpO_2 ($p = 0.67$, 0.55, 0.75, and 0.92, respectively).

Blood glucose and blood lactate responses

Pre- and post-6MWT blood glucose and blood lactate responses for the two MR conditions are also shown in Table 1. Blood glucose concentrations did not significantly vary by MR condition ($p=0.14$) or across time ($p=0.96$). Blood lactate concentrations significantly increased from pre- to post-6MWT ($p<0.01$), an effect that occurred similarly for the two MR conditions ($p=0.45$). No significant sex × condition, sex × time, condition × time, or sex × condition time interaction effects were observed for either blood glucose ($p=0.24$, 0.96, 0.44, and 0.48, respectively) or blood lactate ($p=0.37$, 0.94, 0.82, and 0.76, respectively).

Discussion

This study demonstrated that CHO MR prior to a 6MWT did not influence total distance walked, perceived exertion, heart rate, blood pressure, SpO_2, blood glucose, or blood lactate responses in adults age ≥ 70 years. Heart rate, systolic BP, SpO_2, and blood lactate did significantly change from pre- to post-6MWT, but these changes were not influenced by the CHO MR. To the authors' knowledge, this study is the first to explore CHO MR prior to an aerobic endurance activity in older adults. In doing so, this investigation adds knowledge to the currently-existing CHO MR literature, which has largely focused on the utilization of CHO MR on running and cycling performance in younger athletic adults.

CHO MR is purported to have an ergogenic effect by increasing voluntary force production via enhanced activity of descending motor pathways subsequent to increased stimulation of the sensorimotor cortex (Gant et al. 2010; Jeukendrup et al. 2013; Turner et al. 2014). The results of the current study indicate that this phenomenon is not present in older adults during self-regulated aerobic activity. The findings of this study are similar to the findings of numerous previous investigations that have also found that CHO MR prior to aerobic endurance exercise does not significantly alter exercise performance (Whitham and McKinney. 2007; Gam et al. 2013; Ispoglou et al. 2015; Ali et al. 2016; Kulaksiz et al. 2016; Clarke et al. 2017; Chrysanthopoulos et al. 2018; Feirreira et al. 2018; Pires et al. 2018; Rossato et al. 2019; Muhamed et al. 2020).For example, Pires et al. (2018) examined the effect of a 6.4% glucose MR vs. a placebo MR on 4 km cycling time trial performance in recreational male cyclists. Participants had fasted for 2 h prior to exercise, and were given the MR solutions immediately prior to each trial, with results indicating that mean cycling power and trial completion time (~ 6.4 min) was similar between MR trials (Pires et al. 2018). Rossato et al. (2019) examined the effect of a 6% maltodextrin MR vs. a placebo MR on treadmill running to exhaustion at 100% of VO_{2max} in recreational male runners. Participants had fasted for 8 h prior to exercise, and were given the MR solutions immediately prior to the running trials, again with results indicating that time to exhaustion (~ 3.2 min) was similar between MR trials (Rossato et al. 2019). Similar results have been observed for studies that utilized longer-duration exercise trials lasting approximately 30 min to 1 h (Whitham and McKinney 2007; Gam et al. 2013; Ispoglou et al. 2015; Ali et al. 2016; Kulaksiz et al. 2016; Clarke et al. 2017; Chryssanthopoulos et al. 2018; Ferrreira et al. 2018; Muhamed et al. 2020). These studies utilized CHO MR concentrations ranging from 3 to 15%, and all were repeatedly administered throughout the exercise trials at regular time or distance intervals. Participants in these studies fasted anywhere from 2 h prior to exercise to overnight, and in the study by Ali et al. (2016), participants also completed one of their trials in a glycogen-depleted state. Collectively, these studies also found that CHO MR did not significantly improve performance parameters such as power output, distance covered (for timed trials), or time to completion (for trials involving a fixed distance) and thus support the findings of the current study (Whitham and McKinney 2007; Gam et al. 2013; Ispoglou et al. 2015; Ali et al. 2016; Kulaksiz et al. 2016; Clarke et al. 2017; Chryssanthopoulos et al. 2018; Ferrreira et al. 2018; Muhamed et al. 2020).

