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Gastrointestinal Implications of Post-Exercise Orange Juice Consumption

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Abstract

100% fruit juice (e.g., orange juice [OJ]) in 237 mL doses is considered 1 serving of fruit and generally recommended as a part of a healthy diet. Similar to commercially available sports drinks, 100% OJ contains water and electrolytes, but OJ has twice the amount of carbohydrates and is less acidic. 100% OJ could be a viable beverage after physical activity to promote rehydration and substrate replenishment, but the effects on gastrointestinal (GI) distress are not completely clear. Therefore, the purpose of this study was to compare 100% OJ to a more commonly consumed commercially available carbohydrate electrolyte beverage (CHO-E) and water after cycling in a thermal environment. Twenty-six participants (22.1 ± 3.3 yrs; 72.9 ± 10.0 kg; 174.3 ± 7.9 cm) were included in this randomized, controlled, single-blind parallel group design. Participants cycled for 80 min in a thermal environment at a heart rate matched to 70% VO2max on 5 consecutive days. After each cycling session, participants consumed 237 mL of either OJ, CHO-E, or water. Participants then rested 1 h in an ambient environment. No significant differences occurred post-beverage ingestion between conditions for GI distress symptoms. At 1 h post-beverage consumption, the incidence of serious systemic GI distress symptoms (e.g., headache, urge to urinate) occurred 1.9% in water, 0.6% in CHO-E and 0% for OJ. Hydration, thirst, and palatability were also not significantly different between groups. Rehydration and substrate replenishment is important for recovery after prolonged and/or intense endurance exercise. Based on similar palatability, thirst-quenching, and GI distress scores compared to CHO-E and water, the results of this study suggest consuming 100% OJ could be a viable beverage option after exercise.

Keywords: Gastrointestinal; Exercise; Fluid Intake; Rehydration; Carbohydrate-Electrolyte Beverage

Introduction

Hydration should be prioritized following intense endurance exercise in order to maintain health and prevent potential decrements, such as compromised cardiovascular and thermoregulatory function, during the next activity session [1-5]. While water is a viable rehydration beverage, carbohydrate-electrolyte beverages (CHO-E) are promoted as a superior option [6,7] and are regularly consumed after exercise. The 6-8% carbohydrate content of CHO-E promotes muscle glycogen replenishment and fluid retention while the water and electrolyte (i.e., sodium, potassium) content helps to restore plasma volume [8,9]. Beyond physical performance and hydration maintenance, CHO-E health benefits are limited.

Conversely, 100% fruit juice (e.g., orange [OJ], apple) consumption is associated with additional health benefits beyond basic nutritional value. The combined presence of vitamin C, flavonoids (e.g., hesperitin), folate, and other vitamins and minerals found in 100% fruit juices has been shown to decrease diastolic blood pressure, cardiovascular disease risk, and improve cholesterol [10-13]. However, these health benefits are primarily shown in sedentary or diseased populations [14-17], and there is limited research regarding fruit juice's beneficial effects before, during, or after exercise. Comparison is also difficult as studies promoting the benefits of fruit juice vary in composition, type of fruit juice, serving amounts, and origin of the product. Additionally, little examination has been done using repeated doses of the daily recommended 237 mL of fruit juice [18].

Based on the water, electrolyte, and carbohydrate composition, 100% OJ may serve as an alternative rehydration beverage after exercise. The nutritional profile of 100% OJ is enhanced due to the vitamin C presence, a known antioxidant. 100% OJ also contains double the carbohydrates than a typical CHO-E, potentially enhancing the post-exercise recovery process through greater muscle glycogen replenishment. Finally, 100% fruit juice is a relatively affordable option that may be easier to access than commercial CHO-E. Despite the potential benefits, there are concerns for drinking 100% fruit juice after exercise. The higher carbohydrate content could lead to greater gastrointestinal (GI) discomfort (e.g., nausea, diarrhea) following consumption [19-22]. Anecdotally, 100% OJ is commonly avoided as a post-exercise beverage due to the acidity; however, 100% OJ is actually less acidic than commercially available CHO-E [23]. Still, OJ's taste may provide a palatable option that encourages individuals to increase voluntary fluid intake [9,24,25], promoting full rehydration prior to the next exercise bout. The primary purpose of this study was to examine perceived GI distress symptoms in individuals who consumed the daily recommended 237 mL of 100% OJ after cycling in a mild, thermal environment over 5 consecutive days. Additional measures included urinary hydration, plasma electrolytes, and palatability and thirst. It was hypothesized that OJ would cause greater GI distress symptoms than water and CHO-E. It was also hypothesized that OJ would provide a more palatable option yet be similar to CHO-E and better than water in maintaining euhydration and electrolyte balance and decreasing thirst.

