

HIGH VERSUS LOW CARBOHYDRATE IN SKIMO
RACE PERFORMANCE: A RANDOMIZED
CONTROLLED TRIAL

by

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GLOSSARY or NOMENCLATURE

BF: body fat

BW: body weight

CHO: carbohydrate

GE: gastric emptying

GI: gastrointestinal

GLUT2: glucose transporter 2

GLUT5: glucose transporter 5

HBCD: highly-branched cyclic dextrin

HR: heart rate

HRmax: maximal heart rate

MTC: multiple transportable carbohydrates

SGLT1: sodium-dependent glucose transporter 1

TT: time trial

Usg: urine specific gravity

VO₂max: maximal volume of oxygen consumption

VT: ventilatory threshold

ABSTRACT

Ski mountaineering (skimo) is a high-intensity sport with several race disciplines of varying lengths in which competitors face many challenges that can make consuming food and fluids difficult. There is currently a scarcity of literature on skimo, particularly on nutrition in individual-format races. Exercise >1.5 h, as in an individual skimo race, may benefit from high carbohydrate consumption of ≥ 90 g/h compared to lower recommendations of 60 g/h. However, gastrointestinal upset is worsened with increasing amounts of carbohydrate consumption, especially during high-intensity exercise. Highly-branched cyclic dextrin is a glucose polymer with a low osmolality allowing it to have a fast gastric emptying rate which can decrease gastrointestinal upset during exercise. The first purpose of this study was to survey skimo athletes about their nutrition knowledge and practices. With this new information combined with recommendations on carbohydrate and fluid intake, the second purpose of this study was to test an 18% solution of highly-branched cyclic dextrin + fructose (3:1) in a skimo race. It was hypothesized that an 18% solution (90G) would improve performance in an individual race compared to a 6% solution (30G) without contributing to gastrointestinal upset. Fifteen participants completed the randomized controlled crossover trials. Average carbohydrate consumed was 27 and 85 g/h and race time 105 and 107 min in 30G and 90G, respectively. Overall race times were not significantly different. Gastrointestinal upset trended higher in 90G ($p=0.07$). When the four participants with high gastrointestinal upset (rating >4/10) were removed from analysis, there was a main effect for drink on percent lap time change ($p<0.001$), with 30G having a greater percent increase in lap time throughout the trial. In conclusion, a high-carbohydrate drink was created to address the needs of skimo athletes. It was found that an 18% carbohydrate solution had significantly higher gastrointestinal upset ratings and did not confer additional performance benefit compared to a 6% solution. Additionally, high gastrointestinal upset with the 18% solution appears to have contributed to slower time; however, those without high gastrointestinal upset with the 18% solution had a lesser percentage change in lap time throughout the trial compared to 6%.

CHAPTER ONE

INTRODUCTION

Development of the Problem

Ski mountaineering (skimo) is a high-intensity sport in which athletes ascend (with traction skins on the bottom of the skis or carrying skis on the back) and descend mountainous terrain multiple times. While popular in Europe, skimo racing is a burgeoning sport in the United States and will make its Olympic debut in the 2026 Milano-Cortina Games. Currently, there is a lack of scientific literature specifically on this sport. There are several considerations that add to skimo's difficulty such as high altitude, high intensity, cold weather, and gear handling.

Additionally, there are multiple different race formats, from sprint races (~3-4 min), individual races (~1.5-2.5 h), and ultra-length or multi-day races. Athletes often compete on back-to-back days in the different race disciplines and on several consecutive weekends throughout the skimo season. Therefore, nutrition and hydration recommendations need to be considered specifically for this sport and for each of the race disciplines. The individual-style race is of a length that carbohydrate availability becomes a factor in race performance, especially if competing on consecutive days.

The existing literature regarding skimo athlete nutrition is sparse and nutrition recommendations are few. Two studies on skimo athletes analyzed their nutrition leading up to and during the Patrouille des Glaciers races (26 km and 52 km). Praz et al. (2015) asked participants about their nutrition knowledge and practices during the four days leading up to the race. Athletes demonstrated basic knowledge on adapting nutrition for the race, such as

increasing carbohydrate and fluid intake and avoiding high fat and fibrous foods; however, athletes still fell below the recommended amount of total energy ($83 \pm 17\%$) and carbohydrate intake ($46 \pm 13\%$). Praz et al. (2014) analyzed the intake during Patrouille de Glaciers (26 km, race time $5\text{ h } 51\text{ min} \pm 53\text{ min}$). Energy expenditure for athletes was $22.6 \pm 2.9\text{ MJ}$ while intake was $4.4 \pm 1.3\text{ MJ}$ ($20 \pm 7\%$ of intake). While macronutrient intake was not reported, athletes were 14% below the recommended level of carbohydrate intake (0.7 g/kg/h) as set by the ACSM for endurance sports. Mean body weight loss was $1.5 \pm 1.1\text{ kg}$ of body mass ($2 \pm 1\%$), staying within recommended limits to avoid dehydration. Though not the same length as an individual skimo race, these studies demonstrate the difficulty of adequate fueling in skimo and the need for research and recommendations on other skimo race lengths.

Fueling recommendations for endurance exercise $\geq 1.5\text{ h}$ has been established as 60 g/h of carbohydrate, though research shows performance improvement with higher amounts of $\geq 90\text{ g/h}$ (Stellingwerff and Cox 2014). Carbohydrate intake becomes important when the length of the activity may be affected by glycogen stores, usually around 1.5 h (Burke et al. 2019). When consumed at a rate $>60\text{-}70\text{ g/h}$, glucose transporters in the gut can become saturated and therefore consuming multiple transportable carbohydrates, usually as 2:1 glucose + fructose, allows for a higher rate of uptake and oxidation (Jentjens et al. 2004). This higher rate of carbohydrate with multiple transportable carbohydrates has been shown to improve endurance performance.

Glycogen availability and carbohydrate intake during races can be especially important if competing on back-to-back days. The human body stores about 600 g of glycogen ($\sim 500\text{ g}$ in muscle and $\sim 80\text{-}100\text{ g}$ in the liver). Individual skimo races are of a length that glycogen

depletion may limit performance, and replenishment of glycogen stores becomes important for performance on subsequent days. Gaston et al. (2019) measured the effects of a vertical race (race time 29 min 21 s \pm 4 min 06 s) the day prior to an individual race (race time 1 h 44 min 01 s \pm 24 min 34 s). Athletes were found to have incomplete recovery as evidenced by significantly increased resting lactate and decreased muscle mass. This suggests the possibility of inadequate total energy, protein, and carbohydrate intake between the races.

High carbohydrate intake (≥ 90 g/h) during competition may be a way to enhance recovery between competitions. Viribay et al. (2020) found that participants who ingested 120 g/h of carbohydrate (2:1 maltodextrin + fructose) during an ultramarathon (42.13 km, 1990.40 m elevation gain) had less exercise-induced muscle damage (as evidenced by levels of creatine kinase, lactate dehydrogenase, and glutamic oxaloacetic transaminase) 24 h post-race compared to those who ingested 60 and 90 g/h. Similarly, Urdampilleta et al (2020) found that those who ingested 120 g/h after the same ultramarathon had greater recovery of high-intensity run capacity and neuromuscular function than those who ingested 60 and 90 g/h. Though these studies focused on events much longer than an individual skimo race, they provide evidence that high carbohydrate intake may be a way for athletes to mitigate muscle damage following strenuous exercise.

Highly-branched cyclic dextrin is a glucose polymer (maltodextrin) derived from starch. Its high solubility and low osmolality give it potential advantages to be used as a sports nutrition supplement. Osmolality plays a large role in the rate of gastric emptying, with higher osmolality slowing gastric emptying rate (Takii et al. 2005). Impaired gastric emptying can therefore affect the rate of fluid and carbohydrate uptake and contribute to gastrointestinal upset (Chuychai et al.

2022, Takii et al. 2004). Sports drinks containing highly-branched cyclic dextrin can have a high concentration of carbohydrate with a low osmolality which can be advantageous for efficiently carrying high amounts of fuel during races without additional weight concerns as well as having potential performance benefits.

Gastrointestinal symptoms are a common issue in endurance sports due to several factors such as dehydration, gastric emptying, intensity, and energy/fluid intake. Of participants surveyed in an Ironman triathlon, 93% had gastrointestinal symptoms, with 45% of them being rated as severe (Jeukendrup et al. 2000). Pfeiffer et al. (2010) found a correlation between higher carbohydrate intake and gastrointestinal upset in an Ironman race, but also with a correlation to faster performance. Though gastrointestinal upset can be highly dependent on the person, the aforementioned contributing factors are often faced during competition. For example, skimo has a high level of intensity compared to other sports which can affect gastric emptying (Leiper et al. 2000). The composition of the carbohydrate also has implications for gastric emptying, with multiple transportable carbohydrates (such as 2:1 glucose + fructose) having faster gastric emptying rates and increased fluid delivery (Jeukendrup and Moseley 2010). Additionally, athletes consume fluid and energy during races which may add to potential gastrointestinal upset due to increased osmolality and decreased splanchnic perfusion. Strategies that help to minimize these would be advantageous.

Purpose and Hypothesis

The purpose of this study was two-fold. First, to learn more about skimo athlete knowledge and practices on race nutrition and hydration during individual-style races. This survey would provide insight on the level of importance of nutrition to athletes, what fueling

recommendations they try to follow during races, perceived challenges to adequate fueling during races, and types of products consumed during races. This would then allow for the development of a fueling strategy that addresses the specific concerns in skimo while providing a recommended amount of fluid and carbohydrate. The second purpose was to test the developed fueling method in high and low doses in a simulated individual-style skimo race time trial and analyze the differences in performance and gastrointestinal upset. The hypothesis was that a solution of 18% carbohydrate in a 3:1 ratio of highly-branched cyclic dextrin + fructose would enhance performance compared to the same drink at 6%. Additionally, it was hypothesized that the higher carbohydrate drink would allow for an ease of providing a high carbohydrate amount without contributing to gastrointestinal upset.

Implications

This study is unique for being the first to analyze the nutrition knowledge, practices, and barriers to fueling specific to an individual-style skimo race. Additionally, it is the first to introduce a nutrition intervention in a skimo setting that also takes place in a field setting compared to being laboratory-based.

The results from this study will help to develop skimo-specific nutrition and hydration recommendations for athletes and give insight into the challenges of fueling in skimo. Assessment of gastrointestinal upset in skimo, especially with a high-carbohydrate drink based on highly-branched cyclic dextrin + fructose, is also a novel piece of data. Physiological assessment of athletes and the correlation to race performance further supports findings in other studies.

Limitations and Delimitations

While this study is unique for being a field time trial study on a nutrition intervention (compared to most others using laboratory or real races and focusing on physiology), this does present limitations. Field trials on winter skiing can be difficult to manage due to rapidly and constantly changing snow conditions. In this study, there was a great effort to have participants complete both arms of the crossover at the same time of day which helped to a degree to have similar conditions. However, spring weather can fluctuate day-to-day creating wet conditions in which snow accumulates on the bottom of the ski skins while ascending. Cold, on the other hand, can create icy conditions which can cause mild slipping while ascending and difficulty on descending.

Another limitation faced was underrepresentation of females. Due to low female participation in the local skimo from which the study was recruited, it was not possible to recruit more females for the study.

The first delimitation for this study was the lack of a placebo trial. The carbohydrate doses in the study were chosen to see if the higher recommended dose would be more advantageous than an amount athletes might typically consume. Excluding a placebo was the result of two reasons: first, the time constraint of collecting data and willingness of participants to complete three separate, time-intensive trials; and two, it being well-established that carbohydrate enhances performance in endurance exercise compared to no carbohydrate intake. In the choice of having participants complete two trials, comparing low and high doses was deemed more relevant. Additionally, comparing the 90 g/h highly-branched cyclic dextrin +

fructose to a 90 g/h glucose + fructose drink could have been more advantageous to elucidate gastrointestinal.

Secondly, deciding on how to deliver the carbohydrate drink to the participants to approximate an hourly dosage was a challenge. Participants in a skimo race carry their own water and fuel, so it was desired that they also carry it during the time trials in order to simulate the fueling challenges of a race. This would be in opposition to the option of providing them a drink at certain points on the course. Therefore, it was decided to provide a portion (500 mL) of the drinks for participants to carry from the start of the time trial with the requirement to finish the first 500 mL by an approximate one-hour mark (whenever they finished a lap closest to one hour and could be resupplied). This would allow a self-paced drinking style for them to consume the drinks as they might in a race.

CHAPTER TWO

LITERATURE REVIEW

Introduction

Ski mountaineering (skimo) is a high-intensity sport whereby participants ascend and descend slopes by means of skinning (with skins on the bottom of the skis for traction) and bootpacking (hiking with skis attached to the backpack) uphill and then skiing downhill. Skimo has five main disciplines of racing, with the individual race format lasting ~1.5-2.5 h and consisting of a minimum 1371 m of elevation gain and typically three ascents/descents, one of which is a bootpack. While popular in Europe, skimo is a burgeoning sport in the US and will make its debut in the 2026 Olympic Games in Milano-Cortina. Despite this growth in popularity, there is a paucity of literature specifically on this sport. Skimo has several considerations that make it challenging such as high altitude, cold temperatures, high intensity, and handling of gear. Additionally, the skimo season is quite rigorous with high training volumes, competitions on several consecutive weekends, and racing on back-to-back days in the separate race disciplines, or in back-to-back races on the same day, as with sprint races. The environmental considerations, combined with the range in race length between disciplines, creates many training and nutritional considerations unique to each race situation. Nutrition and hydration strategies such as consuming high-concentration carbohydrate beverages may be an option to efficiently carry nutrition products with ease of access and weight savings while also allowing for an adequate amount of carbohydrate and fluid delivery with low gastrointestinal upset. Optimizing race and

training nutrition to avoid energy deficits and provide adequate carbohydrate availability is paramount not just for performance, but for recovery and overall health.

Skimo Athlete Knowledge and Practices

Little is known about the actual nutrition practices of skimo athletes, and few recommendations are given for these specific athletes. Praz et al. (2015) conducted a survey of skimo athletes competing in the well-known long-distance Patrouille des Glaciers races (26 km and 52 km) to understand their nutrition and hydration knowledge and practices before competition. The athletes were asked about the importance they gave to pre-race nutrition, their food and fluid intake in the days leading up to the competition, use of supplements and “sports” food, and where they got their nutrition information. Six out of the 10 participants said that pre-race nutrition was important to performance. Participants all said eating a lot of pasta was good before competition, and nine out of 10 said it was good to increase water intake before competition. Some athletes also avoided some foods such high fat foods, alcohol, and salads in order to prevent gastrointestinal upset during the race. Athletes cited that their information sources on nutrition was mostly from friends/family, personal experience and education, and some from reading and coaches. Despite displaying elementary knowledge of recommendations such as increasing fluid and carbohydrate intake and reducing foods that may increase gastrointestinal upset, athletes still fell below recommendations of total energy intake ($83 \pm 17\%$ of recommended) and carbohydrate intake ($46 \pm 13\%$ of minimum recommended).

Gasser (2019) similarly surveyed participants of the Patrouille des Glaciers races but instead looked at nutrition practices during the races and concluded that fluid and energy intakes were low for both races. Long and short course race times were $13\text{h } 18\text{ min} \pm 66\text{ min}$ and $6\text{ h } 32$

min \pm 30 min, respectively, with average fluid intake being 5.6 ± 4.6 L and 3.8 ± 2.4 L, and energy intake 5500 ± 2145 kcal and 5000 ± 4327 kcal, respectively. Foods most commonly consumed during the races were dried fruits (84%) and chocolate (62%), with bread and dry meat ranked next. Gels, sportsbars, and sport beverages were ranked low, though participants who consumed these items were faster.

Another study on the Patrouille des Glaciers races analyzed energy expenditure and intake during the races (Praz et al. 2014). Race courses were modified and were therefore 27 km (race Z) and 26 km (race A) long (5 h 7 min \pm 44 min and 5 h 51 min \pm 53 min, respectively). Energy expenditure during the races was 19.2 ± 3.2 MJ (Z) and 22.6 ± 2.9 MJ (A). Intake data for race Z could not be gathered but energy intake in race A was 4.4 ± 1.3 MJ, equating to $20 \pm 7\%$ of the energy expenditure of the race. The authors reported that participants were 14% below the recommended intake of carbohydrate (0.7 g/kg/h, or 5.1 ± 0.9 kJ) as set by the ACSM for endurance sports. Macronutrient content was not reported. Racers also lost 1.5 ± 1.1 kg of body mass ($2 \pm 1\%$), staying within recommended limits to avoid dehydration.

Despite these surveys and studies displaying evidence of intake in skimo athletes, they are not specific to those racing individual-style skimo races or in back-to-back competitions. Patrouille des Glaciers is substantially longer than an individual-style skimo race and direct comparison of intake or recommendations would be inappropriate. However, there is clearly room to learn more about the practices of skimo athletes and how nutrition may be improved in the different race disciplines.

Fueling Considerations and Recommendations

Carbohydrate An area of concern is consuming an adequate amount of energy and fluid during skimo racing and training. Ensuring proper nutrition during and around training and competition is vital for skimo athletes to be able to recover and perform at a high level. Carbohydrates are the primary macronutrient of importance in endurance training and performance with specific amounts, ratios, and timing of intake each a big consideration. Events in which glycogen stores may be a limiting factor, usually beginning around 1.5 hours in length (as with an individual-style skimo race), can benefit from glycogen supercompensation in the 36-48 hours leading up to the event (Burke et al. 2019). Rauch et al. (1995) studied the effects of carbohydrate loading (10.52 ± 0.57 g/kg body weight/day) versus following participants' normal diet (6.15 ± 0.23 g/kg body weight/day of carbohydrate) on endurance cycling performance. Participants completed a 2-h cycle at 75% of their maximal oxygen consumption with five 60-s sprints at 100% of maximal oxygen consumption followed by a 60-min performance ride. Additionally, participants ingested 750 mL/h of an 8 g/100 mL carbohydrate solution during the first two hours and only water ad libitum in the final hour. Results showed that the carbohydrate loading condition significantly increased starting muscle glycogen content ($47 \pm 4\%$ higher) compared to normal diet and that muscle glycogen content after the trials were not significantly different, indicating more muscle glycogen was used in the carbohydrate loading condition. Average power output and speed during the 60-min performance ride was also greater during the carbohydrate loading trial ($p < 0.05$ for both).