In contrast to the current study, as well as the previous studies described above, others suggest that CHO MR may improve either running or cycling performance (Rollo et al. 2010; Sinclair et al. 2014; Ataide-Silva et al. 2016; Fraga et al. 2017; Bataineh et al. 2018; Murray et al 2018; Kamaruddin et al. 2019). In runners, Bataineh et al. (2018) examined the effect of a 7.5% CHO MR vs. a placebo MR or no-MR condition on time to exhaustion during an incremental treadmill test. Participants had fasted for at least 12 h prior to exercise, and were given the MR solutions immediately prior to each treadmill test. The authors found that running velocity and time to exhaustion were higher during the CHO MR trial compared to the placebo MR and no-MR trials (Bataineh et al. 2018). Utilizing longer-duration exercise stimuli, Rollo et al. (2010) examined the effect of a 6.4% CHO MR vs. a placebo MR on distance covered during a 1 h run, while Fraga et al. (2017) examined the effect of a 8% CHO MR vs. a placebo MR on distance covered and time to exhaustion during a run at 85% of VO_{2max}. Participants in the investigation by Rollo et al. (2010) had fasted for 13 h prior to exercise, whereas participants in the investigation by Fraga et al. (2017) had fasted overnight, and in both investigations, the MR solutions were given at 15-min intervals during each run (Rollo et al. 2010; Fraga et al. 2017). In both of these investigations, the authors found that participants' running performance was improved during the CHO MR trial vs. the placebo MR trial for both distance covered (Rollo et al. 2010; Fraga et al. 2017) and time to exhaustion

(Fraga et al. 2017). In a similar fashion, Kamaruddin et al. (2019) examined the effect of a 6% CHO MR vs. a placebo MR on time to exhaustion during a run at 70% of VO_{2peak}, while also examining if participant hydration status affected performance. Participants had fasted overnight prior to exercise, and the MR solutions were given at 15-min intervals during each trial. The authors found that time to exhaustion was highest for the CHO MR trial during which participants were also in the dehydrated state, and that time to exhaustion was higher during both the dehydrated-state CHO MR trial and the euhydrated-state CHO MR trial compared to both the dehydrated-state placebo MR trial and the euhydrated-state placebo MR trial (Kamaruddin et al. 2019).

