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Fluid Intake and Hydration Responses to Mass Participation Gravel Cycling

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ABSTRACT

International Journal of Exercise Science 17(2): 1648-1662, 2024. Gravel cycling is a relatively new cycling discipline, with the Union Cycliste Internationale (UCI) hosting their first World Championships in 2022. Gravel races combine features of road racing, cyclocross, and mountain biking, including terrain of varying technical difficulty, long distances, substantial elevation gain, obstacles, and limited opportunities to stop for in-race nutrition. This study assessed hydration responses to gravel races of three different distances. Data were collected on saliva osmolarity (SOsm), body mass (BM), fluid intake, and nutrition knowledge at a gravel cycling race in April 2023. A total of 121 participants completed pre-race surveys, 53 provided pre-race measures of BM and SOsm, and 38 participants completed post-race testing. Only 22.6% (n = 12) of participants were hydrated before the race, with 56.6% mildly dehydrated (n = 30), 18.9% moderately dehydrated (n = 10), and 1.9% severely dehydrated (n = 1). Post-race, 15% (n=6) were still hydrated, 20% (n = 8) were mildly dehydrated, 47.5% (n = 19) were moderately dehydrated, and 17.5% (n = 7) were severely dehydrated. Analyses revealed significant decreases in BM and increases in SOsm from pre- to post-exercise in the two longer race distances ($p < 0.05$). There was a significant effect of race distance on energy, fluid, carbohydrate, and sodium intake ($p < 0.05$). Sweat rates were not different ($p > 0.05$). Our results revealed an effect of race distance on BM losses, SOsm, and energy, fluid, carbohydrate, and sodium intakes. Future studies could inform optimal feeding and hydration strategies.

Key Words: Endurance cycling, field study, nutrition, dehydration, competition

INTRODUCTION

Maintaining optimal fluid balance is imperative for adequate endurance performance (16). In a dehydrated state, the body is not able to properly maintain core body temperature through heat dissipation and sweating during strenuous exercise. Substantial increases in core body temperature during exercise elicit impaired exercise metabolism and reduced cardiac output (16). These factors contribute to diminished endurance performance. It has been well documented that endurance exercise performance can be reduced when at least 2% of body mass (BM) from water deficit is lost (10,25). Body mass losses from water deficits exceeding 3-5% significantly increase the risk of heat illness (1). It is common practice for elite endurance cyclists to drink water, electrolyte and carbohydrate beverages throughout their races to combat the onset of dehydration and maintain glycogen storage (13,23). Maintaining hydration amongst elite cyclists during races has been well studied (6,7,9,13,23). Armstrong et al. (2012) found that 4 out of 42 male non-elite cyclists arrived pre-race dehydrated based on measures of urine specific gravity (USG), with 11 of 42 still being considered dehydrated post-race; however, most athletes were able to maintain BM in a 164km road cycling race (2). However, how well non-elite cyclists maintain fluid balance and carbohydrate intake during a gravel cycling race needs further investigation.

There is a growing participation in cycling, particularly gravel cycling, in the United States. Data from the popular social media and training app, Strava (Strava, Inc., San Francisco, CA, USA), reported that the number of users logging gravel rides increased 55% in 2023 with a 48% increase among US users (31). Despite the rising popularity of gravel cycling, there is minimal research on the fluid balance of cyclists following a gravel cycling race. Gravel cycling is unique in that it contains a combination of road and off-road segments with large elevation gains and limited aid stations due to the varying terrain and isolation the riders encounter on the course. Lower speeds typically characterize off-road cycling due to more difficult terrain with continuous climbs (21). Uphill cycling can increase body heat production due to the greater power requirements of the increased resistance against gravity (11) and reduced air speed velocity (24).

Endurance athletes' knowledge of properly maintaining fluid and electrolyte balance during training sessions and races is important to reduce their risk of heat illness and severe dehydration during exercise. Some common hydration strategies for endurance cyclists include drinking to thirst or drinking ad libitum leading up to and during a race. Similar physiologic and perceptual responses have been seen with both drinking strategies (3). Veilleux and colleagues revealed that attitudes about hydration and barriers to hydration were associated with fluid intake behaviors among US adults (27). Furthermore, attitudes regarding hydration have a larger impact on fluid intake than hydration knowledge. Winger and colleagues (2011, 2013) found that most endurance runners they surveyed have a poor understanding of the physiological consequences of hydration behaviors (29,30). The degree of hydration knowledge among non-elite endurance cyclists requires further investigation.

This study quantified fluid intake and hydration status in non-elite cyclists participating in a gravel cycling race incorporating three different race distances. We hypothesized that the longer race distances would be associated with greater dehydration and fluid intake.