Carbohydrate intake during endurance exercise has been typically recommended to be 30-60 g/h, though up to 90 g/h has been demonstrated to be beneficial (Stellingwerff and Cox 2014). Importantly, carbohydrate oxidation at rates above 60-70 g/h becomes limited when

ingesting glucose alone due to transporter saturation and must therefore be in the form of multiple transportable carbohydrates (e.g. glucose + fructose) (Jeukendrup 2014).

Carbohydrate is transported from the lumen of the small intestine, across the enterocyte membrane, and into circulation. Transportation into the enterocyte is facilitated by sodium-dependent glucose transporter-1 (SGLT1), which transports galactose and glucose (both of which can also secondarily use glucose transporter 2 (GLUT2)), and glucose transporter 5 (GLUT5), which transports fructose. Transportation from enterocyte into circulation is exclusively mediated by glucose transporter 2 (GLUT2). At high levels of ingestion (>60 g/h) of glucose, SGLT1 transporters become saturated, and no greater performance benefit is conferred with increased carbohydrate consumption rates and gastrointestinal discomfort becomes more likely (Jeukendrup 2017).

In demonstration of this, during two hours of cycling at 50% maximum power output, higher (~55%) peak carbohydrate oxidation was found with a 2:1 glucose:fructose solution compared to both 1.2 g/min and 1.8 g/min of glucose alone, and average carbohydrate oxidation rate (g/min) with the 2:1 solution was significantly higher as well (1.16 ± 0.06 glucose + fructose, 0.75 ± 0.04 1.2 g/min glucose, 0.75 ± 0.04 1.8 g/min glucose) (Jentjens et al. 2003).

Fructose co-ingestion with glucose can be achieved equally as well when ingested as a disaccharide (sucrose) as demonstrated by (Trommelen et al. 2017). During 180 min of cycling at 50% maximal watts, participants consumed either 1.8 g/min glucose, 1.8 g/min 2:1 glucose + fructose, 1.8 g/min 2:1 sucrose + glucose, or water. Peak exogenous carbohydrate oxidation did not differ between the glucose + fructose and glucose + sucrose conditions, but they were significantly higher ($46 \pm 8\%$) compared to glucose alone. Hours two and three of cycling also

had significantly higher ($46 \pm 8\%$) exogenous carbohydrate oxidation in glucose + fructose and glucose + fructose compared to glucose alone.

Highly-Branched Cyclic Dextrin Highly-branched cyclic dextrin is a highly-soluble, low-osmolality glucose polymer (maltodextrin) whose properties might be advantageous in a sport setting. Highly-branched cyclic dextrin is composed of short chains of glucose monomers linked by α -1,4-glucosidic bonds and linked to other chains by α -1,6-glucosidic bonds. A cyclic moiety is created with the use of α -amylase to cleave the bonds of the dextrin chains and a branching enzyme is used to cause cyclization (Choi et al. 2009). Its structure is thus similar to starch (amylopectin) and maltodextrin, and is hydrolyzed by α -amylase into maltose and maltotriose and eventually glucose (Choi et al. 2009). Maltodextrin is also composed of short chains of glucose units linked by α -1,4-glucosidic bonds with occasional branching to other short glucose chains via α -1,6-glucosidic bonds. Notably, α -1,6-glucosidic bonds are digested slightly more slowly than α -1,4-glucosidic bonds, though glucose from digested maltodextrin is still rapidly digested (Hofman et al. 2016).

Due to its low osmolality, highly-branched cyclic dextrin solutions have the potential to decrease gastric emptying time and thus feelings of gastrointestinal upset. Takii et al. (2005) compared the gastric emptying rates at rest of 5% and 10% solutions of highly-branched cyclic dextrin, glucose, maltose, sucrose, and dextrin. All of the 5% solutions had a significantly faster gastric emptying rate than their same 10% solution. A 10% highly-branched cyclic dextrin solution (9 mOsm) had a significantly faster gastric emptying time compared to a 10% glucose solution (646 mOsm) (~ 26.7 min vs. ~ 39.9 min), but significantly slower gastric emptying time compared to a 10% dextrin solution (117 mOsm, ~ 17.3 min). However, when a “sports drink”

solution was made by adding vitamins, minerals, and organic acids (to represent a more realistic market product) to both 10% HBCD and dextrin, the 10% highly-branched cyclic dextrin sports drink (150 mOsm, ~17.0 min) gastric emptying time was significantly faster than the 10% dextrin sports drink (269 mOsm, ~21.9 min).

Highly-branched cyclic dextrin has been touted for its ability to keep stable blood glucose levels which is due to the slower digestion because of its highly-branched and cyclic structure; thus, much research has measured the metabolic response with its ingestion. Saelao et al. (2023) studied the metabolic effects of the ingestion of 1.5 g/kg of body weight of highly-branched cyclic dextrin compared to maltodextrin during a 30-minute run at the first ventilatory threshold followed by a ramped-intensity run to exhaustion. None of the measured glucoregulatory hormones (blood insulin, salivary cortisol) or metabolic responses (blood glucose, blood lactate, serum free fatty acids) reached a significant difference. Additionally, there was no difference in exercise performance between conditions.

Similarly, Piehl Aulin et al. (2000) compared glycogen resynthesis with the ingestion of high- and low-osmolality carbohydrate beverages. Participants completed a glycogen-depletion protocol of a 60-min run then 60-min constant cycle followed by a series of sprints to exhaustion. Participants then consumed a 500 mL drink with 300 g of carbohydrate composed of either 75 g of monomeric and oligomeric glucose from maize starch (350 mOsm) or 75 g of large glucose polymer from potato starch (84 mOsm). It was found that the low-osmolality condition had significantly higher muscle glycogen resynthesis two hours after exercise, with no difference between condition between 2-4 h post-exercise. Additionally, blood glucose and insulin concentrations did not differ between conditions.

These studies are in line with others showing blood glucose responses with ingestion of highly-branched cyclic dextrin during exercise were similar (Chuychai et al. 2022, Takii et al. 2004) or higher (Furuyashiki et al. 2014, Shiraki et al. 2015) than with ingestion of glucose and maltodextrin.

In demonstration of improved exercise performance, Shiraki et al. (2015) tested the effects of a highly-branched cyclic dextrin solution on endurance swimming. Seven elite male swimmers drank either water or a 1.5 g/kg of body weight solution of highly-branched cyclic dextrin or glucose and then performed 10 cycles of swimming for five minutes at 75% maximal oxygen consumption with three minutes rest, followed by a swim to exhaustion at 90% maximal oxygen consumption. Highly-branched cyclic dextrin had a significantly longer time to exhaustion (~70%) and higher blood glucose and blood lactate compared to glucose or control beverages. This suggests a greater amount of carbohydrate oxidation in highly-branched cyclic dextrin compared to glucose and water.

Another endurance performance study also measured body fluid loss. Chuychai et al. (2022) compared performance in participants who ingested 500 mL of 1.5 g/kg of body weight of highly-branched cyclic dextrin or glucose 30 min before start of a running trial consisting of a 3-min warm up then a 30 min run at the first ventilatory threshold followed by running at the second ventilatory threshold until exhaustion. Highly-branched cyclic dextrin resulted in significantly longer time to exhaustion compared to glucose (42.67 ± 4.92 min vs. 40.77 ± 4.40 min, respectively), and less body fluid loss (0.28 ± 0.18 kg vs. 0.50 ± 0.32 kg).

Faster gastric emptying time also has implications for gastrointestinal upset. Takii et al. (2004) measured gastric emptying time and gastrointestinal upset during exercise with highly-

branched cyclic dextrin, dextrin, and glucose sports drinks. Untrained men performed a standardized nine-minute warm-up then drank the given solution within one minute and rested for 10 minutes. Exercise was then continued for 30 min consisting of 10-min blocks at increasing load at 60 rpm. Results showed significantly faster gastric emptying time with highly-branched cyclic dextrin compared to glucose, and faster (though not significant) time compared to dextrin. There were also significantly fewer gastrointestinal symptoms (flatulence, belches) compared to glucose and dextrin. Faster gastric emptying time may therefore help prevent gastrointestinal symptoms.

Gastrointestinal Concerns While it has been demonstrated that high amounts of carbohydrate can be beneficial to athletes, it is important to consider the method of delivery to ensure palatability and minimization of gastrointestinal upset that is often a problem in high-intensity and endurance sports, especially when consuming energy and fluids. Rates of gastrointestinal upset are variable and can depend on the modality of sport and individuality, but it is still quite prevalent. Pfeiffer et al. (2010) found a correlation between higher carbohydrate intake and faster performance during an Ironman race, but also with an increase in gastrointestinal upset. Additionally, of 27 study participants partaking in an Ironman-distance triathlon, 93% reported gastrointestinal symptoms, with 45% of complaints rated as severe, and two participants dropping out of the race due to gastrointestinal issues (Jeukendrup et al. 2000). Therefore, finding fueling solutions that minimize gastrointestinal upset could be of interest to athletes.

Gastrointestinal upset is multifactorial and can be caused by dehydration, exercise intensity, and composition of energy and fluid intake, all of which can be affected by gastric

emptying time. Van Nieuwenhoven et al. (2000) found significantly slower gastric emptying time, which correlated with an increase in nausea, in those who were dehydrated by 3% before 1.5 h of cycling at 70% of maximal oxygen consumption compared to control (euhydrated).

Meanwhile, intermittent high-intensity exercise has been shown to slow gastric emptying. Leiper et al. (2000) compared gastric emptying time of 600 mL of a 6% CHO-electrolyte solution consumed immediately before rest (R) or three cycling conditions (constant power output at 66% of maximal oxygen consumption (C66), intermittent high-intensity averaging 66% of maximal oxygen consumption (I66), and intermittent high-intensity averaging 75% of maximal oxygen consumption (I75)). The median time to empty half of the drink volume was faster in R than C66, but there was no significant difference between C66 and I66 or I75 and I75. However, the median volume of drink delivered to the duodenum was faster in R and C66 than I66 and I75.

Composition of ingested energy and fluids is also important to consider, especially with the high quantities recommended for endurance exercise. Gastric emptying rate can be affected by volume ingested, osmolality of what is consumed, and intestinal feedback. Large volumes of fluid can quicken gastric emptying time, while high-osmolality fluids can slow gastric emptying. Likewise, gastric emptying can be inhibited by feedback from the small intestine if carbohydrate is not absorbed quickly enough and begins to accumulate (Jeukendrup and Moseley 2010). Besides being recommended for higher carbohydrate oxidation, multiple transportable carbohydrates have also shown faster gastric emptying time compared to single source of carbohydrate. Jeukendrup and Moseley (2008) measured gastric emptying, fluid delivery, and hydration during two hours of moderate cycling (50% maximum wattage) with the ingestion of

water, 8.6% glucose, or 8.6% glucose + fructose (2:1) at a rate of 1.5 g/min. Exercise began with ingestion of 600 mL then 203 mL every 15 min. Results showed that gastric emptying and fluid delivery was significantly faster with glucose + fructose compared to glucose from 15 min to the end of exercise.

Even with these many considerations, gastrointestinal upset is still highly individualized. A study by Pfeiffer et al. (2009) compared the effects of both rate and composition of carbohydrate gels on tolerability during 16 km runs. The first trial compared delivery of 1.0 versus 1.4 g/min of glucose + fructose while the second trial compared 1.4 g/min of glucose versus glucose + fructose. Gastrointestinal complaints were rated 0-10 for 17 different symptoms. Results showed there was no difference between conditions in either trial; However, in the first trial, 9% of runners experienced serious symptoms (rated >4) with the higher carbohydrate dose, while in the second trial 19% of runner reported serious symptoms with glucose + fructose and only 10% reported serious symptoms with glucose. This equates to 10-20% of runners across both trials.

With large variability in gastrointestinal upset depending on duration and intensity of exercise and individual differences, gut training has emerged as a solution. Costa et al. (2017) tested the effects of two weeks of gut training on endurance running. Participants completed an initial running test of 2 h of steady-state running at 60% maximal oxygen consumption while consuming 30 g of carbohydrate (2:1 glucose + fructose) every 30 min, followed by a one-hour self-paced distance test receiving ad libitum water only. Participants were asked their rating of gastrointestinal symptoms upon completion. Participants were then randomly assigned to a two-week gut-training intervention group (carbohydrate gel supplementation, carbohydrate food

supplementation, or placebo), which they would consume every 20 min during 1-h runs (90 g total). At the end of the two weeks, the initial trial test run was repeated. Results showed a 44% and 49% mean reduction in gastrointestinal symptoms with carbohydrate gel and carbohydrate food interventions as well as improved one-hour distance test compared to placebo.

While exact mechanisms of the adaptation of the gut to high carbohydrate loads have yet to be elucidated, some of this adaptation is thought to be due to the upregulation of transporters in the gut (SGLT1) (Jeukendrup 2017). High carbohydrate intake over a time course of several days to approximately two weeks has the potential to increase SGLT1, allowing for increased carbohydrate uptake and delivery and thus faster gastric emptying and decreased levels of fullness during exercise.

Recovery Adequate and increased carbohydrate intake becomes even more important on back-to-back competition days for both recovery and performance. Skimo training loads can be quite high, and athletes often compete on back-to-back days and on several consecutive weekends throughout the season. Gaston et al. (2019) analyzed the impact on recovery and performance of a vertical race the day prior to an individual race. The 10 elite participants (11.5 ± 2.5 h training per week) were found to have incomplete metabolic recovery, increased resting lactate, and decreased muscle mass the day following the vertical race/ prior to the individual race. These markers can indicate inadequate intake of total energy or protein and carbohydrate.

It has been found in two separate studies on back-to-back skimo competition days that athletes both under fuel in total energy and consume less than the recommended amount of carbohydrate for endurance activity (Diaz et al. 2010, Praz et al. 2014). This is the case even despite displaying knowledge to increase carbohydrate and energy intake leading up to and

during endurance competition (Praz et al. 2014). Diaz et al. (2010) also found correlation between higher muscle cell damage in skiers with the lowest total energy, protein, and fat intake across a two-day skimo race, while those with the highest carbohydrate intake had the fastest race times.

While there is some mixed evidence whether ingesting >90 g/h carbohydrate has performance benefits in certain situations, Viribay et al. (2020) found lower exercise-induced muscle damage following an ultramarathon (race distance 42.13 km, 1990.40 m elevation gain) when participants ingested 120 g/h carbohydrate (2:1 maltodextrin + fructose) compared to 60 or 90 g/h of carbohydrate. Exercise-induced muscle damage markers were measured before and 24 h post-race. Creatine kinase, lactate dehydrogenase, and glutamic oxaloacetic transaminase all were significantly lower in the 120 g/h carbohydrate group compared to 60 and 90 g/h. This could be a valuable tactic for lowering muscle damage on back-to-back competition days.

In a related study, Urdampilleta et al. (2020) found greater neuromuscular function and recovery of high-intensity run capacity 24h after completion of the mountain ultramarathon in those who had ingested 120 g/h carbohydrate (2:1 maltodextrin + fructose) compared to those who ingested 60 g/h or 90 g/h. Pre- and 24 h-post race, participants completed a jump test, maximum half-squat test, and an aerobic power-capacity test. The 120 g/h group had significantly better performance 24 h post-race compared to the 60 and 90 g/h groups in each of the tests.

Liver glycogen repletion can be important for back-to-back competition when glycogen stores may be depleted and can be a limiting factor to subsequent performance. Fuchs et al. (2016) studied the effects of sucrose versus glucose ingestion on the repletion of liver and muscle

glycogen after exercise. After a 12-h fast, 15 well-trained male cyclists completed a glycogen-depletion cycle until they were unable to hold the appropriate cadence. They then had a five-hour rest period during which they were given a drink volume of 3.33 mL/kg every 30 min equaling 1.5 g/kg/h of glucose or sucrose. Results showed liver glycogen repletion was significantly greater (17 g greater, or ~3.4 g/min greater) with sucrose versus glucose. Muscle glycogen repletion increased in both conditions but did not differ between conditions.

Together, these papers highlight the importance of nutrition before, during, and after skimo competition(s) for optimal performance and recovery. Thus, for individual races lasting between 1.5-2.5 h, recommendations of 90 g/h carbohydrate in a combination of glucose and fructose could help to optimize performance, and if competing on back-to-back days, >90 g/h carbohydrate could help to limit muscle damage.

Energy Balance Fueling around and during long or numerous efforts could help keep athletes in energy balance and avoid energy deficiencies which could lead to low energy availability and relative energy deficiency in sport. In a review on low energy availability in athletes, there was a prevalence between 22-58% across different sports with associations found between low energy availability and risk and stress fractures and missing training due to illness (Logue et al. 2020). Within-day energy deficits can contribute to endocrine dysfunction and overall energy deficits as demonstrated in a study by Fahrenholtz et al. (2017). Females athletes (age 18-38) who were either eumenorrheic or had menstrual dysfunction had their diet and physical activity monitored for seven days. It was found that the participants diagnosed with menstrual dysfunction (60%) had lower resting metabolic rate and 14% lower relative fat mass compared to eumenorrheic participants, without differences in training volume or exercise

capacity. While there was not a difference in 24-h energy availability or energy balance, those with menstrual dysfunction spent more time in energy deficit, which was also associated with lower estrogen and higher cortisol levels. Additionally, low carbohydrate availability, even in the absence of low energy availability, has been demonstrated to have detrimental effects on bone, immunity, and iron biomarkers (Mountjoy et al. 2023).