While the literature previously described above has focused on running and cycling exercise protocols largely utilizing recreational male athletes, it is essential to appreciate the various methodological approaches that these investigations have employed, and to examine if these methodological differences may determine if CHO MR confers a potential ergogenic effect during exercise,. These previous studies, both those that do and do not observe a CHO MR-associated performance effect, all employ a fairly low sample size (e.g. between 6 and 18 participants) and tend to utilize a 6.4% CHO MR concentration, although CHO MR concentrations vary from 3 to 15%. Some of these studies administered the MR once prior to exercise, while others employed a serial MR administration throughout exercise. These studies also collectively vary in exercise stimulus intensity and duration, with most employing exercise trials lasting between 30 min and 1 h, although Pires et al. (2018) and Rossato et al. (2019) utilized protocols with mean completion times of ~3–6 min. Perhaps the key factor that may be associated with an observed ergogenic effect of CHO MR is participant nutritional status (e.g. fed, fasted, glycogen-depleted, dehydrated, or euhydrated-state). In particular, the ergogenic effect of CHO MR on exercise performance tended to be most apparent when participants were in a fasted, dehydrated, or glycogen-depleted state (Ataide-Silva et al. 2016; Bataineh et al. 2018; Fraga et al. 2017; Kamaruddin, et al. 2019; Rollo et al. 2010). Ataide-Silva et al. (2016) suggests that the effects of CHO MR on muscle activity, power output, and exercise performance were more evident when participants were in the glycogen-depleted state vs. the fed or fasted states, possibly because motor drive is enhanced (Ataide-Silva et al. 2016). Kamaruddin et al. (2019) suggests that oral receptors may be more sensitive when the individual is in the dehydrated state; thus, afferent neural information travelling to motor control areas of the brain may be more pronounced. This increased central activation may then translate into improved exercise performance, such as the ability to exercise for a longer period of time before reaching volitional exhaustion (Fraga et al. 2017; Kamaruddin et al. 2019). Similarly, several studies suggest that decreased endogenous glycogen stores and the fasted state may be more likely to yield an observable ergogenic effect of CHO MR because hunger may modify the perceived pleasantness of the CHO MR stimulus (Bateineh et al. 2018; Chryssanthopoulus et al. 2018; Ferreira et al. 2018; Ispoglou et al. 2015; Kulaksiz et al. 2016; Pires et al. 2018; Rollo et al. 2010). Kamaruddin et al. (2019) also suggests that a CHO MR with nutritive properties may have a more pronounced effect on exercise performance compared to a CHO MR that is sweet-tasting, but not nutritive. Ispoglou et al. (2015) comments that CHO MR during the post-prandial period may be more effective when the MR is given for a longer duration (e.g. 10 s), at frequent intervals during exercise (e.g. every 5–6 min), and is accompanied by ad-libitum fluid intake. However, Gam et al. (2013) and Clarke et al. (2017) suggest that repeated CHO MR administrations throughout an exercise trial may interrupt the participants' attention, pacing, and breathing rhythm, which may decrease the likelihood of observing a performance enhancement. While the current study employed a single MR administration for 20 s pre-exercise and utilized a maltodextrin CHO MR, participants were in the fed state, having been required to refrain from food and drink for at least 4 h prior to each MR trial. Therefore, a 4 h post-prandial period may not have been sufficient to alter the participants' endogenous CHO stores to an extent that the CHO MR could provide an observable effect. This mechanism is speculative, considering that findings in the literature regarding the effect of CHO MR in fasted vs. post-prandial individuals is mixed (Chryssanthopoulos et al. 2018).

In the current study, RPE and heart rate were similar between the CHO and the placebo MR trials; findings which are supported by previous literature (Ali et al. 2016; Ataide-Silva et al. 2016; Bataineh et al. 2018; Chryssanthopoulos et al. 2018; Clarke et al. 2017; Ferreira et al. 2018; Fraga et al. 2017; Gam et al. 2013; Ispoglou et al. 2015; Kamaruddin et al. 2019; Kulaksiz et al. 2016; Muhamed et al. 2020; Murray et al. 2018; Rollo et al. 2010; Rossato et al. 2019; Whitham and McKinney 2007). In studies where CHO MR led to improved exercise performance, observing similar heart rate and RPE responses between CHO MR and placebo MR trials may indicate that the CHO MR contributed to a lower perception of work rate, as well as an ability to achieve a higher exercise economy (Bataineh et al. 2018; Gam et al. 2013). Sinclair et al. (2014) noted that CHO MR yielded both increased distance covered and lower RPE scores during a 30-min cycling trial, postulating that the CHO MR contributed to increased motivation and motor control activity which facilitated the improved performance and lower perception of effort. In the current study, neither 6MWT distance achieved, heart rate, nor RPE were significantly impacted by CHO MR, possibly because exercise intensity during the 6MWT was not high enough to be affected by CHO MR, and thus subjective perceived effort was simply not affected (Chryssanthopoulos et al. 2018; Muhamed et al. 2020). Heart rate and systolic blood pressure responses, while exhibiting the physiologically expected increase during the 6MWT, were similar between MR trials, possibly because the sympathetic nervous system and catecholamine-mediated heart rate responses were not significantly influenced by the CHO MR (Chryssanthopoulos et al. 2018; Muhamed et al. 2020). In the current study, SpO_2 did significantly decrease during the 6MWT. However, this mean decrease of 2% (e.g. from 97 to 95%) is within normal limits, and thus is clinically unremarkable. The diastolic blood pressure responses observed in the current study were also within normal limits and displayed typical exertional responses. While a significant sex × condition interaction effect was observed for diastolic blood pressure, the mean responses between MR conditions differed by ~ 2 mmHg. Thus, this change is also clinically unremarkable.