Materials and Methods

Study Design

Using a randomized, controlled, single blind, parallel group design, participants were randomly assigned to one of three groups: OJ (100% OJ, Florida Department of Citrus, Bartow, FL), commercially available orange flavored water (Nestlé Splash Mandarin Orange, Nestlé Waters North America, Stamford, CT), or commercially available orange flavored CHO-E (Powerade Orange, The Coca-Cola Company, Atlanta, GA). Upon meeting all eligibility criteria, participants were randomly assigned to a beverage group using a randomized order list created in excel. One researcher was responsible for assigning subjects to the condition. Participants consumed their assigned beverage on the 5 consecutive exercise days. Beverages were stored in a refrigerator at 1.4 °C. The beverages were removed from the refrigerator when a participant completed the exercise session. Participants had 10 minutes to drink the entire beverage. All beverages were placed in opaque bottles to blind participants to their condition.

Participants

To be included in the study, participants were required to be free of cardiovascular, respiratory, metabolic, musculoskeletal, fluid, electrolyte balance, GI and swallowing disorders. Participants were also required to be moderately endurance trained (> 3 aerobic exercise sessions for a minimum of 30 min per week). To ensure participants met the criteria for moderately trained; they completed a graded exercise test to determine aerobic capacity or peak oxygen uptake ($\dot{V}O_2max$). Males had to obtain > 40 mL/kg/min and females > 38 mL/min/kg. A one-way, non-rebreathing respiratory valve and a nose clip were utilized to collect expired oxygen and carbon dioxide. A Parvo Medics' True One 2400 was used to determine respiratory exchange ratio and oxygen consumption ($\dot{V}O_2$) values every 30 seconds. VO_2max was determined when subjects attained a respiratory exchange ratio value > 1.10 and/or a $\dot{V}O_2$ increase from the previous exercise intensity of < 0.2 L/min.

To minimize influences of diet, medications, and other supplements on the main outcome measures, participants were instructed to discontinue use of non-steroidal anti-inflammatory drugs, vitamin C or citrus fruits, supplements and/or beverages containing citrus or vitamin C, and to refrain from intense, vigorous exercise for a minimum of 24 hours prior to and during the course of data collection. Participant compliance was monitored through dietary and physical activity logs (MyFitnessPal, Inc.) for the duration of the study. Female participants were scheduled during the follicular phase of their menstrual cycle to limit variances in hormones and body temperature. This protocol was approved by the Human Research Protection Program at the University of Kansas. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

Perceptual Measures

Gastrointestinal distress was assessed using a symptom questionnaire adopted from previous research [26,27]. The index is divided into 3 sections: 1) upper abdominal problems (heart burn, reflux, belching, bloating, stomach pain/cramping, nausea, vomiting); 2) lower abdominal problems (intestinal/lower abdominal pain/cramping, flatulence, urge to defecate, side aches/stitch, loose stool, diarrhea); and 3) systemic problems (dizziness, headache, muscle cramps, urge to urinate) [27]. Symptoms are scored on a 10-point scale (0 = no problems at all and 9 = the worst it has ever been). A score of > 4 is considered "serious" [26]. Questionnaires were administered pre-, post-, and 1 h post-exercise.

Palatability was measured using a 9-point scale with verbal anchors ranging from 1 (dislike extremely) to 5 (neither like nor dislike) to 9 (like extremely). Categories included: overall beverage, flavor, sweetness, saltiness, and tartness. Palatability was measured post-beverage consumption immediately following exercise.

Perceived thirst was measured using a 9-point thirst scale, with verbal anchors ranging from 1 (not thirsty at all) to 5 (moderately thirsty) to 9 (very, very thirsty). Participants were asked to rate their thirst pre-, 15-min after beverage ingestion and finally at the end of the 1 h of rest.

Physiological Measures

Hydration status was characterized by Usg, Uvol, and change in body mass. Urine samples were collected pre-, post-, and 1 h post-cycling. Usg was measured using a clinical refractometer (model REF 312, Atago Company Ltd., Tokyo, Japan). All urine following the pre-exercise weight measurement was collected into Uvol containers and urine cups (for Usg measurements) until the final urine collection at 1 h post-exercise. Total Uvol produced over a trial was measured using a graduated cylinder. Pre-, post-, and 1 h post-exercise body mass was measured using a digital scale (model 2084, Toledo Scale, Toledo, Ohio). Total Fvol consumed during the 1 h recovery was measured with a graduated cylinder and recorded. To ensure participants were not overconsuming fluids, potentially increasing GI discomfort, sweat rate was calculated and compared to Fvol.