High levels of carbohydrate during training and competition may therefore help to mitigate large energy deficits. With low body weight and low fat-free mass often correlated with performance in skimo athletes, there is founded concern for the possibility of disordered eating and low energy availability/relative energy deficiency in sport; however, the prevalence of these has not yet been studied in skimo athletes.

Hydration Hydration is an important consideration in all sport and exercise. In skimo, racers must be able to hydrate effectively in long, high-intensity races in which cold temperatures might freeze their water and might decrease the desire to drink. As little as 2% dehydration is known to negatively impact performance (James et al. 2019). In 10 elite-level study participants, Gaston et al. (2019) found 0.5% dehydration after a vertical skimo race and 1.5% dehydration after an individual skimo race (race time $1:44:01 \pm 00:24:34$) that took place the day after the vertical race. This could demonstrate the potential for compounding effects of dehydration.

A study by Below et al. (1994) looked at the effects on performance of high versus low fluid replacement (1330 ± 60 mL of 6% carbohydrate solution versus 200 ± 10 mL of 40% maltodextrin) and carbohydrate (79 ± 4 g CHO) versus no carbohydrate during exercise. Participants cycled at a warm temperature ($31.2 \pm 0.1^\circ\text{C}$) at a volume of oxygen consumption 5% above their lactate threshold for 50 min while receiving one of the drink conditions. A

cycling performance test was then completed. The large volume of fluid replacement was faster by 6.5% in the performance test compared to the small volume, while carbohydrate was 6.3% faster than no carbohydrate. Thus, high fluid replacement and high carbohydrate intake both improved cycling performance.

As detailed earlier, dehydration also causes slower gastric emptying time, correlating with increased nausea (Van Nieuwenhoven et al. 2000). Carbohydrate solutions ingested during exercise introduce an osmolality that favors faster intestinal absorption and can have the potential to ensure adequate hydration due to the solvent drag effect (Rowlands et al. 2022).

Environmental Considerations and Intensity Skimo has several physiological and environmental considerations that make it a difficult sport. Due to the need for mountainous, snowy terrain, competitions are often held at cold, high-altitude venues. Competitors often compete on back-to-back days in high-intensity races of different length. The combination of cold, altitude, intensity, and gear handling can have impacts on physiology and make adequate fueling a challenge.

Many of the skimo disciplines take place at a high level of intensity which can be complicated further by cold, altitude, and gear handling. In a study analyzing the physiology of nine well-trained males in an individual skimo race lasting on average 161.5 ± 22.7 min, the mean heart rate was found to be 152 ± 9 bpm with competitors spending $59.8 \pm 12.5\%$ of time in the high-intensity zone (defined as the top half between ventilatory thresholds 1 and 2) and $20.4 \pm 18.0\%$ in the maximal zone (defined as above the second ventilatory threshold) (Schenk et al. 2011).

Another individual race that was analyzed, in which the studied subjects completed the course in 101 ± 11 minutes, found mean heart rate to be 170 ± 6 bpm ($93.4 \pm 1.8\%$ maximal heart rate) with $51.3 \pm 4.7\%$ of time spent in Z2 (defined as between ventilatory threshold 1 and the respiratory compensation threshold) and $42.0 \pm 6.5\%$ of race time spent in Z3 (defined as above respiratory compensation threshold) (Duc et al. 2011). Duc et al. (2011) compared this level of intensity to other sports, finding participants of the Trace Catalan half-marathon (of similar time length) to perform at 90% maximal heart rate (up to 92-93% of maximal heart rate), whereas an off-road bike race (lasting ~147 min) found racers spending $51 \pm 9\%$ of time in a similar Z2 and $31 \pm 16\%$ in a similar Z3. This is similar to findings by Gaston et al. (2019) who found mean heart rate to be $90.7 \pm 2.1\%$ of theoretical maximal heart rate in 10 elite skimo athletes in an individual race lasting 1 h 44 m 1 s \pm 24 m 34 s.

Skimo races are often held at high elevations and usually ascend another 300-600 m from the base altitude of the race start. Increasing altitude results in a lower partial pressure of oxygen in the atmosphere. This lower partial pressure creates a lesser gradient to drive air into the lungs as well as a lesser gradient for oxygen to diffuse across the lung membrane into the blood. This phenomenon then makes it more difficult to transport oxygen to the body's tissues, especially with increased oxygen needs such as in exercise. Physiological adaptation to higher altitudes (~2000 m-3000 m) include an expansion of blood volume, increased energy requirements, increased iron requirements, and increased glycogen and carbohydrate use.

High altitude is known to change the metabolism of macronutrients, though the range of altitude and prior acclimatization of the individual can also determine the magnitude of effect. Exposure to altitude can reduce the ability to utilize exogenous carbohydrate during exercise

which can highlight the importance of adequate carbohydrate intake prior to exercise (Podlogar and Wallis 2022).

Performance effects of altitude include a decrease in maximal oxygen consumption and maximal heart rate. Maximal oxygen consumption has been shown to decrease linearly with increasing altitude beginning at 300 m to 2800 m with approximately 6.3% decline per 1000 m (Wehrin et al. 2005).

Decline in maximal oxygen consumption with altitude has also been correlated with similar declines in oxygen saturation and maximal heart rate between 1000 m to 4500 m, though change in maximal oxygen consumption was more explained by the change in oxygen saturation most likely due to the faster transit time of red blood cells through the pulmonary capillaries with increased cardiac output (Mollard et al. 2007).

It should be noted that differences in physiological effects and adaptations to hypoxia exposure may exist between sexes (Raberin et al. 2023). This includes possible increased susceptibility to exercise-induced hypoxemia which could contribute to decline in maximal oxygen consumption, as well as greater hypoxemia with exposure to similar hypoxic intensity and duration as men (Raberin). Additionally, it has been established that females have greater fat oxidation during endurance exercise compared to males, including exercise in hypoxic conditions (Raberin).

Conclusion

With the popularity of skimo on the rise in the US and with its introduction to the Olympics in 2026, there is a gap to fill in the sport-specific literature in order to help athletes overcome the unique challenges faced during competition. Competition at cold, high altitudes

create physiological challenges while athletes also contend with gear weight and handling during high-intensity output. Fueling and hydrating during these high-intensity endurance competitions is crucial to peak performance, yet it must be accomplished in the most easily-accessible and efficient way possible. High-concentration, multiple-transportable carbohydrate drinks could be an effective way to deliver the energy needed during competition while preventing dehydration. These fueling methods might also improve recovery when competing on back-to-back days.

CHAPTER THREE

HIGH VERSUS LOW CARBOHYDRATE IN SKIMO
RACE PERFORMANCE: A RANDOMIZED
CONTROLLED TRIAL

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Abstract

Ski mountaineering (skimo) racing is quickly gaining popularity in the US, yet there is a lack of nutrition literature specific to this demanding sport. Additionally, it is known that high-carbohydrate intake ≥ 90 g/h can confer performance benefits for endurance exercise, though this can also increase the risk of gastrointestinal upset. The first purpose of this study was to survey skimo athletes about their nutrition knowledge and practices. With this new information combined with the literature recommendations on carbohydrate and fluid intake, the second purpose of this study was to test an 18% solution of highly-branched cyclic dextrin + fructose (3:1) in a skimo race. It was hypothesized that the 18% solution (90G) would improve performance in an individual race compared to a similar 6% solution (30G) without contributing to gastrointestinal upset. Fifteen participants completed the randomized controlled crossover time trials. Average carbohydrate consumed was 27 and 85 g/h and race time 105 and 107 min in 30G and 90G, respectively. Overall race times were not significantly different. Gastrointestinal upset trended higher in 90G ($p=0.07$). When the four people with high gastrointestinal upset (rating $>4/10$) were removed from analysis, there was a main effect for drink on percent lap time change ($p<0.001$) with 30G having a greater increase in percent lap time change. In conclusion, a high-carbohydrate drink was created to address the needs of skimo athletes. It was found that an 18% carbohydrate solution did not confer additional performance benefit compared to a 6% solution. Additionally, the 18% solution trended toward higher gastrointestinal upset which appears to have contributed to a slower time; however, when those with high gastrointestinal upset were removed from analysis, those who tolerated the 18% solution had a lesser percent increase in lap time throughout the trials.

Introduction

Ski mountaineering racing (skimo) is a high-intensity sport that involves ascending and descending mountainous terrain on skis. Though popular in Europe, skimo racing is now beginning to grow in the US and will make its Olympic debut in the 2026 Milano-Cortina Games. There are many special considerations that contribute to skimo's difficulty such as high-altitude, cold temperatures, high intensity, and handling of gear. However, the sport-specific literature on athlete nutrition and physiology is lacking. Sufficient energy and fluid intake during and surrounding competition and training is important to be able to sustain high training loads and perform optimally. While carbohydrate intake for endurance exercise has traditionally been recommended to be ~60 g/h, performance benefits have been reported with >90 g/h. This rate of carbohydrate consumption, in the form of multiple transportable carbohydrates, has the potential to enhance performance by increasing the oxidation rate. Using highly-branched cyclic dextrin, a maltodextrin derived from starch, can quicken gastric emptying time to allow for faster oxidation and decreased gastrointestinal upset.

Praz et al. (2015) conducted a survey to evaluate the nutritional beliefs and behaviors of skimo athletes competing in either of the Patrouille des Glaciers races (26 km and 53 km). It was found that, despite the athletes displaying basic knowledge of adapting nutrition to competition, actual behavior did not meet recommendations ($83 \pm 17\%$ of recommended intake, carbohydrate intake $46 \pm 13\%$ of minimal recommended (10 g/kg/day)). Other challenges include environmental factors such as high altitude and cold weather that can have negative performance effects due to physiological impact (Wehrlin and Hallen 2006, Quirion et al. 1989). Skimo also takes place at a high intensity, with mean heart rate in a simulated race (average race time $101 \pm$

11 min) found to be $93.4 \pm 1.8\%$ maximal heart rate, comparable to other endurance sports such as Nordic skiing, running, and biking (Duc et al. 2011). Competitors must also contend with the weight and handling of gear, making it a weight-conscious sport. For example, body weight has been found to correlate with race performance (Duc et al. 2010, Schenk et al. 2011). Gear weight is also minimized as much as possible, as Tosi et al. (2009) found that for every 1.25% increase in gear weight there is an increase in energy cost by 2-3% during uphill skiing. Fueling and hydration strategies that help to minimize additional weight that athletes must carry may be advantageous and of interest. Together, these factors compound to make adequate fueling and hydration difficult to manage. The skimo season is quite rigorous, with high training loads, races taking place on several consecutive weekends, and athletes often competing on back-to-back days in the different race disciplines and/or in back-to-back races on the same day, as with sprint races. This high stress can compound and is even more deleterious when not adequately fueling (Diaz et al. 2010). Thus, it is best to employ many tactics to optimize recovery and performance (Gaston et al. 2019). Research expanding on the practices of skimo athletes in training and racing is needed to create better sport-specific recommendations.

High carbohydrate intake during and surrounding endurance exercise is highly beneficial to both performance and recovery (Moore 2015, Cochran et al. 2010), and adequate fueling and hydration for skimo athletes is of great importance to be able to perform well throughout the training and racing season. Carbohydrate intake for activity >1.5 h is recommended to be 60 g/h but may be >90 g/h with multiple transportable carbohydrates (Stellingwerff and Cox 2014). Ingesting high levels of carbohydrate in the form of multiple transportable carbohydrates, such as glucose-fructose mixtures, has been reported to be performance enhancing over single sources of

carbohydrate due to increased ability to transport them from the gut lumen into circulation (Trommelen et al. 2017, Rowe et al. 2022). Trommelen et al. (2017) found peak exogenous carbohydrate oxidation of multiple transportable carbohydrate (as 2:1 glucose or sucrose:fructose) to be $46 \pm 8\%$ greater than glucose alone. Above about 60 g/h, glucose transporters into the enterocyte (sodium-dependent glucose transporter 1) become saturated and therefore become the limiting factor to increasing carbohydrate absorption and performance improvement (Jeukendrup 2014). Therefore, increasing carbohydrate consumption to ≥ 90 g/h with multiple transportable carbohydrate during endurance exercise may improve performance.

During endurance training and competition, athletes must also contend with the possibility of gastrointestinal upset, especially when consuming fluids and energy (Jeukendrup 2017). Gastrointestinal upset in athletes can be multifactorial. Dehydration is known to contribute to gastrointestinal upset due to decreased splanchnic perfusion, with 3% dehydration pre-exercise causing slower gastric emptying compared to control, which also correlated with an increase in nausea (van Nieuwenhoven et al. 2000). Leiper et al. (2000) demonstrated the effect of exercise intensity slowing gastric emptying and increased gastrointestinal upset compared to rest. It was found that intermittent high-intensity exercise at 75% maximal oxygen consumption slowed gastric emptying compared to rest and to constant exercise at 66% of maximal oxygen consumption. Large volumes of fluid can quicken gastric emptying; however, slow absorption in the small intestine can result in a buildup of carbohydrate and fluid which sends inhibitory feedback to slow gastric emptying, resulting in larger volumes in the stomach that can cause gastrointestinal upset (Jeukendrup and Moseley 2010). Osmolality of fluids and types of carbohydrate ingested also affect gastric emptying. For example, it has been shown that multiple

transportable carbohydrates in the form of 60:30 g/h of glucose:fructose have a faster gastric emptying time and increase fluid delivery compared to the same amount of glucose alone (Jeukendrup and Moseley 2008). This is important due to higher carbohydrate intake during exercise being related to faster endurance performance but also increased gastrointestinal upset (Pfeiffer et al. 2010). Highly-branched cyclic dextrin is a glucose polymer (maltodextrin) derived from starch that has a low osmolality allowing for a faster gastric emptying time and showing longer time to exhaustion compared to glucose when consumed during exercise (Wilburn et al. 2021, Chuychai et al. 2022, Shiraki et al. 2015). Blood glucose responses with ingestion of highly-branched cyclic dextrin during exercise were similar (Chuychai et al. 2022, Takii et al. 2004) or higher (Furuyashiki et al. 2014, Shiraki et al. 2015) than with ingestion of glucose and maltodextrin. Less gastrointestinal upset has been reported with highly-branched cyclic compared to glucose, sucrose, maltose, and dextrin when consumed during exercise (Takii et al. 2004). Because of its high solubility and low osmolality, highly-branched cyclic dextrin could be an easy way for weight-conscious skimo athletes to easily carry and consume carbohydrate during competition without need for much dexterity and with lower potential for gastric upset.

With these specific difficulties in skimo, and due to the sparse literature specifically on the sport, there were two purposes to this study. The first purpose was to learn more about skimo athlete knowledge and practices on race nutrition and hydration during individual-style skimo races. These results allowed for assessment of athletes' practices and challenges to then develop a fueling and hydration strategy for skimo racing. The second purpose was to test the developed fueling method in high and low doses in a simulated individual-style skimo race time trial and analyze the differences in performance and gastrointestinal upset. It was hypothesized that an

18% solution of 3:1 highly-branched cyclic dextrin + fructose delivering 90 g/h would improve time to completion compared to a similar solution of 6% delivering 30 g/h. It was also hypothesized that a higher concentration drink solution based on a highly-branched cyclic dextrin + fructose solution could help to increase carbohydrate delivery during a race in an easy manner without contributing to increased gastrointestinal distress.

Methods

Survey of Skimo Racers

Participants Inclusion criteria for participation was 18+ years of age and at least one year of participation in skimo or completion of two individual-style skimo races. The survey was distributed to the local community by word-of-mouth, social media, and at local skimo events and was additionally shared to other skimo race organizations in other states. The survey was approved by Montana State University Institutional Review Board (2023-1132) and subjects gave written informed consent before participating (Appendix D).

Online Survey A 21-question survey was created to evaluate the experience, knowledge, and practices of experienced skimo athletes about race fueling and hydration. Demographics of online survey participants were evaluated by gender, age, subjective level of performance (front-, middle-, or back-of-the-pack), years participating in skimo, and weekly training volume. Knowledge about sports nutrition was evaluated by asking level of formal education on the topic (advanced degrees or certifications), self-education materials consumed (books, podcasts, magazines, scientific literature, other), and awareness of the amount of carbohydrate and fluid recommended for exercise 1.5-3 h in length. Finally, participants' practices were evaluated by

asking the quantity of carbohydrate and fluid they believe they typically ingest during skimo races lasting 1.5-3 h, what their preferred fueling methods were (gels, gummies, bars, liquid calories, nothing, other), and what they perceive as barriers to fueling and hydrating during races (gut issues, cold temperature, accessibility issues, not feeling hungry/thirsty, knowledge deficit of recommendations, don't want to carry extra weight). Full survey can be found in supplemental materials (Appendix A).

Time Trials

Participants Participants were recruited from the local recreational skimo community. Inclusion criteria for participation were 18+ years of age and at least one year of participation in skimo or completion of two individual-style skimo races. Exclusion criteria were any health conditions that would prevent maximal cardiorespiratory effort and diagnosis of diabetes. The study was approved by Montana State University Institutional Review Board (2023-1272). All subjects were informed about experimental procedures and gave their written informed consent prior to participating (Appendix C).

Research Design It was learned from the survey that barriers to fueling that skimo athletes face during racing include impairment from the cold, accessibility, and not being stimulated by hunger/thirst, while preferred fueling method was with drink mixes. Thus, a drink was created in order to easily deliver a high amount of carbohydrate that would be palatable and easily accessible. This study used a double-blind, randomized cross-over design. Participants completed two time trials on snow, one under each condition, at least one week apart. The two drink conditions were a 6% (30G) and 18% solution (90G) of a highly-branched cyclic dextrin sports drink (Skratch Labs, Boulder, CO, USA) plus fructose added to achieve a 3:1 ratio of highly-

branched cyclic dextrin:fructose. An 18% solution was chosen in order to deliver 90 g carbohydrate per 500 mL per hour, an amount reported to confer performance benefits (Jentjens et al. 2003). Fructose was added in a ratio to try to maximize carbohydrate oxidation and decrease gastrointestinal upset, as evidenced when using multiple transportable carbohydrates (Trommelen et al. 2017, Jeukendrup and Moseley 2008), while highly-branched cyclic dextrin was chosen over glucose due to evidence of its fast gastric emptying time and lesser contribution to gastrointestinal upset (Takii et al. 2004, 2005) Measurements during time trials included pre- and post-time trial markers of hydration, palatability of drink solution, level of gastrointestinal upset, gear weight, individual lap times, and total time to completion. Maximal volume of oxygen consumption and body composition were assessed in the laboratory.

