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Comparison of Oral Rehydration Drinks on Physical Performance in United States Military Personnel

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14. ABSTRACT
Exertional heat stress is a serious condition, which continues to be prevalent among active duty members, especially those operating in hot and humid climates such as flight maintainers, flight crew, loadmasters and Special Operations Forces during Sustained Operations Missions (SUSOPS).Even mild levels of dehydration have the potential to cause significant neuromuscular and physiological strain. Water alone may not be sufficient in maintaining physical performance >60 minutes, or preventing dehydration, compared to drinks containing electrolytes and carbohydrates. Therefore, the primary aim of this study was to measure the effects of various oral rehydration drinks on physical performance in highly fit military personnel during a 10-mile run in a normothermic environment.

Consistent with previous investigations, future research may include testing a larger sample size in a thermal chamber where environmental conditions are better controlled.

Additionally, this study may benefit from adding more subjects and controlling pre-exercise hydration, as well as decreasing the volume of fluid consumed.

15. SUBJECT TERMS
Oral rehydration drinks, heat illness, physical performance, military personnel, special forces

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1.0 SUMMARY

This study was conducted in response to the high prevalence of heat illness among military personnel operating in high heat environments. The Defense Medical Surveillance System records and tracks both ambulatory and hospitalization visits of active duty serving in all branches of the military. The report cited an estimated 720 incidents of heat related injuries of personnel serving in Afghanistan and Iraq, and 6.9% of these diagnoses were for heat-related injuries.[1,] In addition, an estimated 1,953 cases of "other heat-related injuries" were cited in 2015 for all Service members.[1] Of particular concern for military operating in tropical climates is to microhydrate during activity. Microhydrating during activity can mitigate a > 2% bodyweight loss, which may result in dehydration ultimately impeding physical performance.[2] Therefore, the primary aim of this study was to determine the effects of military approved oral rehydration solutions (ORS) in highly fit military personnel while performing a 10-mile run in a normathermic laboratory environment. The ORS tested were Gatorade (G) and CeraSport (CS), with water used as the control. Each subject served as his or her own control.

The Independent variable(s) for this study were the ORS. The dependent variables included (1) Exercise Heart Rate (HR);(2) Ratings of Perceived Exertion (RPE); (3) Hematocrit (Hc); (4) Hemaglobin(Hg) (5) Blood Glucose (BG); (6) Blood Lactate (BLa); and (7) Tympanic Temperature (TT), total urinary output and body weight change. Data were recorded before, after, and every 20 minutes throughout the exercise period. The null hypothesis was that there would be no statistically significant differences in the markers measured during a 10-mile run in healthy fit military personnel.

Results of this study indicate that no statistical difference occurred in the hydration biomarkers, probably due to the large volume (1500 mL) of fluid consumed. While no significant differences in BG were detected between G and CS, both CS and G values were significantly higher than water ($p<0.05$) throughout the study. Additionally blood lactate conentrations [BLa] were lower during the last 40 minutes of the study when CS was consumed in comparison to G, approaching significance ($p=0.09$) at Time 7 (T7).

2.0 INTRODUCTION

The physical performance and neuromuscular function of military personnel operating in hot and humid climates during training evolutions or in the battlefield can impede mission success. Exertional Heat Illness (EHI) continues to be prevalent and can arise through a combination of exercise-induced metabolic heat production, environmental conditions (heat, humidity), and the wearing of Personal Protective Equipment (PPE) that impairs evaporative heat transfer. In particular, the wearing of PPE by military personnel during both training and in battle may result in a reduced vapor gradient between the skin and the environment, reducing the rate of evaporative heat dissipation.[3] For example, in specific Military Occupational Specialties (MOS) such as fighter pilots, flight maintainers, and Special Operations Forces PPE is required. For example, subjects' sweat typically drips from the body and becomes trapped within the fabric fibers of the overlying PPE, further resulting in significant reductions in the capacity to remove heat storage that builds up while operating in hot and humid climates.