To further characterize hydration status, blood was collected from the antecubital vein into a 6 mL lithium heparin vacutainer tube at pre-, post-, and 1 h post-cycling to measure plasma osmolality (Posm) and electrolytes. At each time point, tubes were inverted several times to mix, centrifuged at 3000 rpm for 15 min, plasma pipetted into microtubes, and stored at -20 °C until analysis. Plasma sodium (PNa^+), chloride (PCl^-), and potassium (PK^+) were assessed using ion-selective electrodes (EasyLyte® Na/K/Cl electrolyte analyzer, Medica, Bedford, MA). Normative values were defined as follows: PNa^+ > 135 mmol/L [28], PCl^- 98-107 mmol/L, and PK^+ 3.5-5.3 mmol/L [29].

To ensure participants remained at safe cardiovascular limits and to maintain the target heart rate (HR) during the exercise protocol, participants wore a HR monitor (Polar Electro Inc., Lake Success, NY) around their chest. Rectal temperature (Doric 450 Series Digital Thermometer, VAS Engineering, Inc., San Diego, CA) was also monitored throughout exercise to ensure all participants remained at safe limits (<40 °C).

Experimental Protocol

All experimental trials were completed over 5 consecutive days and within 1 h of the participants' day 1 visit. Participants arrived daily at the laboratory in shorts and a t-shirt. Prior to beginning data collection, participants had to be euhydrated (Usg < 1.020). If participants were hypohydrated they were provided water in 500 mL increments until euhydration. Once euhydration was verified, participants then weighed, had baseline HR and Tc recorded, completed a perceived GI distress survey, and provided a blood sample.

Participants were then taken to a mild, thermal environment (30.1 ± 0.2 °C and 51.6 ± 4.0% relative humidity) to complete an 80-minute cycling protocol on a stationary bike (Monark Ergomedic 818e, Monark™, Varberg, Sweden). Prior to a 2.5 min warm-up, participants were provided a target HR equivalent to 70% of the participant's $\dot{V}O_2$max. Participants maintained the target HR for 4-15 min intervals with 3-5 min recovery intervals in between. The protocol concluded with a 2.5 min cool down. At the end of each 15 min interval HR and Tc were recorded. To maintain hydration during exercise, participants were instructed to drink 1.5 mL/kg of water following the end of each 15 min interval.

Post-cycling, participants returned to the laboratory to provide a urine and blood sample, weigh, and HR and Tc were recorded. Participants then completed the GI distress questionnaire and their perceived level of thirst. Within 5 minutes of completing the cycling protocol, participants were given 237 mL of their assigned beverage and instructed to consume all fluid within 10 min. Immediately post-beverage ingestion, subjects then completed a palatability survey. Participants rested in a seated position for 1 h. At 15 min post-beverage ingestion participants rated their perceived level of thirst. Participants were allowed to drink water ad libitum with Fvol recorded. At the conclusion of the 1 h, final urine and blood collection, HR, Tc, perceived level of thirst, GI distress questionnaire, and weight were recorded.

Statistical Analysis

IBM SPSS Statistics (version XXII; IBM Corporation, Armonk, NY) was used for all analyses. Significance was set at $\alpha < 0.05$. Post-hoc power analysis indicated a statistical power of 0.80. Descriptive statistics (mean ± standard deviations [SD]) for all dependent variables were calculated. Demographical differences were assessed using a one-way ANOVA. Data were collapsed across the 5 consecutive days of exercise and averaged for each time point (pre-, post-, 1 h post-cycling) by condition (OJ, water, CHO-E).

Frequency and maximum scores were determined for each GI symptom. Friedman's ANOVA identified differences in GI symptoms between and within conditions. Questions were sectioned into upper, lower, and systemic GI symptoms to reduce multiplicity; responses were averaged and analyzed. Post-hoc analysis was conducted using pairwise comparisons with Bonferroni corrections. Overall incidence (pre-, post-, 1 h post-) for each symptom was determined by the absolute number of incidences of a symptom occurring at any time point and reported as a percentage by condition. Maximum scores were reported as the maximum score reported for that individual symptom. Chi square analysis determined differences in the % incidence of symptoms and differences in percent of symptoms scored > 4 (considered "serious") between conditions across time. Percent serious was calculated as the number of sessions with a score > 4 out of the total number of sessions at that time point.

Three (beverage) x 3 (time) repeated measures ANOVAs determined changes in thirst scores, Usg, HR, and plasma measures. One-way ANOVAs determined changes in Uvol (exercise and 1 h), Fvol (1 h), and palatability scores (overall, flavor, sweetness, saltiness, and tartness) between beverages. Three (beverage) x 6 (time) repeated measures ANOVA determined changes in Tc. Sphericity was violated for Tc, Usg, HR, thirst, and palatability; therefore, Greenhouse-Geisser corrections were used when reporting significant main effects or interactions. Post-hoc analysis was performed for significant main effects using pairwise comparison or one-way ANOVAs with Bonferroni corrections for multiple comparisons.