Laboratory Measures

Body Composition Body composition testing was completed after a minimum two-hour fast and at least 24 h rest from other activity. Participants' height was measured without shoes and then body weight and body composition analyzed while wearing tight-fitting, minimal clothing. Body composition was assessed using air displacement plethysmography (Bod Pod 2007A, Cosmed, Concord CA, USA).

Maximal Volume of Oxygen Consumption After body composition testing, participants then completed testing to assess maximal volume of oxygen consumption. Maximal oxygen consumption testing was completed on a treadmill (Woodway, Waukesha, USA) using a metabolic cart (TrueOne 2400, ParvoMedics, Sandy, UT, USA) which was calibrated before each test using a 3 L syringe and gases of known composition. Heart rate was continuously measured during maximal oxygen consumption testing using a Polar H10 heart rate monitor (Polar,

Kempele, Finland). Maximum heart rate was recorded as the highest heart rate achieved during the maximal oxygen consumption test.

Participants began with a five-minute warm-up at a self-selected moderate pace after which the ramped test began. The same self-selected pace was used throughout the test with incline increasing 2% every two-minute stage until 14%, after which speed increased 0.3 mph until voluntary exhaustion.

Time Trials

Time trial data were collected at a local ski hill. The standardized route consisted of repeating seven laps on the ski hill to simulate the approximate distance and elevation gain of an individual-style skimo race. Characteristics of the full seven-lap course were: ~11.3 km, 1300 m elevation gain, average uphill gradient 18.6%, and maximum elevation 1866 m.

Before time trials, participants were asked to be two hours fasted, well-rested and hydrated, and to refrain from exercise and alcohol for the 24 h prior to control for variability. For the first time trial, participants were asked to record a food log in order to recreate the same diet for the second time trial.

Upon arrival at the ski hill, participants provided a urine sample and were weighed to the nearest 0.1 kg in clean, dry clothes, and the pre-trial survey completed. After ensuring participants were in possession of all the required gear which was then weighed to the nearest 0.1 kg, participants were then fitted with a heart rate monitor and given the first of the flasks containing the carbohydrate solution. Instructions and course descriptions for the time trials were then given. Participants were informed that they had to drink one flask (500 mL) per hour, and the second flask would be given at the closest lap time on the hour. A warm-up was then

performed on a standardized route at the participant's pace of choice (0.68 km, 61 m elevation gain). Individual lap times, minus the time of the bottom (skin-to-ski) transition, were recorded in addition to total time to completion.

Participants were encouraged by the data collector at the bottom transition zone to drink along with there being signs along the course to encourage drinking. Upon completion of the time trial, participants towel-dried and were reweighed in the same clean, dry clothes as before the time trial. A urine sample was again given, and the post-trial survey completed. The total volume of carbohydrate solution drunk during the time trial was recorded. The second crossover day of the time trial was completed in the same manner at least a week apart, with participants recreating their similar intake for the 24 h prior.

Pre- and Post-Trial Survey Questions on the pre-trial survey asked how many seasons (excluding the current one) the participants had done skimo, average weekly training hours, and average amount of races they do per season. Post-trial survey questions asked the level of gastrointestinal distress (0-10; 0= none, 10=bad) and level of palatability of the drink (0-10, 0=bad, 10=good).

Hydration Measures Urine specific gravity was measured pre- and post-time trial using a pen refractometer (Atago, Japan) to assess for changes in hydration status. Weight was measured with a digital scale to the nearest 0.1 kg pre- and post-time trial to assess for changes in hydration.

Statistics

Analysis was done using R Studio (2023.03.0+386 Posit Software PBC) with ggplot for visualization and data represented as mean \pm standard deviation. All tests met assumptions for linearity and equal variance. Linear mixed effects models were used with total time as an outcome and drink as the independent variable and covariates being maximal volume of oxygen consumption, gear weight, drink condition, pre-time trial body weight, training hours, body fat percentage, palatability, and gastrointestinal upset. Random effects were the subjects to control for variability within each subject. Paired t-tests were used to determine the difference between the two conditions for different variables. A separate analysis with overall time as the outcome was done with a subset of the data for those with high gastrointestinal upset (n=4) without covariates due to the small number.

Results

Survey

After an initial screening for eligibility, 63 people filled out the survey. Because not all survey responses were required, 58-63 people responded to each question. Full survey responses can be found in Appendix B. Characteristics of respondents were: 33.48 ± 9.12 years old, 72.5% men and 27.5% women, 4.2 ± 2.97 seasons competing in skimo, 4.89 ± 3.68 races per year. Training hours per week were reported in ranges of five hours with 20% training 0-5 h/wk, 44% training 5-10 h/wk, 25% training 10-15 h/wk, and 10% training 15+ h/wk. From 0-10, the level of importance given to race nutrition and hydration was 7.25 ± 2.54 . Respondents with formal education in sports nutrition was 16.4%, while 81.7% said they consume self-education material on sports nutrition. The most preferred media forms on the topic (rated 0 (not preferred) to 5

(most preferred)) were podcasts (3.26 ± 1.38) followed by scientific literature (2.37 ± 1.35) and books (2.08 ± 1.14).

Participants stating that they were aware of carbohydrate recommendations for 1.5-3 h of exercise was 63%. Responses to what the value of the recommendations are ranged from between 30 g to 200 g per hour. Participants reporting that they were aware of fluid intake recommendations was 62%, with responses ranging from 500 mL to 1200 mL per hour.

The most preferred fueling methods during races (rated 0 (not used) to 5 (frequently used)) were liquid calories (drink mix), gels, and gummies (Table 1).

Top reasons for not fueling properly during races (rated 0 (not an issue) to 10 (large issue)) were “cold temperature (frozen nutrition/hydration),” “high intensity (heavy breathing),” “not feeling hungry/thirsty,” “accessibility issues,” “cold temperature (impaired hand dexterity),” “don’t want to lose time,” and “gut issues” (Table 2).

Field	Range	Mean	Standard Deviation	Variance	Responses	Sum (mean x responses)
gels	0-5	3.18	1.73	2.99	50.00	159.00
gummies	1-5	2.14	1.23	1.51	36.00	77.00
bars	0-5	1.62	1.30	1.68	29.00	47.00
liquid calories (drink mix)	1-5	3.94	1.37	1.89	47.00	185.00
nothing	0-4	1.14	1.55	2.41	7.00	8.00
other (specify)	15	3.63	1.65	2.73	8.00	29.00

Table 1: Survey Responses to “What is your preferred fueling method during a typical race lasting 1.5-3 hours?”

Field	Range	Mean	Standard Deviation	Variance	Responses	Sum (mean x responses)
don't want to lose time	0-10	3.51	2.90	8.43	45.00	158.00
high intensity (heavy breathing)	0-10	5.16	2.49	6.18	43.00	222.00
gut issues	0-10	3.36	2.77	7.69	33.00	111.00
cold temperature (impaired hand dexterity)	0-10	4.81	2.69	7.21	36.00	173.00
cold temperature (frozen nutrition/hydration)	1-10	5.55	2.78	7.72	42.00	233.00
accessibility issues (due to gloves or storage)	1-9	4.72	2.44	5.95	39.00	184.00
not feeling hungry/thirsty	0-10	5.22	2.79	7.78	36.00	188.00
knowledge deficit of recommendations	0-6	2.50	1.99	3.98	22.00	55.00
don't want to carry extra weight	0-9	3.12	2.95	8.69	17.00	53.00
other (please specify)	0-10	4.71	4.37	19.06	7.00	33.00

Table 2: Survey Responses to “What might be reasons for you not to fuel/hydrate adequately during races?”

Randomized Controlled Crossover Study

Participants Fifteen participants (13 male, 2 female) completed testing. Number of seasons competing in skimo and reported training time per week show a moderate to high experience level in the sport (Table 3). All participants lived in and were acclimated to the area where testing took place (1470 m).

Laboratory Measures Body mass and body fat percentages were low with body mass indices within a normal range (Table 3).

	Mean \pm SD	Range
Age	27.53 \pm 8.77	19-44
Height (cm)	176.4 \pm 7.77	162-192
Body Mass (kg)	69.58 \pm 10.61	48.9-92.6
Body Fat %	9.63 \pm 4.78	4.7-21.2
BMI	22.3 \pm 2.59	18.37-26.83
VO ₂ max (mL/kg/min)	65.27 \pm 11.48	38.3-82.7
HRmax	187.67 \pm 10.75	162-205
Training time per week (hours)	11.33 \pm 7.00	5-30
Individual races per season	3.92 \pm 2.49	1-9
Seasons of Skimo	4.93 \pm 4.54	1-15

Table 3: Participant Characteristics

Time Trials Snow conditions varied from “icy” to “soft light powder.” The lengths of the time trials were long enough that conditions occasionally changed slightly from start to finish. Temperatures ranged from -4°C to 7°C .

All participants successfully completed both time trials. Required gear (backpack, beacon, shovel, probe, emergency blanket, whistle, extra top and bottom layers, extra skins, skis, skins, helmet, poles) weighed $7.73 \pm 1.97\text{ kg}$. There were three participants who experienced issues recording heart rate (all in 30G) and this heart rate data was therefore not included in analysis. Individual lap time data for one of these individuals was also not able to be recorded and is thus not included in any analysis comparing lap times. Each participant successfully finished the first 500 mL of drink solution by the end of the closest lap time to 1 h (range 53-70 min). Only one participant required a third serving of 500 mL which they received at their lap time closest to 2 h. Additionally, one participant with gastrointestinal upset in 90G had trouble continuing to consume the carbohydrate solution after the first hour and therefore only drank an average of 304 mL per hour (54.72 g/h CHO). Volume drank per hour was not significantly different between conditions (Table 4). Mean heart rate and heart rate as a percent of maximal heart rate were high, suggesting sustained strenuous activity (Table 4).

Body mass and percent body fat significantly correlated to overall time trial performance ($p=0.009$ and $p=0.049$, respectively) (Figures 1 and 2). There was a range of relative maximal oxygen consumption values, though the mean suggests a moderate-to-high fitness level. Maximal oxygen consumption was also significantly correlated to overall time trial performance ($p=0.002$) (Figure 3).

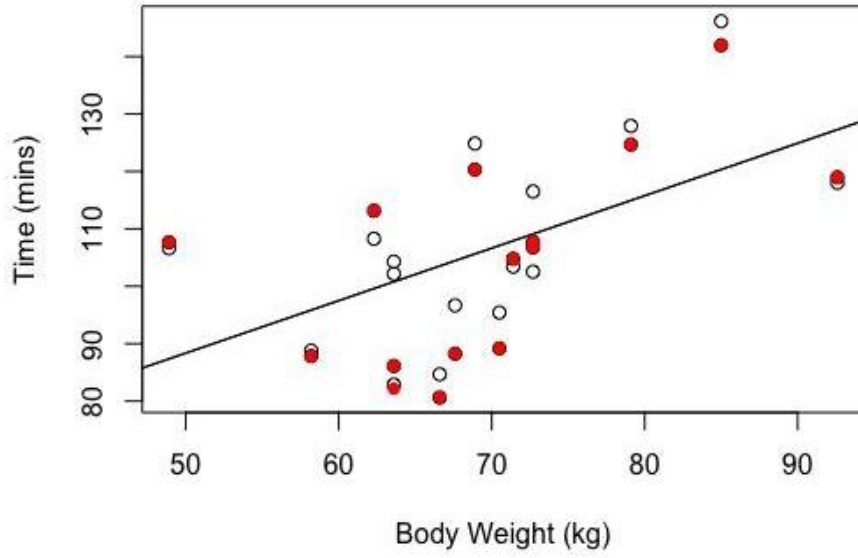


Figure 1: Time vs. body weight (red dots: 90G, white dots: 30G)

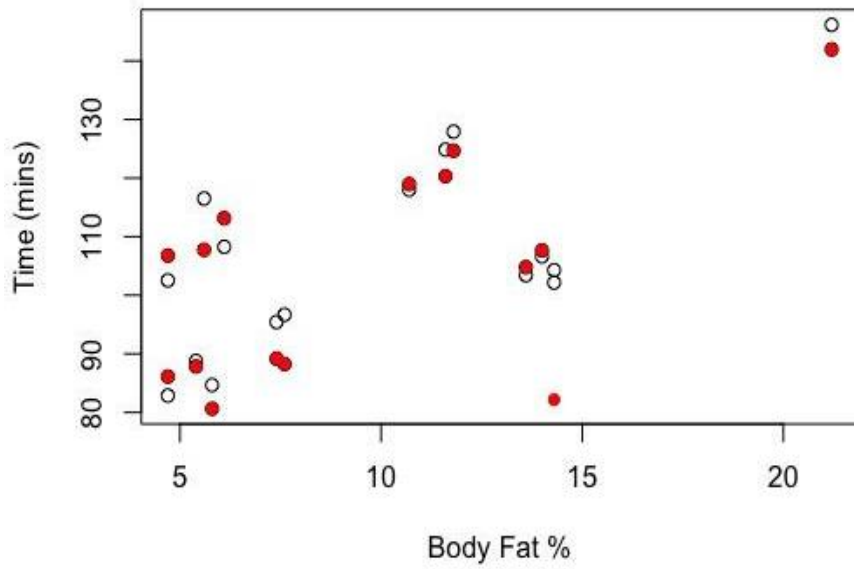


Figure 2: Time vs. percent body fat (red dots: 90G, white dots: 30G)

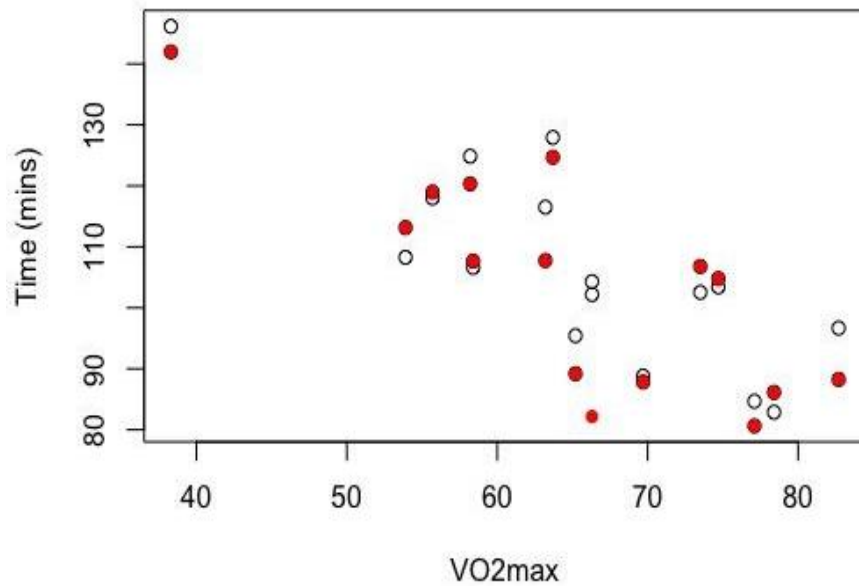


Figure 3: Time vs. Maximal Oxygen Consumption (mL/kg/min) (VO2max) (red dots: 90G, white dots: 30G)

Average finish time was not significantly different between 30G compared to 90G ($p=0.135$) (Table 4, Figures 4 and 5). When time trials were analyzed on a lap-by-lap basis, there was no main effect for drink on percent change in lap time compared to the first lap ($p=0.324$) (Figure 5).