In the current study, blood lactate displayed the physiologically expected increase during the 6MWT, and blood glucose and blood lactate responses were also similar between the CHO and placebo MR trial. These findings that are again supported by previous literature (Ali et al. 2016; Ataide-Silva et al. 2016; Clarke et al. 2017; Fraga et al. 2017; Gam et al. 2013; Ispoglou et al. 2015; Kamaruddin et al. 2019; Kulaksiz et al. 2016; Murray et al. 2018; Rollo et al. 2010; Rossato et al. 2019; Whitham and McKinney 2007). This observation may indicate that sensorimotor integration and other central factors are the more likely mechanisms to be affected by CHO MR, rather than peripheral metabolic factors (Kamaruddin, et al. 2019; Pires et al. 2018). Murray et al. (2018) supported this observation by showing that blood insulin responses, in addition to blood glucose and blood lactate responses, were not significantly affected by CHO MR during a 40 km cycling trial, even when power output and performance time were improved. In contrast, Ataide-Silva et al. (2016) found that blood glucose concentrations during 30 min of cycling at a workload corresponding to 90% of gas exchange threshold were maintained at higher levels when CHO MR was employed. Therefore, it is possible that the CHO MR signaled an increase in sympathetic nervous system activity, thus leading to increased hepatic glucose output and decreased pancreatic insulin release (Ataide-Silva et al. 2016). However, the higher blood glucose levels observed during the CHO trial were fairly small in magnitude, and were not accompanied by a significant difference in CHO oxidation rate between MR trials (Ataide-Silva et al. 2016).

Another possible underlying mechanism may involve age-related declines in gustatory function and taste perception (Fukunaga et al. 2005; Sergi et al. 2017; Wang et al. 2020). Previous literature has indicated that the recognition thresholds of the four basic tastes (e.g. salty, sweet, sour, and bitter) may be significantly higher in elderly vs. younger individuals, which may translate to a decrease in taste perception (Fukunaga et al. 2005; Wang et al. 2020). Taste receptor cell dysfunction, decreased olfaction, salivary gland function and overall oral health, medication side-effects, history of smoking, and presence of certain comorbid diseases are factors that can contribute to decreased taste recognition in older adults (Sergi et al. 2017). The magnitude of age-related changes for specific taste perceptions vary, although all five taste sensations (e.g. bitter, sour, salty, sweet, and umami) appear to be affected (Fukunaga et al. 2005; Sergi et al. 2017; Wang, et al. 2020). Further, while cognitive processes necessary for taste recognition (e.g. language and memory) may decline in older adults, it is more likely that changes in gustatory function at the sensory receptor level are the major contributing factor to age-related declines in taste perception that older adults may experience (Fukunaga et al. 2005). Since no other studies to date have investigated MR applications of varying concentrations and taste sensations in the geriatric population, it cannot yet be determined if using a more concentrated CHO MR solution, and/or a MR solution with a different taste sensation, would have yielded different results. These avenues warrant further investigation.

Strengths and limitations

Significant strengths of this study include its use of a novel population and exercise stimulus. To the authors' knowledge, this is the first study to investigate if CHO MR can influence performance, perceived exertion, and associated physiological responses to an aerobic endurance activity in the geriatric population, with a study sample that included nearly equal numbers of males and females. Whereas the majority of previous studies have utilized higher intensity running or cycling trials, the current study explored the use of a more moderate intensity, shorter duration exercise stimulus—the 6MWT. All participants took part in a familiarization session prior to performing the MR trials, participants served as their own control, and all testing procedures were standardized. This study also included a robust sample size of 33 participants, which is more than twice the size than the majority of the previous studies that have also examined the effects of CHO MR on exercise performance.