From a physiological and neuromuscular perspective, impairment in physical performance due to operating in high heat environments may result in systemic insufficiency of the oxidative energy system. Additionally, the competition for blood flow to active skeletal muscles and skin for conductive heat exchange accompanied by significant loss of plasma volume through sweating results in significant dehydration. Concurrently, the smooth muscle within skin blood vessels dilates, increasing blood flow to the skin. Exertional heat illness (EHI) may set in even when military personnel are performing simple tasks in hot and humid climates. For example, the contraction of skeletal muscles alone while performing routine tasks (e.g., flight maintainers, loadmasters) may increase heat production up to 20 times that produced at rest and in wet bulb globe temperatures (WBGT)+ as low as 65° Fahrenheit (F).[4]

Exertional heat illness (EHI) remains elusive to detect or mitigate, especially in active duty personnel who are required to operate in tropical climates. Therefore, maintaining energy, performance and hydration is critical. For example, when a Service member suffers from a heat-related illness of any kind, an estimated four members of the unit is necessary to carry that member any distance. Therefore, use of an effective ORS could help reduce heat illness among military troops, thereby reducing EHI and improve field performance.[5] Therefore, in an effort to further determine the effectiveness of various ORS on performance parameters the primary aim of this study was to measure the effects of specific military approved ORS on physical performance in highly fit military personnel.

3.0 BACKGROUND

Although consistent water consumption plays a major role in preventing exertional heat illness (EHI), it may not be sufficient by itself to prevent EHI, and may cause a condition known as hyponatremia which is marked by reductions in serum sodium concentrations from norms of 135 to 145mmoL·L to levels below 130 mmoL·L.[6]

Various ORSs or sports drinks containing electrolytes such as sodium and chloride ions as well as varying sources of carbohydrates (CHO) are frequently recommended to increase water absorption and retention and prevent dangerous drops in serum sodium levels.

A weak link in any level of the warfighters chain of fitness, which includes > 2% body weight loss from water deficit could significantly impact performance during patrol evolutions and during war.[7,8] A high operational tempo in Afghanistan and Iraq, characterized by longer and more frequent deployments, has led to an increase in the number and duration of military deployments. In particular, specialized groups such as Special Operations Forces (SOF) must train routinely and vigorously to prepare for missions and deployments in hot and humid climates, which may include special reconnaissance, counterterrorism operations, and counter proliferation.[7]

Although it is common for certain military personnel to perform training evolutions in hot and humid climates, dehydration can also occur in normathermic environments. Both acclimatization and physical fitness helps prevent dehydration. For example, physical training increases blood plasma volume, which helps maintain central blood volume during dehydration. Furthermore, physical training also causes more dilute sweat by reducing its electrolyte content.[9] Humans are stimulated to drink fluids by osmoreceptors in the hypothalamus. The hypothalamus regulates body temperature and is analogous to a thermostat. Thus, the hypothalamus increases the rate of heat production when the body temperature falls, and increases the rate of heat dissipation when the body temperature rises.[9] Functions of these mechanisms frequently require alterations in hydration. Unfortunately, the thirst mechanism does not keep up with the body's fluid requirements, so military personnel or anyone performing in a hot climate can easily experience fluid deficits of > 2% of body weight resulting in decrements in both physical and cognitive performance.[9,2]

4.0 METHODS

Subjects who participated in this training study are defined as "well-trained" according to the American College of Sports Medicine (ACSM) guidelines for exercise testing and prescription.[10] Fifteen fit, healthy trained participants, ages 19-40 (13 men, 2 women), volunteered to participate on this study. Table 2 lists the subject's demographic data. Approval by the Air Force Research Laboratory Institutional Review Board was required prior to the start of the study.

To qualify for the study, subjects were required to show an aerobic capacity at or above the 80th percentile according to the ACSM.[10] Values of VO2max >46 mL/kg/min for men and > 34 mL/kg/min for women, evaluated according to the Ebbeling procedure,[11] were required. Additionally, body fat percentage[10] was measured in triplicate with calipers at three sites (chest, abdomen, and thigh for men; triceps, supra-iliac and thigh for women). For each trial run, the distance consisted of 10 miles at a speed of 5 mph (12 min/mile) and zero grade, with a pause every 20 minutes (as well as prior to the start of the run) for parameter measurements and consumption of 250 milliliters (mL) of fluid, for a total of 1500 mL over the 10-mile distance.

