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EFFECTS OF CHEWING TIME ON GASTROINTESTINAL DISCOMFORT, SUBSTRATE
USE, AND PERFORMANCE DURING RUNNING

By

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B.S. December 2020, Old Dominion University

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ABSTRACT

EFFECTS OF CHEWING TIME ON GASTROINTESTINAL DISCOMFORT, SUBSTRATE USE, AND PERFORMANCE DURING RUNNING

Thomas Ryan Geaney
Old Dominion University, 2023
Director: Dr. Patrick B. Wilson

Previous research has shown that food particle size affects gastric processing. For example, food particles greater than 3 mm may delay gastric emptying under certain conditions. Delays in gastric emptying can be problematic during aerobic exercise, leading to nausea, bloating, fullness, and other gastrointestinal (GI) symptoms. In some cases, symptoms can be severe enough to negatively affect athletic performance. This study investigated the effects of manipulating chewing duration of carbohydrate sports bars on GI discomfort, physiological responses, and performance during endurance running. This crossover study recruited 12 male runners (age: 36.4 ± 7.2 years, VO_{2peak} : 57.2 ± 4.7 ml/kg/min) who completed 20 (20CHEW) and 40 (40CHEW) mastication cycle treatments in a counterbalanced order. The 40CHEW treatment and 20CHEW treatment followed the same testing parameters. Participants attended three testing sessions. The initial visit required a VO_{2peak} test, a 10-minute familiarization run at 60% VO_{2peak} , and a performance test (10 minutes at 90% VO_{2peak} , followed by time to exhaustion at 100% VO_{2peak}). All testing was conducted on a treadmill. The second visit consisted of a 60-minute run at 60% VO_{2peak} , followed by the same performance test. Each participant was fed 45 g of a sports bar in 9-g servings 30 minutes before running. During the 40CHEW trial, participants ingested 27 g of the sports bar in 9-g servings at three time points; each feeding was chewed in 40 masticatory cycles, at 1 chew per second. During the 20CHEW trial, participants performed the same testing, except the bar was chewed in 20 masticatory cycles at a rate of 1 chew per second.

Measured variables included GI symptoms, rating of perceived exertion, overall affect/mood, blood glucose, substrate use, heart rate, and time to exhaustion. Our results showed that TTE, GI symptom changes, substrate use, and blood glucose had no significant between-conditions effects, while RPE and FS had a significant time by condition effect. Nevertheless, despite our different chew conditions, extended chewing likely has less of an impact on physiology and sports performance than hypothesized.

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This thesis is dedicated to the proposition that it doesn't matter who you were the day before, but how you use that person to become the best version of yourself.

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NOMENCLATURE

BG Blood glucose

GI Gastrointestinal

HR Heart rate

HPL Human Performance Laboratory

RPE Rating of perceived exertion

TTE Time to exhaustion

VO_{2max} Maximal oxygen consumption

VO_{2peak} Peak oxygen consumption

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CHAPTER 1

INTRODUCTION

Long distance running applies to distances between 3,000 meters and the standard 26.2-mile marathon, with races beyond the traditional marathon recognized as ultra-marathons (Thompson, 2017). Participation in distance running has increased substantially in recent decades. Between the years 2009-2019, participation in 5-kilometer, 10-kilometer, half-marathon, and full-marathon distances has increased by 57.8% (Andersen, 2019).

Following a proper diet that meets the necessary energetic and substrate demands of endurance running is an essential component for runners (Baranauskas et al., 2015). An endurance athlete's diet generally consists of ingesting an abundance of carbohydrates (Baranauskas et al., 2015). Following a high-carbohydrate diet is essential for most endurance athletes, as muscle glycogen stores are a major fuel source that need replenishing with heavy exercise (Ivy, 1991). Furthermore, the ability for an endurance athlete to perform at high exercise intensities correlates to how much muscle glycogen is available (Ivy, 1991). It is suggested that greater levels of muscle glycogen extend exercise time to exhaustion by helping to maintain glucose oxidation (Cox et al., 2010; Ivy, 1991). In theory, replenishing muscle glycogen stores will optimize performance and recovery (Ivy, 1991).

Muscle glycogen levels progressively decline during exercise, particularly for bouts lasting over 2 hours (Romijn et al., 1993). This progressive decline leads to a subsequent reduction in carbohydrate oxidation rate (Romijn et al., 1993). Cermak and van Loon (2013) recommend athletes should ingest carbohydrates during prolonged bouts of exercise. Ingesting carbohydrates during extended bouts of exercise can ultimately benefit sport performance by

maintaining overall carbohydrate oxidation and sparing muscle glycogen stores (Cermak & van Loon, 2013).

Exogenous carbohydrate feedings typically come in the form of drinks, gels, bars, or a mixture of formats (Guillochon & Rowland, 2017). However, certain sources of carbohydrates, such as sports bars, may produce greater levels of GI discomfort during exercise (Guillochon & Rowlands, 2017). This potential increase in GI discomfort is likely caused by a delay in digestion. Food particles that are too large may delay transit time from the stomach through the pyloric sphincter into the small intestine and result in a longer digestion time (Boland, 2006). Food texture also impacts digestion. Coarser food textures have been known to delay gastric emptying through increases in particle viscosity (Vincent et al., 1995). The likelihood of experiencing GI symptoms may increase when more viscous food is ingested (Krishnasamy et al., 2020). Under some circumstances, this could negatively impact exercise performance, as was experienced in Gullichon and Rowlands (2017).

Problem

There is a lack of research investigating the effects of chewing time of carbohydrate-rich sports bars on GI discomfort and physiological responses in long-distance runners. Research suggests longer mastication time could increase food particle breakdown by shortening the time it takes for food particles to pass from the stomach into the small intestine (Pera et al., 2002). Increased mechanical breakdown of food could, in theory, reduce GI discomfort in long-distance runners that consume carbohydrate-rich sports bars during competition. The aim of this study was to investigate if greater chewing time of carbohydrate-rich sports bars will reduce GI discomfort, change substrate use, alter overall affect, and impact performance during endurance running.

Hypothesis

Chewing carbohydrate bars for 40 seconds, as compared to 20 seconds, will reduce GI discomfort, improve emotional well-being, reduce rating of perceived exertion, increase blood glucose, increase carbohydrate oxidation, and improve performance during endurance running.

Purpose

This study investigated the effects of longer mastication on GI discomfort. It is presumed that longer mastication time will reduce GI discomfort and alter substrate use during running through increased food particle breakdown.

Delimitations

This study had 12 healthy adult males with a history of endurance running complete all of the visits. The participants did not have a history of cardiovascular disease, Celiac disease, inflammatory bowel disease, pulmonary diseases (except controlled asthma), diabetes, nut allergies, chewing difficulties, or swallowing problems. The participants performed the running portion of the experiment on a treadmill. Chewing time of carbohydrate bars in the 40-second condition was longer in duration than what many runners may be used to.

Problem

Even though relative exercise intensity was matched between experimental trials, absolute intensity level of the treadmill was different, as each participant had a different aerobic capacity. Physiological factors such as height, weight, and body composition were different. Each participant's biology with respect to digestive processes (salivary and gastric enzyme

activity, oral health, gastric function) was different and not directly measured in the investigation.

Operational Definitions

1. Abdominal cramping: Pain located in the abdominal region (Abdullah & Firmansyah, 2012)
2. Bloating: Discomfort in the abdomen caused by gas and abdominal distention (Seo et al., 2013).
3. Blood glucose: The concentration of glucose in the blood, usually expressed as mg/dL (Pickering & Marsden, 2014)
4. Carbohydrate oxidation: The process of breaking down carbohydrates and oxidizing them for energy. It can be estimated from oxygen consumption and carbon dioxide production (Patel et al., 2018).
5. Carbohydrate sports bar: A solid food, containing primarily carbohydrate but also some fat and protein, that is used to provide athletes with energy during sports performance and training (Rauch et al., 1999)
6. Chewing/mastication: A complex process involving the breakdown of food into smaller particles by the teeth, tongue, and movements of the mouth (Van der Bilt et al., 2006)
7. Digestion: The process of chemically and mechanically breaking down food into lesser particles to allow sufficient transit through the gastrointestinal system (Boland, 2006).
8. Fullness: A sensation, usually in the postprandial period, that can be described as the feeling of stomach fullness (Khayyam et al., 2010)
9. Gas/flatulence: Gas produced by the large intestine that evacuates through the anus (Azpiroz et al., 2014)

10. Gastrointestinal system: The system of the body that starts from the mouth to the anus.
Through various processes, this system is designed to break down food for the purpose of providing the body with energy and nutrients (Boland, 2006).
11. Nausea: The sensation of sickness, with an urge to vomit (Singh et al., 2015)
12. Pylorus: A pathway in the GI tract that controls the flow of mechanical and chemical digestion from the stomach to the small intestine where nutrient absorption occurs (Ramkumar & Schulze, 2005).
13. Rating of perceived exertion: A scale used for measuring one's effort and intensity level during physical activity (Williams, 2017). In this study, the Borg scale will be used to measure rating of perceived exertion.
14. Reflux/regurgitation: The reverse direction of stomach acid contents into the esophagus (Pluta et al., 2011).
15. Running: A human locomotion activity that consists of producing aerobic energy over extended distances (Folland et al., 2017). In particular, it is a movement gait activity that occurs at faster speeds than walking and has an aerial phase, which occurs when no limbs are touching the ground, and has a modified stance phase to handle faster moving speeds (Tongen & Wunderlich, 2010).
16. Side stitching: A sharp, aching, or stabbing pain typically found on the sides of the abdominal region (Wynne & Wilson, 2022)
17. Trained endurance runner: An athlete capable of running at least 15 miles a week, with at least one 90-minute run every two weeks.
18. Treadmill: A machine designed to create a continuous moving plane as a means to allow the engagement in cardiovascular fitness (Caramenti et al., 2019).