This study did not ask participants to standardize their dietary intake, to keep dietary records prior to each MR session, or to alter their medication intake. While all participants were at least 4 h post-prandial and had refrained from caffeine and alcohol intake for at least 12 h prior to each MR session, there was likely some variability in dietary intake and timing (e.g. some participants may have been exactly 4 h post-prandial whereas others may have experienced an overnight fast). Thus, since the current study did not control for dietary intake or timing beyond the previously described pre-testing guidelines, this study is not able to address if there may have been 6MWT performance differences among participants according to dietary intake, or overnight fasting vs. fed state. All participants were read the same instructional script prior to each 6MWT, which told them to walk "as fast as possible," and all participants were oriented to the meaning of the Borg RPE scale. However, it is possible that there was variability in how hard participants pushed themselves when completing the 6MWT. The effectiveness of the study blinding procedure to MR condition was not assessed; therefore, it is possible that participants may have developed their own perceptions of which MR vial they thought corresponded to each MR condition. Lastly, while this study employed a commonly-used MR preparation (6.4% maltodextrin solution), it is possible that the previously-described age-related declines in gustatory function may have decreased participant responsiveness to the CHO MR.

Conclusions

Mouth rinsing with a 6.4% maltodextrin CHO solution did not significantly impact 6MWT performance, perceived exertion, heart rate, blood pressure, SpO_2, blood glucose, or blood lactate responses in adults age ≥ 70 years. The findings of the current study are similar to other investigations that have utilized CHO MR to examine its potential ergogenic effect, while also utilizing a novel study population and exercise stimulus. Future studies examining MR preparations with different concentrations and taste perception qualities may yield further insight into the potential impact of MR strategies on functional performance, fatigue during exertion, and energy availability in the geriatric population.

Acknowledgements This work was supported by Elon University Faculty Research & Development funds. The authors would also like to thank Kyle Edwards, Rachel Mason, and Nicole Turcotte for their assistance with data collection.

Author contributions ESE and SPB conceived and designed the research study. ESE, TB, MRB, JB, and SPB collected data. ESE conducted data analyses. RHW and GKH created and contributed the MR solutions. ESE, TB, MRB, and JB wrote the first draft of the manuscript, and all authors commented on previous drafts of the manuscript. All authors read and approved the manuscript.

Funding This research was supported by Elon University Faculty Research & Development (FR&D) funds.

Data availability The data sets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors have no conflicts of interest or competing interests to declare that are relevant to the content of this article.

Ethics approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. As stated in the Methods section, all procedures were approved by the Elon University Institutional Review Board (IRB).

Informed consent All study participants gave their written informed consent prior to commencing study procedures.

References

Ali A, Yoo MJY, Moss C, Breier BH (2016) Carbohydrate mouth rinsing has no effect on power output during cycling in a glycogen-reduced state. J Int Soc Sports Nutr 13:19

Arcuri JF, Borghi-Silva A, Labadessa IG, Sentanin AC, Candolo C, Pires Di Lorenzo VA (2016) Validity and reliability of the 6-minute step test in healthy individuals: a cross-sectional study. Clin J Sport Med 26:69–75

Ataide-Silva T, Ghiarone T, Bertuzzi R, Stathis CG, Lenadro CG, Lima-Silva AE (2016) CHO mouth rinse ameliorates neuromuscular response with lower endogenous CHO stores. Med Sci Sports Exerc 48:1810–1820

Bailey SP, Hibbard J, La Forge D et al (2019) Impact of a carbohydrate mouth rinse on quadriceps muscle function and corticomotor excitability. Int J Sports Physiol Perform 14:927–933