METHODS

Participants

Data for this study were collected at the 2023 Belgian Waffle Ride – San Diego (https://www.belgianwaffleride.bike/). The 2023 edition had three race distances: 69 kilometers with 1,350 meters of climbing (Wanna); 125 kilometers with 1,950 meters of climbing (Wafer); and 206 kilometers with 3,300 meters of climbing (Waffle). The Wanna included 24% off-road surfaces, the Wafer included 43% off-road surfaces, and the Waffle included 41% off-road surfaces. Off-road surfaces included fire roads, jeep trails, double-track trails, single track trails, creek crossings, and various other natural and man-made obstacles (gates, hay bales, etc.). Ethical approval was obtained from the California State University San Marcos Institutional Review Board (#2038926-1) and research was conducted in accordance with the ethical policies of the International Journal of Exercise Science (19). Written informed consent was obtained from all participants.

Protocol

Participants were recruited at the pre-race expo on Friday and Saturday. Participants were required to be 18-60 years of age; competing in one of the three race distances on Sunday; regularly engage in physical activity (150+ minutes per week); no history of any metabolic disease; no history of heat illness; and access to telephone and/or e-mail. Study procedures were explained prior to written informed consent being obtained. Participants then completed a pre-race survey on tablet computers (iPads, Apple, Inc., Cupertino, CA, USA) for information on their training, planned hydration and nutrition strategies, and questions on hydration knowledge (Qualtrics, Provo, UT, USA). They were then instructed to meet with the research team prior to the race start on Sunday morning. A total of 121 participants provided informed consent and completed the pre-race survey. Of those, 53 (43.8%) completed pre-race testing on race morning. Of those who completed pre-race testing, 39 (73.6%) returned to the study team post-race for final assessments. One participant's BM and saliva osmolarity (SOsm) data were lost, so the final sample consisted of 4 participants in the Wanna, 16 participants in the Wafer, and 18 participants in the Waffle. Our study participants included 35 male and 4 female athletes (10.3 %). Regarding the female athletes, one completed the Waffle, 2 completed the Wafer, and 1 completed the Wanna. A flow chart of participants is displayed in Figure 1.

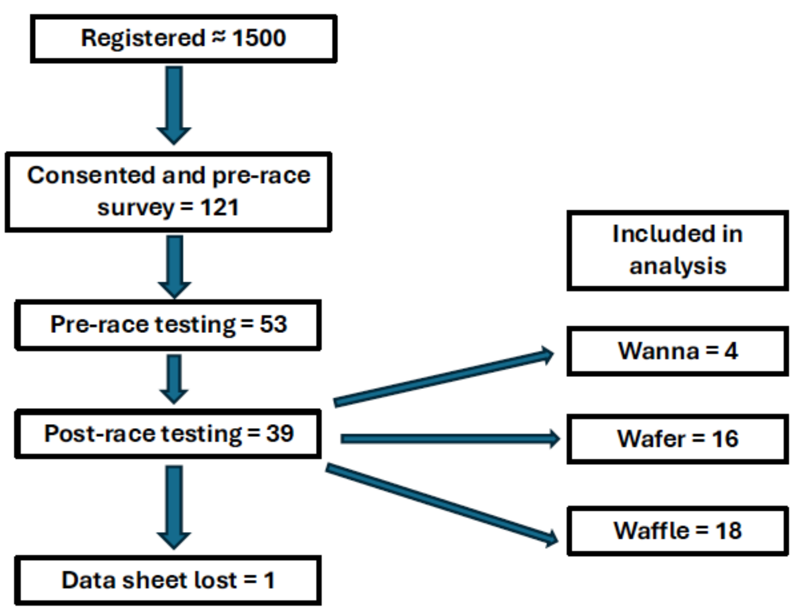

Figure 1. Flow chart of study participants.

Participants completed both pre- and post-race surveys. The pre-race survey was completed immediately after the informed consent. Participants were asked about their training history, age, sex, and other demographic data. The pre-race questions were designed to ask the participants about their *hydration behaviors* and asked the following questions (adapted from (3)):

- *Do you have a hydration strategy for the race? (Yes/No)*
- *Do you have a feeding strategy for the race (Yes/No)*
- *I have an established drinking plan. (1-5, strongly disagree to strongly agree)*
- *I usually drink as much as I can. (1-5, strongly disagree to strongly agree)*
- *I drink when I sense I am dehydrated. (1-5, strongly disagree to strongly agree)*
- *I drink only when I am thirsty. (1-5, strongly disagree to strongly agree)*

The post-race survey was conducted after the participants had weighed in and had their SOsm tested. The post-race survey began by asking participants to rate their perceived exertion during the race using the Borg 1-10 scale (28). The post-race survey questions were designed to ask participants about their *hydration knowledge*. Participants were asked the following questions (correct answers in **bold**):