19. Urge to defecate: Urge to pass a bowel movement (Yoshino et al., 2012).
20. VO_{2max} : The maximal volume of oxygen consumed in ml/kg/min during intense aerobic exercise typically measured by indirect open-circuit calorimetry (Howley et al., 1995).
21. VO_{2peak} : The highest VO_2 measured during a graded exercise test, when a true VO_{2max} is not confirmed with a plateau in VO_2 or via secondary criteria.

Significance

The significance of the study was to observe how manipulating chewing time affected GI discomfort, metabolism, and performance in runners. During prolonged exercise, runners typically consume carbohydrates in the form of gels, drinks, bars, or a mixture of formats (Guillochon & Rowlands, 2017). Our attention focused on the bar form, as they are, anecdotally speaking, popular amongst some athletes, particularly ultra-runners. Research has indicated that carbohydrate bars might increase GI discomfort compared to liquid and gel forms (Guillochon & Rowlands, 2017). GI discomfort is problematic as it can impair sport's performance (Pfeiffer et al., 2010; Wilson, 2015). However, it is possible that longer mastication time could lessen GI symptoms that occur with ingesting sports bars. In theory, chewing carbohydrate sports bars longer will mitigate increases in GI issues and maintain running performance.

CHAPTER 2

LITERATURE REVIEW

Human Digestion

Human digestion is a complex process involving mechanical breakdown, enzymatic hydrolysis, and intestinal absorption of nutrients in food to ultimately attain normal physiological function, growth, and well-being (Boland, 2006). Digestion consists of processing food orally, in the stomach, and intestinally, followed by fermentation and reabsorption of water via the colon (Boland, 2006). It should be noted there is no reverse flow of food particles or digesta in normal healthy people (Boland, 2006). Oral processing is the first process of human digestion. Through chemical and mechanical breakdown, oral processing allows digestion to occur efficiently as digesta passes through the GI tract (Boland, 2006). The mechanical breakdown of food happens by the teeth and tongue, but the chemical breakdown of food orally happens by saliva (Boland, 2006). Saliva consists of mucins and polysaccharides, glycoproteins that function to bind food particles into a mass of food, or bolus, and lubricate the GI tract (Boland, 2006).

Carbohydrate Ingestion in Endurance Athletes

Carbohydrates are heavily relied on by endurance athletes for energy during training and competition. Muscle biopsies have shown muscle glycogen stores were the primary fuel source used at exercise intensities from 65 to 75% $\text{VO}_{2\text{max}}$ (Ivy, 1991). Literature also suggests athletes with greater muscle glycogen stores exhibit prolonged exercise time to exhaustion (Ivy, 1991). Most endurance athletes should aim to follow a high-carbohydrate diet, as ingesting an abundance of carbohydrates enhances glycogen store replenishment in the skeletal muscle and

liver (Cox et al., 2010). A high-carbohydrate diet is suggested to be pivotal to optimizing performance and recovery in endurance athletes (Ivy, 1991).

The amount of carbohydrates that an endurance athlete should consume on a daily basis is dependent on training intensity, frequency, and duration, the product of which is known as training volume. Thomas et al. (2016) recommends athletes training at moderate intensities for one hour per day should consume 5-7 g of carbohydrates per kilogram of body mass per day. Athletes training at moderate-to-high intensities for 1-3 hours per day should consume 6-10 g of carbohydrates per kilogram of body mass per day (Thomas et al., 2016), while ultra-endurance runners training at moderate-to-high intensities for 4-5 hours per day should consume 8-12 g of carbohydrates per kilogram of body mass per day (Vitale & Getzin, 2019).

Regarding during-competition carbohydrate intake, it is suggested the amount of carbohydrate is dependent on exercise duration and intensity. Stellingwerff and Cox (2014) suggest athletes performing in high-intensity exercise bouts for less than one hour will likely benefit from mouth washing a liquid carbohydrate source. Athletes performing in exercise bouts lasting 1-2 h at high intensities will likely benefit from ingesting 30-60 g of carbohydrate during every hour of performance (Stellingwerff & Cox, 2014). Research suggests that athletes performing for over 2 hours, at lesser intensities, will likely benefit from ingesting 40 to 110 g of carbohydrate during every hour of performance (Stellingwerff & Cox, 2014).

Gastrointestinal Symptoms in Endurance Runners

Gastrointestinal discomfort is very common in endurance athletes (Oliveira et al., 2014). Wilson (2017) investigated the prevalence of GI symptoms in runners over the course of 30 days. Runners (n=145) provided a journal of their recorded runs, exertion level while running, and a completed questionnaire of experienced GI symptoms while running. The GI symptoms listed on the questionnaire were nausea, regurgitation, stomach fullness, abdominal cramps, flatulence, and urge to defecate. Over the 30-day period, at least one GI symptom was experienced by males and females on respective averages of 84% and 78% of their runs. The results also showed that men and women on average, over the 30-day-period, experienced moderate-to-severe GI symptoms on 13.8% and 21.7% of their documented runs. Nausea was the least prevalent GI symptom, while urge to defecate was the most prevalent. Based on the results, it appears a large percentage of runners experience GI symptoms during running, while a smaller subset of runners experience moderate-to-severe GI symptoms.

A study by Pugh et al. (2018) surveyed a sample of runners that participated in the 2017 Liverpool and Dublin marathons. In total, 27% of runners experienced moderate symptoms, defined as a 4 out of 7 on a severity scale, while 16% of runners experienced flatulence in training and 8% experienced nausea while competing. A study by Keefe et al. (1984) surveyed runners participating in the Trail's End Marathon. Over one third of the runners felt the urge to defecate during and immediately after the marathon (Keefe et al., 1984).

GI symptoms experienced during training and performance are usually mild but, in some cases, can be moderate-to-severe (Oliveira et al., 2014). In extreme cases, diarrhea, nausea, and intestinal cramping are symptoms experienced during competition. GI symptoms are tolerable enough to perform comfortably in competition, but in moderate-to-severe cases are likely to

impair performance. Stuempfle et al. (2015) investigated GI distress in ultramarathon runners participating in competition. Of the 272 competitors sampled, 43.9% were affected by GI symptoms. Nausea was the highest ranked symptom, with 86.0% prevalence in runners. Of the participants that completed the survey, GI symptoms caused 35.6% of the participants to not finish the race. Nausea, at 90.5%, was the most prevalent GI symptom that caused participants to not finish the race.

One reason that GI symptoms occur during exercise is that blood flow to the mesenteric membrane, or gut, becomes impaired as more blood is needed in the active sites, such as the periphery and contracting skeletal muscle (Rehrer et al., 2001). Additionally, GI vasoconstriction causes GI impairment. Specifically, a high α -adrenergic receptor density in GI vasculature and high [NE] from sympathetic upregulation causes the vasculature in the gut to become constricted (Takala, 1996). Qamar and Read (1987) investigated the effects of exercise on mesenteric blood flow while fasted and postprandial. The study consisted of using a Doppler ultrasound to record blood flow in the superior mesenteric artery. The study consisted of a fasted exercise group, a fed-exercise group, and fed-no-exercise group. Exercise consisted of walking on a treadmill for 15 minutes at 5 km/h at an incline of 20%. The results in the fasted exercise group showed a 43% reduction in superior mesenteric blood flow immediately post-exercise, a 29% reduction 5 minutes post-exercise, and a 24% reduction 10 minutes post-exercise. In addition, although superior mesenteric blood flow increased from baseline with feeding, it was approximately 25% lower at 5 minutes postprandial in the fed-exercise group than the fed-no-exercise group. The results of this study show that mesenteric blood flow is reduced during exercise in a fasted state, and although feeding increases mesenteric blood flow, it may still be negatively impacted by exercise relative to feeding alone.