	30G (mean ± SD)	30G (range)	90G (mean ± SD)	90G (range)	p-value 30G vs 90G
Race time (min)	105.34 ± 17.01	80.63 - 141.97	107.13 ± 17.31	82.87 - 146.15	0.135
HR avg (bpm)	166.25 ± 10.47	152 - 177	164.67 ± 11.93	136 - 182	0.345
HR avg as % HRmax	89 ± 3 %	81 - 94 %	88 ± 4 %	80 - 94 %	0.335
Total V ingested (mL)	802.33 ± 144.68	502 - 1108	831.2 ± 144.7	589 - 1108	
Volume drank (mL/h)	457.93 ± 54.15	344 - 544	470.2 ± 73.61	304 - 588	0.512
gCHO/h	27.48 ± 3.25	20.64 - 32.64	84.64 ± 13.25	54.72 - 105.84	

Table 4: Time trial data

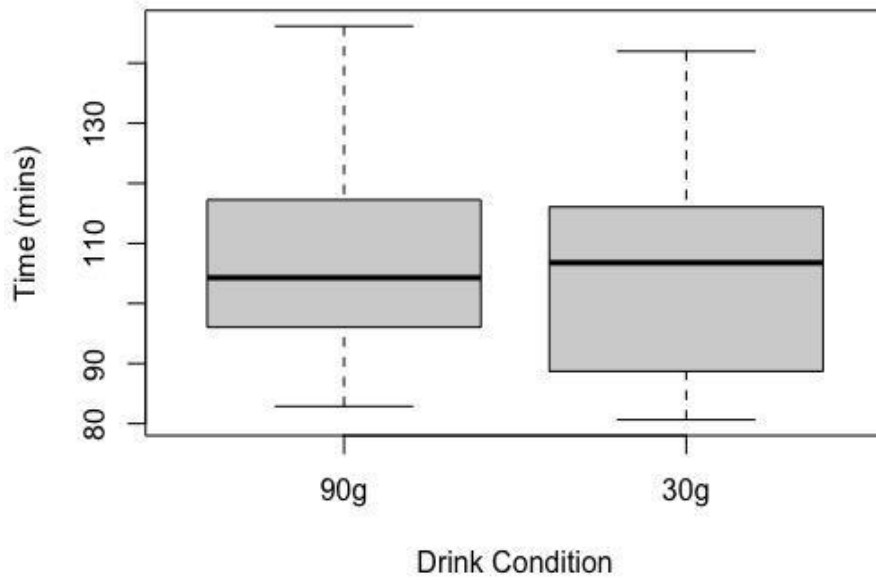


Figure 4: Time vs. drink condition

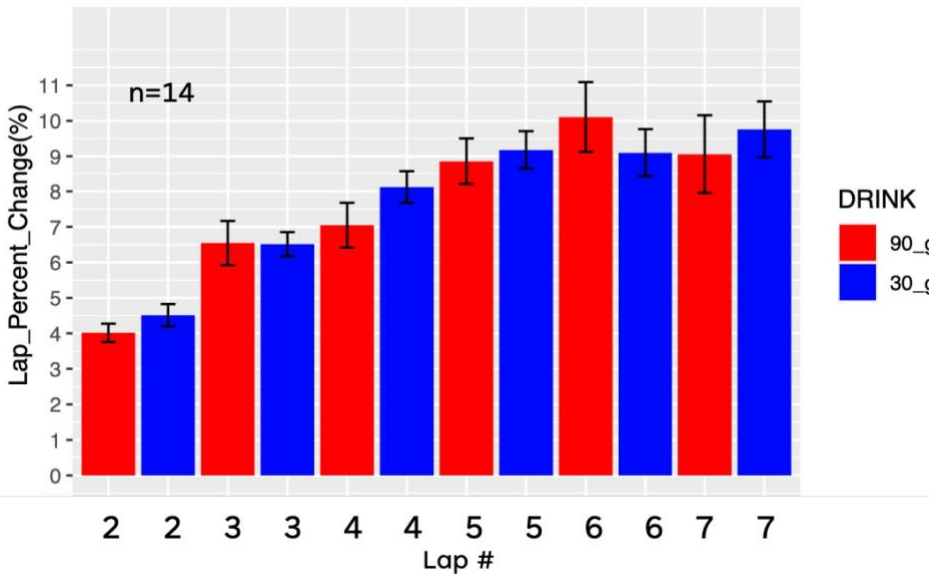


Figure 5: Percent change in lap time (n=14)

Based on urine specific gravity, most, but not all, participants were well-hydrated pre-time trial. There was not a significant difference in the change of urine specific gravity pre- and post-time trial or in change in body weight between 30G and 90G (Table 5). Both conditions stayed below a 2% loss in body weight as well as below the urine specific gravity marker for hydration (Table 5).

	Pre-30G	Post-30G	Change	Pre-90G	Post-90G	Change	P-value 30G vs 90G change
Urine Specific Gravity	1.0123 ± .0117	1.0137 ± .0077	.0014 ± .0059	1.0135 ± .0106	1.0139 ± .0082	.0004 ± .0081	0.596
Body Mass	70.27 ± 10.99 kg	69.78 ± 10.5 kg	-0.61 ± 1.21%	70.56 ± 11.32 kg	70.24 ± 11.06 kg	-0.4 ± 1.13%	0.631

Table 5: Hydration assessments pre- and post-time trial

Gastrointestinal upset was rated on a scale of 0-10 (0=none, 10=severe) and palatability was rated on a scale of 0-10 (0=bad, 10=good). Palatability was not significantly different (Table 6, Figure 6). Gastrointestinal upset trended higher in 90G with the difference between conditions approaching significance ($p=0.073$) (Table 6, Figure 7). Four out of the 15 participants rated gastrointestinal upset in 90G above a four (Table 6).

	30G (mean \pm SD)	30G (range)	90G (mean \pm SD)	90G (range)	p-value 30G vs 90G
Race time (min)	104.01 \pm 18.03	80.63 - 141.97	107.13 \pm 17.31	82.87 - 146.15	0.135
Palatability (0-10)	7.6 \pm 1.76	4 - 10	7.2 \pm 2.37	2 - 10	0.424
GI upset (0-10)	1.07 \pm 1.44	0 - 4	2.4 \pm 2.75	0 - 8	0.073

Table 6: Palatability and gastrointestinal upset. (Palatability rating: 0=bad, 10=good; GI upset rating: 0= none, 10=severe)

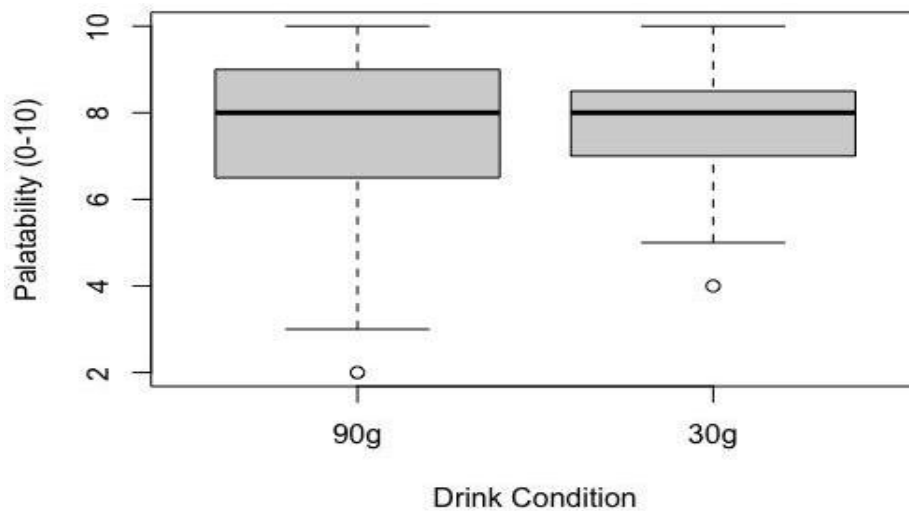


Figure 6: Palatability vs. drink condition

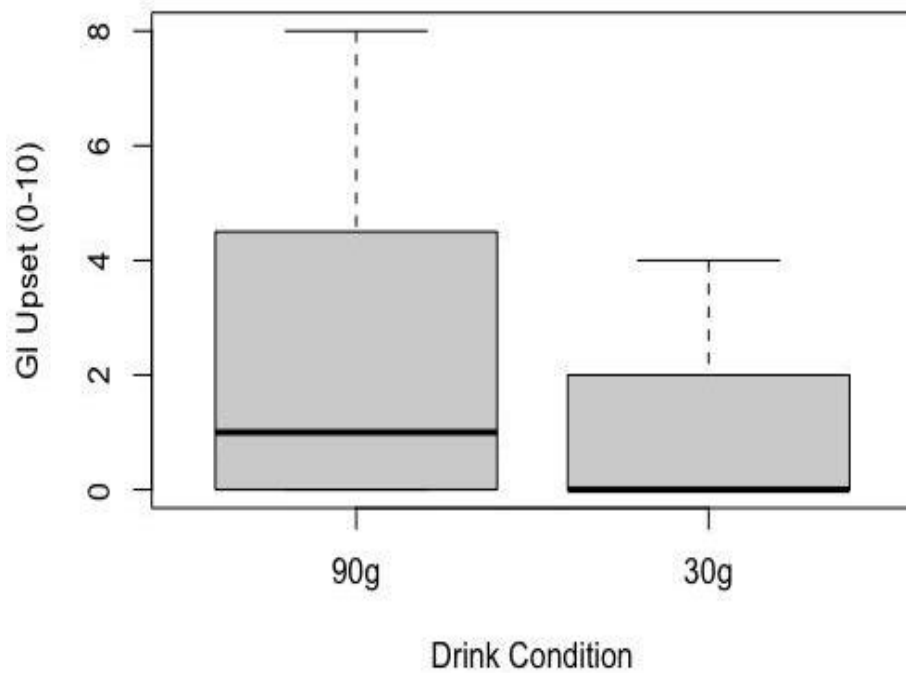


Figure 7: Gastrointestinal upset vs. drink condition

When the four participants with gastrointestinal upset >4 were removed from analysis, total elapsed time was not different between conditions ($p=0.214$) (Figure 8); however, a main effect ($p<0.001$) for condition was measured for percent change in lap time with 30G having a greater percent change in lap time throughout the trial. Percent change in lap time with participants with gastrointestinal upset >4 can be seen in Figure 9. Time per lap in both conditions for all participants, participants excluding gastrointestinal upset, and only gastrointestinal upset can be seen in Figures 10, 11, and 12, respectively.

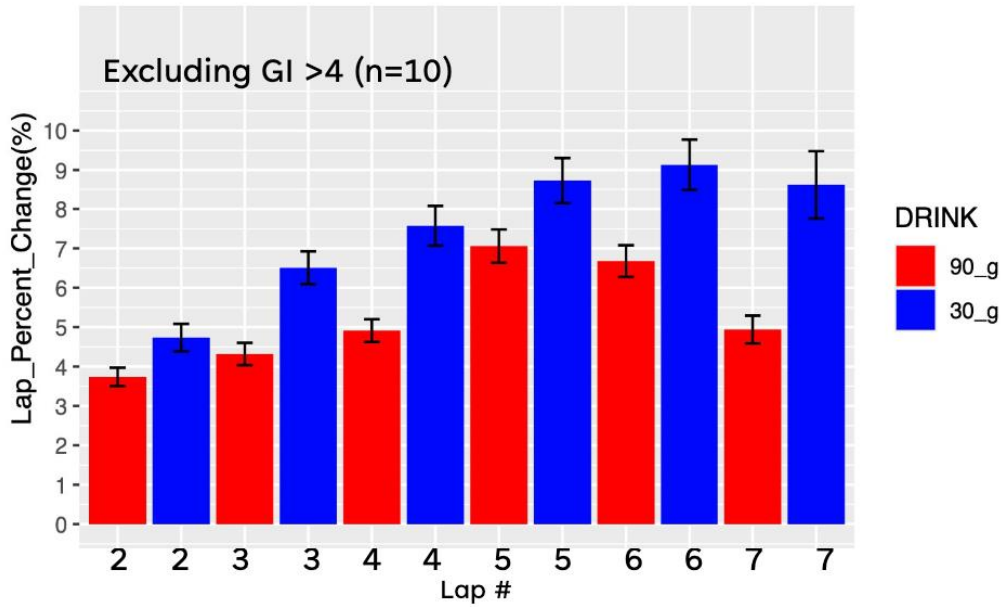


Figure 8: Percent change in lap time (excluding gastrointestinal upset >4) (n=10)

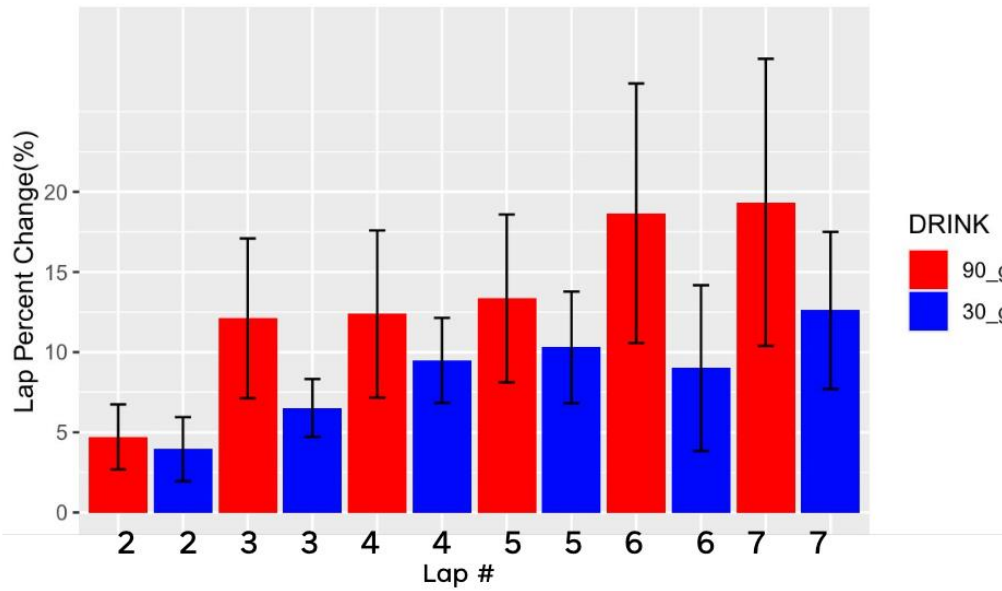


Figure 9: Percent change in lap time for gastrointestinal upset >4 (n=4)

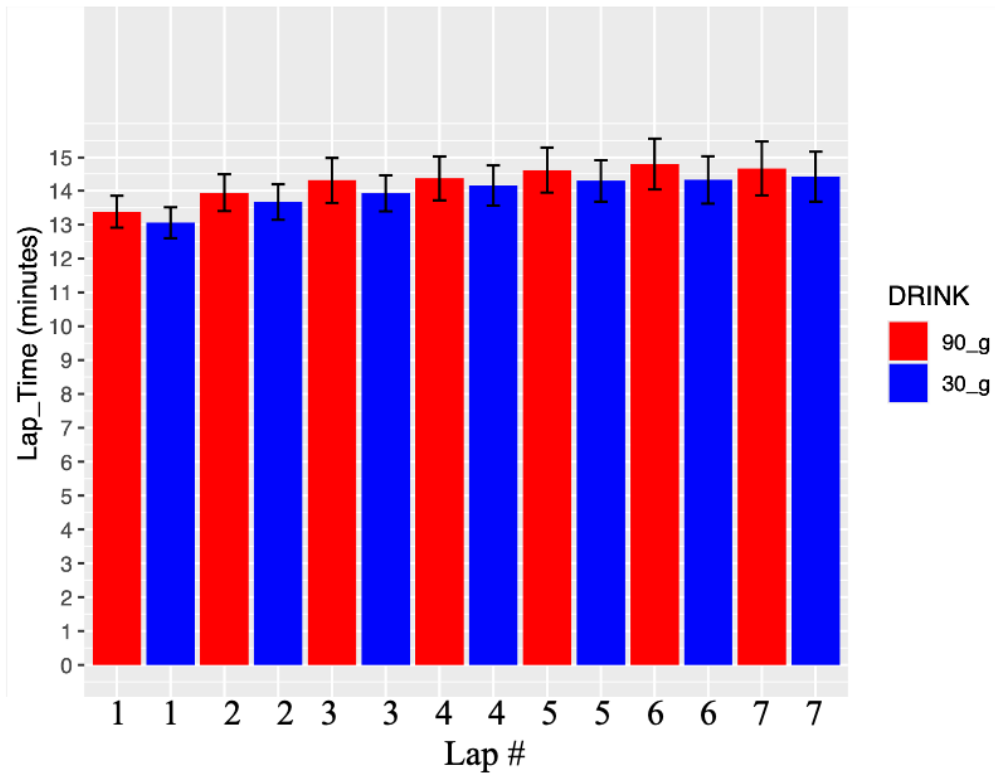


Figure 10: Individual lap times (n=14)

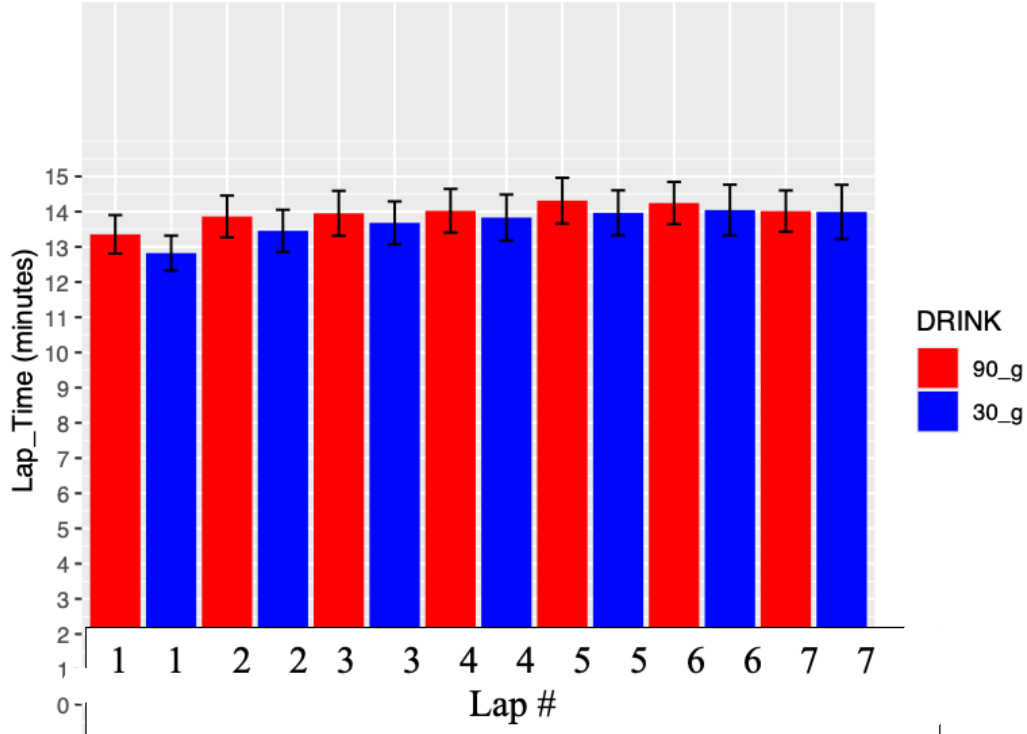


Figure 11: Lap times without gastrointestinal upset >4 (n=10)