Results

Participants

	Overall (N = 26)	CHO-E (n = 9, 6 M, 3 F)	Water (n = 8, 7 M, 1 F)	OJ (n = 9, 7 M, 2 F)	P-Value
Age (yrs)	22.1 ± 3.3	23.1 ± 4.0	21.4 ± 1.9	21.7 ± 3.5	.514
Weight (kg)	72.9 ± 10.0	74.9 ± 11.0	73.0 ± 11.6	70.8 ± 8.0	.706
Height (cm)	174.3 ± 7.9	174.1 ± 7.9	175.0 ± 10.2	173.7 ± 6.3	.946
$\dot{V}O_2$max (mL/kg/min)	48.8 ± 7.3	48.2 ± 8.3	47.2 ± 6.8	50.8 ± 7.2	.592
Sweat rate (L/h)	0.5 ± 0.3	0.5 ± 0.3	0.5 ± 0.3	0.5 ± 0.2	.981
Calories (kcal)	2067.8 ± 584.5	1911.0 ± 522.9	2080.0 ± 798.6	2213.7 ± 429.2	.565

No significant difference between conditions.

List of abbreviations: CHO-E: Carbohydrate-Electrolyte Beverage; F: Female; M: Male; OJ: Orange Juice

Table 1: Participant demographics

Thirty-five participants began the study. Two participants were withdrawn by the researchers for missing data collection days, 4 withdrew due to the intensity of the study, and 3 withdrew due to personal reasons. A total of 26 (20 male, 6 female; male $\dot{V}O_2$ max = 50.0 ± 7.0 mL/min/kg, female $\dot{V}O_2$max = 44.6 ± 7.5 mL/min/kg for females) non-heat acclimatized, moderately endurance trained participants completed the study (Table 1). Females had significantly lower height (p = .006), weight (p = .002), and sweat rates (p = .010) compared to males. Dietary log analysis showed no significant differences between conditions for calories (Table 1) or macronutrients and verified no vitamin C, citrus fruit, or citrus beverage intake. Physical activity logs verified all participants avoided moderate to vigorous activity 24 hours prior to data collection.

Perceptual Measures

Table 2 shows overall incidence of each symptom occurring and the maximum score (aggregated from pre-, post-, and 1 h post-cycling) reported by beverage condition for each GI distress symptom. Urge to urinate was the most frequent systemic symptom reported across all beverage

Symptom	Water		CHO-E		OJ	
	Max	**Incidence**	**Max**	**Incidence**	**Max**	**Incidence**
Upper						
Reflux/Heartburn	-	-	-	-	4	3.7%*
Belching	4	6.7%†	-	-	1	5.2%
Bloating	2	3.3%	3	11.7%‡	2	3.0%
Stomach pain	1	1.7%	1	0.8%	1	2.2%
Vomiting	-	-	-	-	1	0.7%
Nausea	1	3.3.%	-	-	2	6.7%§
Lower						
Intestinal cramps	-	-	4	0.8%	-	-
Flatulence	2	3.3%	3	9.2%	2	4.4%
Urge to defecate	3	8.3%	4	6.7%	3	6.7%
Left abdominal pain/stitch	1	0.8%	-	-	1	0.7%
Right abdominal pain/stitch	1	0.8%	-	-	2	0.7%
Loose stool	-	-	-	-	1	0.7%
Diarrhea	-	-	-	-	-	-
Systemic						
Dizziness	3	3.3%	2	1.7%	5	15.6%‖
Headache	1	3.3%	7	6.7%	3	23.0%¶
Muscle cramps	1	6.7%	3	5.0%	3	10.4%
Urge to urinate	7	17.5%	8	19.2%	8	16.3%

Note: Scores > 4 are considered "serious". Overall incidence was determined by the absolute number of incidences of a symptom occurring at any time point and reported as a percentage. Max is the maximum score reported for that symptom.

*OJ significantly higher incidence than water and CHO-E (X^2(2, n=375) = 9.009, p = 0.011).

†Water significantly higher incidence than OJ and CHO-E (X^2(2, n=375) = 78.716, p = 0.021).

‡CHO-E significantly higher incidence than water and OJ (X^2(2, n=375) = 10.765, p = 0.005).

§OJ significantly higher incidence than CHO-E and water (X^2(2, n=375) = 8.447, p = 0.015).

‖OJ significantly higher incidence than CHO-E and water (X^2(2, n=375) = 22.290, p < 0.001).

¶OJ significantly higher incidence than CHO-E and water (X^2(2, n=375) = 28.118, p < 0.001).