Subjects voided their bladders prior to the start of each session. Total urine output was collected during the test and total volume obtained. Each beverage was assigned to each subject random order, and was consumed during a separate run, with a minimum of one week between trials. Total time for each trial was an estimated three hours. For this investigation, a run was defined as one session consisting of a 10-mile distance (testing pre- post, and every 20 minutes for data collection) and entailing the consumption of one ORS for a total of 1500 mL in 250 aliquots (time zero and every 20 minutes).

Biomarkers included: 1) beginning and ending subject weight (Tanita Digital Physicans Scale (Tanita Corp. of America, Inc. Arlington Heights, IL; to 0.1 lb); 2) hematocrit (Hc) and hemoglobin (Hb); HemoPoint H2 (Stanbio Laboratory,and EKF Diagnostics Company, Boerne, TX); 3) heart rate (HR); 4) blood glucose FreeStyle Freedom Lite (Abbott, Alameda, CA); 5) and lactate (Lactate Plus (Sports Resource Group, Inc., USA); and tympanic temperature (Medline). A finger stick (Safe-t-Lance (Smiths Medical ASD, Inc. (Keene, NH) provided the blood sample. Subjects were required to void their bladders prior to the start of the trial (pre-weight obtained at this time), and total urine output was collected throughout each run (post-weight obtained after final void). Researchers briefed a complete disclosure of the study was given by the researchers, and subjects were required to sign an Informed Consent Document.

Experimental Procedures

Three different fluids were administered during three separate running trials: Water (control), Cerasport® (CS), and Gatorade® (G). Each trial run was at least one week apart. Treatments were randomly administered to subjects. All subjects were asked to refrain from consumption of caffeine for at least 4 hours prior to the run, with only a light, easily digestible meal at least two hours before the start time. Subjects were asked to consume the same foods prior to the start of each run, and to approximate the same exercise pattern the day prior to each run. Two hundred fifty mL of the beverage (water, CS or G) were consumed at the start (time zero) and every 20 min thereafter, with a total consumption of 1500 mL over the 10 mile run. Speed consisted of 5 mph with no incline, pausing every 20 min for measurements, consumption of 250 mL fluid, and bathroom breaks when desired. Static stretching of participants was permitted at each 20 min pause, if requested by the subject.

Blood Samples: Blood lactate (mmol/L) levels were measured with the *Nova Biomedical Lactate Plus (Nova Biomedical, Waltham MA, USA)* meter. The Lactate Plus analyzer requires 0.7 microliters (μL) whole blood to analyze the amount of lactate that is present in the blood. Blood glucose values were obtained via a finger stick, utilizing the FreeStyle Freedom Lite glucose meter (Abbot Diabetes Care, Alameda, CA, USA). Blood lactate and glucose values were measured at the start, end, and every 20 minutes throughout the run. All blood samples were obtained by fingerstick, utilizing *Safe-t-Lance (Smiths Medical ASD, Inc. (Keene, NH)* disposable lancets. Blood Hc/Hb (pre -and post- exercise) was measured utilizing the HemoPoint H2 photometer (Stanbio Laboratory, and EKF Diagnostics Company, Boerne, TX) utilizing HemoPoint H2 nxt Microcuvettes. Fingers were disinfected with an alcohol wipe and finger sticks performed. Lancets and strips were properly disposed of in a biohazard sharps container. Meters were calibrated prior to the start of each run with appropriate standards and following recommended manufacturer protocols.

Drink volume was measured by pouring them into a 500mL measuring cup (Anchor Hocking Co., Lancaster, OH) filling to the 250mL mark at eye level. CeraSport® and Gatorade® were shaken six times vigorously prior to the first measurement to insure homogenization of the fluid. Once measured, all drinks were transferred into a sports drink bottle for consumption by the subject.

Additionally, the Subjective Ratings of Perceived Exertion (RPE) scale, range 6 (Very Very Light) to 20 (Very Very Hard)[10] was measured at the start and completion of each run, and at every 20 minute pause.

Heart rate (HR): the Polar Heart Rate Sensor H1 System was utilized to measure to measure resting HR prior to the start of teach run, as well as during the last minute of each 20 minute segment of the run.