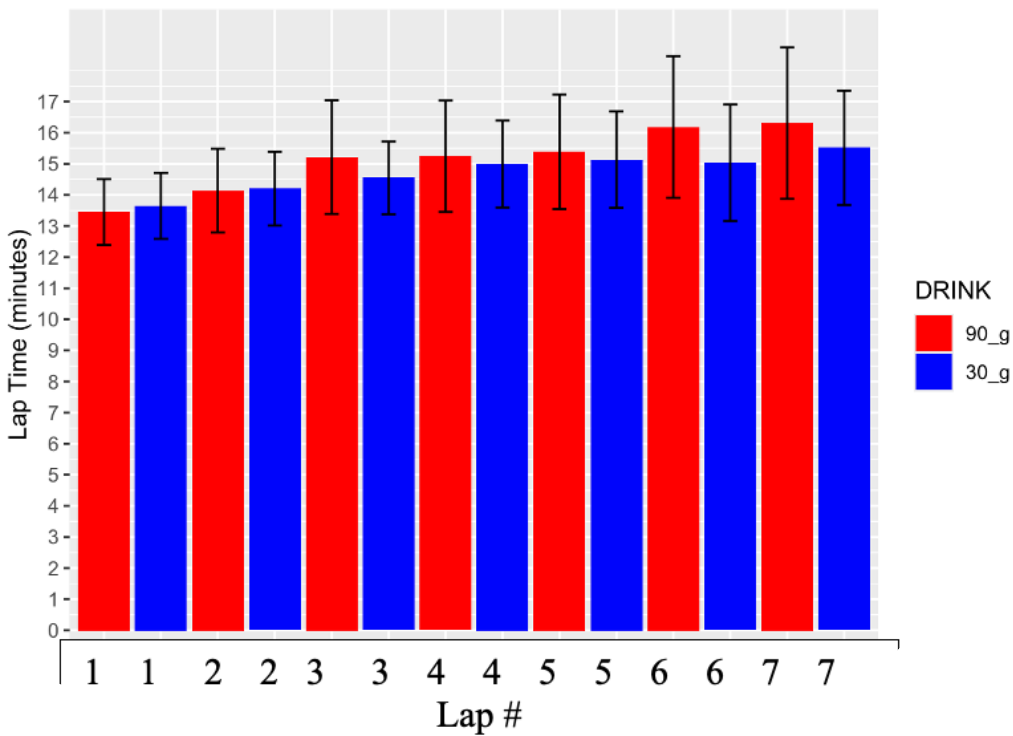


Figure 12: Lap times of participants with gastrointestinal upset (n=4)

Discussion

The purpose of this study was twofold: first, to evaluate the race nutrition and hydration knowledge, beliefs, and practices of skimo athletes; and second, to use these results to create and test a fueling and hydration option at high and low concentrations in an individual-style skimo race time trial. Due to a scarcity of literature on skimo, nutrition practices of skimo athletes specific to an individual race are unknown. Survey responses showed skimo athletes have some knowledge on race nutrition recommendations and that there are a few key perceived barriers to adequate fueling. A fueling strategy was then developed and tested to address these barriers. Prior to this, there has not been research on nutritional interventions to improve skimo performance. It was hypothesized that an 18% highly-branched cyclic dextrin + fructose solution would improve time to completion of an individual skimo race compared to a similar solution of 6%. The main finding was that the higher carbohydrate condition (90G) did not improve time trial performance completion. It was also hypothesized that a higher concentration drink solution based on a highly-branched cyclic dextrin + fructose solution could help to increase carbohydrate delivery during a race in an easy manner without contributing to increased gastrointestinal distress. It was found that participants were able to consume the beverages at a rate close to the intended amount with gastrointestinal upset trending toward being significantly higher for 90G which might have had an impact on a slower time. When participants with gastrointestinal upset >4 (n=4) were excluded from analysis, it was found that there was a significant effect for drink on percent change in lap time between conditions, with 30G having a greater percent increase in lap time.

Survey

There currently exists a gap in the literature specifically on skimo nutrition. While Praz et al. (2015) surveyed skimo athletes participating in one of two long-distance skimo races (26 km and 53 km), this only covered their pre-race nutrition and hydration knowledge and practices. As evidenced by the responses in the survey completed for this study, skimo athletes require nutrition products that are quickly and easily accessible while handling gear and when cold temperatures may impair dexterity or freeze nutrition and hydration products. There must also be an ease of consuming the product while performing at a high intensity even when not stimulated by hunger and thirst cues which may be impaired by altitude, cold, and exercise. Exposure to altitude causes both an increase in basal metabolic rate (+17% at 4300 m) and reduction in hunger-stimulating hormones (Butterfield et al. 1992, Bailey et al. 2015). Endurance exercise and sprint intervals also cause a suppression of hunger-related hormones (Deighton et al. 2012). Mean heart rate as a percent of maximal heart rate across both trials was 88%-89%, suggesting a high intensity which can make fueling while breathing heavily difficult. The top preferred fueling method during races was rated as “liquid calories (drink mix),” perhaps due to ease of access and carrying by combining it with fluid, though this was not asked. While not specifically a study on race nutrition, Duc et al. (2011) reported that 10 elite skimo athletes drank ~0.5 L of carbohydrate solution of between 50-70 g/L concentration and consumed no solid foods during a race lasting 101 ± 11 min. The current results contrast greatly with the findings of Gasser (2019) who surveyed participants of the Patrouille des Glaciers races (mean race times 13 h 18 min and 6 h 32 min), finding that 84% of participants ate dried fruit, 62% consumed chocolate, and bread and dried meat the next most popular food items. Gels, sports drinks, and sports bars were ranked the lowest consumed foods, though there was a correlation of consumption of these

products with faster race times. Patrouille des Glaciers is quite a different race from an individual-style skimo race and thus the intake and energy requirements cannot be directly compared.

Time Trials

Participants Though participants in this study were all experienced skimo athletes, they represented a range of fitness levels across age groups. While the mean relative maximal oxygen consumption was 65.3 mL/kg/min, suggesting fit but non-elite status, the seven highest maximal oxygen consumption values (all male) ranged from 69.7 – 82.7 mL/kg/min, similar to and higher than “elite” status designated to participants in the study by Lasshofer et al. (2021). “Competitive (national level)” skimo athletes (6 men, 4 women) in the study by Duc et al. (2011) had a mean maximal oxygen consumption of 67 ± 8 mL/kg/min. The two females in the present study reported maximal oxygen consumption values of 58.4 mL/kg/min and 66.3 mL/kg/min, values suggesting high aerobic capacity. Notably, two participants had previously been on the US Skimo team, one participant was currently a high-level college track athlete, and others consistently ranked highly in regional and national skimo competitions.

Mean training hours per week of participants was similar to that reported by Gaston et al. (2019) who reported 11.5 ± 2.5 h per week for elite skimo athletes in their study. Duc et al. (2011) reported similar training time (11 ± 1 h/wk) in “competitive (national level)” skimo athletes.

Predictors of Performance Maximal oxygen consumption, training hours per week, body mass, and percent body fat each were significantly correlated with overall time trial times. This is

similar to many other studies across different length skimo races (Wagner et al. 2024, Fornasiero et al. 2017, Gaston et al. 2019).

Intensity Mean heart rate for 30G and 90G was 166.25 ± 10.47 bpm and 164.67 ± 11.93 bpm, respectively, equating to $89 \pm 3\%$ and $88 \pm 4\%$ of maximal heart rate. This is in line with other studies looking at physiology during skimo races (Duc et al. 2011, Schenk et al. 2011).

Gastrointestinal Upset and Drink Palatability Palatability rating did not differ significantly between conditions, with gastrointestinal upset trending toward being significantly higher in 90G. Four out of the 15 participants rated gastrointestinal upset higher than four, which may have contributed to their slowing down throughout the trial. The drink used in the study was formulated to minimize chance of gastrointestinal upset which can be caused by heat, dehydration, high intensity of exercise, and high carbohydrate concentration. Participants in both trials had an average percent of heart rate max of 88-89% indicating strenuous activity. High-intensity cycling at 75% of maximal oxygen consumption for 60 min has been shown to slow gastric emptying time of 600 mL of 6% carbohydrate solution consumed immediately before exercise start compared to rest and cycling at 66% of maximal oxygen consumption (Leiper et al. 2000). Participants in the high-intensity cycling groups exercised at 81-88% of heart rate max, similar to the 88% in the current study. In contrast to the present study, cycling participants had to hold a constant work rate for 60 minutes while the present study was a time trial lasting ~1.5-2.5 h. Additionally, gastrointestinal upset was not measured in the cyclists, so comparison cannot be made between their gastric emptying rate and any gastrointestinal upset.

Heat was unlikely to have been a cause of gastrointestinal upset in the present study due to temperatures being between 23-45° F. Likewise, mean urine osmolality pre- and post-race and

change in body weight indicated participants met parameters of hydration ($U_{sg} < 1.03$, change in body weight $< -2\%$), meaning dehydration was not a likely cause of gastrointestinal upset.

While carbohydrate intake is recommended for endurance exercise and well-known to confer performance benefits, it is also known to cause an increase in gastrointestinal upset during exercise. Pfeiffer et al. (2010) found that higher carbohydrate intake during an Ironman correlated both to higher gastrointestinal upset and faster race times. The present study used a drink based on a combination of highly-branched cyclic dextrin + fructose (3:1) to decrease the chance of gastrointestinal upset. Use of multiple transportable carbohydrates has demonstrated faster gastric emptying which may cause less gastrointestinal upset. Jeukendrup and Moseley (2008) found faster gastric emptying with 8.6% glucose + fructose (2:1) delivering 1.5 g/h during two hours of cycling at 50% maximum wattage compared to 8.6% glucose alone.

The low osmolality of highly-branched cyclic dextrin allows for faster gastric emptying compared to other carbohydrate solutions with higher osmolality (Takii et al. 2005). Despite research studies showing better tolerance of highly-branched cyclic dextrin compared to other carbohydrate during exercise, the rate of gastrointestinal upset in the present study (26%) was similar to rates with different doses of glucose and glucose + fructose in the study by Pfeiffer et al. (2009). In this study, 10-20% of participants experienced gastrointestinal upset during 16 km runs while ingesting carbohydrate of different doses, with there being no significant difference between 1.0 versus 1.4 g/min glucose + fructose or between 1.4 g/min glucose versus glucose + fructose.

Besides gastrointestinal upset being determined by the ingested drink solution, this is also something that varies greatly person-to-person. Individual variability could account for the

26% of participants who experienced high gastrointestinal upset in the present study, though it is unknown what the habitual carbohydrate intake of the participants was. Gut training has been shown to help increase tolerance of ingesting carbohydrate during exercise. Two weeks of gut training consisting of five days per week of running 60 min while consuming 90 g/h carbohydrate as either 2:1 or 1:1 glucose:fructose decreased nausea and gastrointestinal symptoms in a 2 h steady-state run followed by a 1-h distance test compared to the same test pre-intervention and compared to placebo (water) (Costa et al. 2017). The authors attributed this finding to the possibility of upregulation of different transport carriers (GLUT5, SGLT1). Improved gut transport could imply decreased malabsorption and faster gastric emptying time. It is possible that the participants in the present study were not accustomed to the high carbohydrate intake that they consumed during the 90G condition. It is recommended to practice carbohydrate intake in training that would match intake in races in order to stimulate adaptation, usually taking between four days to two weeks (Jeukendrup 2017).

Hydration Urine specific gravity for 30G and 90G both increased but stayed below the marker of 1.002, above which is considered a dehydrated state (Sawka et al. 2007). There was no significant difference between 30G and 90G. Mean urine specific gravity for 30G and 90G were both below 1.002 as a marker of dehydration.

Body mass for 30G and 90G both decreased for changes of $-0.61 \pm 1.21\%$ and $-.04 \pm 1.13\%$, respectively, with no significant difference between conditions. Both drink conditions kept change in body mass well below the 2% loss of body weight, above which it is known to cause detriments to athletic performance (James et al. 2019).

It appears that the rate and amount of fluid ingestion during both time trials adequately maintained hydration in participants as urine specific gravity and body weight were both maintained within appropriate levels. Loss in body mass tended to be less for 90G, though this was not significant. A 500 mL solution with 1.5 g/kg of body weight of highly-branched cyclic dextrin drank 30 min before a time trial to exhaustion was shown to prevent more fluid loss than a similar solution of glucose and resulted in a longer time to exhaustion (Chuychai et al. 2022).

Time Trial Performance Because it was desired to simulate a race situation, participants were asked to recreate their diet from the first time trial to the second for the 24 h prior and be two hours fasted before the time trials began. This could mean that participants had adequate glycogen stores so that the additional 60 g in the 90G condition did not provide additional benefit. It is well known that glycogen depletion during endurance exercise contributes to fatigue and that ingestion of carbohydrate can prolong or improve performance. However, a placebo was also not used in this study, so it is unknown whether either condition would have been different from ingesting no exogenous carbohydrate. This may be unlikely, though, as ingestion of exogenous carbohydrate is recommended for exercise ≥ 1.5 h. Indeed, even small amounts of carbohydrate intake during endurance exercise has shown enhanced performance compared to no carbohydrate intake as with Tsintzas et al. (1993). Participants consumed 250 mL of either water or a 5% carbohydrate solution before the start of a 30 km running road race, then drank 150 mL every 5 km (total ingestion: 1 L with 50 g carbohydrate). Race time was significantly faster in the carbohydrate condition than water (128.3 ± 19.9 min versus 131.2 ± 18.2 min) with speed being maintained consistently throughout, whereas the water condition slowed significantly in the final 5 km.

When removing the four participants with gastrointestinal upset from the analysis, those who tolerated the higher concentration drink (74% of participants), slowed down less over time compared to the lower concentration drink delivering ~27 g/h carbohydrate. It is possible that had the exercise been longer, there would have been more benefit from the higher amount of carbohydrate. In a study by Coyle et al. (1989), it was demonstrated that carbohydrate ingestion (0.4 g/kg/h) during endurance exercise at 71% of maximal oxygen consumption prolonged time to exhaustion by one hour compared to those ingesting only water (water trial time 3.02 ± 0.19 h, carbohydrate trial time 4.02 ± 0.33 h) ($p < 0.01$). Importantly, there was no difference between conditions in glycogen use during the first three hours of exercise, while the additional hour of exercise in the carbohydrate group had little reliance on glycogen use. In a systematic review on the benefits of carbohydrate supplementation during exercise, 83% of the studies on exercise in the 1-2 h range showed a benefit of consuming carbohydrate during exercise (Stellingwerff and Cox 2014). The authors assert that exercise between 1-2 h is likely benefitted by carbohydrate consumption due to a combination of central nervous system stimulation (as is with carbohydrate mouth rinsing in exercise < 1 h) and increased carbohydrate oxidation. Furthermore, 16 of the 17 studies reviewed on exercise > 2 h found benefit from carbohydrate consumption (Stellingwerff and Cox 2014).

Recovery While the current study did not display an improvement in time trial performance of an individual-style skimo race with high carbohydrate (~85 g/h) consumption, there is evidence that consuming high carbohydrate amounts may be beneficial for recovery. A study comparing the effects of 60, 90, and 120 g/h intake of carbohydrate during a mountain ultra-marathon found significantly lower rating of perceived exertion during the race and less

muscle damage 24 h post-race in the 120 g/h condition compared to the 60 and 90 g/h conditions (Viribay et al. 2020). A related study found greater performance in neuromuscular function testing and recovery of high-intensity run capacity 24 h after completing the mountain ultramarathon in participants who consumed 120 g/h of carbohydrate compared to 60 or 90 g/h (Urdampilleta et al. 2020). Additionally, ingestion of combined glucose-fructose (1.5 g/kg/h) has demonstrated faster rate of liver glycogen repletion (~ 7.3 g/h) compared to the same amount of glucose alone (Fuchs et al. 2016). Restoring liver glycogen after exercise is important for repeated exercise bouts, such as in successive days of racing the different skimo disciplines. Glycogen stores may be depleted with 45-90 minutes of exercise, a length shorter or equivalent to an individual-style skimo race. Gaston et al. (2019) analyzed the effect of a vertical race on recovery and performance that took place the day prior to an individual race. The 10 elite participants (11.5 ± 2.5 h training per week) had incomplete metabolic recovery, increased resting lactate, and decreased muscle mass the day following the vertical race/ prior to the individual race. A study on back-to-back days of skimo competition found that athletes both under fueled in total energy and consumed less than the recommended amount of carbohydrate for endurance activity (Diaz et al. 2010). Additionally, those with the lowest protein, fat, and total energy intake across the two days of racing had higher muscle cell damage, while faster race time was correlated to those with the highest carbohydrate intake. Therefore, those competing in multiple race disciplines across a weekend may not only benefit from ingesting high (≥ 90 g/h) carbohydrate during competition but having combined glucose-fructose may offer additional benefit.

High carbohydrate consumption during activity may also be a way to prevent low energy availability and relative energy deficiency in sport. In a study on athlete energy availability, female athletes with menstrual dysfunction spent a longer amount of time in within-day energy deficits compared to eumenorrheic females, despite having the same overall energy intake and training volume as those who spent less time in an energy deficit. (Fahrenholtz et al. 2017). Those with menstrual dysfunction also had lower resting metabolic rate and 14% lower relative body fat mass. Even in the absence of low energy availability, low carbohydrate availability negatively affects bone, immunity, and iron biomarkers (Mountjoy et al. 2013). With the high training and racing loads in skimo, along with body fat and body mass often being correlated with performance, ensuring adequate total energy intake and carbohydrate availability could be an important focus for skimo athletes, and increasing intake during competition might help to mitigate under fueling.

Limitations

While time of day was controlled for as best as possible, snow conditions have high variability from day to day and even within a few hours' time from the beginning to end of the time trials. Skiing conditions can be affected by causing the ski to slightly slip out if icy or snow to accumulate on the skins if it becomes warm. Downhill skiing can be affected if there is more or less powder, icy skiing, or the prominence of bumps on the run. While this study aimed to use time trials in the field to test effectiveness of different carbohydrate amounts, closely controlling ski conditions, such as using a groomed run at the same time of day and at the same temperature would offer better control for comparison. However, coordinating a large group of people to assemble together on the same two dates was impractical for this research study.