- *On a scale of 1 being no effort at all and 10 being maximal, all-out effort, what was your perceived effort during the race? (1-10) (Rating of Perceived Exertion, RPE)*
- *You can be dehydrated without being thirsty. (**True**/False)*
- *Hot and humid environments don't change the amount of fluid needed. (True/**False**)*
- *When you are dehydrated, you are at a higher risk for heat-related illness. (**True**/False)*
- *It's impossible to drink too much water. (True/**False**)*

Participants could weigh in up to 60 minutes prior to the start of the race. Body mass was measured using Seca model 874 scales, which were periodically zeroed and checked for accuracy with 9.07 kg (20 lb) weights. Participants were weighed in their cycling gear, without their helmet and with empty pockets. They toweled themselves off prior to weighing in post-race. Salivary osmolarity was then measured using a point-of-care analyzer (MX3 Hydration Testing System, MX3 Diagnostics, Austin, TX, USA). Participants were instructed prior to weighing in to not drink anything for 5-10 minutes prior to saliva testing. Then, after weighing in, participants were instructed to swallow their saliva and generate a fresh sample from the back of their mouth and to swish around to ensure a heterogeneity of saliva from the salivary glands. They were required to stick their tongue out and the researchers tapped a test strip inserted into the analyzer repeatedly on the participant's tongue for 10-20 seconds until a sufficient volume was detected (~ 1 µL). The MX3 provides both osmolarity values in milliosmoles per kilogram (mOsm) and a descriptive value based on manufacturer determined cutoffs: hydrated (< 66 mOsm), mildly dehydrated (66 – 100 mOsm), moderately dehydrated (101 – 150 mOsm), and severely dehydrated (151+ mOsm). While a published, peer-reviewed paper on MX3 validity for SOsm is lacking, a recent study validated the device for estimation of sodium losses via sweat (8) and others have validated the MX3 for spot hydration assessment in clinical populations (4,12). Furthermore, an internal validation study reported that the change in SOsm from the MX3 correlated well with the percentage of BM loss in 90 participants, and prior research has found that changes in SOsm can track changes in hydration (18,26). Post-race, the research team was positioned just outside the finish chute and directed participants to the study area as soon as they finished. Participants were asked not to consume any fluid for 5 minutes while they completed the post-race questionnaire. They were then weighed and had SOsm measured. Fluid intake was estimated by asking participants how many bottles they consumed during their race (using 3 common bottle sizes of 16-, 20-, and 24-ounces) and whether fluid was water, sports drink, other, or a mix. Participants were not asked about food, gels, or non-fluid nutrient intake due to the error inherent to dietary recall and the inability to weigh and measure food on the course. While we acknowledge self-reported fluid intake can also be prone to error, we did have sample bottles of various sizes on hand to aid in estimation. Energy, carbohydrate, and sodium content were estimated for each individual by searching for their reported beverage's nutritional information. If unavailable, data from the race-supplied sports drink were used (BWR Belgian Berry Endurance Blend, INFINIT Performance Nutrition, Cinncinati, OH, USA), which provided 300 kcal, 71 grams of carbohydrate, and 398 mg of sodium per 20 ounce serving with an osmolality of 305 mOsm/L. Each individual's finish time was recorded, and average speed was derived by dividing the race distance by the finishing time to yield speed in miles per hour. This value was then multiplied by 1.609 to convert to kilometers per hour. Whole body sweat loss was calculated from the change in pre- to post-exercise BM in pounds, which was subsequently converted to ounces, and corrected for fluid intake, and finally converted to liters. Sweat loss was then divided by race finish time to yield sweat rate (5). We did not collect data on urinary losses, but utilizing estimated losses of ~250 mL did not impact the calculations.

Statistical Analysis

Due to the low number of participants completing the Wanna distance, we excluded this distance from statistical analysis. Data were analyzed using linear mixed models for distance (distance effect, Wafer vs. Waffle) and time (time effect, Pre vs. Post) for BM and SOsm. This approach was selected over traditional 2-way repeated measures ANOVA due to the uneven sample sizes between groups. If sphericity was found to be violated, the Greenhouse-Geisser correction was utilized. When main effects were identified, Bonferroni's *post-hoc* test for multiple comparisons was performed. Independent samples *t*-tests were used to examine between-distance differences in fluid intake, nutrient intake, and percent BM loss (distance effect, Wafer vs. Waffle). A Pearson correlation between the percent change in BM and change in SOsm was also performed. Regarding the pre-race survey data, Chi-square tests and independent samples *t*-tests were conducted to compare hydration knowledge between finishers and non-finishers. "Non-finishers" were considered participants who consented to the study and completed the pre-race survey, but who did not report to the study team for testing on race morning. Regarding the post-race survey, Chi-square tests and independent samples *t*-tests were conducted to compare hydration knowledge between Wafer and Waffle competitors. As this was a field study, *a priori* sample size estimates were not performed. Data were analyzed in Prism 10 (GraphPad Inc., La Jolla, CA, USA) and SPSS version 27 (IBM, Armonk, NY, USA), and statistical significance was accepted if $p < 0.05$. Data are reported as means ± SD. For changes in BM and SOsm, 95% confidence intervals (CIs) for the means and 95% CIs for the differences are also reported.