Baltazar-Martins G, Del Coso J (2019) Carbohydrate mouth rinse decreases time to complete a simulated cycling time trial. Front Nutr 6:65

Bastos-Silva VJ, Prestes J, Geraldes AAR (2019) Effect of carbohydrate mouth rinse on training load volume in resistance exercises. J Strength Cond Res 33:1653–1667

Bataineh MF, Al-Nawaiseh AM, Abu Altaieb MH et al (2018) Impact of carbohydrate mouth rinsing on time to exhaustion during Ramadan: a randomized controlled trial in Jordanian men. Eur J Sport Sci 18:357–366

Bautmans I, Lambert M, Mets T (2004) The 6-min walk test in community dwelling elderly: influence of health status. BMC Geriatr 4:6

Bavaresco Gambassi B, de Santana G, Barros Leal Y, Pinheiro Dos Anjos ER et al (2019) Carbohydrate mouth rinse improves cycling performance carried out until the volitional exhaustion. J Sports Med Phys Fitness 59:1–5

Borg GA (1982) Psychophysical bases of perceived exertion. Med Sci Sports Exerc 14:377–381

Carter JM, Jeukendrup AE, Jones DA (2004) The effect of carbohydrate mouth rinse on 1-h cycle time trial performance. Med Sci Sports Exerc 36:2107–2111

Chaffin LE, Holder K, Ichoku C et al (2018) Impact of a carbohydrate mouth rinse on muscle and functional power in older adults. Med Sci Sports Exerc 50(5S):730

Chambers ES, Bridge MW, Jones DA (2009) Carbohydrate sensing in the human mouth: effects on exercise performance and brain activity. J Physiol 587:1779–1794

Chryssanthopoulos C, Oosthuyse ZC, T, et al (2018) Carbohydrate mouth rinse does not affect performance during a 60-min running race in women. J Sports Sci 36:824–833

Clarke ND, Thomas JR, Kagka M, Ramsbottom R, Delextrat A (2017) No dose-response effect of carbohydrate mouth rinse