List of abbreviations: CHO-E: Carbohydrate-Electrolyte Beverage; OJ: Orange Juice

Table 2: Overall incidence (pre-, post, and 1 h post-cycling) of reported GI distress symptom scores by beverage condition

Condition	Upper			Lower			Systemic		
	Max	Mean ± SD	Serious	Max	Mean ± SD	Serious	Max	Mean ± SD	Serious
Water									
Pre	4	0.07 ± 0.36	0%	3	0.06 ± 0.33	0%	7	0.10 ± 0.64	0.6%
Post	2	0.01 ± 0.14	0%	1	0.01 ± 0.12	0%	6	0.16 ± 0.66	0.6%
1 h post	4	0.04 ± 0.32	0%	1	0.00 ± 0.06	0%	7	0.20 ± 0.91	1.9%
CHO-E									
Pre	3	0.05 ± 0.30	0%	2	0.02 ± 0.18	0%	7	0.11 ± 0.64	0.6%
Post	2	0.30 ± 0.20	0%	4	0.07 ± 0.44	0%	4	0.20 ± 0.72	0%
1 h post	2	0.02 ± 0.19	0%	4	0.06 ± 0.38	0%	8	0.24 ± 0.94	0.6%
OJ									
Pre	4	0.09 ± 0.40	0%	2	0.04 ± 0.26	0%	3	0.18 ± 0.52	0%
Post	2	0.04 ± 0.21	0%	3	0.03 ± 0.21	0%	8	0.42 ± 1.14	1.7%*
1 h post	1	0.02 ± 0.14	0%	3	0.01 ± 0.18	0%	3	0.23 ± 0.61	0%

Note: Percent serious calculated as the number of sessions with a score > 4 out of the total number of sessions at that time point
*Post-exercise, OJ reported significantly greater serious symptoms than water and CHO-E ($X^2(2, n=480) = 6.034$, $p = 0.049$)
Table 3: Mean, maximum, and serious gastrointestinal symptom scores for experimental conditions pre-, post- and 1 h post-cycling

conditions. OJ reported significantly greater incidence overall for reflux/belching, nausea, dizziness and headache, while water reported greater incidence for belching and CHO-E greater bloating incidence (Table 2). Further analysis for each individual symptoms reported as serious showed no significant differences between conditions at any time point. Mean, maximum, and percent serious aggregated upper, lower, and systemic GI symptom scores for each beverage condition across each time point are presented in Table 3. Post-exercise (before beverage consumption) systemic symptoms were reported significantly greater in the OJ group, compared to water and CHO-E ($X^2(2, n=480) = 6.034$, $p = 0.049$, Table 3). Although not significant, the overall percent serious systemic symptoms reported for water was greater than CHO-E and OJ.

There were no significant beverage interactions for palatability or thirst scores. Mean palatability scores ranged from 5.9 (6 = like slightly) to 7.5 (8 = like very much) and are presented in supplemental Figure 1a. Thirst significantly decreased at every time point from pre- (4.6 ± 2.2) to 1 h post-cycling (2.6 ± 1.4, 95% CI 1.03 to 2.84, $p < 0.001$). Thirst scores for each beverage condition are presented in supplemental Figure 1b.