RESULTS

Environmental conditions - Weather data were pulled from the National Weather Service and the National Oceanographic and Atmospheric Administration websites, and WBGT were calculated with the Occupational Health and Safety Administration/National Institute for Occupational Safety and Health (OSHA/NIOSH) Heat Index mobile application. The weather for the 2023 race was an anomaly when compared to prior years. Weather on race day was overcast, calm, and cool, with intermittent sun. Wet bulb globe temperatures at the start/finish line (elevation: 200 meters) ranged between 13 - 16°C, while the highest elevation point of the course (elevation: 750 meters) peaked at 17°C by 1300 local time. An examination of the historical weather data indicated this year was the coolest in the event's history.

Participant characteristics - Participants were 40.1 ± 11.6 years of age (mean ± SD), with weekly cycling training volumes of 11.6 ± 6.4 hours and a total training volume (all exercise) of 15.8 ± 10.1 hours per week. Out of all participants, those who completed all assessments were older (43.1 ± 11.6 years) compared to non-finishers (38.7 ± 11.4 years), though this was not significant (independent *t*-test, p = 0.058). Training volumes were not significantly different between finishers and non-finishers. Completion times ranged from 4.4 ± 0.8 hours for the Wanna, to 6.7 ± 0.9 hours for the Wafer, to 9.2 ± 1.4 hours for the Waffle. This equated to an average speed of 16.1 ± 3.2 kph (Wanna), 18.9 ± 2.6 kph (Wafer), and 22.9 ± 3.4 kph (Waffle). Average speed was significantly faster among the Waffle finishers compared to the Wafer finishers (independent *t*-test, $p < 0.0001$). Among finishers, the reported RPE post-race were 8.6 ± 1.1 for Waffle participants, 7.8 ± 1.6 for Wafer participants, and 7.3 ± 2.2 for the Wanna participants. RPEs were not significantly different between race distances ($F_{2,37} = 2.162$, p = 0.130).

Hydration responses - Changes in BM and SOsm, stratified by race distance, are displayed in Figure 2. The linear mixed model for BM revealed a main effect of time ($F_{1,32} = 61.3$, $p < 0.0001$), no main effect of race distance ($F_{1,32} = 0.93$, p = 0.342), and a significant time*distance interaction ($F_{1,32} = 7.39$, p = 0.0105). Post-hoc analysis revealed significant decreases in BM from pre-race to post-race in the Wafer (- 0.83 kgs, 95% CI: -1.31 to -0.35, p = 0.003) and the Waffle (- 1.71 kgs, 95% CI: -2.16 to -1.26, $p < 0.0001$); however, there was no significant difference for the pairwise comparison between the Wafer and Waffle at the post-race time point (-3.02 kgs, 95% CI of difference: -8.38 – 2.329, p = 0.2638). When expressed as the percent Δ BM, ANOVA revealed that the Waffle (-2.17 ± 1.36 %, 95% CI: -2.84 to -1.49) caused greater BM loss than the Wafer (-0.90 ± 0.89 %, 95% CI: -1.37 to -0.42) (95% CI of difference: -2.25 to -0.28, p = 0.0084). Sweat rate ($F_{2,13.67} = 0.1215$, p = 0.887) was not different between race distances, indicating that fluid loss was a function of race time. Regarding SOsm, a linear mixed model revealed a main effect of time ($F_{1,32} = 25.14$, $p < 0.0001$), but no effect of race distance ($F_{1,32} = 0.1701$, p = 0.6828) or time*distance interaction ($F_{1,32} = 0.0486$, p = 0.8269). SOsm increased significantly from pre-race to post-race in the Wafer (+42 mOsm, 95% CI: 14 – 68 mOsm, p = 0.0021) and the Waffle (+38 mOsm, 95% CI: 12 – 64 mOsm, p = 0.0028).