During high-intensity aerobic exercise, the risk of GI symptoms may increase because visceral blood flow becomes impaired to a greater degree. Rehrer et al. (2001) observed this during their investigation of the effect of exercise on portal vein blood flow. The investigators measured each participant's portal vein blood flow using an electronic pulsed Doppler flow monitor during a cycle ergometer protocol. The protocol consisted of cycling for 5 minutes at 30% of their VO_{2max} , followed by 5 minutes of cycling at 50% of their VO_{2max} , then 60 minutes of cycling at 70% of each participant's VO_{2max} . Portal vein blood flow measurements were taken before testing while at rest, and every 10 minutes during the 60-minute cycling test. The results indicated portal vein cross-sectional area, red blood cell velocity, and portal vein flow progressively decreased during the 60 minutes of cycling at 70% VO_{2max} . The investigators proposed portal vein blood flow reduction was caused by a reduction in the vessel's diameter. Furthermore, the investigators proposed that in coincidence with a reduction in the vessel's diameter, blood flow in the vessels that drain the GI tract into the portal vein reduced as well during exercise. Overall, this likely caused a reduction in GI tract arterial blood flow. The investigators concluded this is a factor of high-intensity exercise. High-intensity exercise increases cardiac output to almost maximum capacity. As a result, the contracting muscles and periphery demand a significant amount of blood flow to eliminate the buildup of body heat during exercise (Rehrer et al., 2001; Simmons et al., 2013). In conclusion, the progressive loss of mesenteric blood flow during moderate-to-high intensity exercise can cause GI tract impairment and GI symptoms to occur.

Although ingesting carbohydrates before and during exercise can optimize performance in some circumstances, reductions in mesenteric blood flow – along with other factors like repetitive jostling – can make it difficult to tolerate exogenous carbohydrate feeding during

running, particularly during prolonged, intense bouts. One strategy to mitigate potential intolerance to carbohydrate feeding during exercise is training the gut to better digest food during exercise (Jeukendrup, 2017). The GI system is an adaptable network that is suggested to have the capacity to improve its ability to digest food in competition (Jeukendrup, 2017). Jeukendrup (2017), for example, believes the gut can hold large quantities of food during competition with minimal impairments if trained properly. This increased tolerance to feeding could be achieved by regularly ingesting relatively large amounts of food and/or fluid during training.

As an example, Costa et al. (2017) investigated the effects of a 2-week gut training protocol on GI status, blood glucose availability, fuel kinetics, and performance. During baseline testing, all participants were required to ingest a 30-g carbohydrate gel disc every 20 minutes during a 2-hour treadmill test at 60% of their VO_{2max} , after which they completed a 1-hr self-paced distance test. Following baseline testing, the participants were randomized into a carbohydrate-gel group, carbohydrate-food group, or placebo group. The placebo group ingested a matched formulated gel-disc. Over the course of two weeks, the participants ingested their designated CHO format during each training session. Following the two weeks, the participants replicated the same baseline testing that they practiced at the beginning of the study. The results indicated GI symptoms during the second trial decreased in all the groups. However, the carbohydrate-fed groups experienced a greater decline in GI symptoms compared to the placebo group. Further, the carbohydrate food group and carbohydrate gel-disc group experienced 4.3% and 5.2% increases in exercise performance, respectively, in comparison to the initial gut-challenge trial, whereas the placebo group did not improve performance. The investigators noted the carbohydrate-gel group, compared to the placebo group, exhibited a reduction in malabsorption and had heightened blood glucose availability during exercise in the second trial.

The investigators concluded that a structured gut-training protocol has the capacity to reduce GI symptoms during exercise. Still, research is limited in the effectiveness of training the gut for competition.

Associations Between Particle Size or Food Matrix and Gastric Emptying

The size of food, or food matrix, is believed to have a strong impact on gastric emptying. During oral processing, food particles are chemically and mechanically broken down into a mass of food called a bolus (Mackie et al., 2017). As a bolus enters the stomach, it is chemically broken down by enzymes and stomach acids. A bolus, through the process of chemical and mechanical breakdown, will form into a liquefied state, also known as chyme. Chyme will pass from the stomach into the small intestine for additional processing and nutrient absorption (Mackie et al., 2017). However, particles within chyme larger than 3 mm will likely be retained longer in the stomach before passing into the small intestine (Kong & Singh, 2008).

Mackie et al. (2017) investigated the effects of oatmeal particle size on glucose absorption and satiation. On separate days, participants were required to consume an oat flake porridge and oat flour porridge. Interviews and magnetic resonance imaging, or MRI, were used to measure the differences in satiation and gastric emptying between the two porridges. The results indicated the oat flake porridge, in comparison to the oat flour porridge, further delayed gastric processing and increased satiation. The oat flakes have a more viscous structure, which likely increased satiation, and further delayed gastric processing. Vincent et al. (1995) compared the effects of bran particle size on gastric emptying. The participants ingested a rice meal with either 15 g of fine bran or coarse bran. Ingestion of the coarse bran resulted in a greater delay in gastric emptying compared to the fine bran. Vincent et al. (1995) proposed the increased

viscosity of the coarse bran delayed gastric emptying. The viscosity of the coarse bran was likely greater, as it has significant water retaining capacity.

Krishnasamy et al. (2020) investigated the effects of different physical forms of food on gastric emptying and satiation. On three separate occasions, the participants consumed portions of whole apples, apple puree, and apple juice. Fullness and satiation were the most prevalent when the participants consumed the whole apples. The complex texture and greater viscosity of the whole apples likely caused gastric emptying to be slower and satiation to be greater.

Impacts of Mastication/Chewing on Aspects on Digestive Function and Symptoms

Mastication time and efficiency may ultimately influence gastric emptying. A study by Mercier et al. (1992) recruited 142 participants with mandibular ridge atrophy. Eighty five of the 142 participants were evaluated for digestive symptoms. Evaluation showed 60% of the participants complained of digestive symptoms, including burning abdominal pain, constipation, bloating, and other GI symptoms. Before evaluation, a portion of the participants underwent a procedure to surgically rebuild their mandibular ridge to improve masticatory function. One-year post-surgery, 85% of the participants experienced a reduction in digestive symptoms. The study's results suggest that improved masticatory function reduced GI symptoms, perhaps in part through alterations in gastric emptying.

A study by Pera et al. (2002) investigated the influence of mastication on gastric emptying. This crossover study randomly assigned its participants into two treatment orders. The participants were required to consume the same meal in 50 masticatory cycles or 25 masticatory cycles. The meal consisted of one egg cooked in butter with the yolk coated in 100 mg of C-octanoic acid, 5-mm ham cubes, crackers, and 500 ml of water. The 50 masticatory cycles resulted in a shorter gastric emptying period compared to 25 masticatory cycles. Pera et al.

(2002) concluded that a greater number of masticatory cycles produces smaller particle sizes. As food particles become smaller, they reach a diameter small enough to pass from the pylorus, into the small intestine.

However, some studies have shown no significance of mastication on gastric emptying. Poitras et al. (1995) investigated the effects of mastication with a dental prosthesis on gastric emptying. The participants were required to consume a solid food meal with their dental prostheses on one day, and consume the same meal with no prostheses on a separate day. Gastric emptying rate was recorded using gamma external scintigraphy. Although gastric emptying rates were similar between the treatments, the small sample size and low statistical power may partly explain why no significant differences were found. Farrell et al. (1956) also investigated the effects of mastication on the digestion of food. Portions of unmasticated and masticated food were weighed, individually tied into cotton mesh bags, then digested by the participants. It should be noted that the portions of masticated food were ingested in various chewing conditions. Following ingestion, the food was recovered in the participant's feces for final review and weighing. The results indicated that despite the different consistencies of digested food, digestion was not impacted between the conditions.

In summary, there is mixed evidence on the impact of mastication on GI function and gastric emptying. Explanations for the equivocal evidence is dependent on the fact that digestion and mastication are varied. Everyone's GI system is similar but not physiologically identical. This could potentially be one of the explanations behind the mixed results in the literature previously discussed. Yet, of the available evidence, the results seem to be either null or show that greater/enhanced mastication speeds gastric emptying, which provides a basis for exploring this topic in the context of exercise.