Data were provided to the analyst in Microsoft Excel, with the alpha established *a priori* at the 0.05 level. Data were analyzed by an independent third party, utilizing Bonferonni-corrected linear mixed model and Student's paired t-tests.

5.0 RESULTS

Table 1: Environmental Conditions

	Room Temperature		Relative Humidity (%)	
	Mean	SD	Mean	SD
Water	73.8	4.6	43.9	15.0
Cerasport	73.1	1.8	47.0	16.5
Gatorade	74.9	3.5	46.7	15.3

Table 2. Baseline measures (arithmetic mean / SD)

Variables	Water	Gatorade	p-value*	Cerasport	p-value*
Age (years)	28.07 (5.09)	28.07 (5.09)	1.00	28.07 (5.09)	1.00
Height inches	69.79 (4.2)	69.79 (4.25)	1.00	69.79 (4.25)	1.00
Weight pounds	174.40 (21.53)	174.40 (21.53)	1.00	174.40 (21.53)	1.00
Body mass index	25.11 (1.45)	25.11 (1.45)	1.00	25.11 (1.45)	1.00
Maximal aerobic fitness	52.91 (5.03)	52.91 (5.03)	1.00	52.91 (5.03)	1.00
Body fat	13.17 (6.73)	13.17 (6.73)	1.00	13.17 (6.73)	1.00
Initial hemoglobin	15.14 (1.32)	15.22 (0.97)	0.27	15.11 (1.49)	0.96
Initial Hematocrit	44.53 (3.8)	44.87 (2.83)	0.78	44.47 (4.32)	0.96

Heart rate 1	70.87 (9.69)	71.07 (10.17)	0.95	68.87 (7.96)	0.54
Tympanic temperature 1	98.12 (0.57)	98.15 (0.45)	0.85	98.11 (0.40)	0.97
Blood glucose 1	89.67 (13.88)	90.67 (10.28)	0.82	88.33 (6.80)	0.74
Blood lactate 1	1.87 (0.73)	1.77 (1.04)	0.76	1.69 (1.09)	0.60

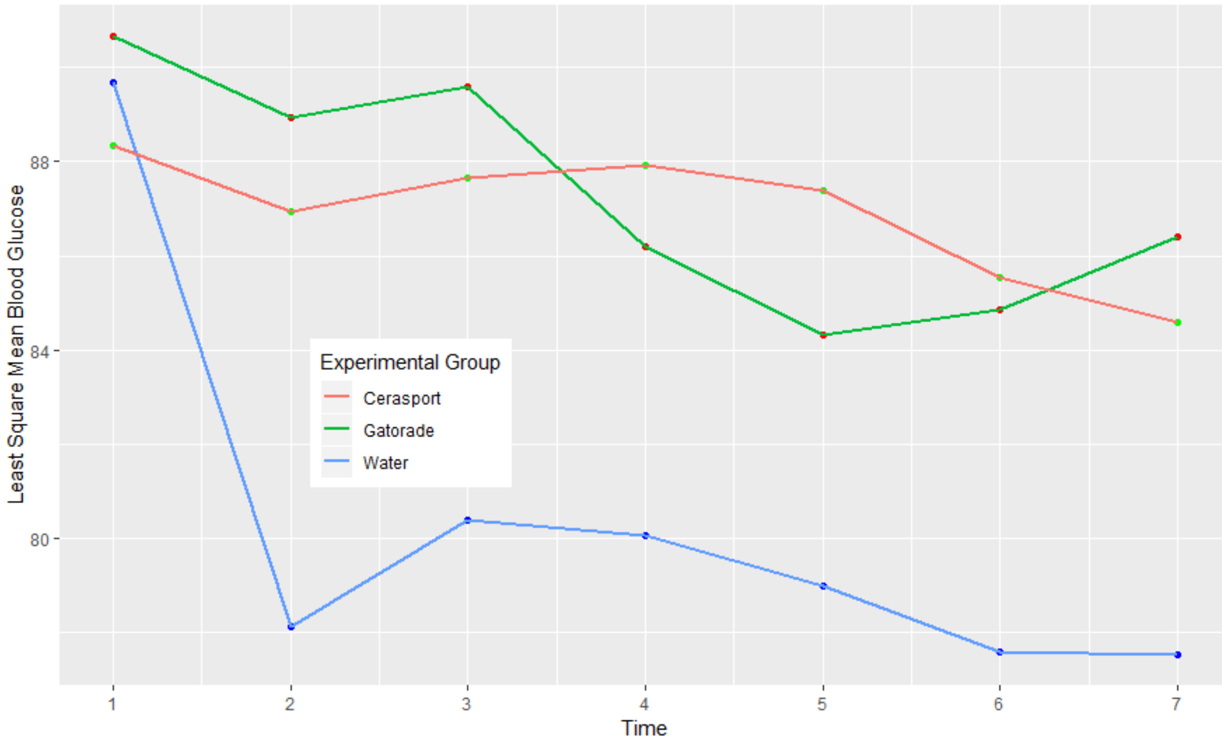
*P-values were derived from Student's t-test comparing mean difference with the Water Group