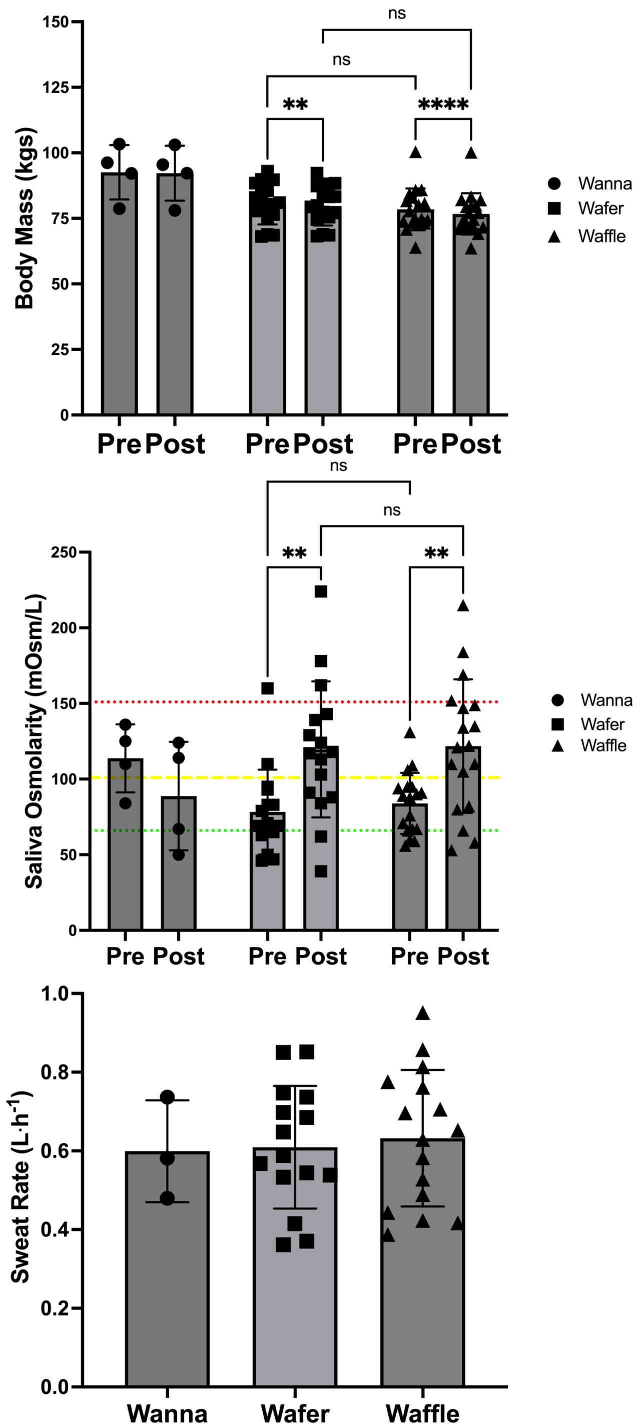

Figure 2. Changes in body mass (top) and salivary osmolarity (middle) between race distances and calculated sweat rates (bottom). The colored lines represent the manufacturer-derived cut-points for hydrated (below green line), mildly dehydrated (between green and yellow line), moderately dehydrated (between yellow and red line), and severely dehydrated (above red line). Circles represent individual participant data for the Wanna; squares represent individual participant data for the Wafer; and triangles represent individual participant data for the Waffle. **p < 0.01, ***p < 0.0001 for Wafer vs. Waffle comparisons.

Fluid & nutrient intake - Data for fluid and nutrient intake are displayed in Figure 3. With regard to fluid intake, participants in the Waffle consumed the most fluid, followed by the Wafer and the Wanna. An independent samples t-test revealed no difference in fluid intake between the Wafer and the Waffle (+0.51 L, p = 0.155). Regarding energy intake, an independent samples t-test revealed that more energy was consumed during the Waffle compared to the Wafer (+576 kcal, p = 0.0323). Carbohydrate (+137 g, p = 0.0232) and sodium intake (+765 mg, p = 0.0132) were also higher in the Waffle compared to the Wafer.