Impacts of Mastication/Chewing on Blood Glucose Responses

Mastication under certain conditions may impact blood glucose responses. Ranawana et al. (2014) investigated how mastication affects the glycemic index. This crossover study randomly assigned 15 participants into three treatments. The participants, on five non-consecutive days, were required to ingest either a 50-g bolus of glucose on three days, or ingest rice on two separate days. On rice ingestion days, the participants were required to either chew each spoonful of rice 15 times or 30 times before ingesting. Finger prick samples were periodically taken to measure blood glucose. In comparison to 30 masticatory cycles, glycemic response was notably lower after the participants ingested the rice in 15 masticatory cycles. Glycemic index was 29% higher after ingesting the rice in 30 masticatory cycles. The investigators concluded that mastication alters glycemic response and that a lower rate may be a potential strategy for lowering the glycemic index of foods.

Tan et al. (2015) investigated the role of digestive factors on glycemic response. This crossover study randomly placed its participants into two conditions. On separate days, participants consumed 50 g of carbohydrate from jasmine and basmati rice in 15 minutes or less. Mastication rate was measured using surface electrode electromyography. Blood glucose samples were taken on a test day after fasting, and a 10-minute rest period. Blood glucose samples were also taken at various times during rice consumption. The results indicated food particles were smaller with more chews per mouthful. This correlates with glycemic response, as more chews per mouthful resulted in a higher glycemic response. Greater mastication rate caused a higher glycemic response, as a greater mastication rate resulted in a smaller rice particle size. As a result, the smaller rice particle size assisted in the complex carbohydrate breakdown of the rice, thus causing a greater glycemic response. The investigators claimed more research should

investigate the effect on gut hormones and satiety mechanisms. Investigating gut hormones could provide more insight on the physiological factors that impact glycemic responses.

Suzuki et al. (2005) investigated the effects of thorough mastication on postprandial plasma glucose concentrations. This crossover study consisted of 16 participants with a normal tolerance to glucose, or NGT group, and 10 participants with either impaired tolerance or type 2 diabetes. During 52 test meals, participants were required to either consume the meals in a normal mastication cycle or thorough mastication cycle. The participants had their plasma glucose and serum insulin concentrations levels measured for 3 hours postprandially, and insulinogenic index calculated 30 minutes postprandial. The results revealed that thorough mastication reduced postprandial plasma glucose concentrations in the NGT group at 90 minutes and 120 minutes, and the area under the curve (AUC) between 15 to 180 minutes postprandial. However, there was no increase in insulin AUC. The impaired glucose tolerance group saw a large increase in postprandial plasma glucose and serum insulin concentrations after thorough mastication. Insulinogenic index was unusually higher in the NGT group after thoroughly mastication. The investigators proposed early-phase insulin secretion caused postprandial plasma glucose concentration to be lower after thorough mastication. In comparison, the impaired glucose tolerance group likely had an increase in postprandial plasma glucose concentration due to a failure to experience early-phase insulin secretion. Overall, this study suggests that the glycemic responses to different chewing behaviors may depend on the metabolic background of the individual.

Sun et al. (2015) investigated the effects of eating methods on eating rate and glycemic response. On three separate days, participants consumed white rice with chopsticks, a spoon, or with their fingers. Glycemic response was measured for 120 minutes postprandially using a

HemoCue Glucose 201 analyzer. The results indicated glycemic response and index was significantly lower when the participants consumed the rice with chopsticks, in comparison to the spoon. No difference was recorded in glycemic response and index when the participants consumed the rice with a spoon and their fingers, and fingers and chopsticks. Sun et al. (2015) noted different eating methods affects chewing time and how much food per mouthful is chewed.

In conclusion, altering mastication processes can affect glycemic responses, which suggests that mastication and eating behavior could impact the blood glucose and substrate responses to exercise. However, to the knowledge of the author, this has not been studied in the context of exercise. In theory, more extensive chewing could increase gastric emptying and facilitate glucose absorption, which could alter substrate utilization during exercise.

Investigation of Effects of Food Form/Matrix on Metabolism or Perceptual Responses During Exercise

Carbohydrates are used in performance events to provide athletes with oxidizable fuel and ultimately avoid performance impairments concurrent with glycogen depletion (Baker et al., 2015). Sport carbohydrates typically come in the form of gels, bars, and drinks (Gullichon & Rowlands, 2017). Sport carbohydrate formats likely vary in digestion during competition. Gullichon and Rowlands (2017) investigated the effects of carbohydrate food form on gut discomfort and performance. This four-way crossover study required its participants, on four separate days, to ingest carbohydrate bars, gels, drinks, and mixture of the formats every 20 minutes during a 140-minute, high-intensity cycling bout. During the test, a visual analog scale was used to record GI symptoms, performance, exertion level, and fatigue. The carbohydrate bars, in comparison to the gels and drinks, impaired performance and increased GI discomfort. There was no notable difference in performance and GI discomfort between the gels, drinks, and

mixture of the formats. The investigators theorized that the semisolid state of the bar, the bar's fat and protein concentration, and/or greater energy concentration of energy likely increased GI discomfort and impaired performance. Guillochon and Rowlands (2017) concluded carbohydrate gels, drinks, and a mixture of the formats are more advantageous for sport performance than sports bars.

Research shows carbohydrate food form can impact endurance performance and carbohydrate oxidation differently. Pfeiffer et al. (2010) investigated the effects of ingesting different carbohydrate formats on performance. This randomized crossover study required its participants to follow a training program at least 3 days a week, which consisted of 180 minutes of exercise at 50% of their maximum work rate on a cycle ergometer. The participants were randomly assigned to ingesting a carbohydrate bar with water, a carbohydrate beverage, or plain water. A questionnaire was administered every 30 minutes, asking the participants to rate their GI symptoms. The results indicated stomach fullness was greatest during the bar treatment, but no other significant differences in GI symptoms were noted. The investigators concluded the bar treatment, in comparison to the carbohydrate drink, exhibited little-to-no difference in oxidation rate. The bar treatment also led no significant differences in carbohydrate oxidation compared to the other treatments. The investigators concluded carbohydrate bars are an effective carbohydrate oxidation source and recommended carbohydrate bars as a possible fuel source to use during exercise. However, given the increased severity of fullness observed in this study and the negative effects on performance and GI comfort observed in Guillochon and Rowlands (2017), it seems prudent that further research be carried out on the efficacy and perceptual effects of carbohydrate sports bars during endurance exercise, particularly running.

Summary

The information in this literature review paints a clear image of the multitude of factors impacting GI symptoms during performance. Oliveira (2014) and Wilson (2017) recognize that GI symptoms are common during aerobic exercise. Food textures are one of the factors impacting gut function. As Vincent et al. (1995) noted, food texture and viscosity impact the rate of gastric emptying. Mackie et al. (2017) concluded food particle size is another factor that impacts gastric emptying. Gulliochon and Rowlands (2017) also claimed that the form of carbohydrate (bar, gel, drink, etc.) impacts gut functionality and GI symptoms differently. The results in their study showed carbohydrate bars caused the greatest experience in GI symptoms compared to the other carbohydrate formats. Despite the risk of GI discomfort, consuming carbohydrate during exercise is often necessary to optimize certain types of sport performance (Pugh et al., 2018).

The results in Pera et al. (2002) and Mercier and Poitras (1992) suggest GI symptoms can be lessened through extended or more efficient mastication. Extended mastication, in theory, can improve gut functionality, as chyme is able to pass from the stomach to the small intestine more quickly (Mackie et al., 2017). The previous literature suggests that ingesting food during endurance competition impacts gut functionality. However, gut functionality and GI discomfort are capable of being minimized through increased mastication rate, gut “training” and diet. This study investigated how mastication impacts metabolic response and GI discomfort.

CHAPTER 3

METHODOLOGY

Sample

Recruitment for the study was conducted by handing out flyers at local running events and running stores in the Hampton Roads area, as well as by word of mouth. Social media posts related to recruitment were also made by the investigators.

The study enrolled 17 participants total (15 male and 2 female), between the ages of 18-55 years old. Of these, 12 males completed all three study visits and were included in the analyses. Among the five dropouts, only one was deemed related to the intervention; this participant decided not to complete the study due to intolerance to the feeding protocol.

Demographics

The participants had a history of distance running, defined as currently running at least 15 miles per week, with at least one 90-minute run every two weeks. The participants had no history of cardiovascular disease, diabetes, pulmonary disease (except controlled asthma), inflammatory bowel disease, swallowing problems, major dental problems, or allergies to the ingredients in the sports bar. These criteria were chosen to protect people that may have an elevated risk of having a negative reaction or event during exercise. Additionally, participants without Celiac disease and nut allergies were recruited, as the bar used in this study is not gluten- or nut-free. Our participants also had no current injuries that interfered with prolonged running (i.e., 60-90 minutes at a time). The participants signed an informed consent that was approved by Old Dominion University's Institutional Review Board. On the day of signing the consent form,

participants were briefed on the study's purpose, requirements, potential risks, and verified that they met the criteria for the study.