Table 3. Outcome measures (arithmetic mean / SD) by 20 minute intervals (1-7)

Outcomes	Water	Gatorade	Cerasport	Water vs Gatorade p-value*	Water vs Cerasport p-value*	Gatorade vs Cerasport p-value*
Heart rate 1	70.87 (9.69)	71.07 (10.17)	68.87 (7.96)	0.95	0.54	0.37
Heart rate 2	135.00 (12.56)	137.90 (13.32)	136.10 (13.80)	0.55	0.81	0.73
Heart rate 3	141.50 (14.21)	140.10 (15.19)	138.30 (12.99)	0.80	0.52	0.72
Heart rate 4	145.53 (15.33)	141.40 (15.01)	139.13 (13.19)	0.46	0.23	0.66
Heart rate 5	145.40 (14.64)	142.73 (15.05)	139.47 (14.15)	0.63	0.27	0.54
Heart rate 6	147.40 (14.38)	144.20 (17.11)	140.87 (14.15)	0.58	0.22	0.56
Heart rate 7	150.40 (13.87)	147.20 (18.41)	145.40 (13.62)	0.59	0.33	0.76
Rating of Perceived Exertion 1	6.53 (0.83)	6.47 (0.74)	6.27 (0.59)	0.82	0.32	0.42
Rating of Perceived Exertion 2	9.20 (1.26)	8.27 (1.39)	8.13 (1.12)	**0.06	*0.0213	0.77
Rating of Perceived Exertion 3	9.93 (1.53)	9.07 (1.53)	8.80 (1.47)	0.13	*0.0484	0.63
Rating of Perceived Exertion 4	10.47 (1.51)	9.73 (1.75)	9.60 (1.84)	0.23	0.17	0.84
Rating of Perceived Exertion 5	10.87 (1.46)	10.33 (2.06)	10.20 (1.78)	0.42	0.27	0.85
Rating of Perceived Exertion 6	11.60 (1.88)	10.73 (2.34)	11.13 (2.10)	0.27	0.53	0.63
Rating of Perceived Exertion 7	12.20 (1.78)	11.47 (2.75)	11.60 (2.16)	0.39	0.41	0.88
Blood glucose 1	89.67 (13.88)	90.67 (10.28)	88.33 (6.80)	0.82	0.74	0.47
Blood glucose 2	78.13 (8.69)	88.93 (11.70)	86.93 (9.34))	*0.0077	*0.0124	0.61
Blood glucose 3	80.40 (6.46)	89.60 (11.23)	87.66 (9.69)	*0.0103	*0.0224	0.62
Blood glucose 4	80.07 (8.16)	86.20 (10.23)	87.93 (8.59)	**0.08	*0.0157	0.62
Blood glucose 5	79.00 (8.40)	84.33 (8.16)	87.40 (9.57)	**0.09	*0.0163	0.35
Blood glucose 6	77.60 (7.79)	84.87 (10.91)	85.53 (9.73)	*0.045	*0.0201	0.86
Blood glucose 7	77.53 (10.47)	86.40 (12.68)	84.60 (8.21)	*0.046	*0.0491	0.65
Blood lactate 1	1.87 (0.73)	1.77 (1.04)	1.69 (1.09)	0.76	0.60	0.84
Blood lactate 2	1.55 (0.88)	1.67 (0.67)	1.60 (0.64)	0.63	0.85	0.72
Blood lactate 3	1.57 (0.73)	1.75 (0.77)	1.72 (1.17)	0.53	0.65	0.93
Blood lactate 4	1.62 (0.80)	1.31 (0.54)	1.59 (0.91)	0.23	0.91	0.32
Blood lactate 5	1.86 (0.92)	1.59 (0.89)	1.61 (0.85)	0.41	0.45	0.93
Blood lactate 6	1.91 (1.21)	1.51 (0.52)	1.31 (0.71)	0.25	0.11	0.38
Blood lactate 7	1.69 (0.95)	1.74 (0.63)	1.31 (0.71)	0.87	0.22	**0.09