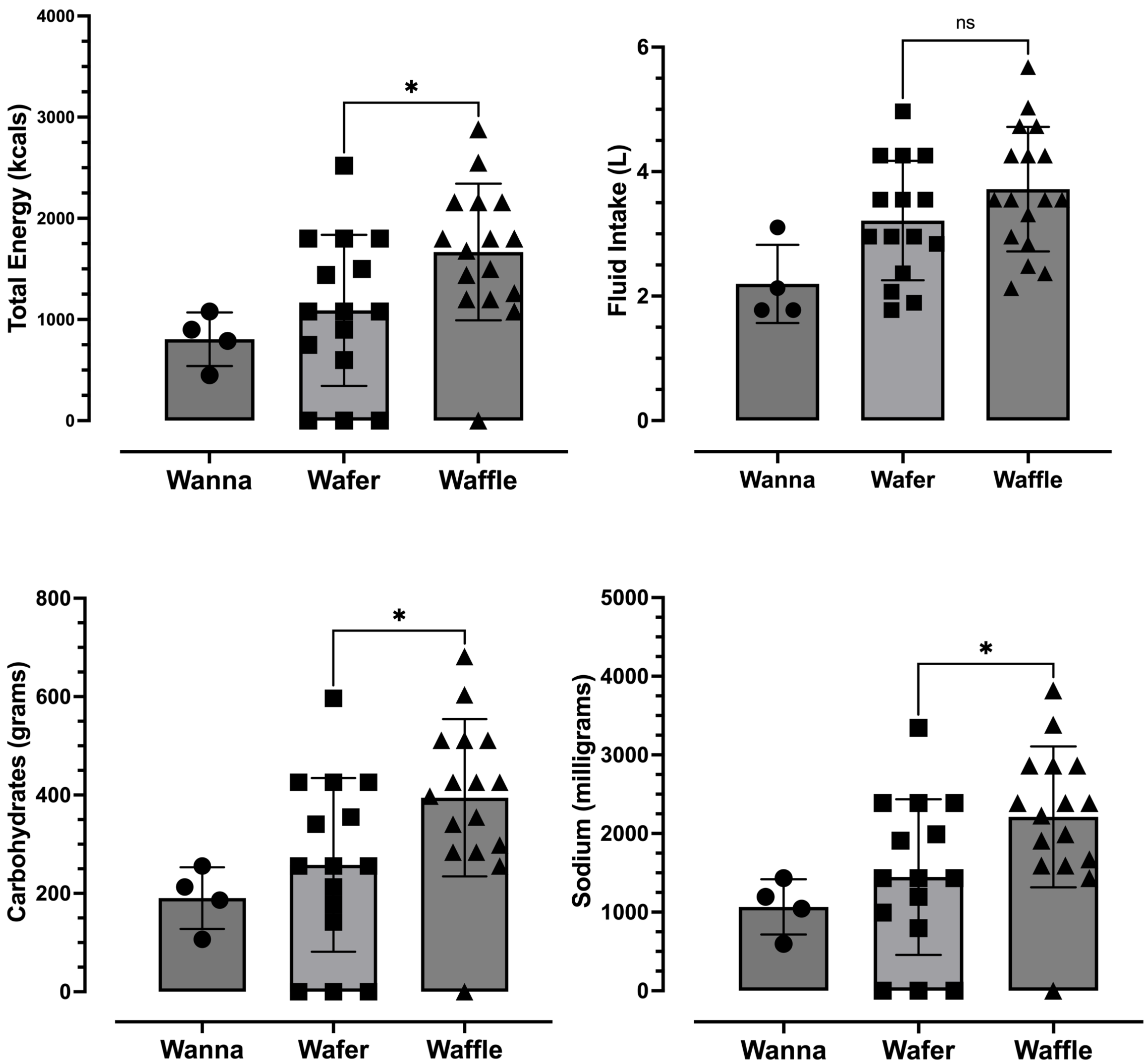

Figure 3. Energy, fluid, and nutrient intake between race distances. Circles represent individual participant data for the Wanna; squares represent individual participant data for the Wafer; and triangles represent individual participant data for the Waffle. *p < 0.05 for Wafer vs. Waffle comparisons, ns = not significant.

Correlations - The Δ BM (%) and Δ SOsm were weakly and non-significantly correlated (r = -0.25, 95% confidence interval: -0.53 to 0.07, p = 0.1183).

Hydration practices - When examining the pre-race survey data, 86.7% of participants stated they had a hydration strategy (n = 104 out of 120), with no differences between finishers and non-finishers (p = 0.361). Ninety percent of participants stated they had a feeding strategy (n = 109 out of 121), with no differences between finishers and non-finishers (p = 0.801). Regarding pre-race hydration practices (Table 1), a similar proportion of finishers and non-finishers agreed or strongly agreed with having an established drinking plan (79.4% vs. 75.9%, p = 0.463). A significantly lower proportion of finishers agreed or strongly agreed with drinking as much as they could compared to non-finishers (47.1% vs. 68.2%, p = 0.04). A similar proportion of finishers and non-finishers endorsed drinking when they sensed they were dehydrated (51.5% vs. 58.8%, p = 0.662). The final pre-race hydration practice question revealed similar proportions of finishers and non-finishers disagreeing or strongly disagreeing with drinking to thirst (50% vs. 72.1%, p = 0.122). Independent samples *t*-tests for group differences in means for the four questions were not significant (all p-values between 0.2 - 0.557).

Table 1. Participants' Responses Regarding Hydration Behaviors Pre-race

	Group	
Question*	Finishers	Non-finishers
I have an established drinking plan	4.2 ± 1.1	3.9 ± 1.2
I usually drink as much as I can	3.5 ± 1.1	3.6 ± 1.2
I drink when I sense I am dehydrated	3.3 ± 1.5	3.4 ± 1.4
I drink only when I am thirsty	2.4 ± 1.2	2.1 ± 1.2

*1 = Strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree

Hydration knowledge - Participants showed a high degree of hydration knowledge for the 4 post-race questions. Regarding the first question, 94.4% of Waffle finishers, 100% of Wafer finishers, and 100% of Wanna finishers answered correctly with no between-group differences (p = 0.565). For the second question, 88.9% of Waffle finishers, 93.8% of Wafer finishers, and 75% of Wafer finishers answered correctly with no between-group differences (p = 0.547). All participants correctly answered the third question, which prevented statistical analysis. Finally, 83.3% of Waffle finishers, 81.3% of Wafer finishers, and 100% of Wanna finishers correctly answered the fourth question, with no between-group differences (p = 0.649).