General Design

This study was an unblinded, 3-visit, randomized crossover design with two experimental conditions. During the 40CHEW condition, participants, at specified intervals, chewed a sports bar in 40 masticatory cycles, at a rate of 1 chew per second before ingesting. The 20CHEW condition involved chewing the sports bar in 20 masticatory cycles, at a rate of 1 chew per second before ingesting. The sports bars were fed before and during treadmill at specified intervals (detailed later).

Randomization Method

The order of the treatments was randomized using a website: <https://www.sealedenvelope.com>. Sex-specific randomization lists, utilizing block sizes of two and four, were created. The randomization lists were generated by an individual who was not responsible for data collection, and the lists were unavailable to the investigators carrying out the data collection until all participants completed the study. The participants were randomized into either the 40CHEW or 20CHEW treatment first, then completed the alternative treatment during the next experimental visit.

Testing Protocol

Prior to the first visit, potential participants were pre-screened via telephone or in person to ensure they met basic eligibility criteria for the study. For those who were eligible based on pre-screening, testing occurred at the Human Performance Laboratory (HPL) at Old Dominion University. Participants were instructed to not perform any vigorous physical training 24 hours

before testing. Caffeine was prohibited 12 hours before arrival to the HPL. In addition, participants reported having not ingested any caloric-containing foods or beverages in the past 4 hours, while they reported to the HPL fasted for at least 8 hours on visit days 2 and 3.

Visit 1. The first visit consisted of giving an overview of the study to the participant and obtaining their informed consent. The participants were required to fill out a background questionnaire that asked about demographics, running history, and history of GI symptoms. Next, the participant's height was measured with a stadiometer, along with using a BOD POD (COSMED USA, Concord CA, USA) to measure body mass and composition.

Next, the participant performed a $\text{VO}_{2\text{max}}$ test on a TrackMaster TMX428 treadmill (Newton, KS, USA). A metabolic cart (TrueOne 2400, Parvo Medics, Salt Lake City, UT, USA) analyzed each participant's oxygen consumption (ml/kg/min), carbon dioxide production (ml/kg/min), and respiratory exchange ratio (based on 30-second averages of data). The metabolic cart's gas and flow sensors were calibrated with standard reference gas and a 3-L syringe before testing. The participant wore a Hans Rudolph (Shawnee, KS, USA) facemask connected to a 2-way non-rebreathing valve, which was connected via a hose to the metabolic cart. A chest-strap monitor was used to monitor HR (Polar H10, Kempele, Finland). The treadmill protocol followed a protocol similar to Wilson and Ingraham (2014). Testing began with a 3-minute walk at a 5.0 km/h and elevation grade of 0% followed by an incremental ramp protocol consisting of 1 minute stages at an elevation of 1% and increasing velocity of 0.64 km/h for each stage until the subject reached his or her self-reported 5-kilometer race pace. Thereafter, grade increased by 1.5% each minute until volitional fatigue.

Determination of $\text{VO}_{2\text{max}}$ versus $\text{VO}_{2\text{peak}}$ was based on evaluating RER and HR relative to an aged-predicted maximum ($208 - 0.7 \times \text{age}$) (Wagner et al., 2020). If a participant achieved an

RER \geq 1.1 and a maximal observed HR of 90% of age-predicted maximum, they were deemed to have achieved their VO_{2max} . After the VO_{2max} test, the participant rested for 15 minutes.

Following resting, the participant performed a 10-minute familiarization run at 60% of VO_{2max} .

This run, and the subsequent experimental trials, were carried out on a T170 DE SPORT MED treadmill (Cosmed, Rome, Italy). The following equation were used to determine the VO_2 that corresponds to 60% of the participant's VO_{2max} .

$$60\% \text{ } VO_{2max} = 0.60 \times (\text{measured } VO_{2max})$$

Subsequently, an equation from Mayhew (1977) was used to find a treadmill speed that approximates 60% of the participant's VO_{2max} .

$$\text{Speed (mph)} = (60\% \text{ } VO_{2max} / 5.34) + 0.82$$

During the 10-minute familiarization run, the participant's VO_2 was analyzed via the Parvo Medics metabolic cart from minutes 5 to 10, to confirm that the speed approximated 60% of VO_{2max} . Minor adjustments to the treadmill speed were made if the measured VO_2 was too high or too low relative to what was expected.

Next, participants were familiarized to a performance test consisting of running on a treadmill at 90% of VO_{2max} for 10 minutes, followed by running at 100% of VO_{2max} to exhaustion. These speeds were derived using the equation from Mayhew (1977) described previously. After the performance test, the participant ingested two 9-g programs of the carbohydrate food bar at the 20 and 40 chew cycles, respectively. A third portion of food bar was offered for additional practice if the participant desired to do so.

Visit 2. Participants arrived fasted for at least 8 hours. They also avoided vigorous physical activity for 24 hours beforehand, and refrained from caffeine ingestion for 12 hours before the visit. To control for the effects of diet leading up to the visit, each participant for 48 hours before visit 2 filled out a food log, followed by replicating the food log 48 hours prior to visit 3. Each participant ingested 45 g (supplying approximately 33 g of carbohydrate) of a sports bar 30 minutes prior to the 60-minute treadmill run. The bar was served in five 9-g portions (i.e., 6.7 g of carbohydrate per portion). The chewing protocol consisted of either 40 chews or 20 chews before swallowing, with a controlled rate of 1 chew per second. A metronome (MR-500, Matrix, Korea) was used to cue participants of when to chew. During the treadmill test, participants ingested approximately 20 g of carbohydrate (27 g of bar) at 5, 25, and 45 minutes, following the same chewing protocol. The bar was served in 9-g portions (6.7 g of carbohydrate). Participants were offered water ad libitum after each bar feeding. The amount of water consumed was recorded during the first trial with a digital scale (i500 balance, My Weigh, Phoenix, AZ), and the participant was required to drink the same amount of water during the next experimental trial.

A feeling scale, RPE/Borg scale, GI symptom questionnaire, blood glucose, and substrate use were assessed throughout the treadmill test at specified intervals (see **Table 1**). Heart rate was monitored throughout the protocol but did not serve as a main outcome of interest.

Table 1. Schedule of Variable Assessment

PRE-EXERCISE		EXERCISE									POST-EXERCISE
-31 min	-30 min	5 min	15 min	25 min	30-33 min	33 min	35 min	45 min	55 min	57-60 min	61 min
<ul style="list-style-type: none"> • Blood glucose • GI • FS 	33 g CHO	20 g CHO	<ul style="list-style-type: none"> • GI • FS • RPE 	20 g CHO	Resp. gases	Blood glucose	<ul style="list-style-type: none"> • GI • FS • RPE 	20 g CHO	<ul style="list-style-type: none"> • GI • FS • RPE 	Resp. gases	Blood glucose
Note. CHO- Carbohydrate feeding, FS- Feeling Scale, GI- Gastrointestinal Symptom Questionnaire, RPE- Rating of Perceived Exertion.											

Respiratory gases were monitored using the Parvo Medics metabolic cart for 3-minute periods, starting at minutes 30 and 57 of the 60-minute run. Estimates of carbohydrate and fat oxidation were calculated from published equations (Jeukendrup et al., 2005) using data from the last minute of each collection period.

$$\text{Fat oxidation: } (1.695 \times \text{VO}_2) - (1.701 \times \text{VCO}_2)$$

$$\text{Carbohydrate oxidation: } (4.21 \times \text{VCO}_2) - (2.962 \times \text{VO}_2)$$

In addition, blood glucose was taken before the pre-exercise sports bar feeding, at minute 33 of the 60-minute run, and immediately after the 60-minute run. Blood glucose was measured using a FreeStyle Lite Blood Glucose Monitor System (Abbott Diabetes Care Inc., Alameda, CA, USA). The participants were asked to rate their GI symptoms, using a validated Likert questionnaire (Wilson, 2017), at baseline and at 15 minutes, 35 minutes, and 55 minutes of the 60-minute run. The GI symptoms were nausea, belching, regurgitation/reflux, stomach fullness, bloating, side stitching, abdominal cramps, gas, and urge to defecate. The participants answered the severity of each symptom on a scale from 0-10, with 0 being nonexistent discomfort, 5 being moderate discomfort, and 10 being unbearable discomfort (Wilson, 2017). At the same time points, the feeling scale was used to assess the participant's core emotions (from -5 'very bad' to

+5 ‘very good’) while exercising (Hardy & Rejeski, 1989). Also, to understand the participants’ perceived level of physical demand while treadmill running, they were asked of their rating of perceived exertion, or RPE, using Borg’s scale from 6-20, with 6 being no exertion, to 20 being maximal exertion (Borg, 1970).