concentration on 5-km running performance in recreational athletes. J Strength Cond Res 31:715–720
Ferreira AMJ, Farias-Junior LF, Mota TAA et al (2018) Carbohydrate mouth rinse and hydration strategies on cycling performance in 30 km time trial: a randomized, crossover, controlled trial. J Sport Sci Med 17:181–187
Fraga C, Velasques B, Koch AJ et al (2017) Carbohydrate mouth rinse enhances time to exhaustion during treadmill exercise. Clin Physiol Funct Imaging 3:17–22
Fukunaga A, Uetmatsu H, Sugimoto K (2005) Influences of aging on taste perception and oral sensation. J Gerontol A Biol Sci Med 60A:109–113
Gam S, Guelfi KJ, Fournier PA (2013) Opposition of carbohydrate in a mouth-rinse solution to the detrimental effect of mouth rinsing during cycling time trials. Int J Sports Nutr Exerc Metab 23:48–56
Gant N, Stinear CM, Byblow WD (2010) Carbohydrate in the mouth immediately facilitates motor output. Brain Res 1350:151–158
Goodman CC, Fuller KS (2015) Pathology: implications for the physical therapist, 4th edn. Elsevier, St. Louis
Ispoglou T, O'Kelly D, Angelopoulou A, Bargh M, O'Hara JP, Duckworth LC (2015) Mouth rinsing with carbohydrate solutions at the post-prandial state fail to improve performance during simulated cycling time trials. J Strength Cond Res 29:2316–2325
Jensen M, Klimstra M, Sporer B, Stellingwerff T (2018) Effect of carbohydrate mouth rinse on performance after prolonged submaximal cycling. Med Sci Sports Exerc 50:1031–1038
Jeukendrup AE, Rollo I, Carter JM (2013) Carbohydrate mouth rinse: performance effects and mechanisms. Sports Sci Exchange 26:1–8
Kamaruddin HK, Ooi CH, Mundel T, Aziz AR, Che Muhamed AM (2019) The ergogenic potency of carbohydrate mouth rinse on endurance running performance of dehydrated athletes. Eur J Appl Physiol 119:1711–1723
Konishi K, Kimura T, Yuhaku A et al (2017) Mouth rinsing with a carbohydrate solution attenuates exercise-induced decline in executive function. J Int Soc Sports Nutr 14:45
Kulasiz TN, Kosar SN, Bulut S et al (2016) Mouth rinsing with maltodextrin solutions fails to improve time trial endurance cycling performance in recreational athletes. Nutrients 8:269
Mänttäri A, Suni J, Sievänen H et al (2018) 6-min walk test: a tool for predicting maximal aerobic power (VO2 max) in healthy adults. Clin Physiol Funct Imaging 38:1038–1045
Muhamed AS, Mohd Puad NFR, Kuan G (2020) Effects of carbohydrate mouth rinsing on salivary lysozyme, mood states, and running performance among recreational runners. Malays J Med Sci 27:87–96
Murray KO, Paris HL, Fly AD, Chapman RF, Mickleborough TD (2018) Carbohydrate mouth rinse improves cycling time-trial performance without altering plasma insulin concentration. J Sports Sci Med 17:145–152
Paterson DH, Govindasamy D, Vidmar M, Cunningham DA, Koval JJ (2004) Longitudinal study of determinants of dependence in an elderly population. J Am Geriatr Soc 52:1632–1638
Physical Activity Readiness Questionnaire—PARQ (revised 2002). https://www.fgcu.edu/mariebcollege/rehabilitationsciences/exercisescience/files/EIM-PAR-Q1-ada.pdf. Accessed 31 July 2020
Pires FO, Brietzke C, Pinheiro FA et al (2018) Carbohydrate mouth rinse fails to improve four-kilometer cycling time trial performance. Nutrients 10:342
Pomportes L, Brisswalter J, Casini L, Hays A, Davranche K (2017) Cognitive performance enhancement induced by caffeine, carbohydrate and guarana mouth rinsing during submaximal exercise. Nutrients 9:589
Rollo I, Cole M, Miller R, Williams C (2010) Influence of mouth rinsing a carbohydrate solution on 1-h running performance. Med Sci Sports Exerc 42:798–804
Rollo I, Homewood G, Williams C, Carter J, Goosey-Tolfrey VL (2015) The influence of carbohydrate mouth rinse on self-selected intermittent running performance. Int J Sport Nutr Exerc Metab 25:550–558
Rossato LT, Fernandes CTM, Vieira PF et al (2019) No improvement in running time to exhaustion at 100% VO_{2max} in recreationally active male runners with a preexercise single-carbohydrate mouth rinse. Int J Sports Physio Perform 14:1178–1183
Sciurba F, Slivka W (1998) 6-min walk testing. Semin Resp Crit Care Med 19:383–392
Sergi G, Bano G, Pizzato S, Veronese N, Manzato E (2017) Taste loss in the elderly: possible implications for dietary habits. Crit Rev Food Sci Nutr 57:3684–3689
Sinclair J, Bottoms L, Flynn C et al (2014) The effect of different durations of carbohydrate mouth rinse on cycling performance. Eur J Sport Sci 14:259–264
Turner CE, Byblow WD, Stinear CM, Gant N (2014) Carbohydrate in the mouth enhances activation of brain circuitry involved in motor performance and sensory perception. Appetite 80:212–219
Wang JJ, Liang KL, Lin WJ, Chen CY, Jiang RS (2020) Influence of age and sex on taste function of healthy subjects. PLoS ONE 15:e0227014
Whitham M, McKinney J (2007) Effect of a carbohydrate mouthwash on running time-trial performance. J Sports Sci 25:1385–1392
Yates BJ, Stocker SD (1998) Integration of somatic and visceral inputs by the brainstem. Exp Brain Res 119:269–275