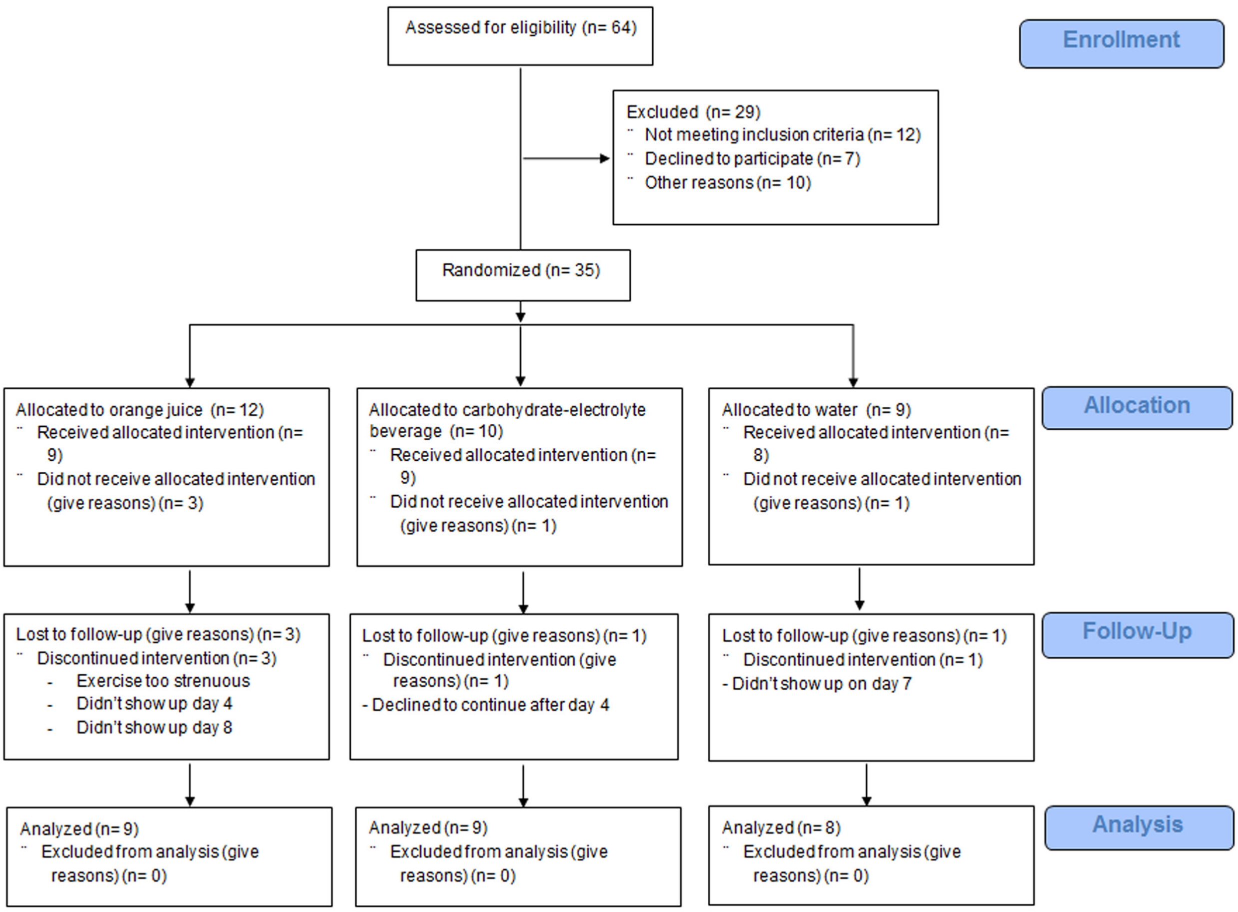

Figure 1: CONSORT flow diagram

Physiological Measures

Table 4 provides hydration and plasma electrolyte measures overall and for each beverage condition over time. Due to invalid Posm measures during analysis, this data is not presented. There were no significant beverage interactions for any measure. All participants began activity euhydrated and, although Usg significantly increased after cycling to the 1 h post-cycling ($F(1.4, 33.2) = 4.0$, $p = 0.039$), participants maintained a euhydrated status (Table 4). PCl^- significantly decreased from post- to 1 h post-cycling ($F(2, 36) = 3.6$, $p = 0.036$) while PK^+ was significantly lower pre-cycling than post- and 1 h post-cycling ($F(2, 46) = 38.9$, $p < 0.001$).

	Overall	Water	CHO-E	OJ
Usg				
Pre	1.011 ± 0.005	1.011 ± 0.002	1.010 ± 0.005	1.010 ± 0.006
Post	1.009 ± 0.005	1.009 ± 0.003	1.007 ± 0.005	1.012 ± 0.006
1 h	1.013 ± 0.005*	1.012 ± 0.003	1.011 ± 0.006	1.016 ± 0.004
PNa^+ (mmol/L)				
Pre	134.32 ± 2.80	134.69 ± 2.04	133.61 ± 3.24	134.69 ± 3.08
Post	134.95 ± 3.89	135.72 ± 4.37	133.93 ± 3.13	135.27 ± 4.35
1 h	133.71 ± 4.47	132.94 ± 3.70	134.94 ± 2.88	133.16 ± 6.28
PK^+ (mmol/L)				
Pre	3.91 ± 0.18†	3.93 ± 0.26	3.82 ± 0.10	4.00 ± 0.10
Post	4.17 ± 0.18	4.18 ± 0.20	4.05 ± 0.10	4.28 ± 0.16
1 h	4.17 ± 0.23	4.27 ± 0.20	3.99 ± 0.13	4.26 ± 0.24
PCl^- (mmol/L)				
Pre	101.20 ± 2.11	101.30 ± 1.59	100.96 ± 2.88	101.36 ± 1.97
Post	101.48 ± 1.66	100.99 ± 1.79	101.08 ± 1.48	102.36 ± 1.57
1 h	100.34 ± 1.99‡	100.13 ± 1.68	100.60 ± 1.44	100.30 ± 2.86