Once the 60-minute treadmill test at 60% of VO_{2max} was completed, the treadmill was briefly stopped so that blood glucose could be taken and that the instructions for the time-to-exhaustion test were reviewed with the participant. The participant ran for 10 minutes at 90% of VO_{2max} , followed by time-to-exhaustion at 100% of VO_{2max} . Based on previous literature that has implemented time-to-exhaustion testing, we presumed the test would be completed in no more than 20 minutes (Blondel et al., 2001). Visit 2 was completed after this portion was finished.

Visit 3. Visit 3 followed the same protocol performed in visit 2, except for chewing protocol. The participant completed the opposite chewing protocol from visit 2.

Carbohydrate Bars

Vanilla Chip Chewy Granola Bar (Cascadian Farm Organic, Skagit Valley, WA, USA) was the administered carbohydrate sports bar during each feeding. This bar was chosen because it has a relatively low concentration of fats and proteins, and most runners are unlikely to choose to ingest bars that are rich in fat and/or protein. The bar’s nutritional information, per serving of 35 g, consists of 140 kcals, 3 g of fat, 26 g of carbohydrate, 2 g of protein, and 1 g of fiber.

Data Processing and Analysis

Given that multiple GI symptoms were assessed across multiple timepoints, sum scores were calculated by adding individual scores from each timepoint together to create total GI and upper GI (nausea, belching, regurgitation/reflux, fullness) symptom variables.

Inspection of histograms and use of a Shapiro-Wilk test were incorporated to evaluate if the data were normally distributed. RPE, feeling scale, blood glucose, HR, and substrate use were compared between trials using 2-way ANOVAs with condition (20CHEW vs. 40CHEW) and time (FS, GI: -31, +15+35+55 min; Glucose: -31, +33, +61 min; HR: [Identify levels of time]; Substrate use: Mid-I [30-33 min], End-of-exercise [57-6-0 min]) as *within-subjects* factors. In the case of any time effects with no interaction effect, pairwise comparisons with a Bonferroni correction were applied. In the case of any interaction effect, between-condition effects at each timepoint were explored using paired t-tests with Bonferroni adjustments for multiple comparisons. Performance time on the time-to-exhaustion test was compared between trials using a paired t-test. GI symptom variables were non-normally distributed, thus the Wilcoxon signed-rank test was used for analysis. In addition, change scores from pre-exercise to 55 minutes were calculated and used in order to reduce the number of statistical tests being carried out.

The alpha level was set at 0.05, and IBM SPSS Statistics 28 (IBM, Armonk, NY, USA) software was used to carry out the analyses. Unless otherwise indicated, normally distributed summary continuous data are reported as (mean \pm SD) and skewed data are reported as (median (IQR)).

CHAPTER 4

RESULTS

Participant Characteristics

Table 2 shows the initial descriptive statistics of the 12 participants who completed all three visits. For the baseline $\text{VO}_{2\text{max}}$ test, the mean and SD of maximum RPE was 18.3 ± 1.7 , maximum HR was 178.5 ± 10.9 bpm, percentage of age-predicted maximum HR was $97.9\% \pm 7.3\%$, maximum RER was 1.09 ± 0.07 , maximum treadmill speed was 9.5 ± 0.9 mph, and maximum treadmill grade was $5.4 \pm 1.4\%$. Even though all participants achieved at least 90% of their aged-predicted maximum HR, and all but two participants achieved a maximal RER of at least 1.05, the term $\text{VO}_{2\text{peak}}$ is used in the remainder of the results given that no $\text{VO}_{2\text{max}}$ verification testing was performed. Calculated treadmill speeds that corresponded to 60%, 90%, and 100% of $\text{VO}_{2\text{peak}}$ were 7.2 ± 0.6 , 10.5 ± 0.8 , and 11.5 ± 0.9 mph, respectively. At the end of the 10-min familiarization run (i.e., final minute), measured VO_2 was 34.6 ± 2.8 mL/kg/min, or 60.5% of $\text{VO}_{2\text{peak}}$.

Table 2. Background characteristics of the participants (n = 12)

	Mean \pm SD or Median (IQR)
Age (years)	36.4 ± 7.2
Weekly running volume (miles)	38.5 ± 13.9
Height (m)	1.80 ± 0.07
Bod Pod mass (kg)	76.9 ± 6.3
Bod Pod Fat (%)	16.9 ± 6.1
GI-symptom history (0-32)	3.5 (4.8)
$\text{VO}_{2\text{peak}}$ (mL/kg/min)	57.2 ± 4.7

GI-symptom history scores were derived by asking over the past few months how frequently participants experienced GI symptoms while exercising (0 = never, 1 = rarely, 2 = sometimes, 3 = frequently, and 4 = almost always). The listed GI symptoms were nausea, reflux/regurgitation, belching, stomach fullness, bloating, abdominal cramps, flatulence, and urge to defecate.

Table 3 provides a summary of water intake during Visits 2 and 3. Median and IQR are reported as the data distribution was right-skewed. Intake was quantified by adding 400 g of water to a 72-g bottle for a total mass of 472 g, then recording the mass after each consumption. Water intake from visit 2 was then replicated on visit 3.

Table 3. Water intake before and during the 60-minute submaximal runs

	Median	Interquartile range
-30-min water (g)	101.9	119.6
5-min water (g)	51.4	40.7
25-min water (g)	57.8	58.9
45-min water (g)	63.0	58.9

Time to Exhaustion

The time-to-exhaustion, or TTE, testing indicates that, during the 20CHEW treatment, participants lasted 266.1 ± 115.3 seconds, while during the 40CHEW treatment, they lasted 296.8 ± 161.6 seconds. It should be noted that 2 participants were unable to complete the TTE portion of the study (1 due to concern over his hamstring, and 1 due to opting out of the performance testing). A paired samples t-test was utilized as each participant performed both conditions. The paired differences from the t-test showed an insignificant mean difference of -30.7 ± 139.8 seconds between conditions, a t-value of -0.69, and a two-sided p-value of 0.505. A Hedges' *g* indicates the effect size was small -0.21 (95% CI, -0.81 to 0.40).

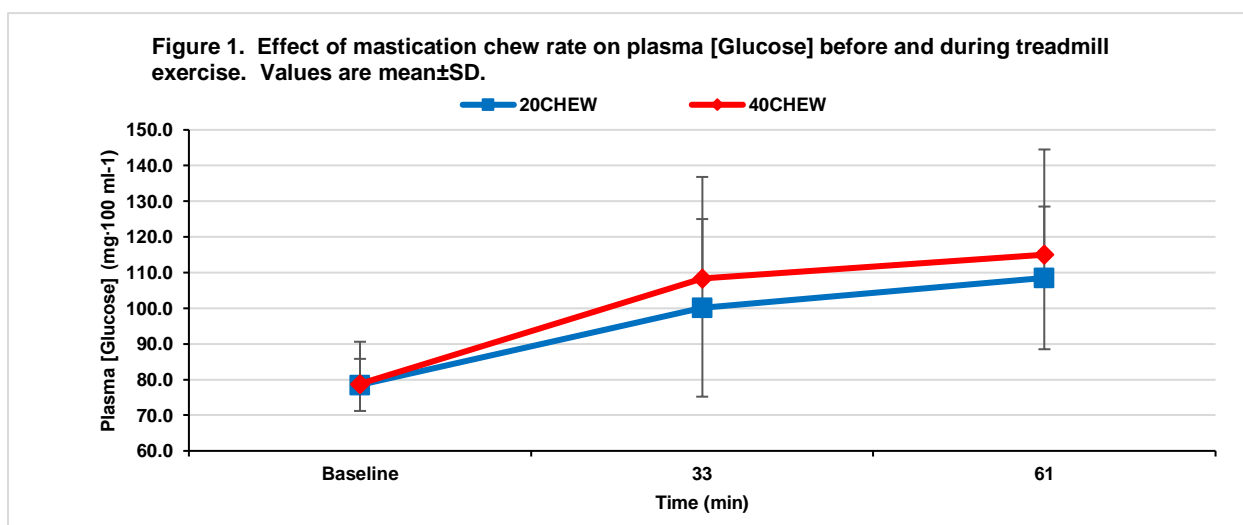
GI-Symptom Changes From Baseline to 55 min

In the 20CHEW condition, total GI symptom scores increased by a median of 5.5 (7.0) from baseline to 55 min. In the 40CHEW condition, total GI symptoms increased by 4.0 (12.0) during the same timeframe, and based on a Wilcoxon Signed Ranks Test, there was no difference in change scores between conditions ($Z = -0.14$, $p = 0.888$). Upper GI-symptom scores increased by a median of 3.5 (4.0) and 3.5 (7.0) in the 20CHEW and 40CHEW conditions, respectively. There was no significant difference in the change scores based on a Wilcoxon Signed Ranks Test ($Z = -0.66$, $p = 0.507$).