P-values were derived from Student's t-test ^Time 1 indicates initial values. *Indicates values are statistically different ($p<0.05$). ** Indicates values are approaching statistical difference ($p \leq 0.09$)

Figure 1: Blood glucose (mg/dL) values by treatment and time



X axis values indicate 20 minute time periods, with Time 1 indicating initial values. Y axis indicares blood glucose values (mg/dL).

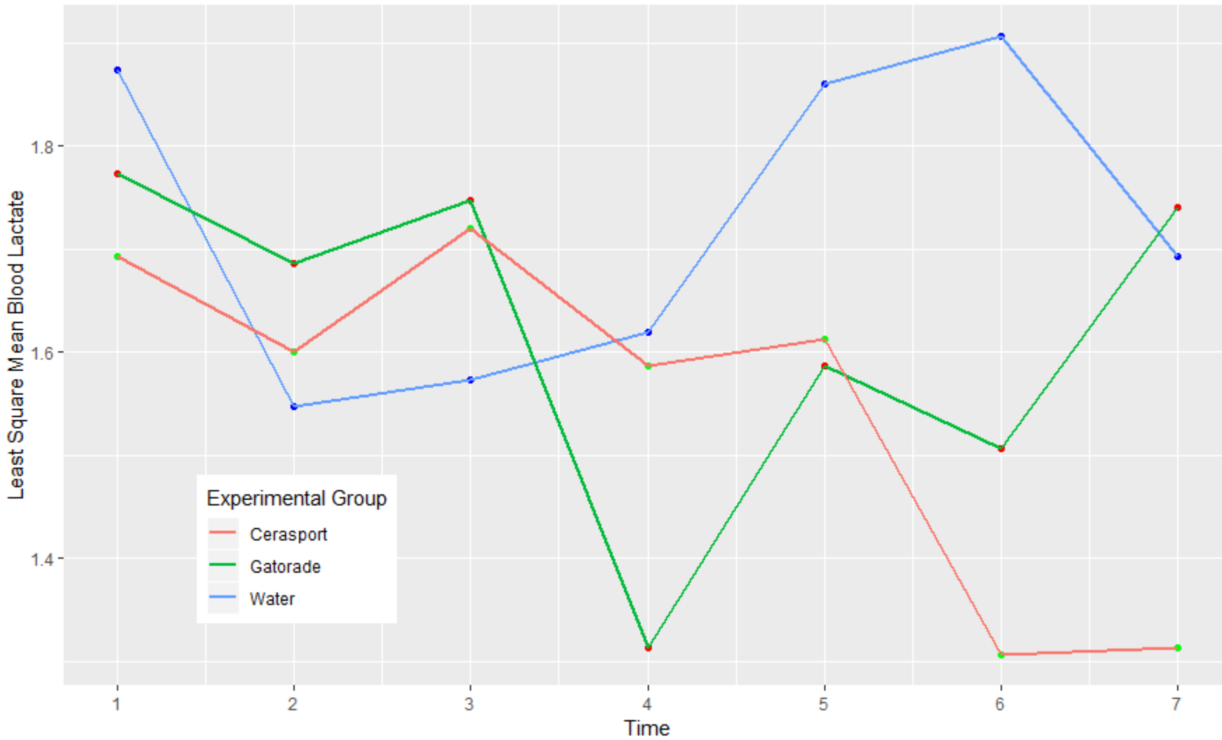


Figure 2: Blood lactate (mM) values by treatment and time. X axis values indicate 20 minute time periods, with Time 1 indicating initial values. Y axis indicate blood lactate values (mM).