Note: Overall mean reflects the results for all subjects combined. Pre-, post-, and 1 h means were collapsed across the 5 consecutive days and averaged for each time point.
List of abbreviations: CHO-E: Carbohydrate-Electrolyte Beverage; OJ: Orange Juice; PCl^-: Plasma Chloride; PK^+: Plasma Potassium; PNa^+: Plasma Sodium; Usg: Urine Specific Gravity
*Significantly higher than post (95% CI 0.001 to 0.005, $p < 0.001$)
†Significantly lower than post (95% CI -0.32 to -0.20, $p < 0.001$) and 1 h (95% CI -0.34 to -0.18, $p < 0.001$)
‡Significantly lower than post (95% CI 0.40 to 1.87, $p = 0.004$).
Table 4: Pre-, post-, and 1 h post-cycling hydration and electrolyte measures overall and for each beverage condition (M ± SD)

There were no significant differences for Fvol or Uvol between conditions. Mean Fvol during 1 h rest = 0.5 ± 0.2 L and mean Uvol = 0.5 ± 0.2 L. Fvol during exercise was not significantly different than mean sweat rate (Table 1). When corrected for body mass, there were no significant differences in Fvol between sex or beverage conditions either during exercise or the 1 h rest.

There were no significant beverage interactions for HR or Tc. Post-exercise HR (141 ± 2 bpm) was significantly higher than pre (76 ± 2 bpm, 95% CI 71.11 to 58.97, $p < 0.001$) and 1 h (76 ± 2 bpm, 95% CI 60.64 to 69.63, $p < 0.001$). Post-Tc (37.6 ± 0.1 °C) was significantly greater than pre- (36.7 ± 0.1 °C, 95% CI 0.69 to 0.98, $p < 0.001$) and 1 h (36.9 ± 0.0 °C, 95% CI 0.24 to 0.88, $p < 0.001$).

Discussion

This study sought to examine the effects of 100% OJ on perceived GI distress symptoms throughout 5 consecutive days of moderate cycling in a thermal environment. We hypothesized that consuming OJ after exercise would increase GI distress symptoms due to the higher carbohydrate content and acidity. However, our results yielded no significant differences between beverage types for GI symptoms after beverage consumption. Further, we found no significant differences when examining hydration, electrolyte, thirst and palatability measures, suggesting 100% OJ is a viable post-exercise rehydration strategy.

Gastrointestinal symptomology varies amongst individuals, with various intrinsic (e.g., hydration status) and extrinsic variables (e.g., environment) exacerbating GI distress. As exercise begins, blood is redirected from the GI tract to prioritize cardiovascular, thermoregulatory, and metabolic function. The GI tract is vital to maintaining fluid balance by providing nutrient and water delivery and controlling motility. Gastric emptying, the regulatory process responsible for controlling the rate of fluid and nutrient absorption, can be slowed by compromised physiological function and/or by the type of beverages consumed. For instance, exercising in a hypohydrated state compromises skin blood flow and sweat rate, which can further decrease GI blood flow and lead to an increased rate of Tc rise and GI distress. Some symptoms, such as diarrhea (i.e., unrestricted gastric emptying) or vomiting, cause additional fluid and nutrient losses beyond those typically experienced during exercise and can negate the hydrating capability of a beverage. Consequently, beverage composition is extremely important to physically active individuals in order to replenish fluid losses and prevent GI distress.

When a beverage's carbohydrate content increases above 8%, gastric emptying is delayed and greater GI distress symptoms occur [19-22]. Increasing carbohydrate content has also been shown to decrease water and electrolyte absorption rate, impeding fluid restoration [20,21]. The OJ used in the present study was 12% carbohydrate and the CHO-E was 6%; therefore, we speculated that GI symptoms would increase with OJ consumption (supplemental table 1). The other concern for consuming OJ is an assumed higher acidity, as increased acidity in a beverage may promote GI distress [30]. While the acidity of the OJ used in this study was not directly measured, according to the American Dental Association and contrary to popular belief, 100% OJ is less acidic than commercially available CHO-E [23]. The reported perceived GI distress between conditions was not significantly different. While overall systemic symptoms were reported significantly greater in the OJ group post-exercise, this was prior to beverage consumption. Further, when analyzing individual symptoms (e.g., bloating) by condition, OJ was no longer significantly greater. Our results suggest 100% OJ did not result in greater GI distress, as hypothesized, and could be a viable post-exercise beverage option.

Because of the GI tract's vital role in water and nutrient absorption and in order to assess other factors that could induce GI distress, the secondary study aim was to examine a number of hydration measures. No differences were found between beverages for Usg. Importantly, Fvol was similar to the sweat rates, indicating that subjects were not overconsuming fluids that would increase GI discomfort. Regarding electrolytes, limited research is conflicting as to whether the addition of either potassium or sodium similarly rehydrates individuals [31-33], and whether sodium is the superior cation for rehydration [6,34,35]. The OJ in this study contained 443 mg of potassium and 5 mg of sodium, while the CHO-E had 100 mg of sodium and 24 mg of potassium, allowing comparison of a high potassium to a higher sodium beverage. Our results showed no significant differences between beverages for PNa^+, PK^+, or PCl^-. Additionally, the similar hydration status and lack of difference in Uvol suggests similar fluid replacement properties between the beverages used in this study and no indication of increased diuresis with the increased amount of potassium [36].