DISCUSSION

The present study's primary objective was to quantify changes in hydration levels during mass participation gravel cycle racing. We also sought to quantify fluid and nutrient intake, pre-race hydration behaviors, and post-race hydration knowledge. Our results revealed, in the context of the present study, that gravel cycling leads to 0.9-2.2% BM loss and increased SOsm. Together, these results would suggest some level of dehydration in this population, despite favorable weather conditions. In terms of hydration behaviors, those who completed the race did not show different levels of (dis)agreement when compared to those who did not. Finally, regardless of which distance they competed in, participants displayed a high level of hydration knowledge in the post-race survey. These data suggest that despite high levels of hydration knowledge, and the favorable environmental conditions, dehydration still occurs in gravel cycling. Eleven out of 18 Waffle participants had greater than 2% BM loss, and 7 had greater than 3% BM loss. In the Wafer, however, 7 out of 16 participants lost greater than 1% BM but only 1 participant lost more than 2% of their BM. For the first time, we have estimated fluid losses and fluid and nutrient intake during gravel cycle racing.

Participants in the Wafer and Waffle were significantly more dehydrated following their race compared to pre-race values. No significant differences in hydration were found in participants that raced the Wanna. Our data revealed race distance did not significantly impact hydration response, despite differences in prolonged physical exertion between each races' distances. The Wanna, being the shortest race with the least elevation gain of the Belgian Waffle Ride, likely does not cause a significant depletion of bodily fluids that participants are unable to maintain during the race. Conversely, the longer distances and larger elevation gains in the Wafer and Waffle may cause significant fluid loss that the participants were unable to maintain, despite significantly more fluid intake reported in the longer race distances compared to the shorter race distances. The participants in the Wafer and Waffle races likely had less adequate hydration and nutrition strategies compared to the participants in the Wanna. The longer racing duration of the Wafer and Waffle could lead to more complex management of fluid intake, thus leading to inefficient hydration and nutrition strategies. Overall, this may have caused significant dehydration by the end of the Wafer and Waffle races. It is also likely that the participants in the Wafer and Waffle are more experienced and better-conditioned cyclists. Therefore, these participants may have pushed themselves harder than those in the Wanna, leading to greater sweat loss and reduction in hydration. Alternatively, the Wanna may have more less experienced cyclists who paced themselves more conservatively, thus did not experience as severe physical exertion.

Armstrong et al. (2012) found that recreational cyclists were able to maintain their BM, losing only 0.78kg (0.9%) of their BM following a 164 km race with ambient temperatures over 39 °C (2). This decrease in BM is similar to the average mass lost in the 126km Wafer race (0.83kg, 0.9%); however, the average BM lost was higher in the 206km Waffle race (1.71kg, 2.17%). Another study by Armstrong et al. (2014) measured BM losses of 1.78kg (2.22%) and 2.03kg (2.29%) in recreational cyclists competing in the same 164km bike race when drinking to thirst or drinking *ad libitum*, albeit no differences between the two conditions were observed (3). Mean sweat rate in the present study was 0.62 $L \bullet h^{-1}$, with a range of 0.36 - 0.95 $L \bullet h^{-1}$. This is about half of that observed by Armstrong et al. in hot conditions (1.13 $L \bullet h^{-1}$)(3). Armstrong et al. also reported that ~10% of their cyclists (4/42) lost over 4% of their BM following the race, whereas in the present study, only 1 of our 38 participants (in the Waffle distance) lost more than 4% of their BM (2). About 12% of the cyclists measured in Armstrong et al. (2012) were dehydrated (measured via urine specific gravity, USG) before the race and about 26% were dehydrated after the race (2). Conversely, of the cyclists we measured in the present study, approximately 21% before and 65% after the races were moderately to severely dehydrated (measured via SOsm). There are a few possible reasons for the discrepancy between our results and those of Armstrong et al. (2). First, environmental conditions were significantly different. Second, it is possible that SOsm may have over-estimated dehydration. Given the weak correlation between the change in SOsm and change in BM, this speculation is tempting. However, other common hydration assessments (i.e., USG) have also demonstrated weak relationships with the change in BM and other "gold standard" methods of hydration assessment such as serum or plasma osmolarity (22).