Table 4: Overall summary of urine output for the main treatments, Mean (SD)

	Water (W)	Cerasport (C)	Gatorade (G)
Urine Output, mL	343.8 (331.9)	470.8 (353.1)	417 (439.6)

Table 5: Overall Summary of Weight Loss for the main treatments, Mean (SD)

	Water (W)	Cerasport (C)	Gatorade (G)
Starting Weight	172.4 (20.5)	172.5 (21.0)	172.1 (10.2)
Ending Weight	170.5 (19.9)	170.5 (20.2)	170.1 (19.3)
Weight Change	-1.9 (1.4)	-2.0 (1.3)	-2.0 (1.6)
% Weight Change	-1.1 (0.7)	-1.1 (0.7)	-1.1 (0.8)

Table 6: Paired T-Tests (Percent Weight Change)

Contrast	Mean Difference	T-Score/df	P-Value
Water – Cerasport	-127	-1.8147/14	0.191
Water – Gatorade	-73.6	-1.0189/14	0.326
Cerasport – Gatorade	53.4	0.92574/14	0.3703

Table 7: Composition of CeraSport and Gatorade (based on label and 1500 mL consumption)

Ingredient	CeraSport	Gatorade
Carbohydrates (g)	60	91
Sugars (g)	12	86
Calories	240	364

No significant differences were found ($p>0.05$) in the temperature and humidity levels observed between each of the running trials (Table 1) or in the demographics for any of the runners (Table 2). No differences ($p>0.05$) were observed for any of the initial values (Time 1) for any of the parameters measured (Table 2). Blood glucose values were significantly higher ($p<0.05$) for all T2-7 when CS was compared to water, and for all periods except 4 and 5 (approached significance) when water was compared to G (Table 3). Blood glucose levels remained relatively more stable across the trial periods for CS in comparison to water and G (Figure 1). Additionally, although BLa levels were not significantly different between treatments, differences between CS and G approached significance ($p=0.09$) during the last 20 minutes of the run (Time 7, Table 3). Figure 2 illustrates these differences. Hydration status based on changes in body mass, urine output, Hc and Hg, with plasma volume calculated from these numbers. There were no differences in Hc, Hg or plasma volumes (calculated from Hc and Hg, Van Beaumont,[12] observed during the trial for any treatment (data not shown). Likewise, there were no differences in body weight change (Tables 4 and 5) or in urinary output (Table 6) for any of the treatments.

6.0 DISCUSSION/CONCLUSIONS

As noted previously, there were no significant differences (environmental conditions were normothermic) in the temperature and humidity levels observed during each of the runs (Table 1) or in the demographics for any of the runners (Table 2). No differences ($p>0.05$) were observed for any of the initial values (Time 1) for any of the parameters measured, indicating that all subjects started exercising with similar biomarker values for every treatment. Blood glucose values were significantly higher ($p<0.05$) for all time periods (2-7) when CS compared to water, and for all periods except 4 and 5 (approaches significance, $p\leq0.09$) when water was compared to G, which confirms that consumption of an ORS maintains blood glucose values much better for endurance activities than consumption of water with the same volume.

No significant differences between CS and G for BG was observed despite the total consumption of 86 g of sugar in 1500 mL of G and only 12 g of sugar in 1500 mL of CS (Table 7). The CHO content was 91 g for G (mostly consisting of sugars) compared to 60 g in CS, mostly from the medium chain CHO, maltodextrin (MD), with an energy