This study had a range of participant fitness levels as evidenced by the range of maximal oxygen consumption. While this helps to represent the recreational skimo community, those with the fastest times perhaps would not necessarily need to consume such a large amount of carbohydrate for the length of their time trial. Additionally, only two participants were female. Both females had a high level of fitness and were not outliers from the participants as a whole. However, this is not to say female physiology can be generalized to that of males. There is an increasing push for female representation in the scientific literature, though female representation in the local skimo community from which the study recruited was small.

Conclusion

In conclusion, this study was the first to evaluate the nutrition and hydration practices of skimo athletes specific to an individual-style skimo race. Accessibility of nutrition products, which can be impaired by cold and gear handling, and high intensity (heavy breathing) were cited as top reasons for impaired fueling during races. Liquid calories (drink mix) was also top-ranked for preferred fueling method during races.

This was also the first study to test the performance effects of a high carbohydrate intake during a skimo race while also measuring gastrointestinal upset. No difference was found in overall performance during an individual-style skimo race when ingesting 27 g/h versus 85 g/h of a solution based on highly-branched cyclic dextrin + fructose. Gastrointestinal upset affected 27% of participants with the high dose of carbohydrate. When those with high gastrointestinal ratings were removed from analysis, it was found that the 90G slowed down less over time compared to the 30G condition. There was also a similar amount of gastrointestinal upset with highly-branched cyclic dextrin compared to literature on gastrointestinal upset with other

carbohydrate sources. Gut training may be a method to mitigate gastrointestinal upset with high carbohydrate consumption.

Future research may look into the effect of high carbohydrate consumption on recovery during skimo racing on consecutive days. Additionally, it may be interesting to evaluate the use of high carbohydrate on mitigating within-day energy deficits.

CHAPTER FOUR

CONCLUSION

The first purpose of this study was to evaluate the nutrition knowledge and practices of skimo athletes. This survey also gave insight to the barriers to fueling during a skimo race and the most preferred fueling methods. Athletes perceived accessibility issues, cold temperatures, high-intensity of effort, and lack of hunger and thirst cues as the biggest reasons for not fueling during races. Liquid calories (drink mix) was the highest-rated method of fueling during races.

The findings from the current survey, recommendations from the literature on high (≥ 90 g/h) carbohydrate intake, and the potential benefits of highly-branched cyclic dextrin informed the creation of a drink solution that was then employed in the second part of this study. This was the first nutrition intervention study in an individual skimo race. Additionally, this was the first to evaluate gastrointestinal upset in a skimo race. It was hypothesized that an 18% solution of highly-branched cyclic dextrin plus fructose (3:1) at 90 g/h would improve performance in an individual skimo race compared to a similar solution at 30 g/h. Fifteen experienced participants (two female, 13 male) completed the study. The main finding was that the 90G condition did not have significantly better overall performance (race times 30G: 105 ± 17.01 min, 90G: 107.13 ± 17.31 min) ($p=0.135$). There was a trend for gastrointestinal upset to be higher in 90G. There was no main effect for drink on the percent change in lap times; however, when the four participants with high (>4) gastrointestinal upset were removed from analysis, there was a significant main effect for drink, with 30G having a greater percent change in lap time.

Urine specific gravity and body mass pre- and post-race was not significantly different between 30G and 90G. Average urine specific gravity remained <1.003 and body mass change remained $<2\%$ showing participants maintained a hydrated status.

There may be several reasons why a performance benefit was not demonstrated in 90G. Because it was desired to simulate a race situation, participants were asked to recreate their diet from the first time trial to the second for the 24 h prior and be two hours fasted before the time trials began. This could mean that participants had adequate glycogen stores so that the additional 60 g in the 90G condition did not provide additional benefit. However, a placebo was also not used in this study, so it is unknown whether either condition would have been different from ingesting no exogenous carbohydrate. This may be unlikely, though, as ingestion of exogenous carbohydrate is recommended for exercise ≥ 1.5 h.

In the 90G condition, delivering ~ 85 g/h of carbohydrate, 26% of participants had gastrointestinal upset, potentially causing them to slow down as the race progressed. The drink used in the study was formulated to try to minimize chance of gastrointestinal which can be caused by high-intensity exercise, high osmolality, decreased carbohydrate absorption, heat, and dehydration. Participants in both trials had an average percent of maximal heart rate of $\sim 88-89\%$ indicating strenuous activity which could have contributed to slowed gastric emptying in these participants. Heat and dehydration were unlikely factors as the temperatures were 23-45° F and participants stayed within a hydrated status. Osmolality of the drink could have played a part in gastrointestinal upset; however, there was not a condition of an isocaloric solution with lower or higher osmolality against which to compare. The habitual carbohydrate intake of the participants was unknown, and thus participants may not have been accustomed to consuming such high

carbohydrate loads (~85 g/h) during exercise, which may have caused gastrointestinal upset. Pfeiffer et al. (2009) saw great variability in responses to runners consuming 1.0-1.4 g/h of glucose or glucose + fructose, with 10-20% experiencing gastrointestinal upset, demonstrating the high variability of gastrointestinal responses. Individual variability could account for the 26% of participants who experienced high gastrointestinal upset in the present study. Gut training (habitually consuming high carbohydrate in training and life) has been shown to increase tolerability of high carbohydrate loads during exercise (Costa et al. 2017). This is most likely due to the upregulation of transporters in the gut, allowing for faster carbohydrate uptake (Jeukendrup 2017).

For those who tolerate higher carbohydrate (>90 g/h), this dose of carbohydrate could be a method to improve recovery for consecutive days of racing and prevent low energy availability. Diaz et al. (2010) found in a study on back-to-back days of skimo competition that athletes with the lowest protein, fat, and total energy intake across the two days of racing had higher muscle cell damage, while faster race time was correlated to those with the highest carbohydrate intake. Additionally, female athletes with menstrual dysfunction spent a longer amount of time in within-day energy deficits compared to eumenorrheic females, even with the same overall energy intake as those who spent less time in an energy deficit (Fahrenholtz et al. 2017). Even in the absence of low energy availability, low carbohydrate availability negatively affects bone, immunity, and iron biomarkers (Mountjoy et al. 2013).

Future research should compare a similar high carbohydrate amount (90 g/h) with other forms of carbohydrate (i.e. glucose + fructose) to elucidate differences in gastrointestinal upset. Additionally, evaluating the use of high carbohydrate as a method to improve recovery on back-

to-back days of skimo competition could prove valuable. Because of the several different lengths of skimo races, research should focus on how to fuel differently for each race discipline.

In conclusion, this was the first study to evaluate the nutrition knowledge and practices, barriers to fueling, and preferred fueling methods of skimo athletes in an individual race. This was also the first study to evaluate the performance benefits of a high-carbohydrate drink in skimo race performance while also measuring gastrointestinal upset. It was found that the high dose (~85 g/h) of carbohydrate did not confer overall performance benefit compared to a lower dose (~27 g/h) carbohydrate during an individual skimo race time trial. Approximately 26% of participants had gastrointestinal upset, all with the higher carbohydrate dose. When these participants were removed from the analysis, there was a main effect for drink for percent change in lap time, with the lower dose having a greater percent change in lap time. Gastrointestinal upset therefore could have had influence on race performance. The high dose of carbohydrate also could have helped to sustain performance as the race progressed. Gut training may be a way to mitigate gastrointestinal upset with high carbohydrate loads. In those who can tolerate it, high carbohydrate intake during races may be a valuable way to improve recovery for back-to-back competition days and prevent low energy availability.

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APPENDICES

APPENDIX A

SURVEY QUESTIONS ON NUTRITIONAL KNOWLEDGE
AND PRACTICES OF SKIMO ATHLETES

1. Have you competed in skimo for at least one season and/or have you competed in at least two individual-length races (~1.5-3 hours long)?
 - a. y/n
2. What is your age?
3. In which category do you compete
 - a. Women, men, non-binary
4. How many years have you been competing in skimo? (not including this current winter)
 - a. 0-10 scale
5. How many races, on average, do you compete in per season?
 - a. 1-20 scale
6. Would you consider your performance:
 - a. Back-of-the-pack
 - b. Middle-of-the-pack
 - c. Front-of-the-pack
7. Approximately how many hours per week do you train for skimo?
 - a. 5-10
 - b. 10-15
 - c. 15+
8. How would you rate your knowledge of nutrition for athletics/racing? (please select 0 if 0)
 - a. 0-10 scale
9. Do you have formal education in sports nutrition?
 - a. y/n
 - i. If yes: What level of formal education in sports nutrition do you have?
 1. Undergrad classes, undergrad degree, grad degree, other (specify)
10. Do you consume self-education materials in sports nutrition and hydration?
 - a. y/n
 - i. If yes: Which type of self-education material do you consume? (please select 0 if 0)
 1. Books, podcasts, magazines, scientific lit, other (specify)
11. How much importance do you give to race nutrition and hydration? (please select 0 if 0)
 - a. 0-10 scale
12. Are you aware of suggested carbohydrate intake recommendations during exercise?
 - a. y/n
 - i. If yes, what do you believe the recommended range of carbohydrate intake per hour is for 1.5-3 hours of exercise? (please give grams/hour)
13. Are you aware of suggested hydration recommendations during exercise?
 - a. y/n
 - i. If yes, what do you believe the recommended range of water intake per hour is for 1.5-3 hours of exercise? (please give milliliters/hour average) (500mL= ~17oz)
14. How many grams/hour of carbohydrate do you believe you ingest, on average, for a race lasting 1.5-3 hours? (please give grams/hour average) (or respond "unsure")

15. How many milliliters/hour of water do you believe you ingest, on average, for a race lasting 1.5-3 hours? (please give milliliters/hour average) (500mL= ~17oz) (or respond "unsure")
16. What is your preferred fueling method during a typical race lasting 1.5-3 hours? (please select 0 if 0)
 - a. 0-5 scale: gels, gummies, bars, liquid calories, nothing, other (specify)
17. What might be reasons for you not to fuel/hydrate adequately during races? (please select 0 if 0)
 - a. (0-10 scale) don't want to lose time, high intensity (heavy breathing), gut issues, cold temperature (impaired hand dexterity), cold temperature (frozen nutrition/hydration), accessibility issues (due to gloves or storage), not feeling hungry/thirsty, knowledge deficit of recommendations, don't want to carry extra weight, other (specify)

APPENDIX B

RESPONSES TO SURVEY

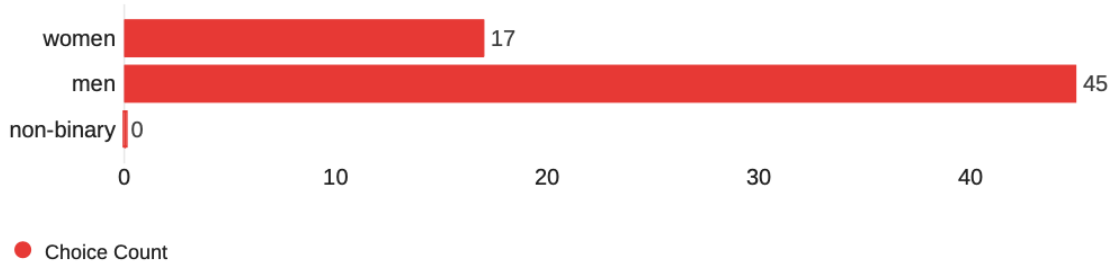
Q0 - Have you competed in skimo for at least one season and/or have you competed in at least two individual-length races (~1.5-3 hours long)?



Q1_2 - years old

Field	Min	Max	Mean	Standard Deviation	Variance	Responses	Sum
years old	20.00	60.00	33.48	9.12	83.17	61	2042.00

Q2 - In which category do you compete?



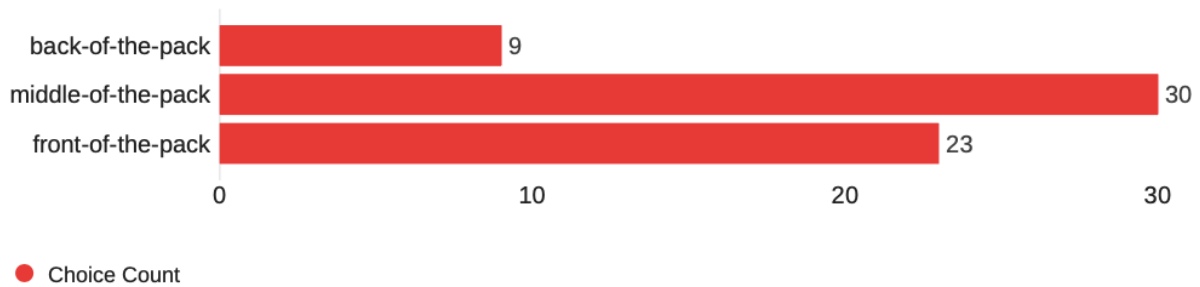
Q3_1 - years

Field	Min	Max	Mean	Standard Deviation	Variance	Responses	Sum
years	0.00	10.00	4.20	2.97	8.81	61	256.00

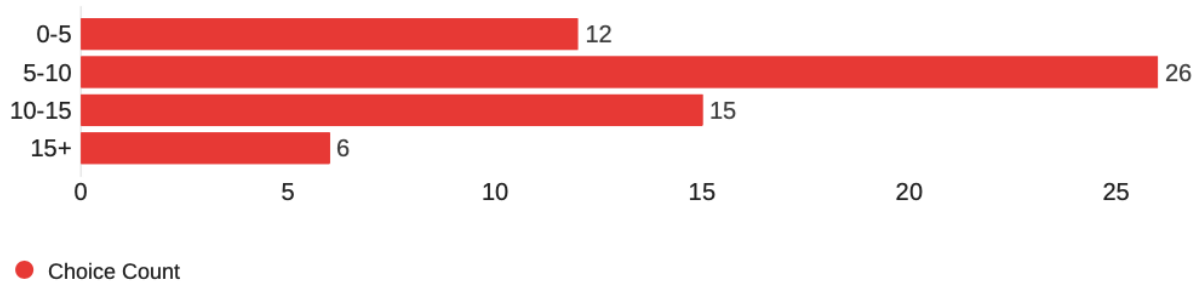
Q4_1 - races per year

Field	Min	Max	Mean	Standard Deviation	Variance	Responses	Sum
races per year	1.00	20.00	4.89	3.68	13.52	62	303.00

Q5 - Would you consider your performance:



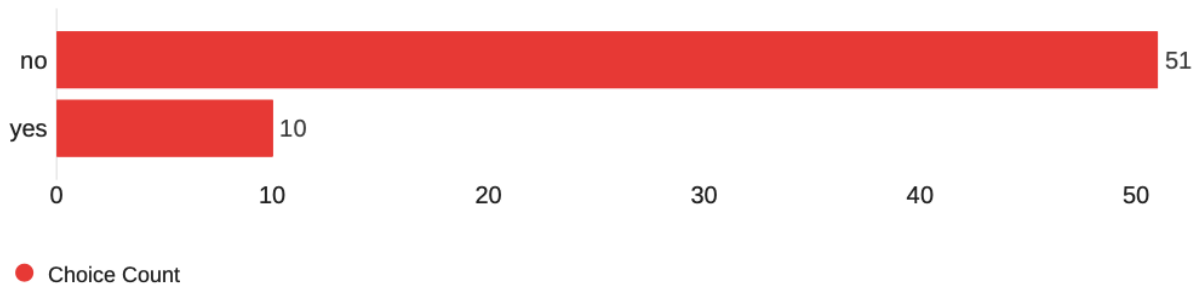
Q6 - Approximately how many hours per week do you train for skimo?



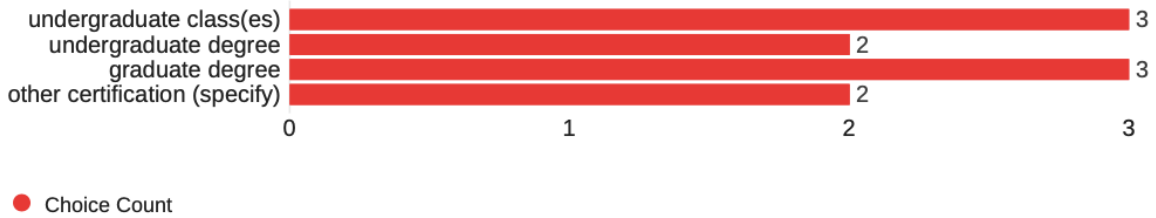
Q7_1 - knowledge

Field	Min	Max	Mean	Standard Deviation	Variance	Responses	Sur
knowledge	2.00	10.00	6.63	1.97	3.87	60	398.0

Q8 - Do you have formal education in sports nutrition?



Q9 - What level of formal education in sports nutrition do you have? - Selected Choice



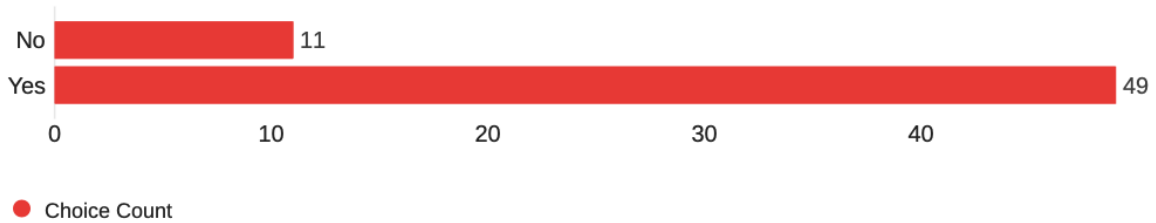
Q9_4_TEXT - other certification (specify) - Text

other certification (specify) - Text

Personal Trainer

UESCA

Q10 - Do you consume self-education materials in sports nutrition and hydration?



Q10b - Which type of self-education material do you consume? (please select 0 if 0...)