Blood Glucose

Figure 1 visually shows how blood glucose values changed over time in each condition. The 20CHEW treatment had blood glucose values at baseline, 33 minutes, and post-run of 78.5 ± 7.3 , 100.1 ± 24.9 , and 108.5 ± 20.0 mg/dL. Values for 40CHEW at baseline, 33 minutes, and post-run were 78.8 ± 11.8 , 108.3 ± 28.5 , and 115.0 ± 29.5 mg/dL. Based on repeated measures ANOVA (condition x time), there was a significant change in blood glucose over time, but no significant differences between the conditions, nor was there a significant time by condition effect. The p-values for the time effect, condition effect, and time by condition effect were <0.001 , 0.31 , and 0.36 , respectively. Post hoc testing revealed that +33 min and +61 min were different ($p < .05$) from baseline.

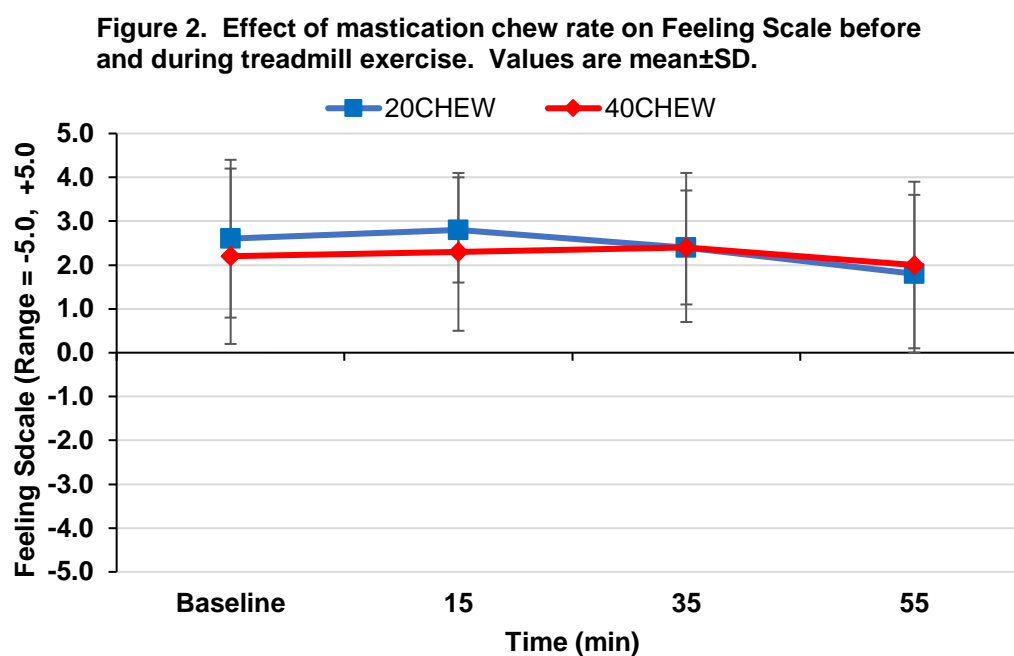
The Hedges' g values for blood glucose differences at 33 min (-0.41 , 95% CI, -0.98 to 0.17) and post-run (-0.24 , 95% CI, -0.79 to 0.32) indicate possible small effects.



Feeling Scale

The data from the Feeling Scale (Figure 2) indicates that for 20CHEW, values at baseline, 15 minutes, 35 minutes, and 55 minutes were 2.6 ± 1.8 , 2.8 ± 1.2 , 2.4 ± 1.3 , and 1.8 ± 1.8 . For 40CHEW, values at baseline, 15 minutes, 35 minutes, and 55 minutes were 2.2 ± 2.0 , 2.3 ± 1.8 , 2.4 ± 1.7 , and 2.0 ± 1.9 . The results indicate that there was no time effect or condition effect, but there was a time by

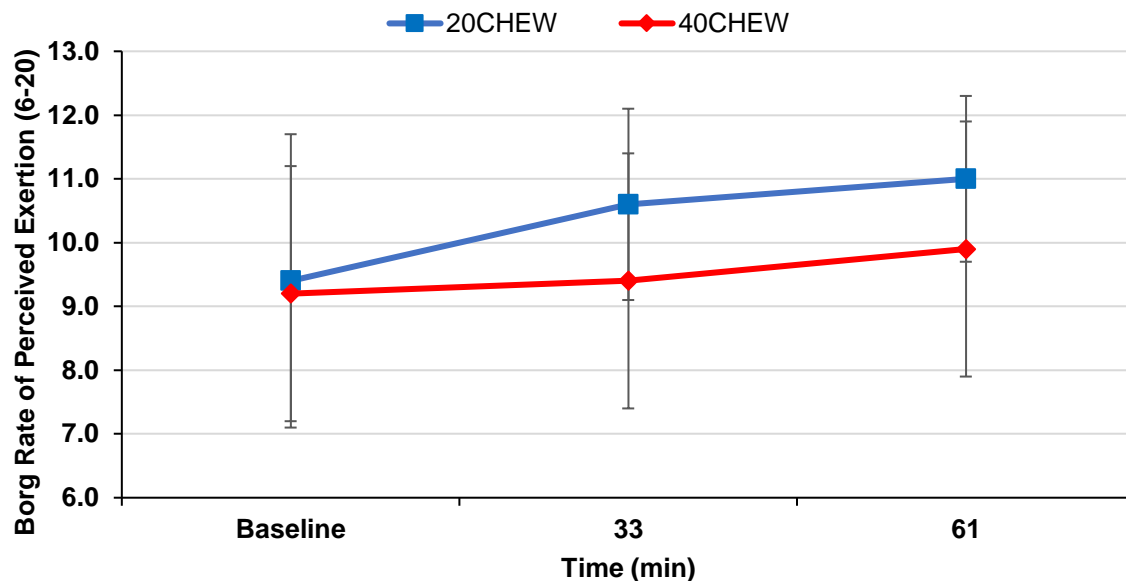
condition effect. The p-values for the time effect, condition effect, and time by condition effect were 0.25, 0.73, and 0.04, respectively. The figure shows that both treatments experienced a decline in overall feeling over time, but at different rates. However, post hoc testing revealed no significant differences between conditions at any individual timepoint.



Rating of Perceived Exertion

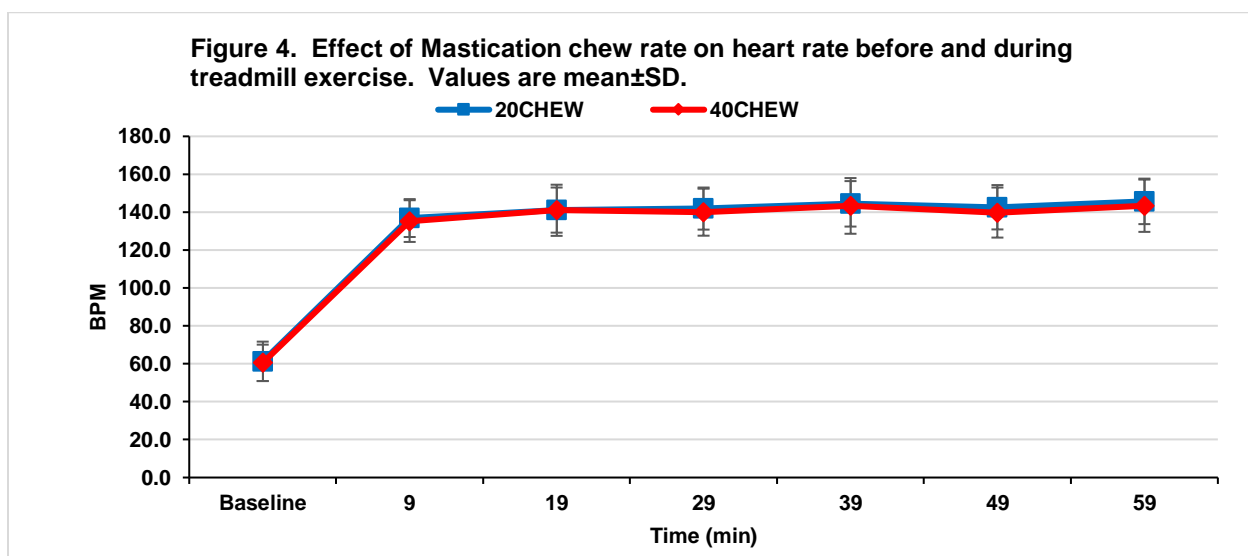
Rating of Perceived Exertion, or RPE, values in the 20CHEW treatment at 15 minutes, 35 minutes, and 55 minutes were 9.4 ± 2.3 , 10.6 ± 1.5 , and 11.0 ± 1.3 . RPE values for the 40CHEW treatment at 15 minutes, 35 minutes, and 55 minutes were 9.2 ± 2.0 , 9.4 ± 2.0 , and 9.9 ± 2.0 . There was no condition effect, but there were time and time by condition effects. The p-values for the time effect, condition effect, and time by condition effect were <0.001 , 0.08, and 0.02, respectively. This indicates that RPE progressively increased in both treatments over time but that the increase tended to be more pronounced in the 20CHEW condition (see Figure 3). However, post hoc testing revealed no significant differences between conditions at any individual timepoint.