While nutrient intake among professional Tour de France (TdF) cyclists or simulated TdF riding has been previously reported (6,7,9,23), intake among recreational cyclists remains relatively unexplored. During cycling in the heat, Armstrong et al. reported that their female participants consumed between 247 – 1,100 kcals and their male participants consumed 84 – 970 kcals from all sources, with women consuming 2.8 - 6.8 L of fluid and men consuming 1.9 - 10.9 L (2). In another study of male cyclists completing a 210-km race, it was reported that energy intake ranged from 955 – 3,654 kcal with a mean of 2,095 kcal, while fluid intake ranged between 0.28 - 1.17 L•h^{-1}, with a mean total intake of 4.3 liters (14). In comparison, the present study observed a range of energy intake of 0 – 2880 kcals, and fluid consumption ranged from 1.8 L – 5.7 L, with means of 1,321 kcal and 3.3 L. Given the difference in environmental conditions between the studies (both involved warmer conditions than the present study), it is not surprising our participants consumed less fluid. In regard to carbohydrate intake, it was reported that men consumed between 17 – 207 grams (mean = 106 grams) and women consumed between 52 – 243 grams (mean = 116 grams) (2), compared to 0 – 682 grams with a mean of 313 grams in the current study. In another study of male cyclists, carbohydrate intake ranged from 208 – 870 grams with a mean of 445 grams, which is more in line with the present results (14). Sodium intake was higher in the present study, with a range of 0 – 3820 mg, compared to 124 – 2352 mg for men and 413 – 1940 mg for women (2). It should be noted that Armstrong et al. considered all food and fluid intake consumed and compared to our results and those of Havemann and Goedecke, these values seem low. However, hot and humid conditions have been known to negatively affect appetite and energy intake, and this could have influenced the participants' fueling strategies in prior research (17).

Knowledge regarding hydration and fluid intake is important for endurance athletes, given the metabolic demands of endurance exercise and the associated increase in heat production, in addition to water and electrolyte losses via sweating. It has been reported in some studies that endurance athletes have higher hydration and nutrition knowledge than their counterparts in non-endurance sports (15,20). In addition, endurance athletes were reported to have lower prevalence of dehydration as assessed via USG (> 1.020) compared to other university and club sports prior to practice sessions (15). These results contrast with the current study as a larger portion of our sample had SOsm values indicative of dehydration prior to competition (~20.8% vs. ~10%); however, our participants had high levels of hydration knowledge based on the post-race questionnaire results. A separate study examined pre-event hydration status and drinking behaviors in middle-aged adults (32), and data indicated most began the race in a hydrated state on the basis of USG and urine color. Participants who began slightly dehydrated had similar finish times and fluid losses when compared to participants who were slightly hyper-hydrated or euhydrated (32). Interestingly, the authors also found that without personal hydration assessments (such as changes in BM, thirst, or urine color) that the participants in their study tended to use personal experience (trial and error) and exercise performance were primary influences on behavior (32) – which may suggest that while athletes may have a hydration plan

(~87% of athletes in the present study), they can modify it based on their own experiences and current exercise performance.

This study has numerous strengths. First, we conducted a field study which improves ecological validity and the translation of our results to athletes. Second, we had a wide range of participants and ability levels, reflective of the heterogeneity that is gravel cycling. Third, we recruited sufficient participants to permit statistical comparisons between the longer race distances. This study also has some limitations that merit consideration. Foremost, attrition between the consent process and initial survey and pre-race testing was over 60%. Future research should strive to increase retention when data are collected over multiple days. Second, resources for race day analysis were limited and some participants may have elected to skip the data collection line rather than wait. Third, we did not collect data on urine losses between weigh ins, which likely means our estimates of fluid losses and thus sweat rate are underestimated. We also did not collect data on non-fluid energy and nutrient intake. Thus, our energy values and sodium intake are likely underestimated. The MX3 has not been fully validated in the peer-reviewed literature for the assessment of exercise-induced dehydration, and for accurate readings requires participants to abstain from food and drink for 5-10 minutes before testing. This level of standardization was not always possible in the present study, especially at the finish line, and may have influenced the accuracy of our data. We did not collect any other biological fluids for testing such as blood or urine. We lacked the ability to quantify the energy expenditure of the cyclists through power meters, as only a handful of participants had one. Given the limited number of female participants (n = 4), we did not perform any comparisons between sexes. A final limitation was that participants were tested up to 60 minutes before the start of the race, and it is possible they could have consumed food and fluid after testing with the study team that altered their hydration status.

The present study, for the first time, quantified measures of hydration status in response to gravel cycle racing across different distances. Our results show that cyclists competing in a gravel race have a high level of hydration knowledge, but that they can still experience dehydration. In the longest race distance, despite the fastest average speed, 61% of participants had greater than 2% BM loss. This suggests that during longer cycling races, participants should consume additional fluid to offset the potential negative consequences of dehydration. Future research into gravel cycling should include collection of dietary data, power data, and additional biological specimens to capture a more holistic picture of the demands of this new form of sport.

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