Field	Min	Max	Mean	Standard Deviation	Variance	Responses	Sum
books	0.00	5.00	2.08	1.14	1.30	39	81.00
podcasts	0.00	5.00	3.26	1.38	1.91	43	140.00
magazines	0.00	3.00	1.11	0.79	0.62	27	30.00
scientific literature	0.00	5.00	2.37	1.35	1.83	35	83.00

other (specify)	0.00	5.00	2.71	1.91	3.63	7	19.00
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Q10b_5_TEXT - other (specify) - Text

other (specify) - Text

Self experimentation

Consultation with professional friends in the field

Work material

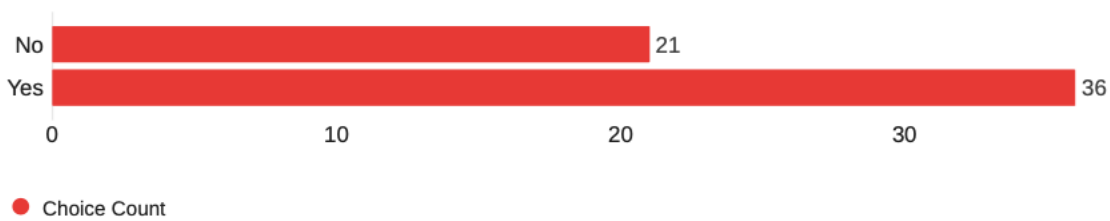
word of mouth

Newsletters

Q12_1 - level of importance

Field	Min	Max	Mean	Standard Deviation	Variance	Responses	Sum
level of importance	1.00	10.00	7.25	2.54	6.47	57	413.00

Q13 - Are you aware of suggested carbohydrate intake recommendations during exercise?



Q14 - If yes, what do you believe the recommended range of carbohydrate intake per hour is for 1.5-3 hours of exercise? (please give grams/hour)

If yes, what do you believe the recommended range of carbohydrate intake per hour is for 1.5-3 hours of exercise? (please give grams/hour)

80 -100

60-90

60-100

90-100g per hour

200 grams/hour

100g/h but I find that. 50g/h what I do mostly by feel now

200-300 cal/hour

50-75

90

100

30-60 grams

2

30-60+

50

30?

50

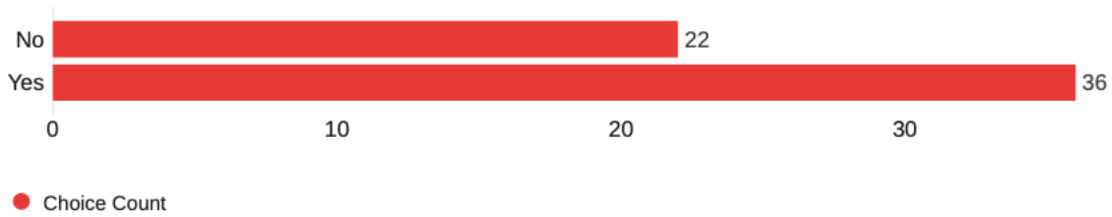
90-120

100g per hour

200?

30-60

Q15 - Are you aware of suggested hydration recommendations during exercise?



Q16 - If yes, what do you believe the recommended range of water intake per hour is for 1.5-3 hours of exercise? (please give milliliters/hour average) (500mL= ~17oz)

If yes, what do you believe the recommended range of water intake per hour is for 1.5-3 hours of exercise? (please give milliliters/hour average) (500mL= ~17oz)

750 - 1250ml

1L per hour

500

250mL /hour

600-800

500

500

600-1200

1L

1000

500 depending on conditions

500

500

I think it varies a lot by person, sweat rate

600ml/hour

I usually do like... 250ml per hour?

600-1200

1L/hr

250-1000ml/hour

500ml

Q17 - How many grams/hour of carbohydrate do you believe you ingest, on average, for a race lasting 1.5-3 hours? (please give grams/hour average) (or respond "unsure")

How many grams/hour of carbohydrate do you believe you ingest, on average, for a race lasting 1.5-3 hours? (please give grams/hour average) (or respond "unsure")

90

40-60

80-90

200

80g

150 grams/hour

100 calories per hour?

0-50g/hr try for every hour but if short then skip

200-300

Unsure

200-300 cal per hour

Unsure

50-75

110

Q18 - How many milliliters/hour of water do you believe you ingest, on average, for a race lasting 1.5-3 hours? (please give milliliters/hour average) (500mL= ~17oz) (or respond "unsure")

How many milliliters/hour of water do you believe you ingest, on average, for a race lasting 1.5-3 hours? (please give milliliters/hour average) (500mL= ~17oz) (or respond "unsure")

500

300-500

48oz

500

500

300 mL/hr

Unsure

Unsure none

1200ml

Unsure

500mL per hour

Unsure

500-750

200

32

500

500ml

Unsure

500

500+

Q19 - What is your preferred fueling method during a typical race lasting 1.5-3 h...

Field	Min	Max	Mean	Standard Deviation	Variance	Responses	Sum
gels	0.00	5.00	3.18	1.73	2.99	50	159.00
gummies	1.00	5.00	2.14	1.23	1.51	36	77.00
bars	0.00	5.00	1.62	1.30	1.68	29	47.00
liquid calories (drink mix)	1.00	5.00	3.94	1.37	1.89	47	185.00
nothing	0.00	4.00	1.14	1.55	2.41	7	8.00
other (specify)	1.00	5.00	3.63	1.65	2.73	8	29.00

Q19_6_TEXT - other (specify) - Text

other (specify) - Text

Crackers

Apple sauce

Fireball

Fig newtons

Spring energy

Smoothie packs, homemade food

Maple syrup

Baked goods and pizza

Sandwiches, nuts, chips, dried fruit

unsure

120

60

Unsure

50

Depends on a lot of things like how cold it is but average 25-30. etc.

Q20 - What might be reasons for you not to fuel/hydrate adequately during races?...

Field	Min	Max	Mean	Standard Deviation	Variance	Responses	Sum
don't want to lose time	0.00	10.00	3.51	2.90	8.43	45	158.00
high intensity (heavy breathing)	0.00	10.00	5.16	2.49	6.18	43	222.00
gut issues	0.00	10.00	3.36	2.77	7.69	33	111.00
cold temperature (impaired hand dexterity)	0.00	10.00	4.81	2.69	7.21	36	173.00
cold temperature (frozen nutrition/hydration)	1.00	10.00	5.55	2.78	7.72	42	233.00
accessibility issues (due to gloves or storage)	1.00	9.00	4.72	2.44	5.95	39	184.00
not feeling hungry/thirsty	0.00	10.00	5.22	2.79	7.78	36	188.00
knowledge deficit of recommendations	0.00	6.00	2.50	1.99	3.98	22	55.00
don't want to carry extra weight	0.00	9.00	3.12	2.95	8.69	17	53.00
other (please specify)	0.00	10.00	4.71	4.37	19.06	7	33.00

Q20_10_TEXT - other (please specify) - Text

other (please specify) - Text

Forgot

I'm just lazy and the performance benefits aren't crucial to my average performance

Too focused

Stuff is expensive

APPENDIX C

RANDOMIZED CONTROLLED TRIAL INFORMED
CONSENT DOCUMENT

SUBJECT CONSENT FORM FOR PARTICIPATION IN HUMAN RESEARCH AT
MONTANA STATE UNIVERSITY

Study Title: Effects of Different Fueling Methods in Skimo

Investigators: ¹Mary Miles, Ph.D.; Rachel Topf, B.A.

¹Health & Human Development

Montana State University, Bozeman, MT

Phone: (406) 994-5001

mmiles@montana.edu

IRB contact: irb@montana.edu

Summary:

You are being asked to volunteer as a participant in a research study of different fueling strategies during a skimo time trial. Two different fueling strategies will be used and the subsequent impact on time trial length and hydration will be measured. Each fueling method will be used in a separate time trial with the participant completing both trials at least a week apart. Many things have an impact on athletic performance including nutrition and hydration. The individual skimo race format (~1.5-2.5 hours) is long enough that carbohydrate and fluid consumption can have a great impact on performance.

Purpose:

The purpose of this study is to determine how different fueling methods in skimo affect time trial performance and hydration status. Specifically, we are asking the following questions:

1. How do different fueling methods affect hydration during a skimo time trial?
2. How do different fueling methods affect skimo time trial performance?

With skimo becoming a bigger sport, and with little existing literature on the sport, this research will help inform better fueling and hydration strategies and influence future research direction.

Participants in the study:

You have been asked to participate in this study because you meet the following criteria: 18+ years of age; participation in skimo competition for at least one prior season and/or at least two individual-length skimo races. You may not be a participant if you do not meet eligibility requirements because of health history, symptoms, issues, or risks. You are not eligible to participate if you are pregnant or if you have other health concerns or conditions that may interfere with your participation in the study.

Procedures:

Participation is voluntary. If you agree to participate in this study, you will be asked to complete one visit to the Exercise Physiology Lab and two on-snow skimo time trials. The lab visit will take approximately 45-60 minutes to perform a VO₂max test on the treadmill and body composition testing in the BodPod. The on-snow skimo time trials will be approximately 1.5-2.5 hours depending on performance with a short amount of time on either side for a warm-up and cool-down and brief measurements of weight and urine sampling to assess hydration and pre-/post-trial surveys. There is a minimum one-week separation between skimo time trials on snow and at least one day from the VO₂max test. You will be asked to follow simple nutrition and exercise guidelines leading into each day of testing.

Completion of the study will take three separate days with at least a week between time trial sessions and one day separating the VO₂max test.

Lab Visit: This visit will take 45-60 minutes and include the following activities:

- 1) **Informed consent.** Read and provide written informed consent (this form). We also will provide you with a copy of this form and discuss it with you prior to proceeding with any additional activities in visit 1.
- 2) **Skimo activity questionnaire.** Complete a 3-question survey that asks questions about your activity level in skimo.
- 3) **Weight measurements.** The researcher will take baseline measurements of weight.
- 4) **Measurement of muscle and fat tissue using the BodPod.** This test involves being weighed and sitting in the BodPod device which measures body composition. Subjects will show up after an overnight fast and will have to wear minimal, tight clothing (ie shorts, sports bra) during the test.
- 5) **VO₂max Test.** An assessment of maximal volume of oxygen uptake (VO₂max) will be performed in a ramped test (gradually increasing intensity) on a treadmill. This test requires participants to go until VO₂max is reached and exceeded, often until exhaustion.

Skimo Time Trials (separated by a minimum 7 days): You will need to refrain from eating, exercising, tobacco use, and consuming alcohol for two hours prior to each time trial. You should drink plenty of water so that you are well hydrated throughout the study. Each visit will take approximately 2-3 hours.

- 1) **24-hour diet recall.** A 24-hour diet recall will ask you to report the types and quantities of foods and beverages consumed the day prior. This is for your personal use so you can recreate the same eating pattern for the second time trial.
- 2) **Gear check and weighing.** The researchers will confirm that you have all the proper and required equipment for the time trial. Gear will then be weighed.
- 3) **Urine Sample.** Participants will provide a preliminary urine sample at the ski hill to assess hydration.
- 4) **Body weight.** Participants will be weighed in clean, dry clothes. This is used as another assessment of hydration.
- 5) **Course familiarity and procedure review.** The participant will be familiarized with the course and rules during the time trial.
- 6) **Time trial.** Participants will complete a self-selected warm-up before starting the trial. During the trial, participants will complete the required ski course while being required to consume a carbohydrate beverage at certain time intervals.
- 7) **Post-trial survey, reweigh, urine sample, and snacks.** After completion of the trial, participants will dry off and be reweighed in the same clean, dry clothes. A second urine sample will be taken. They will then complete a short survey assessing the products consumed during the time trial. Participants will also be provided a recovery snack.

Risks: Skiing is inherently dangerous. During the skimo time trials, participants should ski in control and at their own ability level. Risks for this project include:

- 1) Skiing an intermediate downhill ski run.
- 2) The VO₂max test asks participants to exercise until confirmation of VO₂max or until exhaustion. Treadmills can be dangerous if improperly used. Participants will be accompanied the entire time and may terminate if need be.
- 3) Stomach upset may occur in the process of drinking the required drink mix during the time trials.
- 4) Any allergy to the drink mix will disqualify participants

Biospecimens: Urine samples will be tested for purposes of this study and then destroyed upon completion of analysis.

Benefits: You may gain some benefits by participating in this study, such as body composition and VO₂max assessment. No other benefits are guaranteed.

Compensation: Participants will be entered into a guaranteed prize drawing for items donated by different companies/businesses and will receive gift cards after completion of each time trial.

Freedom of Consent: You have the right to withdraw from participating in the study at any time with a no questions asked policy. You may withdraw in writing, over the phone (to Mary Miles at

994-6678), or in person. If you withdraw, you will not lose any benefits you incurred up to the time of withdrawal. Your participation in this study is completely voluntary.

Funding: This study is funded by the Kreighbaum Endowment and the Nutrition Research Lab at MSU.

Please ask any questions: You are encouraged by the researcher to ask any and all questions you may have, as well as addressing any concerns about the study. The researcher will answer your questions as fully and as accurately as possible. Your peace of mind and comfort in the study is of utmost importance to the researchers.

Confidentiality: All data and information received from you for this study will be kept completely confidential. Participant data could be breached during the study. You will be given a subject identification number that will be used to describe all data. This data will be kept locked in a file cabinet in the Nutrition Research Laboratory. This information could be published in scientific and/or medical journals, but your identity will remain confidential. If you withdraw from the study at any time, all of your information will be deleted from the study records, and you will not be contacted again regarding the study. There are absolutely no penalties for withdrawing.

In the event of injury due to participation in this study, medical treatments such as first aid and help getting to adequate health care providers (such as transport to Bozeman Deaconess Hospital) will be provided; However, there is no compensation for any of this provided by Montana State University. You can access further information involving this policy and treatment by contacting Mary Miles at 994-6678, or emailing her at mmiles@montana.edu.

Any other questions you may have regarding your rights as a participant may be answered by the chairman of the Human Subjects Committee, Mark Quinn. He can be reached at 406-994-4707 or mquinn@montana.edu.

STATEMENT OF AUTHORIZATION

Study Title: Effects of Different Fueling Methods in Skimo

AUTHORIZATION: I have read the above and understand the discomforts, inconveniences, and risk of this study. I, _____ (name of subject), agree to participate in this research. I also agree that my health information can be collected and used by the researchers and staff for the research study described in this consent form. I understand that I may later refuse participation and that I may withdraw from the study at that time. I have received a copy of this consent form for my own records.

Signed: _____

Date: _____

Investigator: _____

Date: _____

APPENDIX D

SURVEY INFORMED CONSENT DOCUMENT

SUBJECT CONSENT FORM FOR PARTICIPATION IN HUMAN RESEARCH AT
MONTANA STATE UNIVERSITY

Study Title: Skimo Nutrition & Hydration Survey

Investigators: ¹Mary Miles, Ph.D.; Rachel Topf, B.A

¹Health & Human Development

Montana State University, Bozeman, MT

Phone: (406) 994-5001

mmiles@montana.edu

Summary:

You are being asked to volunteer as a participant in a research study of how food may influence your body's response to a meal. This response will include the measurement of many different markers in the blood. Many different substances will be measured that relate to inflammation, health, and metabolic markers in your blood. These substances are produced by your immune system and chemical reactions in your body (metabolites) or the microorganisms such as bacteria that are in your digestive system. One of the many things we will measure in the blood are called "bile acids". Bile acids are compounds made from cholesterol and amino acids (from proteins) that help with breaking down fat in your intestine during digestion.

The types and quantities of carbohydrate, fat, protein, fiber, and antioxidants in foods can influence the amount of bile acids that enter your gut during digestion. We are specifically interested in how different foods affect bile acids, inflammation, metabolism, and other health measures.

Purpose:

The purpose of this survey is to determine the knowledge, beliefs, and practices of athletes around fueling and hydration during skimo races. This survey will provide preliminary data to compare to later data from a participatory race simulation.

Learning about athletes' fueling and hydration knowledge and practices compared to the reality of what athletes do will better help inform future education and recommendations in this sport.

Participants in the study:

Eligibility for this survey includes having participated in skimo for at least one season prior or two individual-length format skimo races (lasting ~1.5-3 hours).

Procedures:

Participation is voluntary. Completion of this survey will take about 5-15 minutes.

- 1) **Informed consent.** Read and provide written informed consent (this form). We also will provide you with a copy of this form and discuss it with you prior to proceeding with any additional activities.

Risks: There are no known risks for this survey.

Benefits: There are no known benefits of this survey.

Compensation: There is no compensation for this survey.

Freedom of Consent: You have the right to withdraw from participating in the survey at any time with a no questions asked policy. Your participation in this survey is completely voluntary.

Funding: This study is funded by the Nutrition Research Lab at MSU.

Please ask any questions: You are encouraged by the researcher to ask any and all questions you may have, as well as addressing any concerns about the survey. The researcher will answer your questions as fully and as accurately as possible. Your peace of mind and comfort in the survey is of utmost importance to the researchers.

Confidentiality: All data and information received from you for this study will be kept completely confidential. This information could be published in scientific and/or medical journals, but your identity will remain confidential. Any other questions you may have regarding your rights as a participant may be answered by the chairman of the Human Subjects Committee, Mark Quinn. He can be reached at 406-994-4707 or mquinn@montana.edu.

Participation is voluntary, and you can choose to not answer any questions you do not want to answer and/or you can stop at any time.

Proceeding with the survey/interview/questionnaire indicates your consent to participate.

Contact info for Rachel Topf: rachel.topf7@gmail.com

Contact info for the MSU IRB: irb@montana.edu

STATEMENT OF AUTHORIZATION

Study Title: Skimo Nutrition and Hydration Survey

AUTHORIZATION: I have read the above and understand the discomforts, inconveniences, and risk of this study. I, _____(name of subject), agree to participate in this research. I also agree that my health information can be collected and used by the researchers and staff for the research study described in this consent form. I understand that I may later refuse participation and that I may withdraw from the study at that time. I have received a copy of this consent form for my own records.

Signed: _____

Date: _____

Investigator: _____

Date: _____