consumption of 240 Cal with CS compared to 364 Cal for G. The CHO of G consisted of 95% sugar whereas the CHO of CS consisted of 20% sugar, ultimately resulting in 2 g of sugar intake every 20 min in 250 mL of CS vs ~14 g every 20 minutes 250 mL of G. Gluc is primarily absorbed in the duodenum and jejunum by the SGLT1 transporters.[5,13] However, researchers have recently identified two additional gluc transporters in the ileum.[14] This could indicate that gluc may be absorbed farther down the gastrointestinal tract than originally thought. OSR drinks containing more complex CHO absorbed farther down the gastrointestinal tract than originally thought. Therefore,
In contrast to other sports drinks containing sugars (mostly absorbed from the duodenum), the longer CHO chains present in CS may decrease digestion in the duodenum/jejunum and allow more of the CHO to reach the ileum, which may result in a slower and more sustained release of gluc. Alternatively, digestion and absorption of MD may occurred in the duodenum/jejunum. Although the mechanism is unclear, these data provide clear evidence that CS maintains blood glucose levels just effectively as G during an endurance event, but with much a lower sugar/CHO intake. These data also suggest that molecular structure of nutrient components may play a significant role in maintenance of exercise performance.

The differences in the structural CHO content between CS and G may have an impact on physiological function of other factors, not just BG. One of the most interesting findings from this study is the progressive rise in [BLa] with G in comparison to CS (Table 3 and Figure 1). Despite no differences in BG levels, BLa values were lower (approaching significance at p=0.09) for the last twenty minutes of the ten mile run (T7, Table 3, blood lactate 7) when CS was consumed, in comparison to G. Blood lactate levels also remained steady for the last 40 minutes of the CS run in comparison to G (Table 3 and Figure 1). Had the run been greater than 10 miles, and/or the number of subjects been increased, the data may have provided additional evidence that more lac is generated when G is consumed in comparison to CS during endurance events.

It is widely accepted that the end product of glycolysis under oxygenic conditions is pyruvate (transported into the mitochondrion for further oxidation via the Krebs Cycle and ETC), while under anaerobic conditions, it is lactate. However, several studies have indicated that the end product of glycolysis is lactate and not pyruvate, under both low oxygen (anaerobic) and high oxygen (aerobic) intracellular environments.[15,16,17,18]

Lactate is a product of catalysis of pyruvate to lactate, as follows:

$$\text{Pyruvate}^- + \text{NADH} + \text{H}^+ \leftrightarrow \text{Lactate}^- + \text{NAD}^+$$

This reaction is catalyzed by the enzyme lactate dehydrogenase (LDH). With an equilibrium constant of 1.62 x 11 M-L, this reaction strongly favors the formation of lactate,[19] as does a large free energy (standard $DG^{0'}$) change of -25.1 kJ/mol.[20] The energy states indicated by these values heavily favor lactate production and provides evidence that the end product of glycolysis is indeed lactate, not pyruvate.

The efflux of lactate from exercising muscle while under oxygenated cellular conditions have been observed and reported by previous researchers.[16,17,18,21] Several factors may play a role in increasing [BLa], including metabolic rate, mitochondrial activity, and O_2 tension.[22] This may in part explain the significance of the higher BLa levels observed in runners consuming G vs CS (Table 3, T7). The higher sugar content of G may mean that cellular glucose uptake is greater (while still maintaining BG) than when CS is consumed, increasing the [lac] to the point where greater cellular efflux occurs, thus increasing the [lac] in blood.

Scientists who conducted research in the early 19th century concluded that lac was a waste product of metabolism. [23] More recent research studies have associated increased [lac] to be the cause of increased pain and decreased contractile force. [24] Several additional authors provide evidence which suggests that [lac] in exercising skeletal muscle and blood has a much greater role in metabolism, and may still play a vital role in exercise exhaustion, pain, and recovery time, although the exact mechanism of action is yet to be determined.[25]

These data provide initial evidence that consumption of CS in the same volume and time as G result in maintenance of blood glucose values with lower sugar and CHO consumption and without a concomitant rise in [Bla]. Although there were no statistical differences in the biomarkers of hydration, potential differences may be more clearly distinguished in future studies conducted in different environmental conditions (higher temperatures and humidity), with a larger subject pool, and/or with a more prolonged exercise period.

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LIST OF ABBREVIATIONS AND ACRONYMS

csv	comma separated value
LMM	linear mixed model

TT	tympanic temperature
Lac	lactate
[Blac]	blood lactate concentration
BLac	blood lactate
Gluc	glucose
[gluc]	glucose concentration
Hc	hematocrit
Hb	hemoglobin
CHO	carbohydrate
MD	maltodextrin
HR	heart rate
RPE	ratings of perceived exertion
BG	blood glucose