Figure 3. Effect of Mastication chew rate on Borg Rate of Perceived Exertion before and during treadmill exercise. Values are mean \pm SD.



Heart Rate

Figure 4 displays the HR data by each condition. The p-values for the time effect, condition effect, and time by condition effect were <0.001 , 0.21, and 0.96. This indicates that HR increased over time, similarly in each condition. Based on post hoc testing, baseline and +9 min were lower than all other timepoints, while +39 min was higher than +19 min and +49 min ($p < .05$).



Substrate Use

Table 3 displays substrate use data by each condition. There was no significant time, condition, or time by condition effects (all $p > 0.05$).

Table 3. Substrate use recorded at 30 minutes and 57 minutes into 60-minute treadmill run

	RER	CHO Oxidation (g/min)	Fat Oxidation (g/min)
20CHEW			
30 min	0.87 ± 0.03	1.9 ± 0.3	0.6 ± 0.2
57 min	0.87 ± 0.03	1.9 ± 0.3	0.6 ± 0.2
40CHEW			
30 min	0.86 ± 0.04	1.8 ± 0.3	0.6 ± 0.2
57 min	0.88 ± 0.04	1.9 ± 0.3	0.6 ± 0.2

CHO, carbohydrate; RER, respiratory exchange ratio.

CHAPTER 5

DISCUSSION

This study investigated the effects of chewing time on GI discomfort, perceived effort, glycemic responses, substrate use, and performance during endurance running. We expected to see lower RPE, blood glucose response to be higher, greater carbohydrate oxidation, greater measured emotional well-being, less severe GI symptom changes, and TTE to be longer in the 40CHEW condition as compared to the 20CHEW condition.

After analyzing the data, the difference in TTE between conditions showed a small, non-significant effect size (Hedges' $g = -0.21$, $p = 0.505$). The lack of significant performance benefit likely could be related to the fact that there were no significant differences in blood glucose response, substrate use, and GI symptom changes between the two conditions, as these variables likely impact performance. For example, Rowlands et al. (2012) investigated the effects of ingesting composite versus transportable carbohydrate solutions on performance on a cycle ergometer. The single transportable carbohydrate solution substantially reduced performance by increasing GI discomfort. Likewise, Guillochon et al. (2017) noted that GI symptoms were the highest, and performance was reduced the most, while ingesting solid carbohydrate bars, in comparison to ingesting carbohydrate drinks and gels. In support of the idea that increasing carbohydrate oxidation can enhance performance, Wright et al. (1991) investigated how no carbohydrate ingestion, and carbohydrate ingestion before, during, and a combination of the two, impacts cycling performance. The cyclists' performance and CHO oxidation were the highest while ingesting carbohydrates before and during cycling.

Regarding GI symptom changes from baseline to 55 minutes, there was no significant difference between the treatments. It is possible that the difference in mastication duration was not enough to result in meaningful downstream digestive effects. Non-exercise research findings are equivocal. For example, Mercier et al. (1992) noted that improved masticatory function post-surgery resulted in reduction of digestive symptoms. In contrast, Poitras et al. (1995) investigated the effects of mastication on gastric emptying with and without a dental prosthesis and showed no significant differences in gastric emptying between the conditions. Inducing a larger difference in mastication cycles (e.g., 20 vs. 50-60 chews) could have increased the probability of obtaining meaningful effects in the present study, but that level of extensive chewing might not be realistic in a competitive setting like an endurance race.

Other explanations for the lack of GI-symptom differences between conditions include the relatively short duration and intensity of the exercise protocol. Rehrer et al. (2001) observed portal vein blood flow before exercise, at rest, and every 10 minutes during a 60-minute cycling test at 70% of maximum aerobic capacity. The results indicated that portal vein blood flow progressively reduced during the cycling test. Regarding exercise duration, Gaskell et al. (2023) showed that gastrointestinal functional responses and gastrointestinal symptoms were ranked highest when participants performed 2 and 3-hour treadmill runs at 60% of their VO_{2max} , compared to 1-hour of treadmill running at the same intensity. Overall, the results of these studies suggest that the lack of GI-symptom differences between our conditions could be a result of the exercise protocol being too short in duration and/or too moderate in intensity.

For blood glucose response, there was a significant time effect for both treatments, but no significant condition effect or time by condition effect. In line with other studies that have fed carbohydrate-rich bars before and during exercise (Horowitz et al., 1999; Mason et al., 1993),

our results confirm that blood glucose increases as food is ingested. However, the number of mastication cycles is likely not impactful on blood glucose response during one hour of exercise at a moderate intensity. It is possible that our conditions either did not create a large enough contrast in bolus composition to elicit a significant difference in blood glucose response, or despite the different treatments, the gut was able to absorb a similar amount of carbohydrate in the small intestine. That said, a small effect of the 40CHEW treatment on blood glucose cannot be ruled out due to the modest sample size of the study.

There was no significant time effect or condition effect in FS scores, but there was a significant time by condition effect. This suggests that less masticatory cycles might negatively impact overall feeling while exercising. RPE had no condition effect, but there was a time effect and time by condition effect. Both treatments led to an increase in RPE over time, but the 20CHEW treatment led to a greater increase in RPE. This alludes to fewer mastication cycles increasing RPE more. Reasons for the time by condition effects for RPE and FS are uncertain (especially given the lack of differences in other outcomes) but could include our inability to control stress, sleep, complete replication of food logs, or simply findings by chance.

Limitations

Certain outside factors such as sleep and stress were unable to be controlled. Additionally, some participants were unable to completely replicate their 48-hour food log. It should also be noted that our sample size of 12 participants deems small effects as non-significant, and longer treadmill running could potentially elicit a greater difference in blood glucose and substrate use response. Furthermore, insulin responses and exogenous carbohydrate oxidation were not measured, both of which would have been informative. For example, even

though total carbohydrate oxidation was not different between treatments, that does not rule out differences in the amount of carbohydrate oxidized from the bars.

CHAPTER 6

CONCLUSION

It is evident that ingesting food before and during exercise impacts physiology and performance. However, perhaps mastication duration is more limited in its impact than was predicted. Our study did detect condition by time effects in favor of 40CHEW for RPE and FS, but it is possible that this could also be more related to outside factors that could not be easily controlled, such as stress, sleep, and complete replication of the food logs. Future studies should further examine the impact of mastication on GI discomfort, substrate use, and performance during running. Investigators should consider extending treadmill running to a longer duration or imposing other GI stressors like heat. Measuring other variables such as insulin response and exogenous CHO oxidation may also help better understand the impact of mastication cycles on physiology.

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- Supervisor and exercise programmer of Therapeutic Exercise to Maximize Participant Outcomes (TEMPO), a fitness program for populations with chronic disease and Regular Exercise for Healthy and Independent Living (FOREVERFIT), a fitness program for aging populations
- Monitor participant's vital signs pre-exercise and post-exercise
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Student Observer, Sentara Norfolk General, Acute and Inpatient Therapy Center, Norfolk, Virginia; June 2018 – July 2018

- Observed the operations at an in-patient physical therapy clinic, Sentara Norfolk General Facility Manager and Coach, Fit Body Boot Camp (FBBC), Virginia Beach, VA; December 2020 – June 2021

- Managed the day-to-day operations, specifically payroll, coaches, inventory, memberships, prospect interactions, and social media networks
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Assistant Coach, Folks Stevens Tennis Center, Old Dominion University, Norfolk, VA; August 2017 – August 2019

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