Regardless of a beverage's physiological benefits, a person's beverage choice differs based on factors such as beverage temperature, flavor, availability, and texture [25,37-39]. Providing a beverage that is appealing is important in increasing ad libitum fluid consumption [24,25,37], particularly post-exercise, in order to replace fluid and electrolyte losses and ensure euhydration prior to the next exercise session. Palatability is often used to assess the acceptability or "liking" of a beverage and is typically evaluated using a category scale where participants rate their pleasure for the beverage's sweetness, tartness, saltiness, and flavor. The more palatable a beverage the more likely a person will voluntarily consume the fluid during exercise [40]. Despite the clear differences in the composition of OJ compared to water or the CHO-E, palatability was rated relatively similar and thirst decreased similarly for all beverages. Although palatability and perceived thirst are subjective, the overall beverage liking suggests OJ could be another option for post-exercise rehydration, especially for those who prefer not to drink CHO-E or plain water.

Although the findings of the present study provide some novel insight for post-exercise 100% OJ consumption, there are some important contexts and limitations to acknowledge. It is well established excess potassium has serious consequences on cardiovascular function [41-43]. Therefore, consuming a high potassium beverage may be a concern for some individuals. Plasma K^+ remained within normal limits for all beverage conditions and there were no significant differences for any of the cardiovascular measures, indicating no cardiovascular compromise. Another potential consideration is regarding the participants' PNa^+ values, which were clinically indicative of hyponatremia (< 135 mmol/L). Low PNa^+ was likely the result of requiring participants to arrive euhydrated and maintain euhydration throughout the exercise protocol. No subjects presented with signs and symptoms consistent with hyponatremia, as all participants completed the entire protocol without complications or medical adverse events. A more accurate indication of hydration (e.g., Posm) would have also been beneficial, unfortunately too many invalid measures led to an inability to appropriately assess Posm variance between conditions. Because exercise intensity and environmental strain also impact GI distress, we controlled all participants to exercise at the same relative intensity and environmental strain. However, the cycling protocol utilized an intensity matched to 70% of the subject's HR during the qualifying VO_2max from an ambient environment. Subjects were non-heat-acclimatized and the cycling occurred in a thermal environment, leading to increased cardiovascular strain. A subsequent decrease in the wattage was needed in order to maintain the target HR goal, resulting in participants working below the 70% VO_2max wattage in order to maintain HR. At this given workload we did not find beverage differences, but beverage affects may be different if participants worked at higher intensities that induced greater sweat rates and Tc. Gastrointestinal symptoms were likely mitigated by using cycling and euhydrated participants. Perceived GI distress is more apparent in hypohydrated individuals [44,45] and when doing more intense exercise, such as running [46,47]. Despite the intended blinding, subjects potentially knew which beverage they consumed based on different fluid compositions and textures. While subjects were not formally asked, anecdotally several subjects made comments regarding which group they were in and assumed incorrectly (e.g., they thought they were in OJ when they were in water).

Future research should examine the effects of 100% OJ in individuals who begin exercise hypohydrated and maintain hypohydration during exercise. Research is also warranted on different exercise modes (e.g., running), intensities, lengths, in different environments (e.g. moderate to severe thermal strain), and in various populations (e.g., military, recreationally active). Ingesting 100% OJ should be examined as a potential hydration beverage before and during activity to determine GI distress implications, palatability, thirst perceptions, and changes in fluid-electrolyte balance. Additionally, many studies examining the benefits of fruit juice typically use a higher dose than 237 mL [10,14,15,17]. Therefore, one unique aspect of this study is that it utilized the recommended daily dose of 100% OJ and future studies should continue examining this recommendation. Lastly, due to the carbohydrate content, examining 100% OJ ingestion on glycogen replacement during and after exercise is also warranted.

Conclusion

The present study demonstrates that a single serving of 100% OJ provides a palatable, thirst quenching option that will not induce GI distress. Moreover, all participants maintained euhydration throughout the protocol and no additional diuresis was noted with the increased K^+ in OJ. Consuming the daily recommended 237 mL of OJ is a viable rehydration beverage that will not induce GI distress after moderate-intense cycling when individuals start exercise euhydrated and consume fluids regularly throughout.

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Conflict of Interest

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Supplemental Materials

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